Wisconsin
Space Grant Consortium

WSGC

Proceedings of the 20th Annual

Wisconsin Space Conference

DAWN OF A NEW AGE

August 19-20, 2010
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Sheboygan, Wisconsin

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DAWN OF A NEW AGE

20th Annual Wisconsin Space Conference
August 19-20, 2010
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Preface and Acknowledgements

Happy 20th anniversary to our Wisconsin Space Conference! For two decades, this conference has been a powerful vehicle for getting the most current space-related science and education results out to a wider audience, and for the last decade, I have been privileged to oversee the Conference and these Proceedings.

Not long ago, I was going through airport security, when a TSA employee saw the NASA mission stickers adorning my laptop cover and said, "NASA, huh? Why aren't you guys figuring out ways to plug that oil leak in the gulf?" My answer was less than stellar (pardon the pun), for of course, we all think of witty retorts after the fact. But here's what I should have said: "I'm glad experts are working on that problem. My expertise is in acquiring the data and asking the questions that will help us anticipate and avoid the next problem."

Emergencies can bring out the panic in some — that's understandable. But what if someone had found a way to avoid the emergency altogether? How much would that be worth? Yes, there must be those who devote themselves to solving today's problems — some of the papers in this volume address those problems and are written by those people. But there also must be those who devote themselves to anticipating tomorrow's problems before they happen — the work of those people is also represented in this volume.

This is what working in space-related fields is all about —what's next. I am proud to be the Director of a program that gives students, faculty, educators and professionals some of the tools to help them work on what's next!

This volume represents the collected works of those who presented at our 20th conference and I'm grateful to each person who made that Conference and these Proceedings possible. The Wisconsin Space Grant Consortium especially extends thanks to our host, the University of Wisconsin—Sheboygan, and especially Conference lead Dr. Harald Schenk and his staff of helpful volunteers for their hospitality and their skill in running such a smooth conference. Our session moderators, as well, kept everyone on time and we thank them for that. The conference benefitted tremendously from our excellent keynote speakers: Dr. Marc Rayman, Chief Engineer, Jet Propulsion Laboratory, NASA Dawn Mission and Max Mutchler, Research and Instrument Scientist, Telescope Science Institute. Finally, as always, we in the WSGC office extend our appreciation to all the scientists, engineers, students, educators and others, who contributed papers to this volume.

Forward!

R. Aileen Yingst, Ph.D.
Director

Wisconsin Space Grant Consortium

Programs for 2010

Student Programs

- Undergraduate Scholarship
- Undergraduate Research
- Graduate Fellowship
- Dr. Laurel Salton Clark Memorial Graduate Fellowship
- University Sounding Rocket Team Competition
- Student High-Altitude Balloon Launch
- Student High-Altitude Balloon Payload
- Student High-Altitude Balloon Instrument Development
- Industry Member Internships
- NASA Academy Leadership Internships
- NASA Centers/JPL Internships
- NASA Reduced/Gravity Team Launches
- Relevant Student Travel

(see detailed descriptions on next page)

Research

The Research Infrastructure Program provides Research Seed Grant Awards to faculty and staff from WSGC Member and Affiliate Member colleges and universities to support individuals interested in starting or enhancing space- or aerospace-related research program(s).

Higher Education

The Higher Education Incentives Program is a seed-grant program inviting proposals for innovative, value-added, higher education teaching/training projects related to space science, space engineering, and other space- or aerospace-related disciplines. The Student Satellite Program including Balloon and Rocket programs is also administered under this program.

Industry Program

The WSGC Industry Program is designed to meet the needs of Wisconsin Industry member institutions in multiple ways including:

1) the Industry Member Internships (listed under students above),

2) the Industry/Academic Research Seed Program designed to provide funding and open an avenue for member academia and industry researchers to work together on a space-related project, and

3) the Industrial Education and Training Program designed to provide funding for industry staff members to keep up-to-date in NASA-relevant fields.

Aerospace Outreach Program

The Aerospace Outreach Program provides grant monies to promote outreach programs and projects that disseminate aerospace and space-related information to the general public, and support the development and implementation of aerospace and space-related curricula in Wisconsin classrooms. In addition, this program supports NASA-trained educators in teacher training programs.

Special Initiatives

The Special Initiatives Program is designed to provide planning grants and program supplement grants for ongoing or new programs which have space or aerospace content and are intended to encourage, attract, and retain under-represented groups, especially women, minorities and the developmentally challenged, in careers in space- or aerospace-related fields.

Wisconsin Space Conference

The Wisconsin Space Conference is an annual conference featuring presentations of students, faculty, K-12 educators and others who have received grants from WSGC over the past year. The Conference allows all to share their work with others interested in Space. It also includes keynote addresses, and the announcement of award recipients for the next year.

Regional Consortia

WSGC is a founding member of the Great Midwest Regional Space Grant Consortia. The Consortia consists of eight members, all Space Grants from Midwest and Great Lakes States.

Communications

WSGC web site www.uwgb.edu/wsgc provides information about WSGC, its members and programs, and links to NASA and other sites.

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WSGC

Wisconsin Space Grant Consortium

Student Programs for 2010

Undergraduate Scholarship Program
Supports outstanding undergraduate students pursuing aerospace, space science, or other space-related studies or research.

Undergraduate Research Awards
Supports qualified students to create and implement a small research study during the summer or academic year that is directly related to their interests and career objectives in space science, aerospace, or space-related studies.

Graduate Fellowships
Supports outstanding graduate students pursuing aerospace, space science, or other interdisciplinary space-related graduate research.

Dr. Laurel Salton Clark Memorial Graduate Fellowship
In honor of Dr. Clark, Columbia Space Shuttle astronaut and resident of Wisconsin, this award supports a graduate student pursuing studies in the fields of environmental or life sciences, whose research has an aerospace component.

University Sounding Rocket Team Competition
Provides an opportunity and funding for student teams to design and fly a rocket that excels at a specific goal that is changed annually.

Student High-Altitude Balloon Instrument Development
Students participate in this instrument development program through engineering or science teams. Working models created by the students will be flown on high-altitude balloons.

Student High-Altitude Balloon Payload/ Launch Program
The Elijah Project is a high-altitude balloon program in which science and engineering students work in integrated science and engineering teams, to design, construct, launch, recover and analyze data from a high-altitude balloon payload. These balloons travel up to 100,000 ft., considered "the edge of space." Selected students will join either a launch team or a payload design team.

Industry Member Internships
Supports student internships in space science or engineering for the summer or academic year at WSGC Industry members co-sponsored by WSGC and Industry partners.

NASA Academy Leadership Internships
This summer internship program at NASA Centers promotes leadership internships for college juniors, seniors and first-year graduate students and is co-sponsored by participating state Space Grant Consortia.

NASA Centers/JPL Internships
Supports WSGC students for research internships at NASA Centers or JPL.

NASA Reduced Gravity Program
Operated by the NASA Johnson Space Center, this program provides the unique "weightless" environment of space flight for test and training purposes. WSGC student teams submit reduced gravity experiments to NASA and, if selected, get to perform their experiments during a weightless environment flight with the support of WSGC.

Relevant Student Travel
Supports student travel to present their WSGC-funded research.

20th Annual Conference
TABLE OF CONTENTS

Solid Rocket Motor Thrust Oscillation with Inhibitors Due to Vortex Shedding, Brandon Jackson, Undergraduate Student, Milwaukee School of Engineering

Life Support Systems/Particulate Matter and Lunar Dust Filtration, Chelsey Y. Erickson, Undergraduate Student, University of Wisconsin-Madison

Part 8: Chemistry

Space and Earth Carbon Research, Dan Hawk, Undergraduate Student, Lawrence University

Part 9: Physics and Astronomy

The Development of a Transition-Edge Hot-Electron Microbolometer for Observation of the Cosmic Microwave Background, Emily Barrentine, Graduate Student, University of Wisconsin-Madison

Characterizing Magnetohydrodynamic Turbulence in the ISM, Blakesley Burkhart, Graduate Student, Department of Astronomy, University of Wisconsin-Madison

Millimeter-wave Bolometric Interferometer, Amanda C. Gault, Graduate Student, University of Wisconsin-Madison

Hydrodynamic Simulations of Double-Bent Radio Sources, Jacob Miller, Undergraduate Student, University of Wisconsin-Madison

Big Bang Blackbody Simulator, Sara Stanchfield, Undergraduate Student, University of Wisconsin-Madison

Part 10: Education and Public Outreach

A Celebration of Life! An African American Ethnic Academy and BioPharmaceutical Technology Center Institute Science Outreach Partnership, Barbara Bielec, K-12 Program Coordinator, BioPharmaceutical Technology Center Institute

Fly Girls, Loretta Krenitsky, Woman in Technology Program Coordinator, Applied Research and Grants, Milwaukee School of Engineering

Science Outreach for Spanish Speakers, Kay Kriewald, Sr. Outreach Specialist, UW Space Place, University of Wisconsin-Madison

To the Moon and Beyond: Lunar Expedition, Chrissy Paape, Vice President, Space Explorers, Inc.

Elementary Rockets for Schools, Judy Schieble, Elementary Chair, Rockets for Schools, Great Lakes Spaceport Education Foundation

Combining Writing Across the Curriculum Strategies in Community-Based Programs: Teaching Core Concepts in Science, James Kramer, Executive Director, Simpson Street Free Press, Madison, WI

Journey to Planet Earth: A Public Outreach and Teacher Training Course, Margaret C. Turnbull, President, Global Science Institute

Biotechnology Teacher Training, Barbara Bielec, K-12 Program Coordinator, BioPharmaceutical Technology Center Institute

Spaceflight Academy for CESA Distric #2, Bradley J. Staats, President, Spaceflight Fundamentals, LLC

A Taste of the Solar System, Mary Williams-Norton, Professor, Physics Department, Ripon College

Early-Career Leaders in Science Education (ECLIpSE), Eric Brunsell, Assistant Professor, Science Education, Curriculum and Instruction, University of Wisconsin-Oshkosh

Investigating Student Views of Relevancy in Introductory Astronomy, Dr. Shauna Sallmen, Associate Professor, Department of Physics, University of Wisconsin-La Crosse

A Space Sciences Capstone Curriculum at Carthage College, Kevin M. Crosby, Professor, Department of Physics, Carthage College

Flight, Floating, and Mars; New Courses at Ripon College, Sarah J. Desotell, Assistant Professor, Department of Physics, Ripon College

Appendix A: 20th Annual Conference 2010 Program

20th Annual Conference
Part One

Student Satellite Program
High Altitude Balloon

Elijah Project Balloon Payload Team

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UWM, MSOE,
Carthage, St. Norbert,
Marquette, UW-Madison

Abstract

Under the direction of Milwaukee School of Engineering's Dr. Farrow with support from the Wisconsin Space Grant Consortium and NASA, six students designed and fabricated experiments to be carried out on a high-altitude balloon. The goal was to investigate the phenomena of near-space (stratosphere) at altitudes up to and sometimes exceeding 100,000 feet. In doing so, the team was allowed two payloads- one 6-lbs payload and one 2-lbs payload. This year's team has a total of four experiments to determine the effect of increasing altitude: the breakdown voltage in high voltage circuits, static charge on the balloon, solar efficiency using a built in solar tracking system, and atmospheric mercury levels. All but the breakdown voltage experiment were successfully launched on August 7th from Mt. Horeb, WI and recovered near Milton, WI.

[1] A special thanks to the Wisconsin Space Grant Consortium for funding the project, and Dr. Farrow of the Milwaukee School of Engineering for being the team's advisor.

Project Background

The Elijah Project is a Wisconsin Space Grant Consortium internship that has been running for several years now. The goal of the project is to get students interested in science and engineering within the space program by conducting high altitude experiments on a weather balloon. The balloon is filled with helium to lift a 6-lb (and an optional 2-lb payload) to an altitude up to and sometimes exceeding 90,000-ft. The team is provided a $4000 budget and directed to devise their own experiments to test something that interests them.

Voltage & Charge Experiments

Background. Two experiments were conducted in the voltage/charge phenomena. The first experiment uses high voltages and circuitry. When working with many electronics at high altitudes, whether or not they are in airplanes, missiles, or shuttles, they become more susceptible to short circuit. This is because at higher altitudes there is a higher concentration of electrical charge. In the case of many circuits within airplanes, they must be insulated properly or else the electricity can arc across to another part of a circuit that can make certain instruments completely useless.

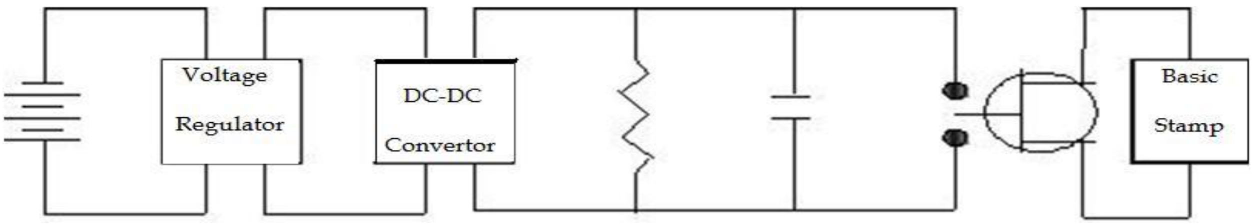
This arcing occurs because the air that separates different electronics becomes a conductor instead of an insulator. When it reaches a certain potential difference, or breakdown voltage, the molecules start to break apart and become ionized. This allows electricity to flow through the gas. Due to the high probability of damaged electronics, this phenomenon is not generally researched. It is just seen as a flaw in circuitry that should be avoided at all costs. Many people have found ways around the problem by increasing air caps between circuits, adding extra insulation, and pressurizing electronic chambers whenever it is possible.

The main reason that arcing is such a problem with electronics at higher altitudes is because the breakdown voltage goes down as altitude increases. The breakdown voltage depends on temperature, pressure, humidity, and the geometry of the electronics at either end of the gap. All of these things change in a way that makes this phenomenon more probable at higher altitudes.

The second experiment uses a transistor, basic stamp, battery power, and a gate antenna wire to detect the existence of a static charge in the atmosphere, as particles collide and build up on the payload balloon. This interest was risen because there are a number of aircrafts and other objects that are involved with high altitude flights that need to be aware of static build up to ensure the safety of the product, its hardware, and possible passengers that are involved. Static charge occurs at all levels in the earth's atmosphere and it is imperative that research is conducted in many fashions to get an idea of how the various atmospheres affect the buildup of static charge on objects because it can be dangerous. This research has been able to corroborate other research by the occurrences of charge found in the data collection process.

Method. In order to determine the breakdown voltages at different altitudes, we decided to create a circuit with movable electrodes so that we could see what distance the spark could jump across. By using a motor, gear, and gear rack, we could manipulate the distances effectively. This way we could move the gap from smaller to larger distances in order to see the change in the breakdown voltage. As shown in Figure 1, a housing was manufactured by the Rapid Prototype Center (RPC) at the Milwaukee School of Engineering to protect the other experiments from the high voltage.

Figure 1- The breakdown voltage housing. The motor controls a gear rack to move an electrode from a gap distance of .02 cm to 1 cm.



Since the arcing phenomenon generally only happens at 3 kV/cm at standard room temperature and pressure, we knew that this was going have to be high voltage circuit. To make this circuit, a DC-DC converter with a 1 to 100 ratio was used. With the differences in temperature and pressure, it turns out that the voltage needed was only about 500 volts instead of 2 kilovolts. In order to calculate this number, we used Paschen's Law equations, shown in Figures 2 and 3 below. We came up with the circuit, shown above, in order to make sure that the electrodes carried a constant potential difference of five volts. Then, a transistor detects whether or not the spark jumps the gap. If the transistor detected electricity the Basic Stamp recorded the position of the electrodes along with the time of the spark.

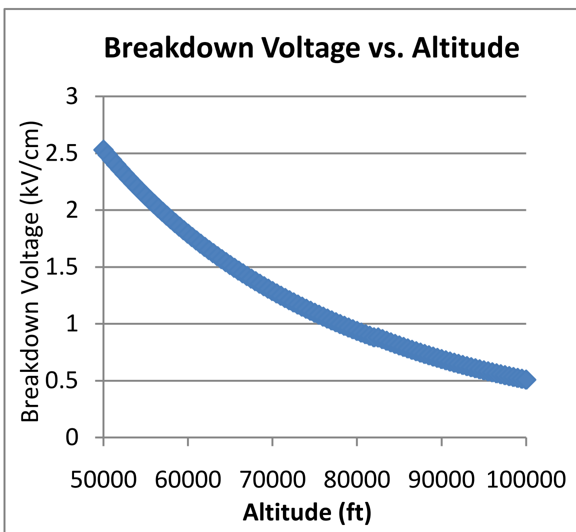


Figure 2- The expected breakdown voltages.

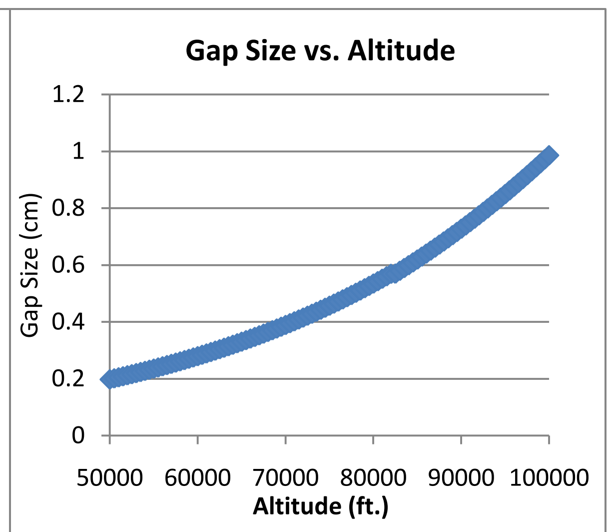


Figure 3- The expected gap distances.

The design of the experiment for static charge involves circuitry and programming to detect if a static charge is present at various altitudes. We will be testing the buildup of static charge on the payload balloon itself until it reaches 100,000 ft and bursts. The setup of the design includes a circuit board that the components will be soldered to, one JFET transistor, one nine volt battery, a wire that will help identify the static charge, one basic stamp and connecting wires. The basic static charge setup is shown below in Figure 4.

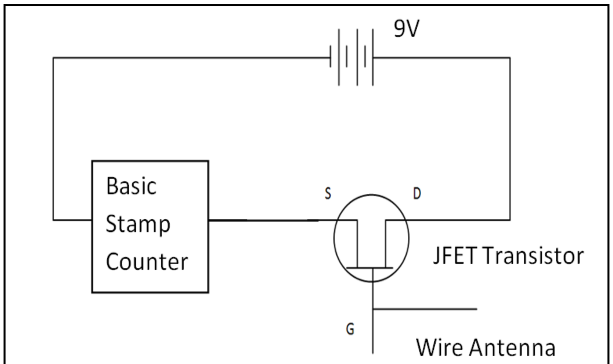


Figure 4- The static charge circuit.

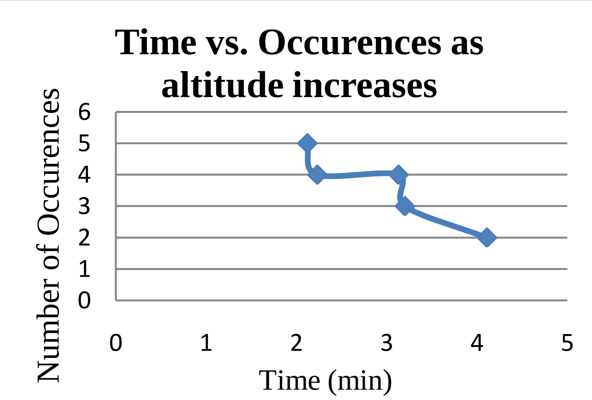


Figure 5- Graph of static charge decreasing

Results. Unfortunately, due to complications with the breakdown voltage experiment, it has yet to be tested in the high altitude balloon payload. Whenever we would test the circuit and create a spark, the resultant pulse was so strong that it interfered with other electronics and was not compatible with other experiments and could have possibly created problems with the tracking payload that was attached.

The results for the static charge experiment were fascinating. Figure 5 below shows that the amount of occurrences of voltage readings decreased as the payload balloon rose. There was also a one and a half hour period where there were no readings at all. This period occurred from minute four until the payload landed. It shows that static charge build up does decrease as altitude increases. It was also clear that when the balloon rose, the static charge was changing constantly and there would be several sets of readings saying the charge would be there and then not. This could have been due to the path of travel to altitude with a rough journey in the air.

Solar Efficiency

Background. With oil prices on the rise and the harmful bi-products created from fossil fuels, alternative energy sources are necessary in order to answer the increasing demand for power. The sun hits the Earth with roughly 4.3 X 10^{20} Joules of energy every hour. This is enough energy to fulfill humanity's energy needs for an entire year. Why do we not try to satisfy most or even all of our energy needs will this unlimited and underused supply? The answer is efficiency.

Today's solar cells only have an efficiency of around 15-20%. This means that if a cell gets hit with ten Joules of energy, only about two Joules can actually be obtained through the cell. This low conversion factor, combined with the cost of producing solar cells, still makes solar energy just as, if not more costly than fossil fuel energy sources. Another problem is that when the sun goes behind clouds, or even as it moves across the sky, the amount of light hitting the panel decreases.

In our experiment we hope to test how the power output of a solar cell varies as it goes up in altitude. It is known that the amount of sunlight higher in the atmosphere is significantly greater than that on the surface of the earth. This is due to the lack of cloud cover, smog and the atmosphere attuenuating the light rays. The amount that light gets absorbed or diffracted within the atmoshpere is called extinction. Figure 6, shows the amount of extinction that occurs throughout the atmosphere. With these factors reducing the light and possibly the output of a solar cell, would it be reasonable to try and build a solar base above the clouds?

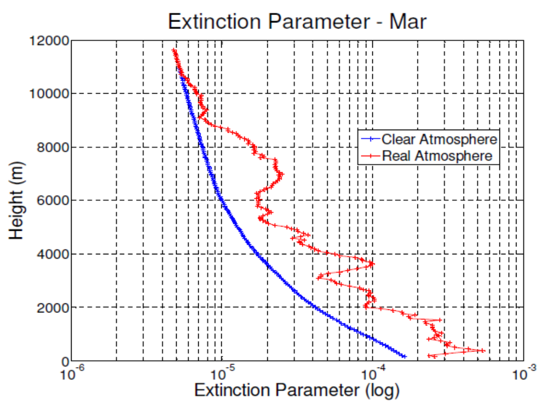


Figure 6- Extinction throughout the atmosphere. Less light penetrates Earth's atmosphere as it gets closer to the surface.

Table 2: Expected output from 1kWp PV devices

Altitude	Yearly output from 1kWp facility [kWh]
Ground Based	1130* (750-900)**
6 km	4170
12 km	5480
Geostationary (Solar Power Satellite)	12000

*Value directly calculated from the Irradiation at Southampton
** Practical values suggested by manufacturers of PV for installations in England

Figure 7- Expected solar panel output. Studies show that higher altitudes should increase the solar efficiency by up to 600%.

As seen in the graph, light is extinct by a significant amount as it gets closer to the surface of the earth. According to this data, the amount of power output by a solar cell could increase by as much as 600% by putting it to an altitude of 12,000 meters. In Figure 7 above, there are the different values for power output from a similar study by University of Southhampton School of Engineering Sciences. Based on the information from the England study, we predict that we will see a steady increase in power output by the cell as the payload goes up in altitude.

Method. The way that we tested this hypothesis was to construct a solar tracking system that kept the solar panel centered on the sun for a majority of the flight. The main reason for doing this was to keep the cell from getting off-centered, thus lowering the output of the panel throughout the flight. By keeping the cell centered on the sun, the number of data points should have been greatly increased. The tracking system consisted of a cross-shaped holder that had five photo resistors attached to it, one in the middle and one on each appendage. Each resistor was then connected to a basic stamp input through a voltage divider. When the sun hit one of the side photo resistors, it lowered the resistance in the voltage divider, which caused the input signal to the basic stamp to increase. The basic stamp sensed this and turned a motor so that the cell rotated until it was perpendicular to the sunlight.

We measured the power of the solar cell by connecting a resistor in series to the cell. As the current produced by the cell traveled through the resistor, it created a voltage. By measuring this voltage and using the known resistance, power was determined using Ohm's law. The voltage was measured by sending it into an analog to digital converter, which converted the DC voltage into a digital reading. This digital reading was then sent into the basic stamp and stored there.

Results. The results that we received did not completely coincide with our hypothesis. As seen in Figure 8, the amount of power that was outputted by the solar cell increased as it moved through the clouds. However, once the cell went above the cloud cover the amount of power output decreased as altitude increases. One hypothesis for this result is that while in the clouds, some light rays are diffracted around. This could cause the solar rays to be more directed towards the solar cell. When the cell gets above the cloud cover, a majority of the solar rays are the ones coming directly from the sun. As the solar cell gets closer to the atmosphere boundary, less and less diffracted rays are affecting the cell. Another explanation for this phenomenon could be the that cell becomes less efficient as its temperature decreases to below freezing levels. As the temperature of the cell goes down so does the energy of the electrons within the cell. If the energy of the electrons decreases enough they would move around less freely, thus reducing the amount of current running through the resistor.

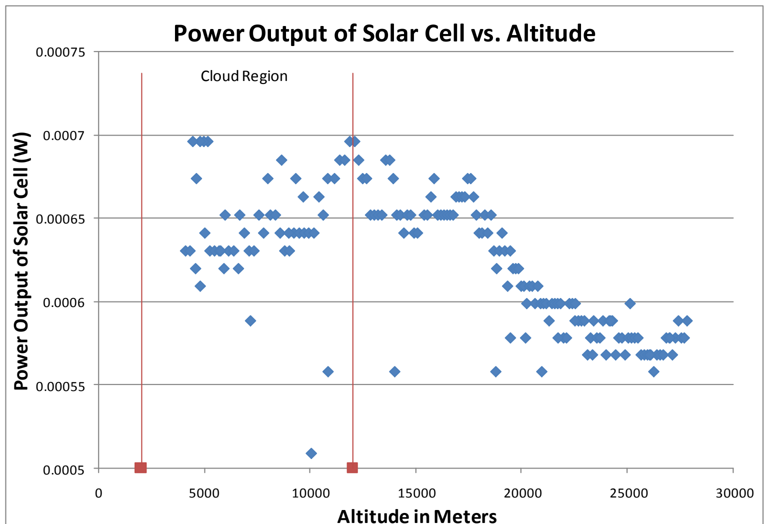


Figure 8- Power output of solar cell at varying altitude.

Atmospheric Mercury

Background. One of today's major concerns is the pollution of our planet and related environmental issues. Particularly in the atmosphere, with the increasing awareness of greenhouse gases and their effects, it is a mission to regulate and monitor their levels. As a major source of our energy, economy, and problems of this concern, the burning of fossil fuels, particularly coal-burning power plants, results in an increase of mercury concentrations[1]. Pertaining to Wisconsin in particular, as where our testing was done, the DNR estimates that 5,000 pounds of mercury is released into Wisconsin's environment and that one hundred percent of bodies of water within the state are contaminated with mercury[2]. A majority of the mercury enters the waterways from the atmosphere. According to various sources including the Wisconsin Department of Natural Resources, there are multiple advisories to not eat, or at certain limitations, fish from Wisconsin water bodies, as consuming them may result in mercury poisoning[2]. A serious health hazard, in result of mercury poisoning, one may experience memory loss, vision impairment and cardiovascular problems[3].

It is therefore crucial to understand the mercury cycle and be able to detect the localized atmospheric levels. We then assumed that the mercury level in the atmosphere will also be relevant to what is found on the surface of the earth. No previous accounts of high-altitude balloons measuring mercury levels were discovered, nevertheless, we anticipated having results in comparison to concerning levels on the surface.

Method. To measure the amount of mercury in water, soil, and air samples, we found an instrument called a gold trap is used. A gold trap is a quartz tube ¼ inch in diameter and approximately 10 cm long. Within the tube, there is a section of approximately 1 ½ inches that contains gold coated glass beads. As the air sample flows through the tube and gold, the mercury present in the air amalgamates with, or sticks to the gold. After the sample has been taken, the trap is heated to separate the mercury from the gold and the amount present is measured quantitatively. There is also the option of using gold coated sand instead of glass beads. We were fortunate to find a company, Brooks Rand Labs in Seattle, that specializes in mercury sampling. Our contact explained to us a lot of beneficial information about the process. We learned that we want to use glass beads versus sand, as the glass beads are used for air samples, whereas the sand is used for water samples. Once we used the traps to take samples, we sent our traps to their labs, where they were analyzed to find out how much mercury was present.

One of the biggest concerns with using the gold traps was contamination and condensation. Since the traps are able to detect mercury levels at such a low level, we did not want the traps to be exposed to the air until they were ready to be sampled. Similarly, they should not be exposed at any time after the sample was completed either. We also had to work on preventing condensation from building up on the traps, as the moisture can later the effectiveness of the amalgamation process. Since the payload travels through very cold temperatures and then warmed up again upon decent, we needed to determine how to keep the traps at or above ambient temperature at all times. Most of the instruments used for measurements are not made to function properly in such varying temperatures either, so the payload had to be properly insulated. Fortunately, with the combination of the insulation product used to build the payload box along with the use of multiple batteries, no outside source of heat was needed within the payload in order to keep the traps at the appropriate temperature.

When using the gold traps, there is a set manner in which samples are typically taken, but as ours will travel in a balloon payload, we have had to be creative. Using our resources with Solid Works and the Rapid Prototyping Center at MSOE, we created parts and a housing unit for the traps. The design can be described as a revolver barrel, where only the inner cylinder rotates to align the appropriate trap. An exploded view of the design is shown in Figure 9 below.

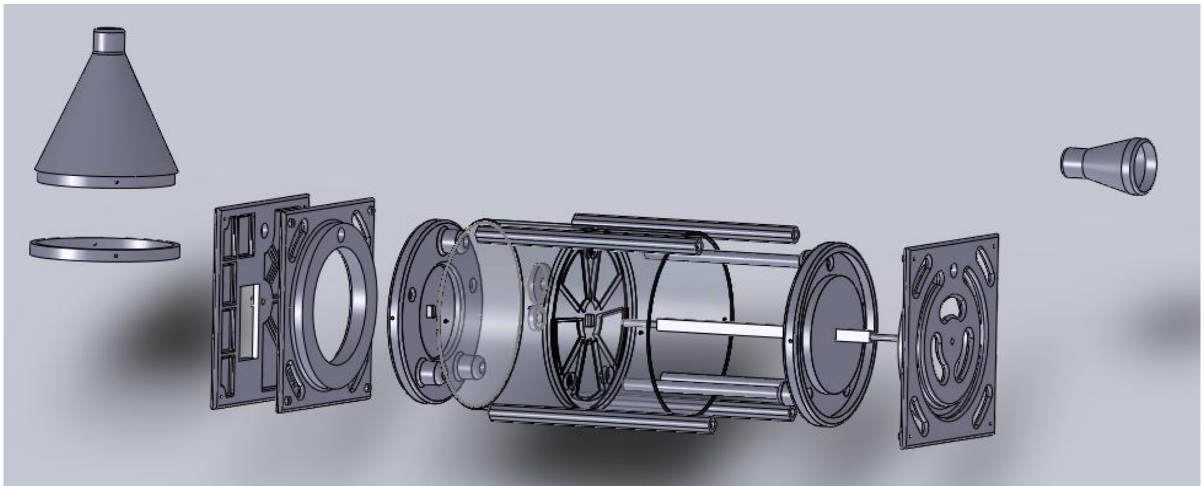


Figure 9- The mercury contraption. This is an exploded view to display individual components. Air enters the funnel on the left, travels through the contraption, and out the vacuum adapter on the right.

We took a total of three samples at varying altitudes, with one additional ground test, along with two positions serving as "dummy traps", or the locations of the cylinder when no sample was being taken. These dummy traps served to isolate the good traps from the elements, so we only drew air through them when desired.

Attached at the end of the contraption is a miniature vacuum. The vacuum was connected with a hose and directed to flow through the appropriate trap only at any given time. A predetermined amount of air needed to be drawn through each trap, as later described. The programming for the predetermined altitudes will depend on time, so a time-altitude calculation was carried out. The rotation of the cylinder occurred from a 180 degree servo motor gear that is meshed with a smaller gear on the cylinder as to allow nearly 360 degrees rotation of the cylinder.

We did not anticipate, or find, particulate mercury to be a problem. When using gold traps for air samples, there is a filter typically used to defer any particulate mercury that may be in the air. As our project is a special case for using the traps to sample mercury, a simple mesh screen was placed over the end of the funnel that air was drawn in through from outside of the payload.

Calculations. After launch, the gold traps were sent to Brooks Rand Labs for analysis. The amount of mercury collected during each sample was determined here, but those numbers are useless without some basis to compare them. What we are really after is the mercury concentration in the air at the different altitudes, so a method to determine the mass flow rate of air through the vacuum at any given altitude was derived.

The first step was to measure the performance of the vacuum at different pressures. Using a Bell Jar and a vacuum gauge to quantify the pressure inside the jar, the vacuum pump was hooked up to the tubing and gold trap. The free end of the tubing was vertically placed into a glass of water alongside a ruler to measure the water height within it. The height differences were recorded for various pressures, which allowed us to produce a pressure difference plot based on altitude. Because the Bell Jar could only simulate an altitude of 30,000 feet, we had to extend the trendline to forecast the vacuum performance at higher altitudes. The expected pressure difference plot generated by the vacuum is shown above in Figure 10.

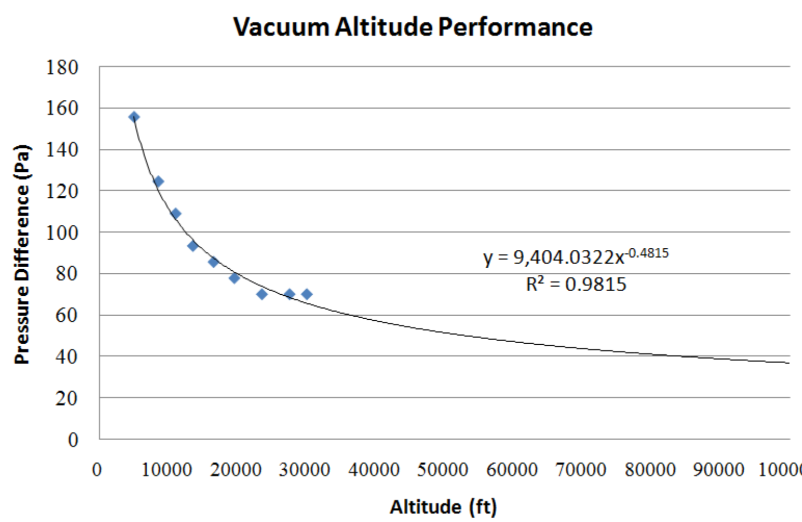


Figure 10- Expected pressure difference generated by vacuum.

The second step was to convert the pressure differences to airflow rates into the vacuum. The flow through the tubing was treated as flow through a pipe with a head loss, allowing for the application of Bernoulli's Equation (Eq. 1), relating inlet and outlet pressures ( ), densities ( ), and gravitational potentials ( ).

(1) — — — —

An approximate velocity of inlet air was measured with a velometer to be 40 feet/second, yielding a Reynolds's number of approximately 6000, which means turbulent flow. Equation 1 can be simplified by assuming constant density throughout the tubing, as well as consistent tubing heights. With an appropriate friction factor (assume to be a rough pipe because of the filter and beads in the gold trap), the head loss term is known, and allows for the velocity of air entering the vacuum to be calculated. The final step is to use the densities at various altitudes to determine the velocity of air entering the vacuum and the mass flow rate at different altitudes. These two aspects were then plotted and shown in Figure 11.

Our desired altitudes for testing were 30000, 60000, and 80000 feet, so the sample times to acquire four times the minimum suggested mass of air for each were calculated using the mass flow rates from the above plot. The minimum suggested mass of air to be drawn through each trap was provided by Brooks Rand Labs was determined to be 5.625 g.

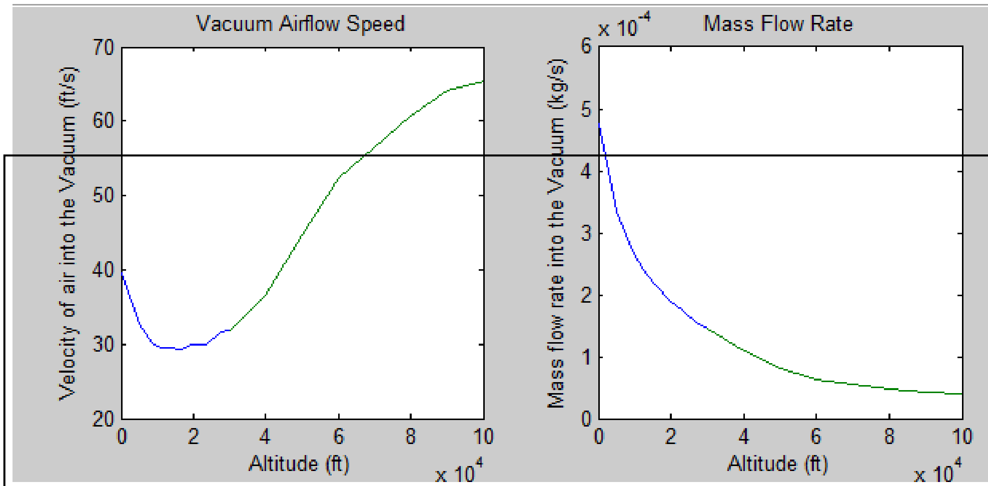


Figure 11- Plots of expected airflow speed and mass flow rate into the vacuum.

Results. We expected to find about 1.5 ng/m^3 of mercury present in the air based on several NASA studies in the past. Figure 12 summarizes our results, with the corresponding altitudes. As you can see, there is no consistent trend in the mercury levels based on altitude. It is interesting to note, however, that the ground level mercury was nearly zero, while the upper 40,000 foot sample captured a considerable amount of mercury. This could be a direct result of location, rather than altitude, as this sample was taken closest to the Madison metropolitan area. Further studies would be needed to obtain a more consistent location for each sample so as compare mercury levels of only one geographical position versus a spread out region.

Sampled Altitude (ft)	Mercury Level (ng/m^3)
1158	0.123
24550-39100	1.328
46900-48950	4.739
79300-85200	1.283

Figure 12- Mercury levels at different altitudes.

Conclusion

The 2010 Elijah Project team successfully designed four experiments, three of which were tested at altitudes up to 90,000 feet with the other planned to launch in September. The team is thankful for the opportunity and the experience gleaned from the internship. We hope that the findings will serve as a gateway to future further research.

References

[1] "Mercury in the Environment", U.S. Geological Survey Website, June 22, 2010. <http://www.usgs.gov/themes/factsheet/146-00/>

[2] "Clean Wisconsin, Inc., Air Campaign", Clean Wisconsin Website, June, 20, 2010. <http://www.cleanwisconsin.org/campaigns/air.html>

[3] "Are Fish From Wisconsin Waters Safe to Eat?", Clean Wisconsin Pressroom Website, June 20, 2010. <http://www.cleanwisconsin.org/pressroom/press_releases/043009b.html>

Elijah High Altitude Balloon Project Launch Team

Please Note: Due to the deadline for this report, it will focus primarily on the first launch of 2010. While another launch has been completed and will be mentioned briefly, details mentioned in the report will be focused mainly on the first launch.

Launch Team Members

The members of the 2010-2011 Elijah High Altitude Balloon Launch Team are as follows. Eric Deering of Milwaukee School of Engineering, Peter Schmalz of Marquette University, Vicky Salas of Marquette University, and Kevin Weathers of University of Wisconsin La Crosse. The team is advised by Dr. William Farrow of Milwaukee School of Engineering.

Equipment

Overview

The 2010 Launch Team is again using the StratoSat flight package developed by StratoStar Systems. This system was first used by the 2008 Launch Team and has proven to be a valuable resource. The StratoSat flight package consists of the following components that can be seen in Figure 1:

- Command Pod with on board GPS transmitter
- Three payload pods with built-in wireless transmitters
- Two $900Mh_z$ modules and tracking antennae
- A battery charger for the command pod
- StratoSat software that interfaces with Microsoft MapPoint
- Parachute
- Cabling and tethering

Figure 1: StratoSat system

In addition to the StratoStar Flight Package, the launch team also used high altitude weather balloons, helium, and the payloads to be flown. These payloads were provided by the WSGC payload team.

Balloons

The Elijah Launch Team began the year by utilizing 1200 g balloon models that were purchased through StratoStar Systems. The first flight first ended up utilizing both of these 1200 g balloons due to an on the ground failure of the first balloon. Using the 1200 g model in the first flight, a maximum altitude of 27710 m or 90912 ft was reached. In the second launch, a smaller 600 g model was used to achieve a lesser altitude and reduce overall flight time due to payload restrictions. The 600 g balloon used in the second launch was also overfilled to ensure a lower burst ceiling. The 600 g balloon produced a maximum altitude of 24368 m or 79950 ft. In general, the larger the balloon the greater the altitude if filled to the same amount of lift. By experimenting with the smaller balloons, a more cost effective way of launching was discovered. Since the smaller, 600 g balloons are about half the cost of a larger 1200 or 1500 g model, two launches can now be completed in the cost of one without sacrificing greatly on maximum altitude.

Command and Payload Pods

The StratoSat system is comprised of one command pod and three payload pods. The command pod serves as the brains of the operation and is the unit that transmits all data back to the ground through it's GPS system. Every 30 seconds the command pod sends out a GPS ping which is received by the GPS receivers included in the StratoSat system. The command pod allows for real time and reliable tracking of the payload while it's in flight.

Also included in the StratoSat System are three payload pods that contain wireless transmitters that are capable of wirelessly communicating with the command pod. Each payload pod has hookups for sensors that can collect data at altitude. This data is then wirelessly transmitted back to the command pod where it is then transmitted back to the ground via GPS.

The payload pods have yet to be utilized by any launch or payload team. However this year's team will be focusing on trying to get this additional aspect of the StartoSat system up and running. By including the payload pods into the launch system, valuable data can be collected on each launch, adding to the payload teams results.

Equipment Testing

Since once of the major responsibilities of the Launch Team is to track and recover the balloon and payload, it was a high priority to become familiar with the StratoSat System and to be sure all aspects of the system were in working order. During the first meeting, one of the first tasks was to try to get the command pod syncing with the StratoSat receiving hardware and software. This was done in one of the parking lots with two vehicles set up for tracking, and one vehicle driving around Milwaukee with the command pod. It was quickly realized that the antennae for the system are very directional in order to maintain contact with the command pod at great altitudes. By pointing the antennae in the direction of the command pod a signal was more easily obtained. The command pod can be seen in figure 2.

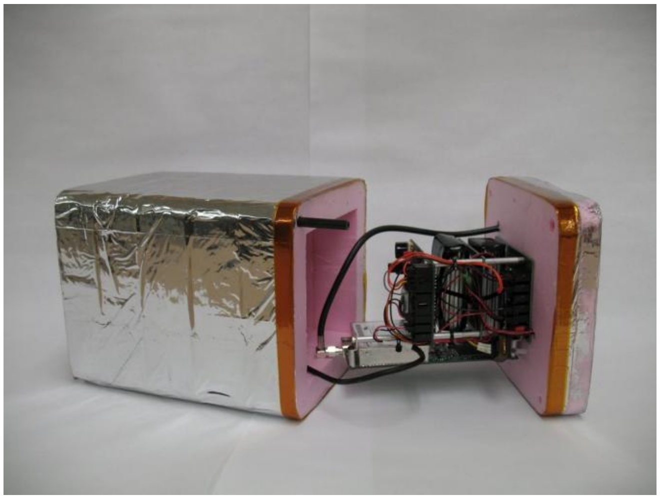


Figure 2: StratoSat Command Pod

Another aspect of the recovery of the balloon that needed testing was the radio tracking receiver and dog collar transmitter. The 2009-2010 Launch team had implemented a secondary tracking system which was comprised of a radio signal transmitting dog collar and a hand held radio receiver which could directionally locate the payload after landing. The directional nature of the StratoSat system made the payload difficult to find after it had landed due to obstructions such as hills and trees. The radio system allowed for a relatively bulletproof method of retrieval as long as the StratoSat system could get close. This system was also tested in the parking lot during the first meeting to ensure everything was functioning properly.

Launch Planning

Location and Launch Date Choice

The largest responsibility of the launch team is likely the choosing of the date and time as well as the location of a launch. By choosing a date and time that is advantageous to launching, harm to equipment and payloads is minimized while data gathering conditions are maximized. By choosing a good launch site, chase time is minimized and the balloons landing site is maximized.

Starting with the choosing of a launch site, quite a few things go into the final decision. The first step in the selection of a launch site is the use of an online resource on the website nearspaceventures.com.

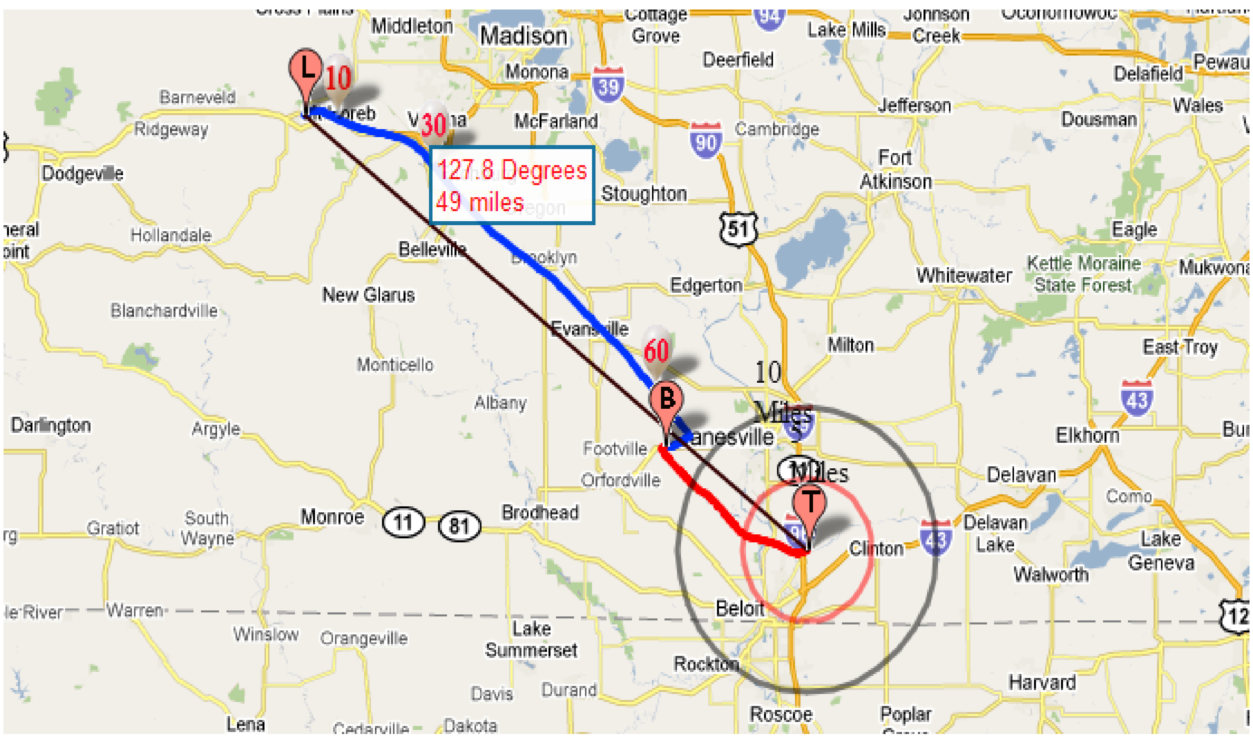


Figure 3: Flight Prediction from Nearspaceventures.com for August 14th Flight

Once on the near space ventures website, a program accessed through a link titled "Online Flight Prediction Page" creates a flight prediction based upon local weather patterns at specified times. The user inputs the GPS coordinates of a takeoff location, as well as the predicted ascent rate, descent rate, and burst altitude of the balloon. By using this input data and by collaborating with local weather accessed through local weather stations, a plot is created that shows the predicted flight path of the balloon with burst and landing points. The output of this software is shown in Figure 3. This software is extremely helpful in determining a suitable launch site because it allows the user to see on a map the predicted landing point of the balloon. All of this information is of course dependent upon the accuracy of the ascent and descent rates as well as the burst altitude of the balloon. Rarely is the prediction perfect however a general idea of a landing zone can be achieved.

The next step in the planning process is selecting a date. While selecting a launch site and date go somewhat hand and hand, the selection of a date is more dependent upon weather in the upper atmosphere and jet stream. This information is accessed through the following website, squall.sfsu.edu. Squall gives detailed jet stream forecasts throughout the country which is extremely helpful in making the decision on whether to launch or not. On the output map shown in Figure 4, gray areas denote turbulent jet streams. A general rule adopted by the launch team after the second launch is not to launch into gray. By launching into gray, the team risks the payload and tracking equipment becoming tangled in the jet stream which can lead to a non-deployed parachute.

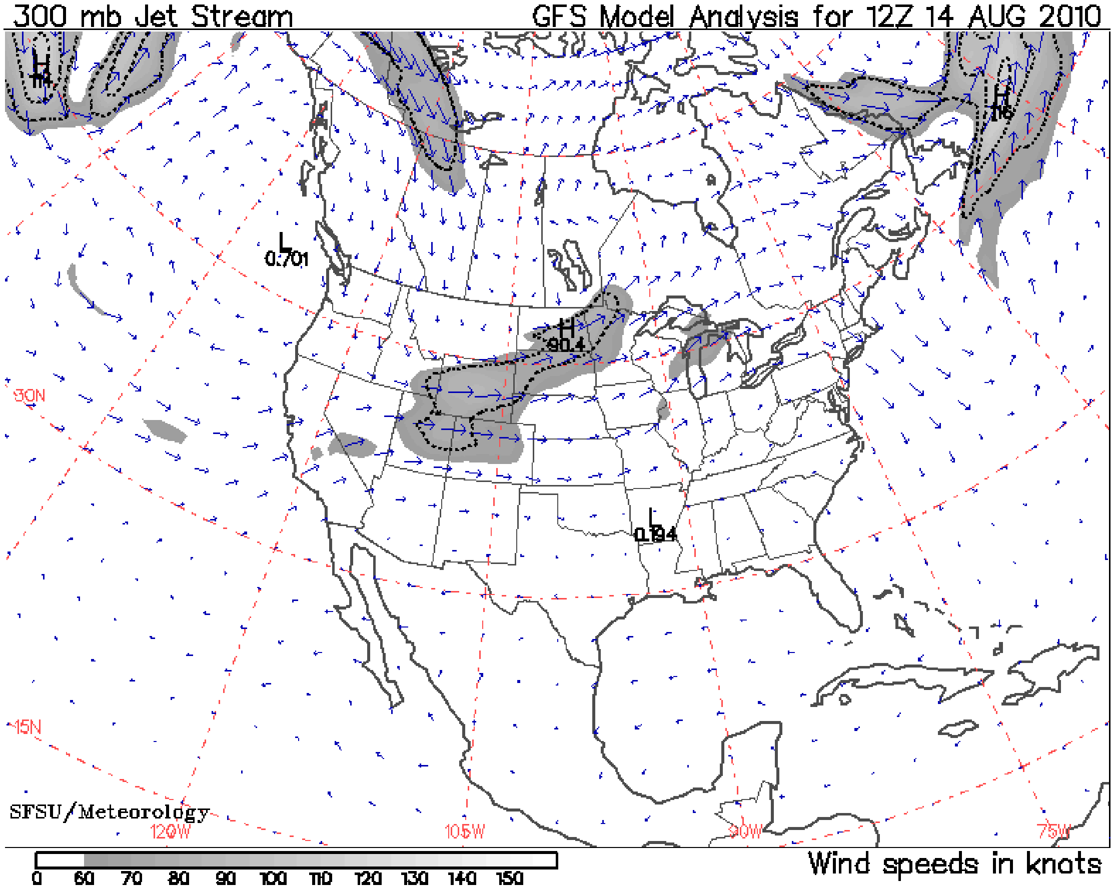


Figure 4: Flight Prediction from Squall Jet Stream Analysis

Launch Day Activities

Launch

After a disappointed first attempt the launch team rallied and set a launch date for Saturday, August 7. The team had to wait until closer to the launch date to choose a good location for the launch. After days of checking the flight predictions and monitoring the jet streams, the location was selected for the launch. The team selected a little town west of Madison called Mt. Horeb. The site was primarily chosen due to its western distance from Lake Michigan and its rural surroundings. The best locations are ones with lots of open space and limited power lines in the area. These would include football fields or community parks. Mt. Horeb had a great football field to use for the launch. Team members were to meet up in Madison around 9am where they were to regroup and eat some food before the 6 hour adventure began with all the team members. From WIFI hot spots such as McDonalds and Panera the team was able to check flight and weather predictions. An early launch time was decided on to keep winds to a minimum during the filling of the balloon.

After arrival, the team began setting up the launch location while accompanying members of the payload team began preparing the payload. The main concerns for the launch team were to fill the balloon, to make sure the command pod was correctly communicating with the tracking antennas, and to check and tie all equipment together securely.

Figure 5: Balloon Filling

The team had decided on the 1200 gram balloon in order to achieve a higher altitude and a slower ascent rate, which would help the payload cameras obtain more photos. The filling process begins by measuring total weight of the payloads. The balloon was then calculated to be filled with 1.5 times the lift of the payload weight. Using a digital fishing scale, the team was able to accurately measure the lift force when the winds were low. If the winds increased the team could use a bucket filled with the correct weight of water to test the lift of the balloon.

Figure 6:. Teammate Vicky Salas measures the lift force of the balloon

As the balloon started to fill disaster struck as the tank was opened up to quickly and a hole was ripped into the balloon. Equipped with a second balloon the team readjusted the tank nozzle and began filling the second balloon. During the filling process, the rest of the StratoStar equipment (command pod, parachute ring, connection tethers, etc.) was laid out and ultimately assembled. This process is shown in Figures 5 and 6. Command pod communications tests took place near the end of the balloon fill process and once the balloon was determined to be full. Both these tests confirmed the GPS system was operational and transmitting valid location data. The payload team members also confirmed that the cameras and mechanical systems attached to the payload were operational and functioning as expected.

At around noon a final check of all balloon, recovery, and payload equipment was performed. Nothing was found out of order, and the balloon was released shortly thereafter with a final lift of approximately 15 lbs.

Tracking and Recovery

After launch, members from both the launch team and the payload team began tracking the balloon to determine its initial direction and speed. The team lost sight of the balloon and payload in the clouds seconds after launch so the tracking system would have to work flawlessly. The balloon immediately headed in the predicted direction, cruising south east at 32 knots.

It was decided with this information that the team should head east on I-39 while maintaining distance from the balloon. The tracking strategy adopted by the team was reactionary in nature, although a program was used to guess the flight direction of the balloon. The program used the balloon parameters and the weather forecast conditions on the day of launch. Decisions concerning where the tracking vehicles should head were made by determining the general trend of the balloon's course and speed, and determining the best path for continuing to track or intercept the balloon.

The balloon's ascent was characterized by a very rapid climb in altitude during the initial and main phase of the flight, followed by a slower ascent once the balloon was above the jet stream. Between 30,000 and 50,000 ft, the balloon encountered the jet stream where it reached speeds over 100 mph. Ultimately, the balloon rose above the jet stream and steadily slowed in ground speed. After more than two hours of flight, the balloon finally gave out at approximately 90,000 ft near Evansville, WI. The flight path of the balloon can be visualized using Figure 7. The launch team waited at a gas station to see the balloons next move. At first the balloon started to back track towards Mt. Horeb as it fell back to earth. The team decided to wait until the balloon re-entered the jet stream and deployed the parachute before continuing the chase. It was the teams belief that the balloon would then head back east at a fast rate. After 10 intense minutes, the balloon finally changed course and sped east. The launch team proceeded to track the descent of the balloon and its payload, eventually locating it in Milton, WI.

Figure 7: GPS-Generated Ground Track of Balloon's Flight

After approximately 1 hour, the balloon location was narrowed down to a two square mile cornfield. Despite the massive challenge ahead, spirits were high in the teams. The launch team decided to use its secondary dog collar tracking system to locate the payload. The team also listened for the beeper to give away its location. After 2 hours of using the StratoStat system on the ground, a final GPS point was eventually obtained. This point showed the location of the command pod to be only 100 ft into the corn field. Using the latitude and longitude, the team was able to track the payload down on foot using hand held GPS devices. The balloon and payloads were found intact and still functioning properly. The Elijah launch team's first official launch was a success.

Flight Analysis

A review of the entire system after the flight showed that the system performed almost flawlessly during flight. The GPS system was found to be accurate in its measurements and the payload was shown to have worked as expected. Data from the GPS system showed that the parachute deployed perfectly and descended at a normal rate. Camera footage later confirmed a comfortable flight home. By putting the GPS data collected from the command pod into Google Earth as shown in figure 7, the effectiveness of the tracking system can be seen. The tracking system received data throughout the flight and never lost contact with the receivers. Overall the flight was a success.

Conclusion

The launch team has completed two successful launches and plans to complete numerous more launches in the coming months. With the help of the StratoSat System and secondary tracking devices, the recovery of the high altitude balloons now allows for a much higher percentage than in years past. Some things the launch team will continue to work on this year include documenting processes to make transitions between launch teams easier. By creating a manual for the WSGC launch team much of the smaller issues faced each year by new launch teams will be eliminated. The launch team has also talked about working with the StratoSat payload pods and to try and get them functioning and on flights. While much still needs to be done to perfect the art of launching high altitude balloons, the launch team is working on ways to do this and has made progress so far this year. With multiple launches planned for the future, the launch team plans to further refine the system of launching the balloons with an ultimate goal of passing as much knowledge as possible on to future launch teams.

20th Annual Conference
Part Two

Student Satellite Program
Rocket Design Competition

First Place, Non-engineering: Red Hawk Rocketry
2010 WSGC Intercollegiate Rocket Competition

Team Members: Matt Maginnis, Bryant Vande Kolk, Charolette Evans
Team Contributors: Nyi Nyi Aung, Rabin Gurung

Ripon College Faculty Mentors: Dr. Sarah Desotell and Dr. Mary Williams-Norton

Executive Summary

Goal/Intent:

The intent of Red Hawk Rocketry was to complete the assigned task of the Wisconsin Space Grant Consortium which was to design, construct, successfully launch a single stage, heavy-lift rocket to an altitude of 1500ft, and have the rocket have the ability to be re-launched with minor field repair.

Team:

Red Hawk Rocketry consisted of three team members and two international contributors, all of which were physics majors. The team manager was Matt Maginnis '12. The other two team members were Charlotte Evans (UW-River Falls) '12 and Bryant Vande Kolk '12. Our contributors were Nyi Nyi Aung '12 and Rabin Gurung '11.

All participants in Red Hawk Rocketry had little experience of heavy-lift or high-powered rocketry, with the basis of knowledge being limited to Estes model rockets and an elective course offered at Ripon College that focused on foundations of flight.

Rocket:

Initially, the rocket was intended to be 35lbs and 8ft tall. However, over the course of construction and experimentation, the rocket's dimensions soon changed to better fit the specifications of flight. Included in this report are the design features, construction, and specifications of the rocket.

Challenges/Complications:

There were many challenges when constructing this rocket. Some challenges that were faced were: determining the diameter and length of the rocket, determining the size of the parachute to ensure a safe landing, and creating a budget that would allow for mistakes.

Some complications that were faced were inclement weather on the practice launch date, the attachment of the nose cone to the rocket with epoxy, and the creation of a solid mass of mortar which could not be easily altered.

Budget:

The allowance for the budget was up to $1000. The final budget of Red Hawk Rocketry amounted to $660.45, which can be seen in detail later in this report.

Design Features of the Rocket

Nose Cone:

As in any rocket moving through a compressible fluid medium, the nose cone is vital to the aerodynamics of the rocket and protection of its internal elements.

This nose cone was made from Polystyrene PS, a common plastic, and the shape was a hollow ogive. With a wall thickness of 0.125in and weight of 1.135lbs, the cone had a 13in length. The inside diameter was 5.5in and outside diameter was 5.57in.

Body Tube:

The body tube houses all the components of a rocket.

The body tube was Blue Tube 2.0, a high-density, high-strength paper which prevented shattering or cracking in the event of a rough landing. The tube weighed 2.18lbs with a length of 76.25in. The inside and outside diameters were 5.5in and 5.57in, respectively.

Motor Tube:

The motor tube holds the high-powered, K1100 rocket motor and its casing.

The motor tube was cardboard and had an inside and outside diameter of 2.126in and 2.25in, respectively. The weight of the motor tube was 0.172lbs.

Centering Rings:

Centering rings secure the motor tube in the center of the rocket and provide strength for the fins and support for the large mass of the rocket.

The rocket had four plywood centering rings with a diameter of 5.5in attached along the motor tube with epoxy. The inner diameter was about

2.25in so that the motor tube would fit inside. The four centering rings were located at 0.0in, 5.5in, 11.125in, and 16.25in from the bottom and had a total weight of 0.756lbs.

Parachute:

The parachute slows down the fall of the rocket to the ground. Calculations showed that the rocket could safely land with a vertical velocity of 15-20ft/sec.

The Top Flight Recovery 1.9oz ripstop nylon parachute had a diameter of 120 in with no spill hole, weighed 1.32lbs, and had 16 edges.

Rail Buttons:

Rail buttons ensure that the rocket launches straight off the pad.

The two rail buttons from What’s Up Hobbies were made of Delrin (polyoxymethtlene) and had the attributes of being stiff, stable, and having low friction. They were screwed in at 0.5in and 27.125in from the bottom of the rocket.

Fins:

Fins are used for directional stability during flight.

The three sanded G-10 fiberglass, a glass expoxy laminate, fins known for their high-strength and moisture resistance were trapezoidal in shape to reduce drag and each weighed 0.485lbs, and had an area of 42.8in^2 and thickness of 0.093in.

Electronics Bay and Electronics:

The electronics bay holds the instruments that allows for flight analysis.

The electronics bay was located between the upper and lower sections of the body tube and was housed in a coupler. It consisted of a turn buckle with two eye hooks, a 9-volt battery, and an AIM 2.0 altimeter, and weighed approximately 3.17lbs.

The AIM 2.0 altimeter works up to 40,000ft, is dual-deployment, and allows for flight analysis when connected to the a computer.

Added Weight

Added weight allows for a rocket to become heavier without changing the dimensions of a rocket.

A coupler with 25lbs of mortar and iron rods was located 11.5-27.125in from the bottom of the rocket.

Diagram of the Rocket

1. Nose Cone
2. Bulk Plate
3. Coupler
4. Parachute
5. Electronic Bay
6. Weight
7. Center of Gravity

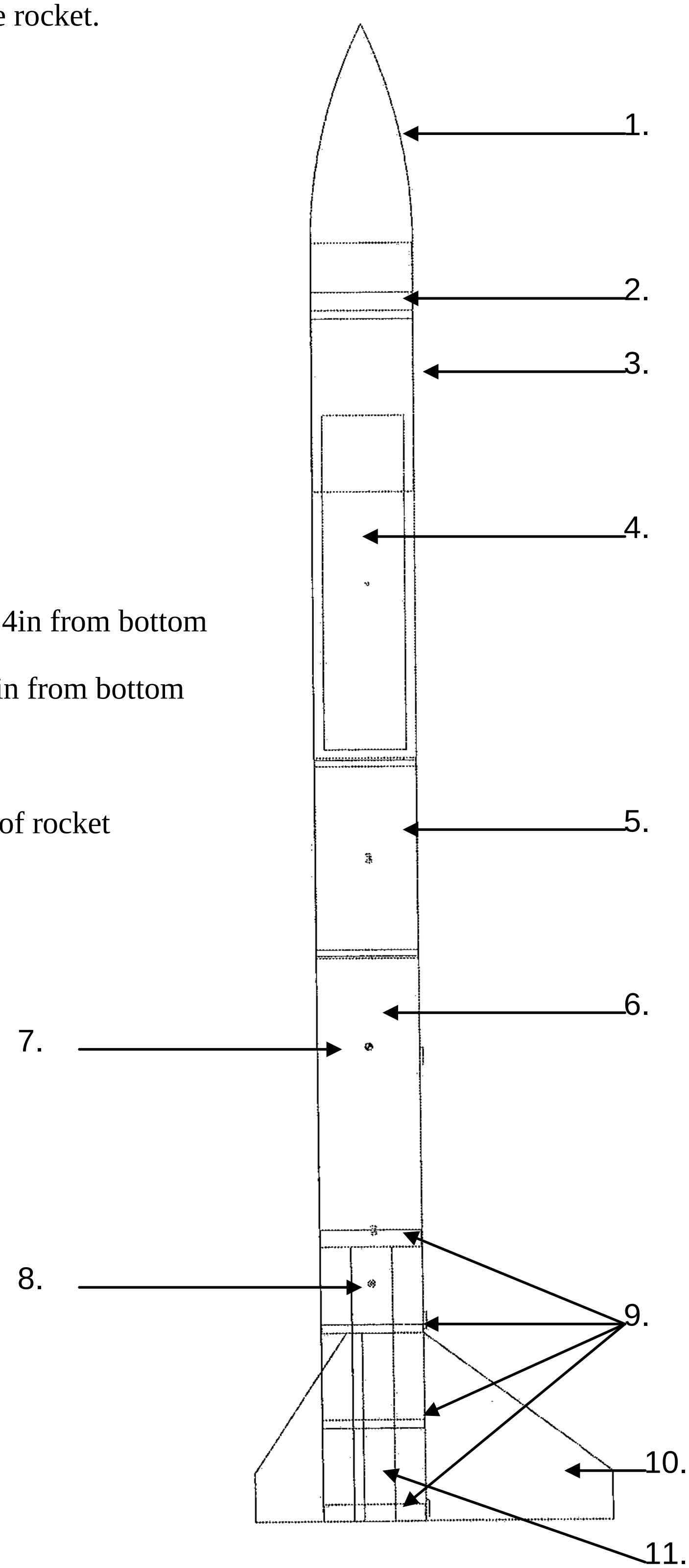
   Located – before burnout: 28.4in from bottom

   Located – after burnout: 28.9in from bottom

8. Center of Pressure

   Located: 13.8in from bottom of rocket

9. Centering Rings
10. Fins
11. Motor Tube



Analysis of the Anticipated Performance

RockSim Software was implemented to determine the estimated maximum altitude and acceleration of the rocket. The software can estimate the stability of the rocket when various components are entered. The software allowed for the best placements and weights of components were to determine the most efficient performance to reach the desired altitude and acceleration. RockSim has a 5% error.

The launch conditions were assumed to be at an initial altitude of 0ft at 40° F with relative humidity at 50%. After entering all of the necessary component information of the rocket, the RockSim provided the following:

Launch guide data:

- Launch guide length: 36.0000 in.
- Velocity at launch guide departure: 35.7675 ft/s
- The launch guide was cleared at: 0.158 Seconds
- User specific minimum velocity for stable flight: 43.9993 ft/s
- Minimum velocity for stable flight reached at: 55.8785 in.

Max data values:

- Maximum acceleration: Vertical (y): 275.645 Ft/s/s/s Horizontal (x): 0.323 Ft/s/s Magnitude: 275.645 ft./s/s
- Maximum velocity: Vertical (y): 261.800 ft/s, Horizontal (x): 0.0000 ft/s, Magnitude: 265.3111 ft/s
- Maximum range from launch site: 132.82281 ft.
- Maximum altitude: 1228.36234 ft.

Recovery System data:

- Time to burnout: 1.601 sec
- Time to apogee: 9.336 sec
- Optimal ejection delay: 7.735 sec

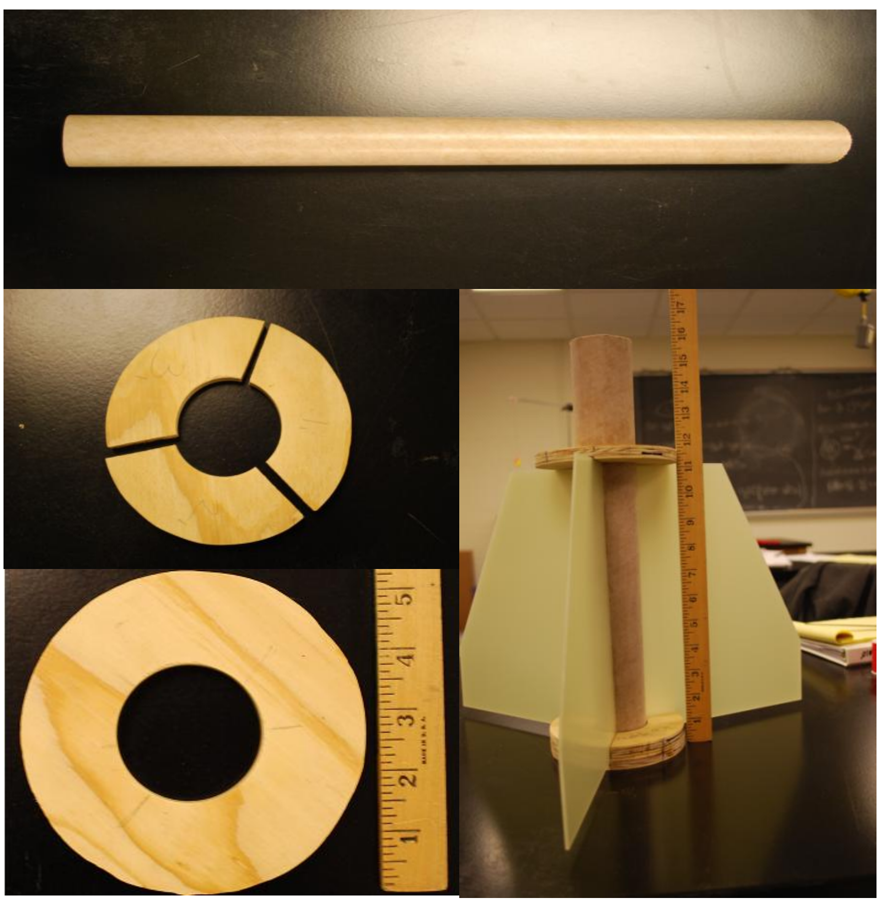
Landing Data:

- Time to landing: 63.957 sec.
- Range of landing: 460.57233
- Velocity at landing: 25.0784 ft/s

Construction of the Rocket

Motor Tube and Centering Rings:

Construction began with the motor section. The initial 54mm motor tube was cut to 16.25in to fit in the motor retainer. The next job was to mark equidistant distances around the tube to place the fins. Three of four centering rings were to hold the fins in place, while the bottom centering ring was kept as a solid ring with a second ring on top that had spaces cut out in order to hold the fins. The middle centering ring was cut into three sections and placed between the fins for stability, and the third was grooved in to fit the fins and securely hold them in place. The fins were glued in using a two-step epoxy, which was then reinforced using liquid nails. The fourth centering ring was placed at the top of the motor tube and consisted of two plywood rings glued together for strength. This was then glued to the motor tube using two-step epoxy and reinforced with liquid nails.



Bottom Section of the Body Tube:

The next section was the body tube that houses the motor section of the rocket. This section was made of the Bluetube 2.0 described above and was 3ft in length and 5.5in in diameter. At the base of the tube, the lines in which the fins would be located were marked and then cut out the slots using a traditional saw and sanded to prepare for glue.

Top Section of the Body Tube:

The top section of the rocket was built next. This section was cut to a 3ft section, like that of the bottom section. Without knowing the consequences of securely attaching the nose cone, the nose cone was glued to the top section. To attach the 15ft shock cord, a wing nut and bolt fastened a carabiner were used. The shock cord was then fed through a bulk plate that was glued in place at the base of the nose cone. The parachute was attached to this shock cord.

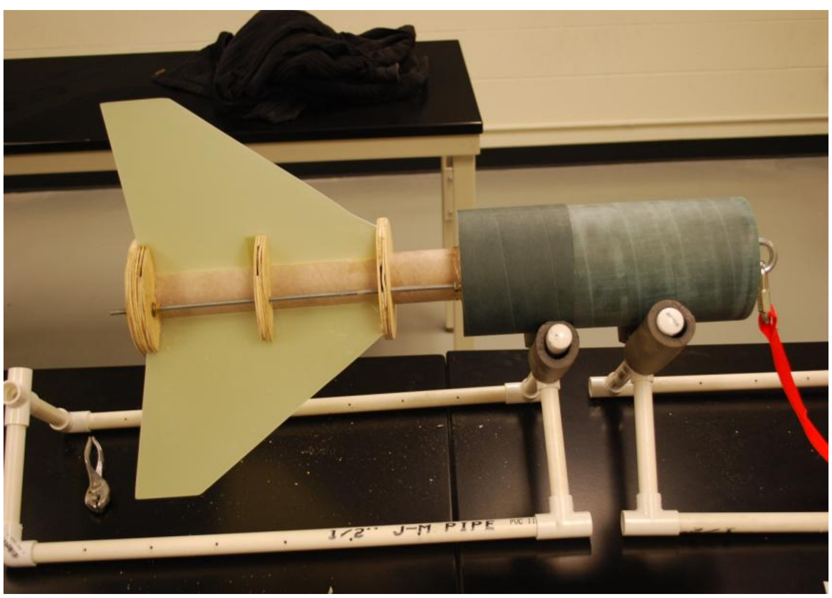
Later, to account for the attached nose cone, a coupler was used to separate the nose cone from the rest of the body to ensure the rocket could break apart correctly and have a successful parachute deployment.

Electronics Bay:

For convenience, the coupler that connected the two body sections together as the electronics bay was utilized. Another coupler was spliced, shortened, and placed inside of the electronics bay to keep the two bulk plates used as end cads in place. Two rods and a turn buckle were threaded inside the electronics boy to secure the end caps to each other. The altimeter and battery were fastened to the turn buckle. The shock cords were connected from the top and bottom sections of the rocket to the turn buckle.

Added Weight:

To create a rocket that was heavy as possible that can reach an altitude of 1500ft, a 20lb weight was required. Through RockSim, it was determined that the weight could be attached and secured to the top of the motor tube to ensure that the center of gravity was located above the center of pressure. The weight was created out of mortar and iron rods and had two threaded rods placed through it with two plates on the top. Holes were drilled through the centering rings and had to two threaded rods fastened to them using nuts and liquid nails. After the liquid nails dried, epoxy was used to glue the motor rube and the added weight into the bottom of the rocket.



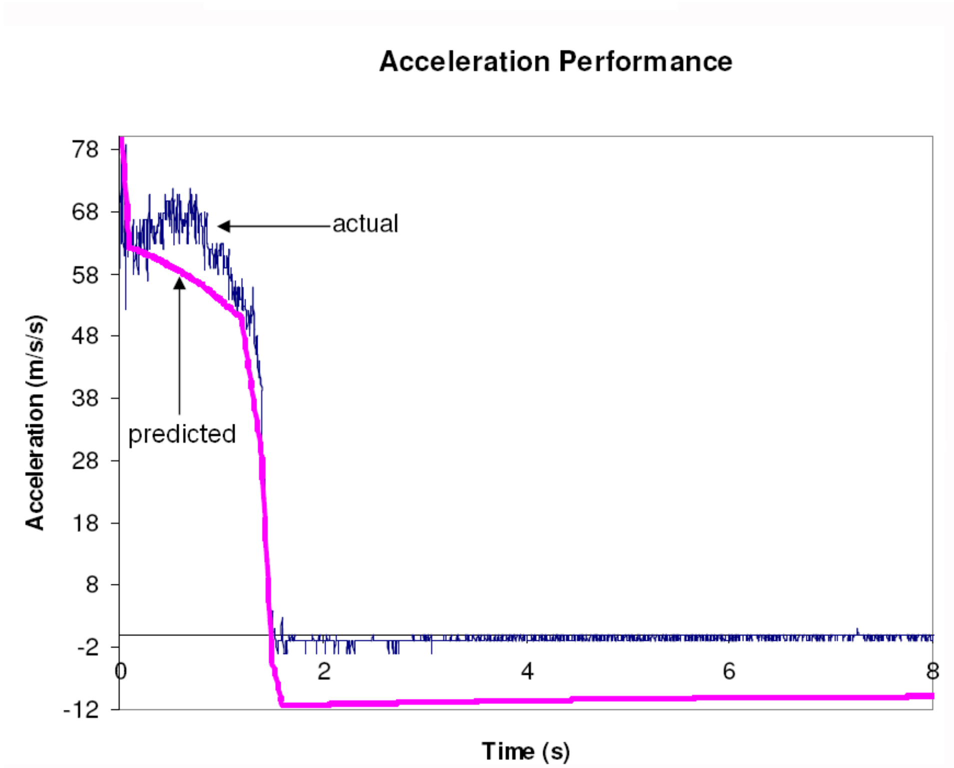
Launch Results

Launch:

Preparing for the launch on May 1 brought some surprises. In addition to one of our vehicles breaking down that prevented us from making the morning meeting, we walked around looking for any kind of advice, instruction, and assistance. With the help of the other Ripon College team, we were able to launch fourth, as planned. Setting up at the rocket launch pad was a great experience; the man helping us was very helpful, and we learned a few new things about our rocket's motor and how it's fired.

Acceleration:

The actual maximum acceleration the rocket achieved was 76.518m/s^2 while the predicted maximum acceleration was 84.12m/s^2.



Apogee and Altitude:

After launch, the rocket shot straight up in the air, hitting apogee at an altitude of 1033ft, which was less than expected altitude of 1500 ft. It is assumed that it was due to variation in weight. A successful deployment of the parachute glided the rocket to a safe landing.

Landing:

All the components of the rocket landed without fracture a few hundred yards from the launch pad, which is a result from a successful deployment of the parachute.

Weight:

The rocket weighed 40 lb, more than expected as the measured and calculated weight was around 35 lbs. The unexpected weight impeded the height of the launch that we expected to be about 1200 ft.

Difficulties:

The major difficulty was the excessive weight of the rocket which prevented the rocket from reaching the desired altitude and the inability to easily alter the added weight because it was made of mortar.

Conclusion

Fulfillment of Goal/Intent:

The goal/intent, as stated in the Executive Summary was designing, constructing, and successfully launching a single stage, heavy-lift rocket to an altitude of 1500ft, ensuring a safe landing and recovery for the rocket, appears to be on track.

While RockSim estimates and calculations approximated the height of the rocket to exceed the altitude of 1500ft, the actual flight of the rocket fell short at 1033ft.

Summary of Rocket Design and Construction:

Through research and trials, the rocket that was constructed was successful for novice rocket designers and focused on the fundaments of flight. The knowledge obtained can be used in future years.

Observations:

After inclement weather crippled the ability to execute a test launch and after RockSim calculated the excessive weight, Red Hawk Rocketry worked to decrease the added weight. However, with epoxy holding the mortar in, the weight was difficult to alter. On the launch date, the expectation that the excess weight would add a problem came to fruition and the maximum altitude came short of what was calculated. In the future, Red Hawk Rocketry use added weight that is more easily varied.

Student Rocket Design Competition

Team Space Badgers[1]
Chelsey Erickson, Daniel Grossheim, Nathan Woodruff
University of Wisconsin-Madison

The goal of this year's rocket design competition was to design, develop, construct, and fly a single-stage, heavy-lift rocket. For a successful flight, the rocket must reach a minimum altitude of 1,500 feet using an Aerotech K1100 motor, have successful separation at apogee, and be safely recovered under parachute. To accomplish these goals, Team Space Badgers first focused on the assembly of the rocket, the payload, and the recovery system. A 4" rocket diameter was chosen after doing simulations using RASAero which determined maximum altitude was not significantly affected by airframe diameter. A large portion of the weight of the rocket will be in a payload tube located behind the electronics bay. The sections are secured together by a large threaded rod. To achieve a stable flight, the payload can be move forward and back to move the center of gravity with respect to the center of pressure.

Two deployment electronics will be used to determine apogee and deploy the parachute. The system is redundant to ensure proper deployment. The parachute was chosen based on the estimated total weight of the rocket of approximately 30 lb. The parachute is a SkyAngle Cert 3, which will provide a descent rate of 23 ft/s from 1500 ft.

A modified Performance Rocketry 4" Arrow kit was chosen for the rocket airframe to accommodate all the selected and designed components. The predicted altitude for the rocket weighing 29.0 pounds is 1707 ft and the peak acceleration during motor burnout is estimated to be 248 ft/sec^2.

[1] Sponsored by the Wisconsin Space Grant Consortium (WSGC)

Design Features

The basis of the competition is to reach a minimum altitude of 1500 ft while maximizing the weight of the rocket. The initial design idea would be a minimum diameter rocket with a very dense payload. Optimally, the smaller diameter rockets should perform the best due to their lowered coefficient of drag. To validate the initial design, simulations were run using RASAero, which is a flight simulation software designed for high power rockets. The simulations were performed for multiple diameter rockets starting at the minimum diameter of 2.12” and including diameters of 2.5”, 3”, 4”, and 6” while maintaining equal proportions of length and fin sizes. The competition specified Aerotech K1100 motor and an assumed weight of 30 pounds without the motor was used for these simulations. The simulated flights are shown in Figure 1.

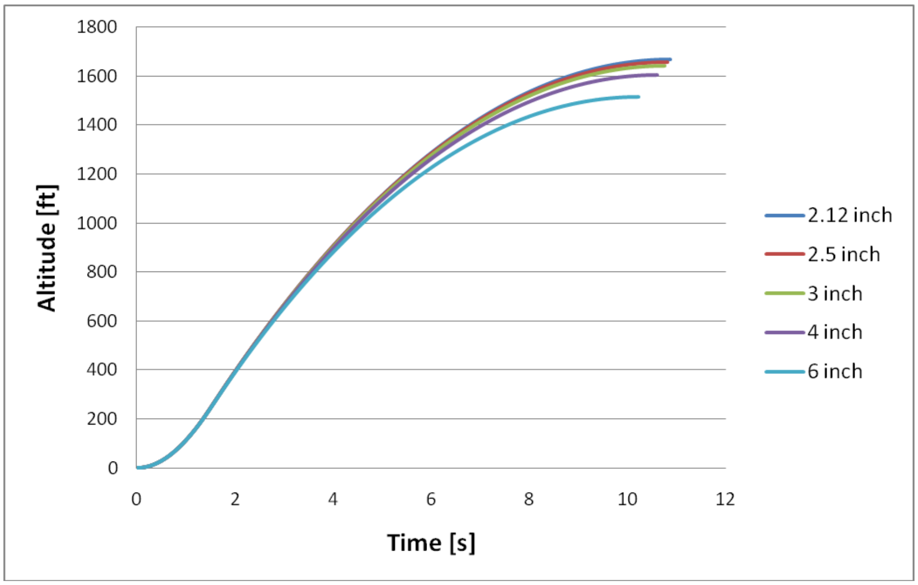


Figure 1: Flight Simulations for Varying Diameter Rockets

Though the minimum diameter rocket shows a maximum altitude of 1668 ft, the 4” diameter rocket shows a maximum altitude of 1606 ft, which is only an altitude difference of 62 ft. The conclusion from these simulations is that rocket diameter is not a major consideration for the design and other parameters were considered to optimize the rocket design.

Other parameters included adding weight to the rocket and having a successful recovery of the rocket. For these reasons, a 4” diameter airframe was selected to provide the necessary space requirements, attain a heavy mass, and maintain stability while only sacrificing the prior mentioned 62 ft due to increased drag. To add weight and strength to the rocket airframe itself, fiberglass was used in its construction.

In addition to airframe diameter, the length of the rocket must be considered to allow for enough internal space, and also for stability. There are two factors that affect the stability of the rocket, center of pressure (CP) and center of gravity (CG). Further information on the rocket stability is discussed later, but in basic design, it is important to know that the CG should be slightly in front of the CP, to cause the CP to rotate about the CG, which will always produce a stable flight pattern. When considering the design of the rocket, a longer airframe will improve stability because there is a larger area to evenly spread out the weight and locate the CG exactly where it needs to be.

With these factors considered, Performance Rocketry's Arrow 4 fiberglass kit was purchased and slightly modified by increasing the overall length by 7 inches. The total length of the rocket is 8 feet 11 inches from the tip of the nosecone to the end of the boattail, and is 4 inches in diameter. The sections of the rocket, as shown in Figure 2 are the nosecone, parachute section, electronics bay, payload section, fin section, and boattail.

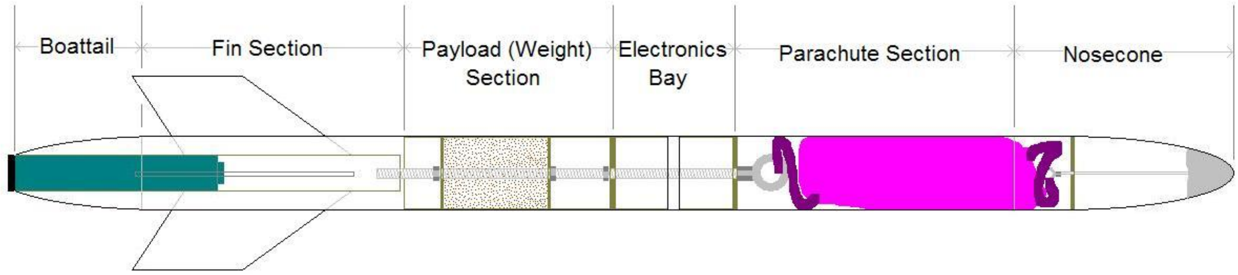


Figure 2: Rocket Design Schematic

As previously discussed, the objective of this competition is to fly the heaviest rocket to 1500 ft. Therefore, the payload section in the rocket is mass. Three main considerations in determining what type of mass to use were ease of adding and removing weight, ease of locating mass in the rocket, and safety of the mass.

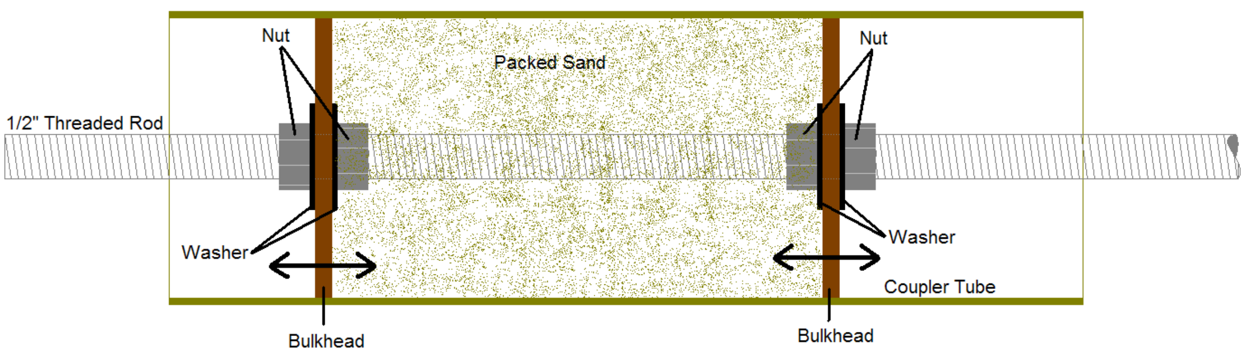


Figure 3: Payload (Weight) Section Schematic

To optimize these criterion, the payload section, shown schematically in Figure 3, consists of a 1⁄2" threaded rod, a coupler tube, several bulk heads, nuts, washers, and concrete powder. The weight of the rocket is 16 pounds, meaning that the payload section should weigh approximately 13 pounds. A steel threaded rod runs from the back of the payload section through the electronics bay. The load due to the payload section gets transferred from the threaded rod to the electronics bay to the airframe of the rocket, which is important because the mass can experience 10g of acceleration during motor burnout, so 13 lbf would become 130 lbf. In addition to load transfer, the threaded rod allows the payload section to be positioned along it to ensure flight stability. The location of the mass can be changed simply by moving the nuts, washers, and bulk heads along the threaded rod. Using powder as the weight allows mass to easily be added or subtracted from the payload section to achieve the desired rocket weight. Furthermore, if something catastrophic were to happen to the payload in flight, powder would fall to the ground instead of one massive weight.

Recovery System Selection

In high power rocketry, safety is always a major consideration. In parachute selection, safety is the primary consideration, not only for the people and property at the launch site, but also for the safety of the rocket itself. For this competition, the rocket will be heavy and will reach low altitudes, posing a safety risk, which is why recovery is the most important part of the flight.

The SkyAngle Cert 3 – Large parachute was selected because it is designed to be used in rockets weighing 16.2 to 35.0 pounds. The parachute, with a surface area of 57 ft^2 requires 4" diameter airframe and 18" of airframe to safely pack, which can be accommodated by the Arrow 4" kit. Using the SkyAngle Cert 3 - Large parachute, the rocket is expected to descend at a rate of 23.15 ft/sec, or 15.78 mph from 1500 ft in approximately 64 seconds. A descent rate of 20 ft/sec is often suggested as a rule of thumb for a safe landing for a model rocket.

To deploy the parachute after apogee, black powder charges will be used. To set off the deployment charges at the appropriate time, two recovery electronics will be used. The first set of electronics is a Missile Works RRC2 Mini Altimeter and the other is a PerfectFlight Mini ALT/WD. Both are proven reliable electronics that have worked in the past. The electronics will be wired to be dual redundant. Each electronics set will set off the deployment charges at apogee (maximum altitude) and set off secondary deployment charges at 1000 ft.

Stability

Flight stability is one of the most important considerations in rocketry and is determined by the center of gravity (CG) and the center of pressure (CP) of the rocket. The center of gravity is the balance point for all the weight in the rocket. The center of pressure is similar to the center of gravity except the forces acting on the rocket involve air pressure as opposed to weight. This is the point where there is as much air pressure in front of it as behind it. If the center of pressure is not concentric with the center of gravity, a resultant force causes rotation of the rocket about the center of gravity.

If the CP is in front of the CG and the flight of the rocket deviates from a perfectly straight line, the resulting drag forces cause the CP to rotate about the CG, increasing the rocket's angle of attack. This increased angle increases the force, and causes even more rotation, propelling the rocket on an unstable flight path. If the CP is behind the CG and the flight deviates from a perfectly straight line, the resulting force causes the CP to rotate about the CG again. However, because the CP is behind the CG, the rocket's angle of attack is decreased, producing an inherently stable flight. However, if the CP is far behind the CG, the flight becomes overstable. In windy conditions, a large moment causes rotation of the rocket like before, cocking the rocket's flight into the wind, decreasing maximum altitude, though still producing a stable flight. In rocketry, the rule of thumb is to locate the center of pressure one rocket diameter behind the center of gravity, which is 4" in this case.

Center of Pressure and Center of Gravity at Launch. Barrowman's theory[2] was used to calculate the center of pressure for the competition rocket and is located 68.3" from the tip of the nosecone, as shown in Figure 4. The ideal location for the CG would be 72.3" from the tip of the nosecone.

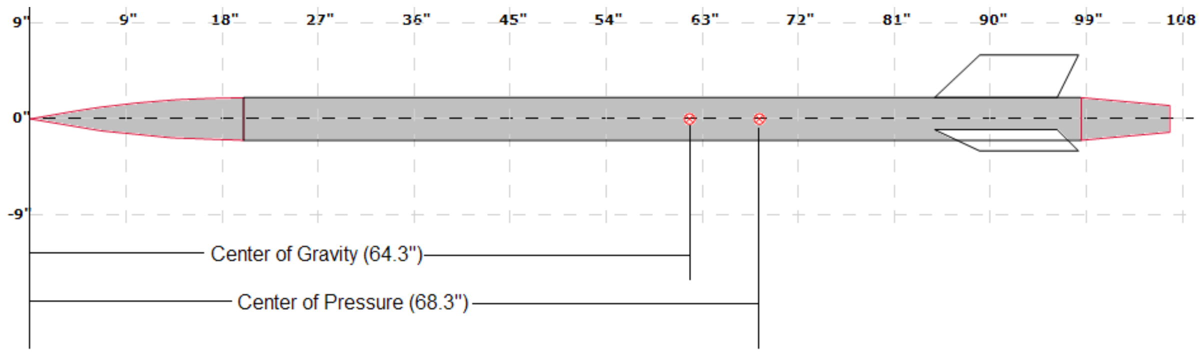


Figure 4: CP and CG of Rocket

Center of Pressure and Center of Gravity after Motor Burnout. As the motor burns, the center of gravity of the rocket assembly moves forward due to the reduction of mass in the rear of the rocket. Typically this would cause the rocket to become overstable. However, the approximate weight of the motor is 1.92 pounds, while the remaining mass of the rocket is 28 pounds. This loss of weight in the rear of the rocket has a minimal effect on the location of the center of gravity, which is concentrated in the payload section at original center of gravity. The rocket will continue on its stable path to coast to a maximum altitude.

Anticipated Performance

Ideally the rocket was designed to attain an altitude of exactly 1500 feet. RASAero software was used to determine how much weight could be added to successfully reach this altitude. With a rocket mass of 31.1 pounds without the motor, the simulation shown in Figure 5 predicts a maximum altitude of 1504 ft.

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[2] Barrowman, James. **Calculating the Center of Pressure of a Model Rocket.** Catalog No. TIR-33. Centure Engineering Company. Phoenix, AZ.

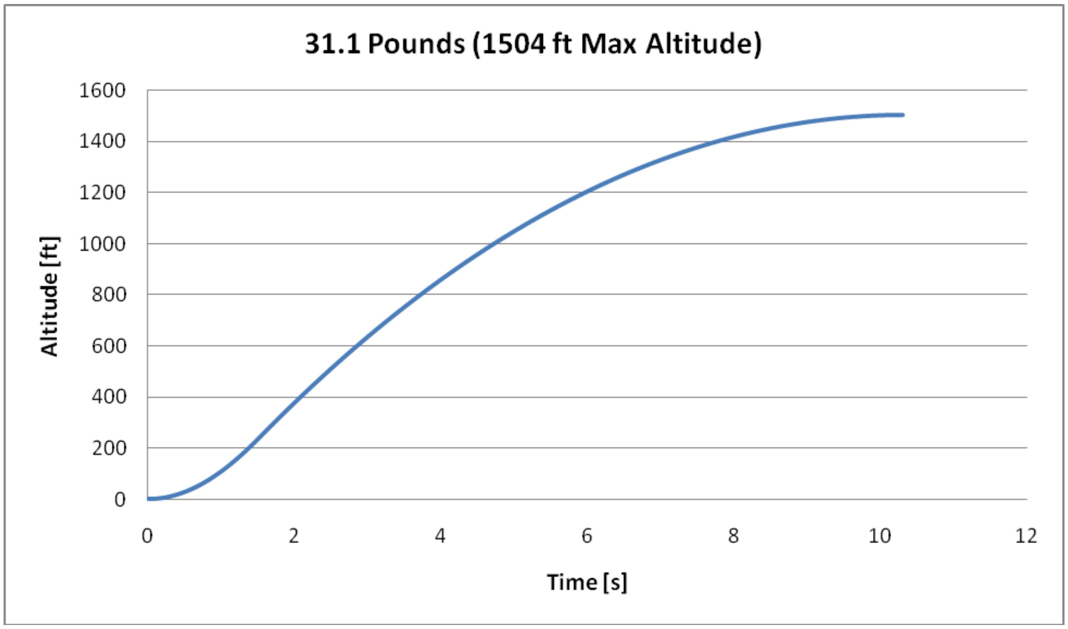


Figure 5: Predicted Rocket Altitude

However, this simulation assumes that the rocket leaves the ground perfectly perpendicular to the plane of the ground, without rail friction, with a perfect motor burn, and without excessive wind forces. In order to have a successful flight and actually reach the 1500ft lower limit, a simulated maximum altitude of approximately 1700 feet was used to determine the optimal rocket weight. The simulation in Figure 6 shows a rocket flight reaching 1707 feet with a rocket of 29.0 pounds without the motor.

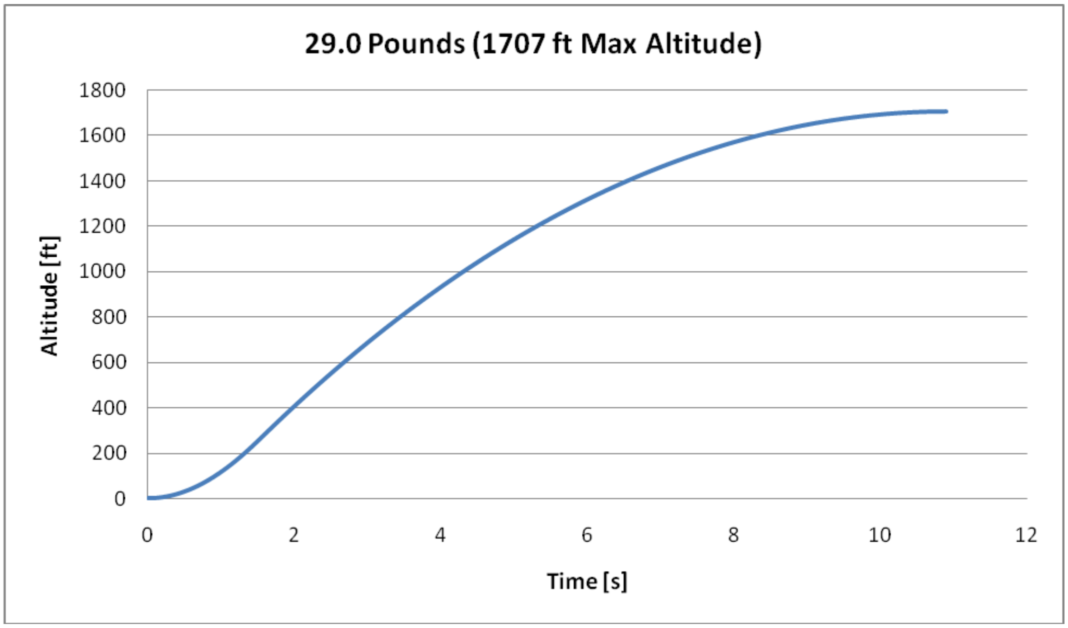


Figure 6: Predicted Rocket Altitude

After we determined how much the rocket should weigh, a simulation was done to determine the peak acceleration. The simulation shown in Figure 7 shows the positive acceleration on the rocket. The peak acceleration during motor burnout is estimated at 248 ft/sec^2.

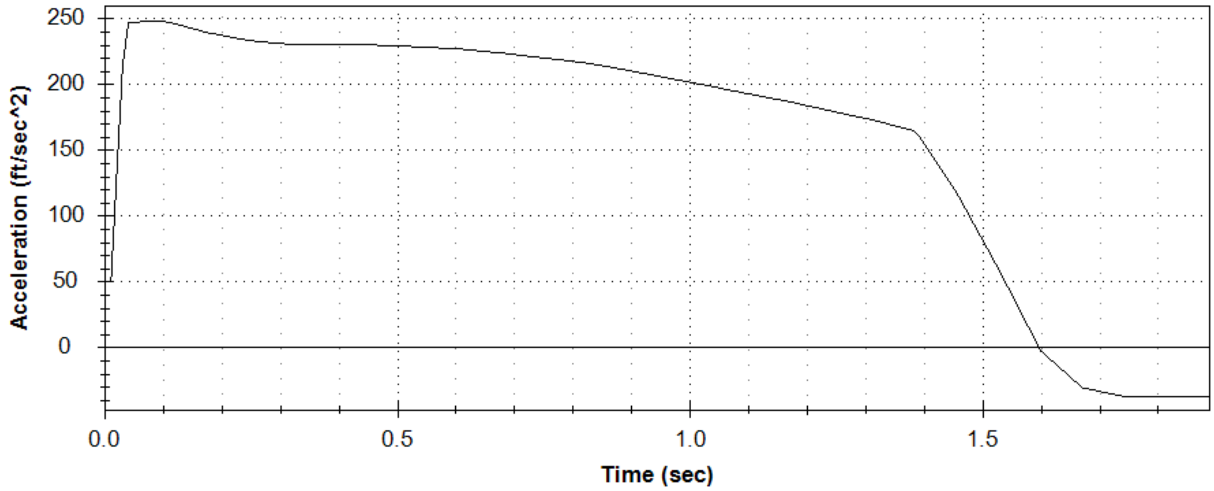


Figure 7: Rocket Acceleration

Launch Conditions
Launch order was specified prior to launch day. Team Space Badgers elected to launch early in the order because the wind is typically lower earlier in the morning. The launch day weather at Bong Recreation area consisted of mild temperatures, partly to mostly cloudy skies and moderate winds. As predicted, the wind was much calmer earlier in the day. At the time of launch, third in the order, the wind speeds fluctuated around 15mph at ground level. At higher altitudes, based on how the parachutes behaved in the air, the winds were even stronger.

Competition Flight and Flight Performance
Team Space Badgers along with completed rocket, shown in Figure 8, was the third team to launch on the competition day. The rocket weighed in at 33.0 pounds, at the time of the launch, as was predicted for peak performance.


Figure 8: Team Space Badgers

Figure 9 shows a successful launch off the pad for Team Space Badgers. The remainder of the flight was stable and successful. At apogee the charges deployed and the parachute was ejected.

The rocket drifted safely to the ground under parachute and all parts were recovered in re-flyable conditions for a successful flight. The team's on-board electronics beeped an altitude of 1506 ft.

Figure 9: Space Badgers' Launch

The flight data was taken from the judges' Rdas mini altimeter. The maximum altitude reached was 1516ft. The plot showing the altitude over the course of the flight is shown in Figure 10. Because a minimum altitude of 1500ft was attained, the flight was deemed as successful.

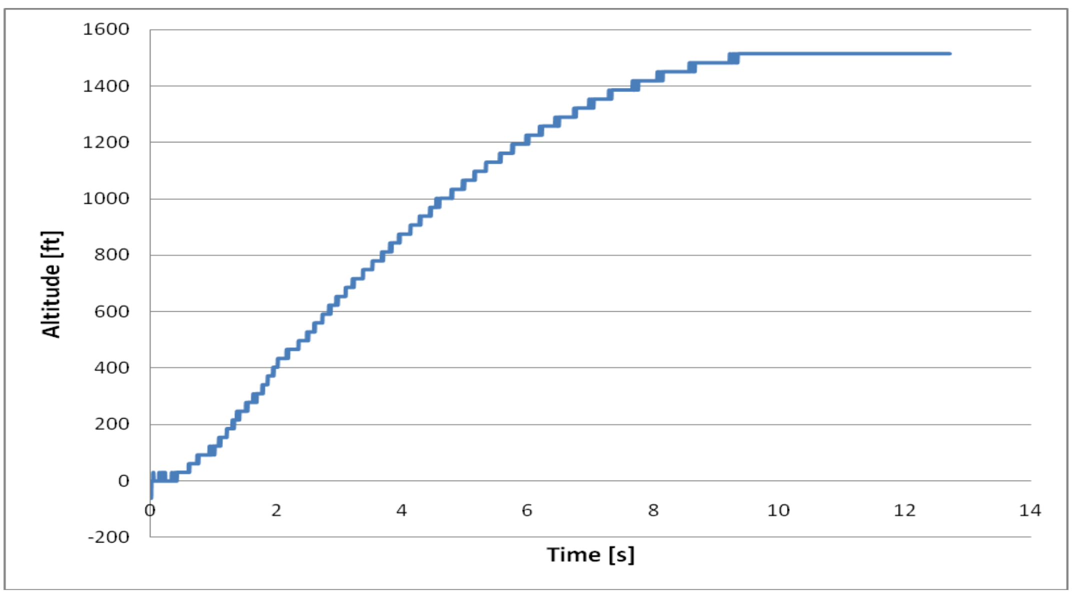


Figure 10: Space Badgers Flight - Altitude Data

The maximum acceleration during the flight was 289.8 ft/sec2. The plot of this data is shown in Figure 11.

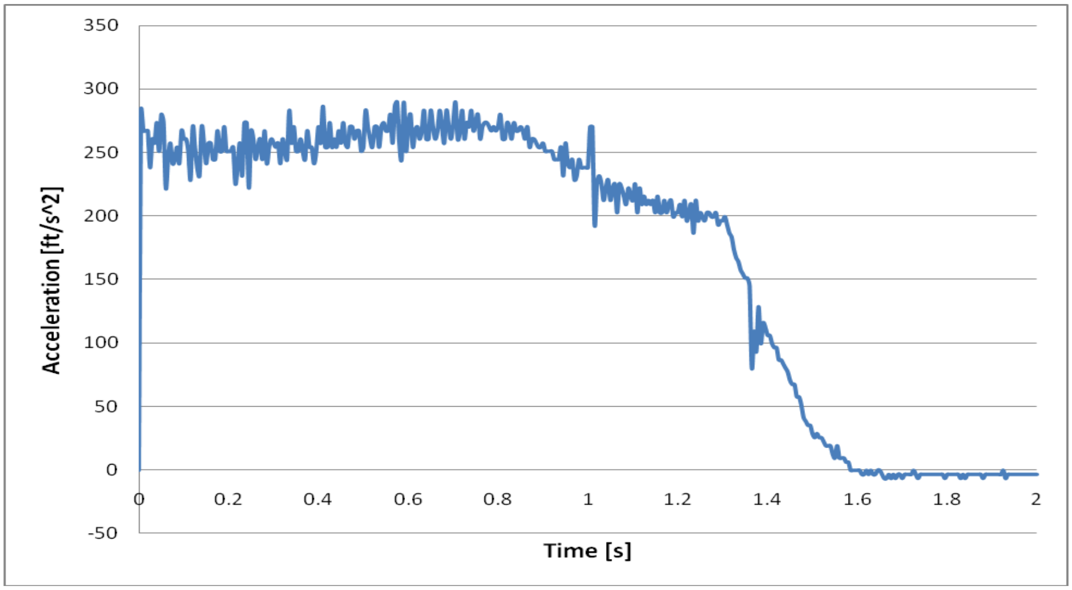


Figure 11: Space Badger Flight - Acceleration Data

Performance Comparison

The actual flight performance showed a maximum altitude of 1516 ft, while the estimated altitude was 1506 ft based on the RasAero software prediction. This difference is only 0.66%, or 10 feet, which is approximately one rocket length. The difference between the actual and estimated flight performance for altitude is insignificant. The actual maximum acceleration during flight was 290 ft/s^2 though the predicted maximum acceleration was only 239 ft/s^2, which is a difference of 17.5%. The degree of uncertainty in both the altimeter data as well as the uncertainty in the RasAero models can account for this difference. Because the estimated and actual altitudes were so close, the difference in acceleration can be accounted for using these uncertainties.

Conclusion

Team Space Badgers completed a successful flight as determined by the requirements of the competition as well as a successful recovery. The rocket, with a total mass of 33.0 lb, successfully reached an altitude of 1516 ft, which is over the 1500 ft minimum. The electronics in the rocket successfully deployed the charges and the recovery system brought the rocket down safely.

This competition was ultimately deemed a success for us. We enjoyed seeing our design pay off when we were able to add more weight after a test flight and our well built, strong, rocket survived after having a successful flight. This year's design competition helped our team learn about rocketry, the importance of testing and modeling, and about teamwork. It was also a building year and good stepping stone as two new members were brought into the WSGC program as one team member will be graduating from it.

Design, Construction, and Results for Juggernaut

Justin Kenter, Matthew Braunschweig, Marcus Fritz, Justin Hare

Wisconsin Space Grant Consortium Collegiate Rocket Competition

April 30th – May 1st , 2010

Executive Summary

The competition required us to design a rocket capable of lifting a heavy payload to a minimum altitude of 1500 ft. The only items provided to us were the K1100 rocket motor and the R-DAS Tiny.

The overall design of the rocket was fairly simple. The rocket was single staged 4 in diameter body tube with an elliptical nose cone. We decided to use G10 fiberglass for the body tube and fins because from past experiences we learned that it is strong and durable.

Based on the performance of the K1100 rocket motor and a calculated value for the coefficient of drag of .315, we determined that we could lift a total of 32.5 lbs to an altitude higher than the required 1500 ft. To increase the overall mass of the rocket, we used a threaded steel rod that was 16 inches in length. The rod was secured in the lower section of the body tube just above the motor with a series of centering rings. Additional weight could be added with the use of hex nuts. This allowed us to increase the overall mass of the rocket as well as reposition the center of gravity as we saw fit.

Overall Design Plan

The rocket was separated into three sections. The lower section of the rocket contained the motor and a steel rod which was used to vary the weight of the rocket as well as the center of gravity. The middle section was used to house the parachute. Finally the upper portion of the rocket was used to hold the electronics.

Mechanical Components

Nosecone

When determining what type of nosecone to use for Juggernaut, stability was the primary concern. After investigating the fluid mechanics of flow around various types of nosecones and consulting with the industry advisor, the elliptical nosecone was determined to be the most stable design for subsonic flight, which was the condition Juggernaut flew under.

Airframe

The airframe was made of wound fiberglass. The airframe was in two pieces to accommodate an ejection charge that would deploy the parachute. The nosecone would not be separating from the rocket because that was where the electronics would be stored. This was also so we could access the steel rod easier to adjust the weights inside the rocket.

Added mass

In order to reach what was calculated to be an ideal weight that would allow the rocket to reach 1500 feet, a 1.5 in. thick threaded steel rod was added (16 in. long) just above the rocket motor. This rod was secured to the rocket with G10 fiberglass centering rings. On this steel rod were as many as 10 steel hex nuts (nine were ultimately used on launch day). These were used to adjust the center of gravity as needed, and also to add mass.

Fins

A sheet of G10 fiberglass was cut to create the four fins used on the rocket. The team traveled to Orbital Technologies, Inc. to use the band saw there under supervision of the team's industry advisor. The fin shape and size was calculated using RockSim. RockSim used the values for the center of gravity and center of pressure to calculate the static margin for each iteration of the fin design. The user of RockSim only had to select a fin shape that generated a static margin close to 1.5.

Bulkheads/Centering Rings

All of the bulkheads and centering rings were cut from the same sheets of G10 fiberglass as the fins. These were also cut at Orbital Technologies. In the rocket, the bulkhead below the electronics section in the nosecone was triple-layered, with epoxy between each layer. There was a bulkhead between the rocket motor and the steel rod as well. Centering rings were placed around the motor mount tube and the steel rod.

Motor Retention

To keep the motor in the motor mount tube, a motor retainer was purchased from Giant Leap Rocketry. The retainer was made of aluminum and worked by epoxying its base component over the bottom of the motor mount tube. The motor was then inserted into the motor mount tube, and the retainer cap was screwed onto the base. A thread protruding from the interior of the motor retainer kept the motor from ejecting upward into the dart, and the retainer cap kept the motor from falling out the bottom of the mount when the rocket was at rest.

Ejection Charge

There was one ejection charge built into Juggernaut. This charge was fired at apogee, and separated the top third of the airframe from the bottom section. The parachute then deployed out of that gap. The reason for the cut section of the airframe below where the parachute deployed was so the team could access the steel rod and make adjustments to the center of gravity, and add or remove mass as needed.

These ejection charges were made of Pyrodex secured in a paper tube, an electric match that ignited the Pyrodex, and an electrical wire leading from the electric match to the flight controller that released the electric charge.

Electrical Components

ALTS1

For the ejection charge in Juggernaut, a single-deployment controller (ALTS1, Adept Rocketry) was purchased to facilitate ejection at apogee. The ALTS1 was chosen because it records maximum altitude, and could serve as a second reading coinciding with the R-DAS Tiny Altimeter (see below). The charge was set by the hardware to eject at apogee.

R-DAS Tiny Altimeter

The R-DAS Tiny is the altimeter provided by the WSGC to accurately and uniformly judge maximum altitudes attained by all of the competing teams. The R-DAS also records acceleration over time, and has a USB port for easy transmission of data to a personal computer. Acceleration data from the R-DAS was used in the post-launch report determining the accuracy of pre-launch predictions.

RockSim Analysis

To determine fin size and the drag coefficient, RockSim was used. This resulted in an analysis of center of pressure and center of gravity. Using accurate shape descriptions of the nosecone and fins (the two critical locations on the rocket in terms of drag besides the tail end where the motor is located), and also using an accurate center of pressure/center of gravity ratio, maximum altitude and acceleration were calculated. This was done primarily to compare RockSim results to MATLAB results, and verify the expected apogee altitude. Given launch conditions of 3-7 mph wind speed, a temperature of 70 degrees F, and a clear sky with no precipitation, RockSim calculated a maximum altitude of 1787.22 feet, and a maximum acceleration of 331.08 feet per second squared. Clearly, such ideal conditions are not practical. As a result, launch conditions were then simulated with wind speeds between 8 and 14 miles per hour, partly cloudy skies, and a temperature of 50 degrees F. Maximum altitude lowered to 1761.28 feet and the maximum acceleration remained at 331.08 feet per second squared. Because of this variance in apogee altitude, it was decided to keep the weight on the rocket variable. This was why nuts were used on a long threaded rod: so the weight could be shifted up or down, and weight could be added or removed depending on launch conditions.

In order to maximize these values it was necessary to minimize the drag force on the major components of the rocket, while maintaining stability. An elliptical nose cone has a lower coefficient of drag at the velocities that the rocket was subjected to. Another critical point was at the fins. An added bonus to using RockSim is its calculation of center of pressure and center of gravity. With the motor in place with fuel, the center of pressure for Juggernaut was 39.3616 inches from the top of the rocket, and the center of gravity before launch was 32.9305 inches. The center of gravity after launch was calculated to be 31.8805 inches. This resulted in a static margin (relationship between center of pressure and center of gravity) of 1.61 for the rocket before launch and 1.87 after. The static margin is calculated as found in Figure 1, and is a leading factor in determining how a rocket will fare once launched in varying conditions.

Static margin is calculated in RockSim by averaging both diameters for the whole rocket margin, and solely the dart diameter for the dart margin.

Regarding static margin, in our competition last year industry advisor Mike Fidler suggested keeping close to a margin of 1.5, because in his experience it represented the best tradeoff between stability and resistance to wind. Additionally, a static margin over 2.0 resulted in a message in RockSim that the rocket was over-stable (which could result in a rocket over-correcting against any wind forces), and a margin under 0.0 meant the rocket was not stable enough (the rocket could go in any direction at random, and would be extremely susceptible to wind forces). Both of these problems would be enhanced by the fact that the Bong Recreational Facility is extremely flat, and very susceptible to wind. Last year, we experienced firsthand that the launch site will usually have at least a light breeze at all times.

After the RockSim model was complete, the coefficient of drag was taken from the model and used in the MATLAB code to calculate apogee. At the maximum velocity obtained by the rocket (319.41 ft/s for the less-than-ideal launch conditions), the Cd was given as 0.315.

MATLAB Model and Anticipated Performance

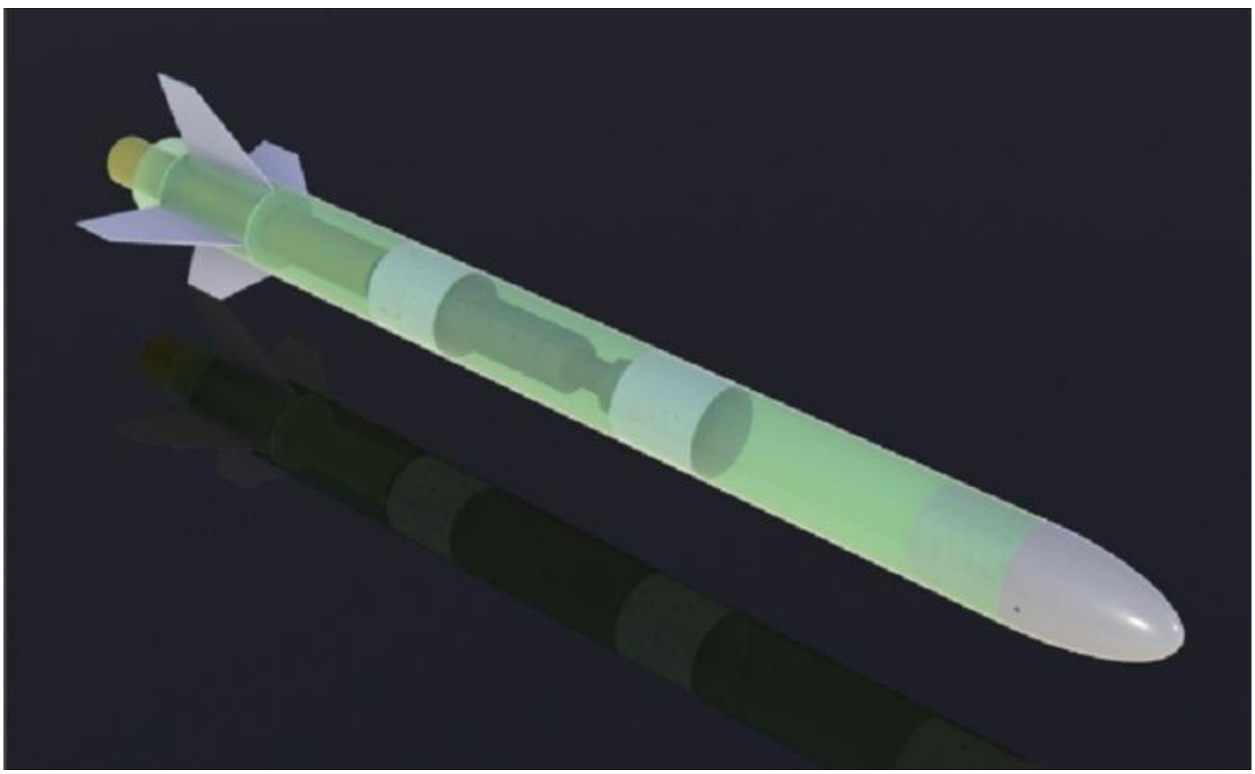
We used Matlab to program an iterative code to determine the performance of our rocket. The code runs in two stages. The first stage is during the burn of the engine. This code determines the forces acting on the rocket to find acceleration. These forces include drag, gravity, thrust from the rocket. Additionally, the mass lost during the burn is taken into account. This code iterates over every data point available for the thrust curve of the engine. The second stage of the code tracks the rocket after the motor finishes firing. Similar to the first stage, this portion of code tracks force on the rocket to provide acceleration. Additionally, the code now iterates every .001 seconds and takes into account the deployment of the parachute.

The Matlab simulation determined several relevant variables for our design. The first iteration of code was to find the performance of the rocket if drag was not taken into account. This provided us with several key values to start our design process. The first value was the absolute maximum mass that could reach 1500 feet with the given engine. The second value from the inviscid run was the maximum acceleration (234.07 ft/s^2). These two values provided ballpark estimate for the stresses during flight and for the geometry that would be needed for our design.

The second iteration included the drag on the rocket and the geometry determined from the first iteration. The maximum possible mass to reach 1500 feet determined by this iteration was found to be 34.15 lbs. Additionally, a margin of safety was added to account for unexpected atmospheric conditions. Given a 12% margin of safety, the mass for our first launch was determined to be 32.5 lbs.

SolidWorks Model

The SolidWorks model was used to develop an internal layout of the rocket. A visual representation of internal components allowed us to avoid several layouts which would have been impossible to build. Using the initial layout we were able to determine an estimate of the center of mass for the rocket. Once the initial simulations were completed a second iteration of the SolidWorks model was generated. This second model was used to determine the parts list and budget for the rocket.



An additional use for SolidWorks was to confirm the coefficient of drag predicted by RockSim. Using the FloWorks software found in SolidWorks we were able to find the drag on the rocket at speeds the rocket will be traveling at.

Construction of “Juggernaut”

In preparation for constructing Juggernaut, the team went to Orbital Technologies in Middleton, WI to have the industry advisor help cut the G10 fiberglass into the fins, bulkheads, and centering rings for the rocket. The team also went to Orbitec because they were not able to use the student shop on campus in Madison to cut fiberglass. Using a vacuum to keep fiberglass particles out of the air, they cut the shapes using a band saw and CNC.

For the actual construction of Juggernaut, the team first epoxied the fins and motor retainer to the motor mount tube at the base of the rocket. They used a pair of centering rings to keep the tube centered inside the rocket. Next, they fixed the metal rod inside the body of the rocket. Because they needed to be able to adjust the weights on launch day, the rod needed to be able to be exposed. This was accomplished by epoxying the rod on a bulkhead just above the rocket motor. Just below the top of the steel rod, a fiberglass centering ring was epoxied to the rod, to keep the rod centered and to help keep it from moving. The airframe was cut to separate at the center of the rod, so that weights could be adjusted.

The electronics were placed in the nosecone of the rocket, similar to last year. This was to maximize the altitude readout, and to keep the electronics out of the way of the parachute. The parachute deployment method was to fire an ejection charge at apogee using the electronics, which would separate two halves of the rocket (a cut was made through the body tube to accommodate this). A coupler was used to keep the two components together during liftoff/coast to apogee. Because of this method, the nosecone did not need to be separated and could keep the electronics stored there.

Construction Pictures

Results and Comparison to Expected Values

Overview

Upon successful recovery and data retrieval of our rocket's flight we were able to compare the data from the RDAS Tiny with our predicted performance. On the surface, our predicted result shows a 9.65% margin in error in total altitude reached by the rocket when compared to the actual flight results recorded by the RDAS Tiny. We predicted an altitude of 1565 ft and achieved an altitude of 1414 ft with a weight of 32.5 lbs. In terms of maximum acceleration, the percent error recorded is 8.21%.

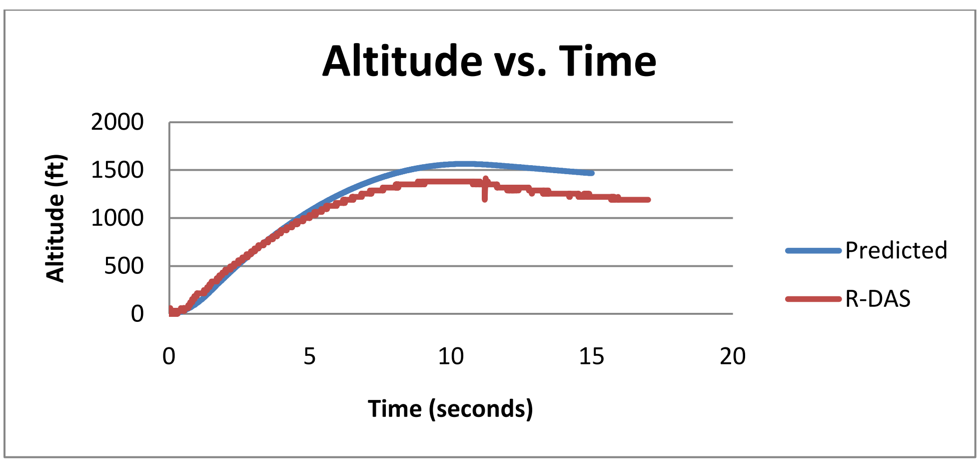
Collected Data

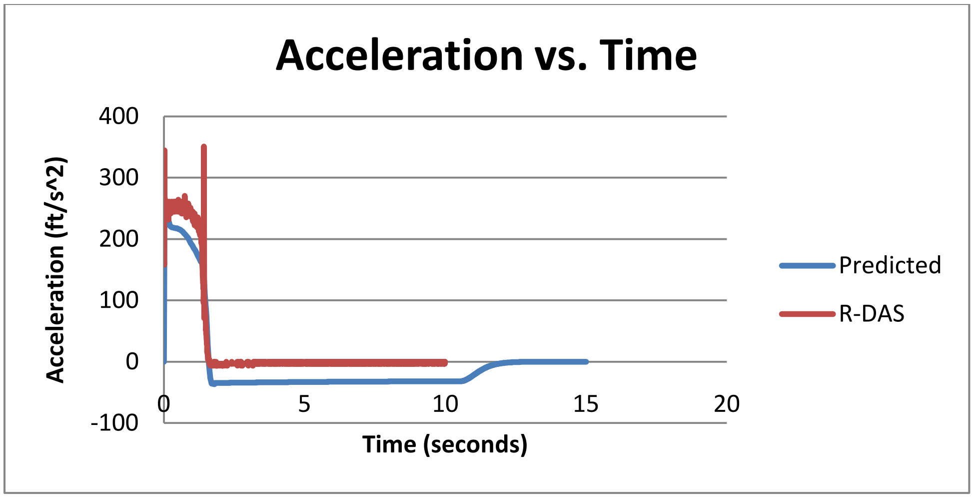
	Maximum Altitude	**Maximum Acceleration**
Anticipated Performance	1565 ft	244.01 ft/s^2
Launch-Day Performance	1414 ft	264.04 ft/s^2
Percent Error	9.65%	8.21%

Reasons for Error

This margin of error is undoubtedly attributed to multiple factors including drift, minor instabilities, environmental factors, as well as possible error in the recording hardware. We feel that the biggest source of error came from drift. Our maximum acceleration was slightly greater than expected, but our maximum altitude was lower than expected. Because of this, the rocket launched as expected (in terms of gravity and acceleration), but there was an extra factor not accounted for as engine burnout occurred. Because of the observed correction into the wind on launch day, it can be concluded that the rocket did not reach the expected altitude because a good deal of its velocity transitioned into an x-directional velocity. The rocket coasted up to apogee at more of an angle than anticipated – in the Matlab model, there was no angle assumed. The launch was idealized as going straight up and straight back down.

When comparing our predicted data with that from the RDAS Tiny this discrepancy is noticeable. This discrepancy is noted in the following graphs.





Conclusion

Having compared the altitude curves from the predicted results with those retrieved using the RDAS Tiny we are able to conclude that, although our predicted altitude was off by approximately 10%, we are able to account for this error margin by considering drift of our rocket instead of the idealized “straight-up, straight-down” model.

Appendices

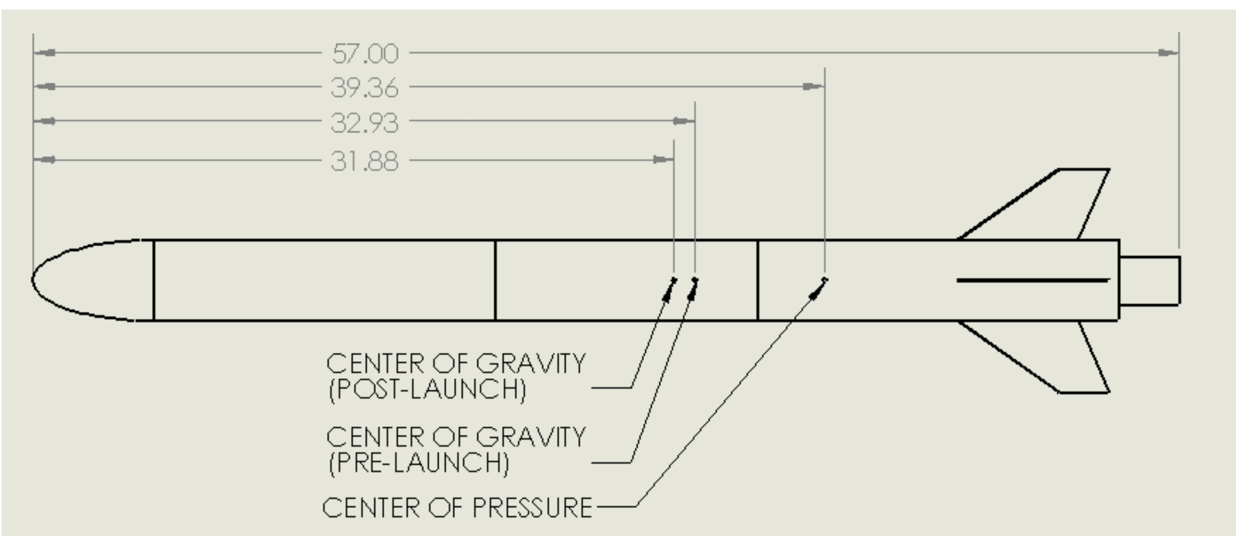


Figure 7.1 Location of Center of Pressure and Center of Gravity pre and post launch.

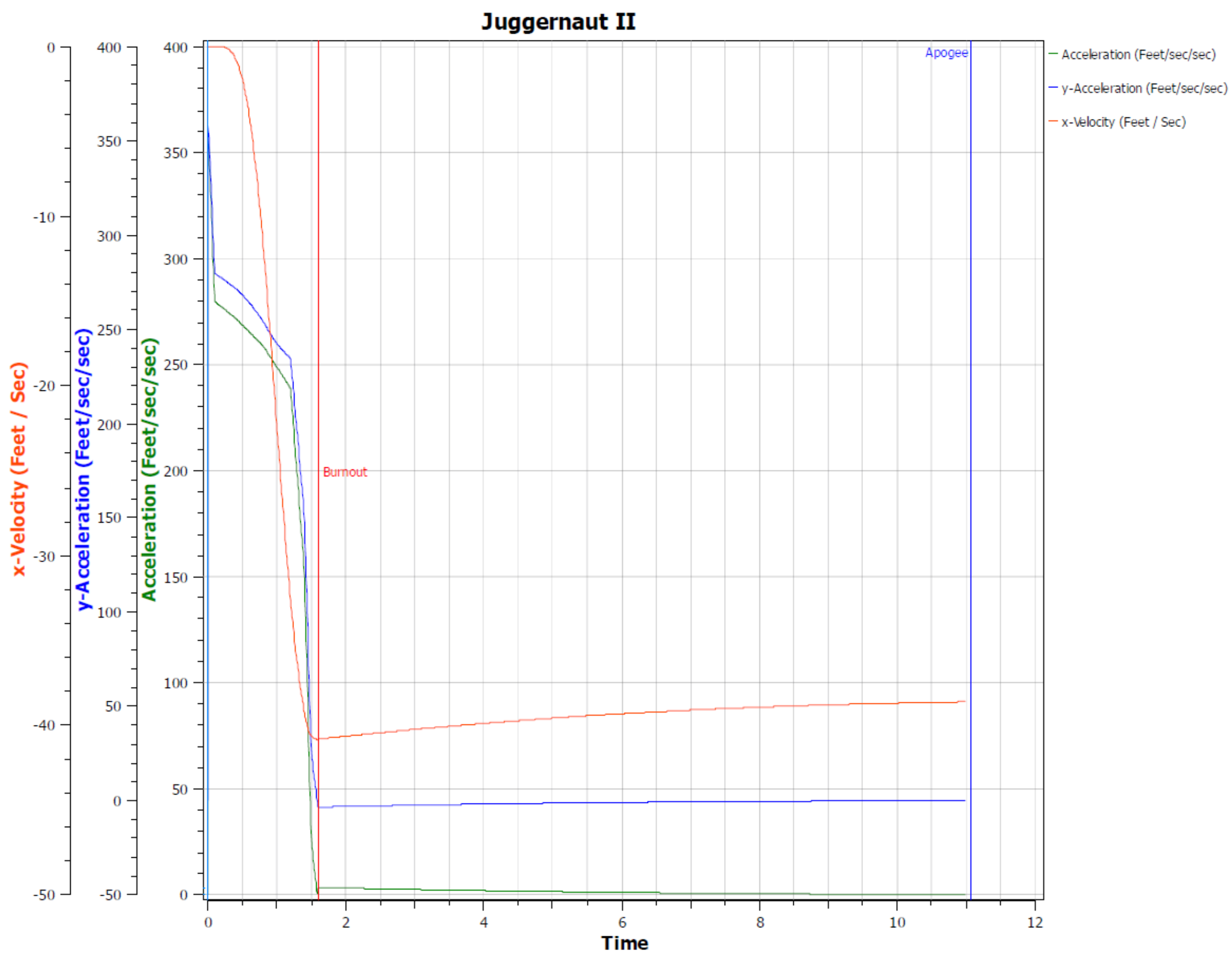


Figure 7.2 RockSim Acceleration vs. Time graph

Student Rocket Design Competition
"Team Rally Axe"

Alex Gonring, Ryan Bahr, Tyler Van Fossen[1]

Engineering Mechanics & Astronautics
University of Wisconsin-Madison

Abstract

The 2010 Rocket Design Competition's objective was to fly the heaviest possible rocket to a minimum of 1500-feet at apogee. With this being Team Rally Axe's first year in the competition, it was decided to make a majority of the rocket by hand, with a limited number of pre-manufactured components. The basic design featured two specialized sections, located above and below the point of separation for parachute deployment. The top-most section stored the parachute and electronics for recording flight data, while the bottom section housed the dead weight and custom made motor mount. The mount centered the motor while anchoring the fins in perfect alignment. Most of the rocket was comprised of wood and PVC, which means more complex operations in the manufacturing process were avoided. Before construction took place, several calculations were carried out to find critical points on the body of the rocket. It was found that the margin between the center of pressure and center of gravity was 0.93738 for the fully-loaded motor and 1.14907 when the motor was empty. The analysis of the rocket's expected performance was calculated using MATLAB's ode45 function to solve the equation of motion, which depends on changing mass, temperature and pressure. The calculations resulted in a maximum height of 1548-feet with a weight of 34.516-pounds. Since both margins were sufficiently close to one, the rocket should have undergone a stable flight, but unfortunately the stability of the rocket was jeopardized by the inadequate method used for calculating the center of pressure. This critical value was found exclusively in RockSim, because the team was unaware of analytical methods such as Barrowman's Equations. When the analytical method was used in post-flight analysis, it was found that the rocket was quite over-stable, which explains the observed erratic flight path and the subpar official competition flight reaching a mere 653 feet at apogee.

[1] A special thanks to the Wisconsin Space Grant Consortium for funding the project, and John Murphy of the University of Wisconsin-Madison for his help as Team Rally Axe's faculty advisor.

Objective

The WSGC 2010 Collegiate Rocket Design Competition objective was to construct the heaviest rocket that will reach a minimum altitude of 1500-feet at apogee. The engine of choice was the AeroTech K1100T, which produces 1100-Newtons of average thrust for 1.6 seconds. The rocket had to be safely recovered in flyable condition to earn the most points. Along with the competition flight, competitors were required to submit a design report, give a presentation the eve of the launch, and submit a post-flight analysis demonstrating an understanding between the differences in expected and actual flight performance.

Design Features of the Rocket

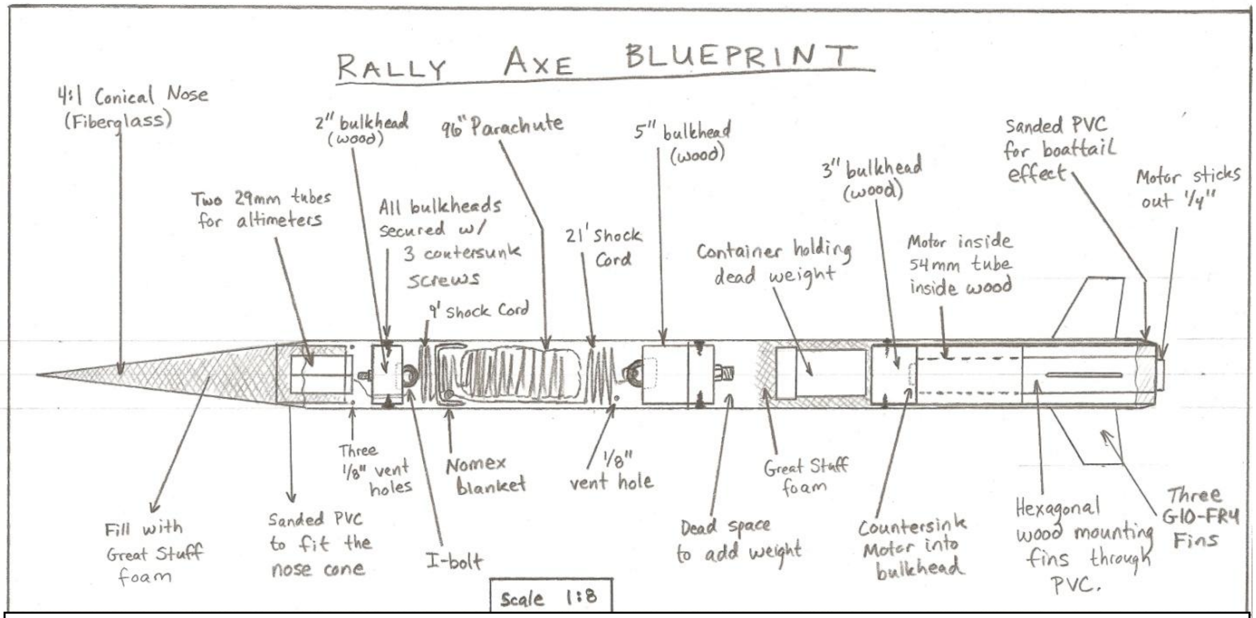


Figure 1- Blueprint of the rocket. The blueprint was drawn to a 1:8 scale, but was then resized. A more appropriate scale is 1:11.

PVC body tubing. The body tube was made of PVC piping, with an outer diameter of $4^1/_2$-inches and a thickness of $^1/_4$-inch. This material was chosen mainly because it is cheap, durable, and easy to work with. It allowed for the bulkheads to be screwed directly through the body tube for extra strength, and the screws to be countersunk to maintain an aerodynamic design. The rocket was split near the halfway point for parachute deployment, so there were two sections of body tubing used. For this location and others, refer to Figure 1 above.

Recovery system. The parachute was located in the top half of the rocket with the ejection charge directly above it. With this positioning, the charge should effectively force the bottom half of the rocket downward. To ensure proper deployment, the parachute was attached to both halves of the rocket separately, so as the bottom half drops off, it would essentially pull the parachute out if it had not been dislodged already. With a launch weight of close to 35-pounds, a large parachute was required. The parachute was acquired from Fruity Chutes and sported a 96-inch outer diameter, a customized color scheme, and durable $^1/_{32}$-inch thick rip-stop material. This size chute yields a descent rate of 20-feet/second for a 33-pound rocket, which is well within the acceptable 30-feet/second recommendation. Sixteen shroud lines supported the parachute, each with a length of $8\frac{1}{2}$-feet. These lines connected to a harness, which then connected to a carabineer fastening two shock cords together. Each cord secured one half of the separated rocket via an I-bolt in the bulkheads.

Douglas fir bulkheads. The bulkheads were all made from green-treated Douglas Fir. Each bulkhead was secured through the body tube by three equally-spaced, countersunk screws. Countersinking effectively hides the screw heads, and after covering with epoxy, minimizes air resistance. The screws were also in line with the altimeter vent holes to keep the fluctuations in drag equalized. Three bulkheads were used: one to mount each half of the rocket to the parachute, and one to secure the dead weight and the motor mount.

G10-FR4 fins. The fins were designed in RockSim to optimize the overall coefficient of drag for the rocket. The chosen material was G10-FR4, which is an extremely durable, fiberglass-reinforced plastic. The fins were mounted through the body tube into slits in the hexagonal motor mount. For safe measure, a plastic epoxy was applied to seal the cracks and bond the fins to both the PVC pipe and the motor mount. The shape and dimensions of the fins are shown to the right in Figure 2.

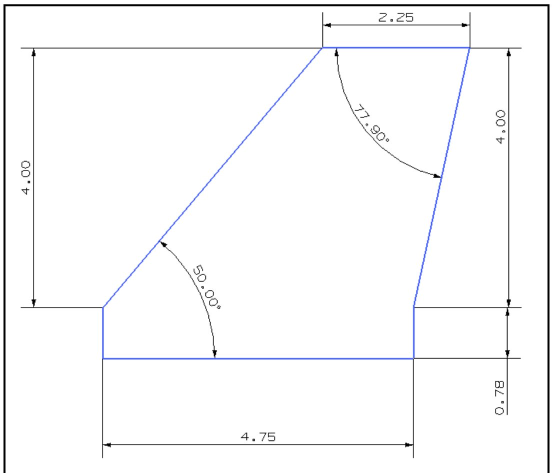
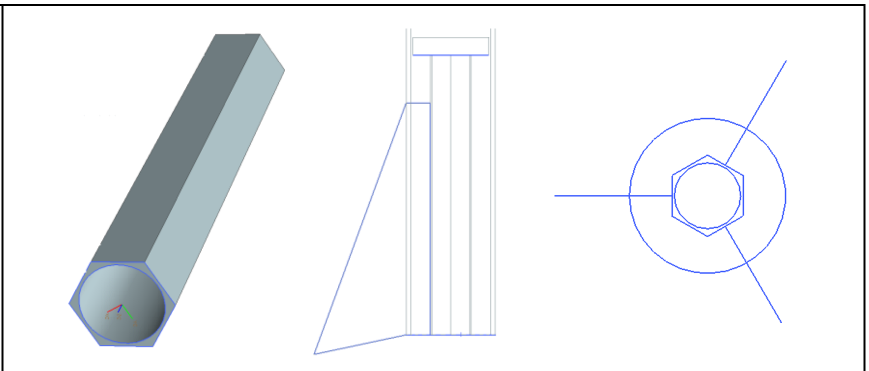


Figure 2- Dimensioned fin layout.

Hexagonal motor mount. The motor mount prevents the engine from blasting its way through the rocket body, and in our case, ensured fin alignment. It was decided that the motor mount be a hexagonal cylinder, a shape that guarantees the necessary 120-degree spacing for a three fin set (Figure 3). For this mounting system, a Douglas Fir 4x4 was selected since wood is easy to work with. To center the mount at the top, the motor casing nozzle was countersunk into the adjoining bulkhead. Directly above the motor mount was a vacant space used for positioning the dead weight. With strategic manipulation, the dead weight could be positioned at just the right location to provide the rocket with the correct center of gravity to ensure a sturdy flight.

Figure 3- Concept of the hexagonal motor mount. Fins are attached through the body tube to the motor mount. The shape ensures proper spacing and helps reduce human error while attaching the fins. The motor fits snugly inside the hole drilled in the mount.



Fiberglass nose cone. The nosecone was a 4:1 fiberglass cone purchased from Wildman Rocketry. It had a slightly larger than 4-inch maximum diameter, so it fit perfectly into the body tube. The reasoning behind the conical shape is that it allowed for the greatest altitude in RockSim tests, as compared to other shapes. The length from the shoulder to the tip was 16-inches, which created a 14.25-degree angle of attack at the tip. Since the maximum outer diameter of the nosecone was about $^{1}/_{4}$-inch less than the outer diameter of the PVC body tube, the top end of the tube was sanded down to match the slope of the nosecone. The nosecone was then screwed directly into the body tube, allowing easy access to the electronics while still providing security during flight.

Electronics. The nosecone of the rocket conveniently housed the electronics, which included two altimeters. One altimeter was supplied by the WSGC for measuring competition flight data, while the other was purchased from Apogee, Inc. for triggering the ejection charge. The purchased altimeter was a dual-event altimeter, meaning it has the capability of ejecting both a drogue chute and a main chute. Though unnecessary for this year's design, this feature may be beneficial in next year's competition. For our purposes, the igniter was automatically triggered at apogee. Each altimeter was contained in its own 29-mm cardboard tube within the nosecone and secured by Great Stuff foam. To allow proper air pressure readings by the altimeters, three equally spaced vent holes were drilled into the top of the body tube. Similarly an additional $^{1}/_{8}$-inch vent hole was drilled just above the separation point to avoid pressure differences in the body tube's recovery section, which could prematurely separate the sections.

Boat tail. One idea that came up in the design process was to reduce the turbulent airflow off the bottom edge of the rocket with a boat tail. The body tube was simply sanded down conically (much like the upper section near the nosecone) to save cost and eliminate another connection between adjoining parts. This conical shape helps smooth the airflow off the back end of the rocket.

Safety Factors of Manufactured Regions

Since some of the materials chosen were not pre-qualified parts from licensed rocketry vendors, analysis was done to ensure the safety of the design. The maximum expected force experienced on any part was 1627-Newtons of thrust force. The three possible areas of concern identified were the bearing stress on the bulkheads from the screws, the shear stress in the screws, and the bearing stress on the PVC from the screws. Table 1 shows the resulting safety factors, which brought us the confidence necessary to launch. The bulkheads provide a factor of safety of 8.9 for bearing stress, while the $^{3}/_{16}$-inch thick zinc screws provide a safety factor of 7.8 in shear. The PVC is much weaker, but still holds a safety factor of 2.5 for the maximum bearing stress.

Stress	Material	Factor of Safety
Bearing on bulkhead	Douglas Fir	8.9
Shear in screw	Zinc	7.8
Bearing on PVC	PVC	2.5

Table 1- Safety factors for areas of concern. These results confirm that the rocket is structurally sound.

Analysis of Anticipated Performance

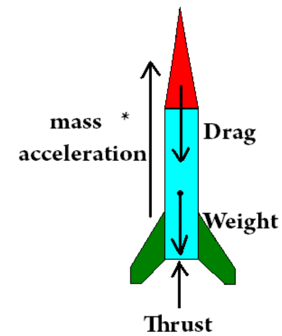


Figure 3- Free body diagram. Both the body forces and inertial forces are shown. Balancing these yields the equation of motion.

Early on in the planning stages, a simple calculation was carried out to obtain a ballpark value of weight that would reach the required 1500-feet at apogee. The estimate came out to be roughly 35-pounds. With this number in mind, a more extensive analysis was done. The performance of the selected design was first simulated in RockSim's flight analysis software, followed by a MATLAB calculation. This calculation essentially solved the second-order differential equation of motion (EOM) associated with the rocket's flight by using the fourth and fifth-order Runge-Kutta method, ode45. The script itself was written to solve for altitude, velocity, and acceleration at any time of the flight. Therefore, finding the maximum weight was an iterative process where different weights were inputted until the desired altitude was achieved.

Without going into too much detail, the EOM was derived from a simple free-body diagram to balance the forces of weight and drag with thrust. This is shown above in Figure 3. Assuming only these forces, which means a perfectly vertical and windless flight, the balance of forces lends Equation 1:

$$(1) \quad mass \times acceleration = thrust - weight - drag$$

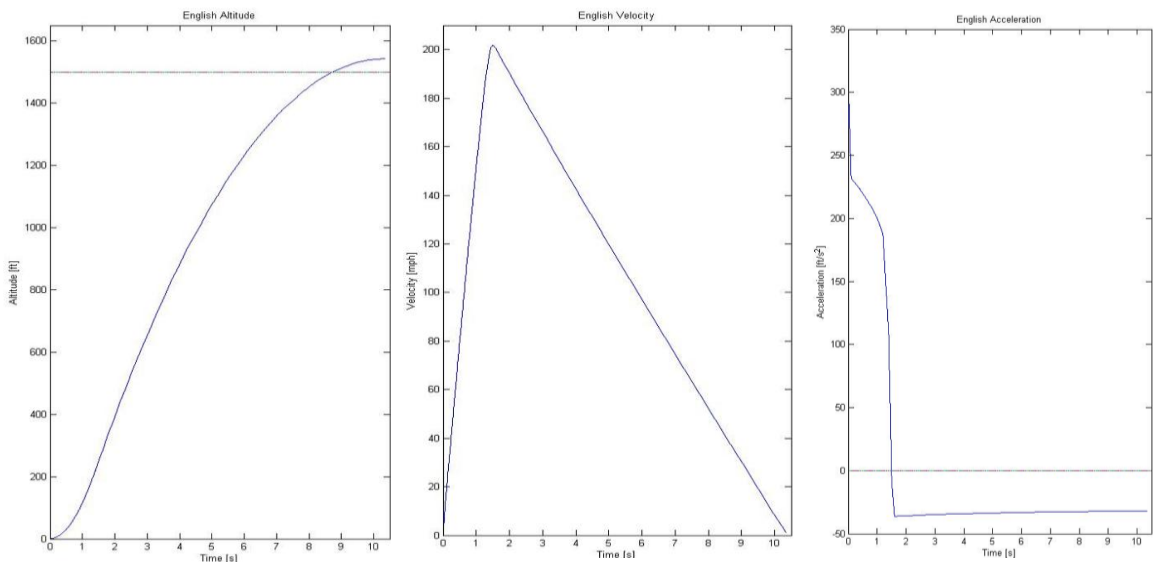
There are several important aspects to this equation that make it much more difficult to solve than one would expect. For starters, the mass decreases linearly throughout the burn stage with the loss of propellant mass. Second, the thrust of the engine is not constant and in fact varies substantially throughout the 1.6-second burn region. Weight, like mass, decreases over the burn period, and drag depends on several changing factors as well such as varying temperature and pressure. After all of the dependent substitutions were made, the final EOM, Equation 2, was obtained, where g is gravity, c_d is the coefficient of drag, A is the projected area of the rocket, y is altitude, R is the universal gas constant, temp is the temperature, and t is time.

$$(2) \quad \left(\frac{d^2y}{dt^2}\right) = \frac{thrust}{\left(mass_{total} - \frac{0.773}{1.6} \times t\right)} - g - \cdots$$

$$\frac{\left(\frac{dy}{dt}\right)^2 \times c\_d \times A \times 100 \times \left(\frac{44331.514 - y}{11880.516}\right)^{5.255966}}{2 \times R \times (temp - 0.002 \times y) \times \left(mass_{total} - \frac{0.773}{1.6} \times t\right)}$$

Equation 2 could then be used with ode45, but was only solvable for one region of thrust at a time. In order to accurately account for the changing thrust of the motor, eight regions of linearization were formed using the thrust curve for the AeroTech K1100 from http://www.thrustcurve.org. Once the function for the EOM was defined in MATLAB, it was as simple as determining the initial conditions to use for each stage. The first stage used the initial launch conditions of zero velocity and the elevation of the launch site. Solving in succession, the second stage used the last data set from the first stage, the third stage from the second stage, and so on. The coast stage, or the region from propellant exhaustion to arrival at apogee, was solved in the same way, but with zero thrust.

Once the solution to the EOM was obtained, plotting was fairly straightforward. Plots 1, 2 and 3 show the altitude, velocity, and acceleration versus the time from ignition to apogee, respectively. Note that the slope of the altitude is the velocity and the slope of the velocity is the acceleration. Also noteworthy is that acceleration becomes negative slightly before the coast stage, because the thrust force is not strong enough to overcome gravitational and drag forces in the last few moments before coasting. As a check, the acceleration during the entirety of the coast stage should be approximately the value of gravity, which is true. There is a slightly stronger negative acceleration right after the burnout (1.6-seconds) because the rocket is traveling around 200 mph, which causes a significant amount of drag as well.



Plot 1 (Left)- Altitude over time. The altitude increases rapidly through the burn stage, followed by a parabolically decreasing rate through the coast stage. A maximum altitude of around 1550 feet is projected at about 10 seconds into flight.

Plot 2 (Middle)- Velocity over time. Velocity is the derivative of the position, so it is logical that the velocity peaks at the inflection point in Plot 1. A top speed of around 200 mph is anticipated at burnout.

Plot 3 (Right)- Acceleration over time. Acceleration is the derivative of the velocity. If you look closely, there is an initial spike in acceleration where the impulse of the motor "jumps" the rocket off the pad. When the motor runs out (1.6 seconds), the acceleration quickly falls to a close-to-constant value of nearly gravity, with only minor drag additions.

After iterating to achieve a safe altitude of around 1550-feet, we predicted that 31-pounds, 5-ounces would reach a maximum altitude of 1548.58-feet. The corresponding maximum acceleration was 310.99-ft/s^2.

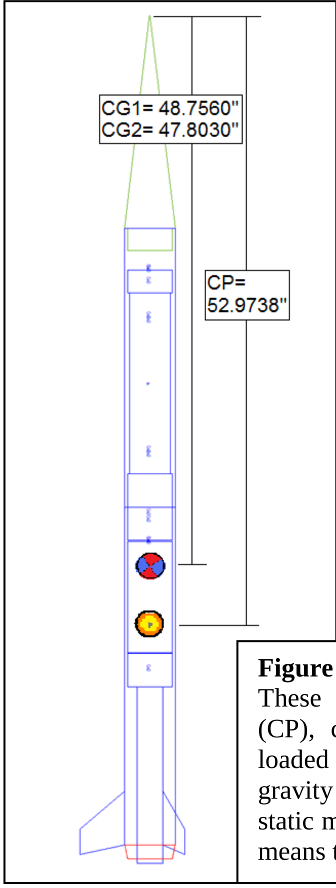


Figure 4- Key points of the rocket. These include: center of pressure (CP), center of gravity with fully-loaded motor (CG1), and center of gravity after burnout (CG2). Both static margins are close to one, which means the rocket is stable.

One other calculation was required in order for the rocket to endure a stable flight. The static margin, or the difference between the locations of the center of pressure and the center of gravity should be about one body tube diameter. The center of pressure was found using the rocket's structure in RockSim, which came out to be 52.97-inches from the nose tip. This value effectively does not change throughout flight, assuming the flight is ideal. The center of gravity, however, changes because of the lost propellant mass. Therefore, the center of gravity before launch *and* after burnout must be found to ensure stability at both stages. These were measured by finding individual component masses along with their corresponding locations for center of gravity. The two values were then multiplied together for each component, summed, and divided by the total mass. The resultant centers of gravity along with the center of pressure are shown in Figure 4, where the fully-loaded rocket and the rocket after burnout have centers of gravity at 48.76-inches and 47.80-inches from the nose tip, respectively. The static margin comes out to be 0.93738 for the fully-loaded motor, and 1.14907 for the empty motor. Both margins were sufficiently close to one, which if calculated properly, would have enabled a stable flight.

Construction of the Rocket

Sanded nosecone. To make the top end of the body tube and the nosecone align, the PVC body tube was simply sanded down until the slopes of the nosecone and PVC matched. This way, the bottom of the nosecone was the same diameter as the top of the body tube, so a smooth transition was created.

Constructed bulkheads. The bulkheads were made from a wood 4x6, that was trimmed down and shaped into a cylinder with a band saw. The cylinder was tightened with a belt sander until it fit snuggly inside the body tube. For the I-bolts, holes were drilled for the threads to pass through. The bolt heads was then countersunk into other, larger holes (Figure 5). Additionally, holes to secure the bulkheads were drilled. To finish off, plastic epoxy was added to fill in the holes in an attempt to keep the surface of the body tube as smooth as possible.

Figure 5- Upper bulkhead. The countersunk I-bolt is shown.

Fabricated motor mount. After some discussion with the Student Shop Staff, an appropriate self-feed bit with extension had to be purchased due to the uniqueness of the design (Figure 6). Even with the shop's largest drill press, however, it was not possible to drill one solid section. With the help of Eamon Bernardoni, a fabrication specialist, the 4x4 block was cut into two pieces, and drilled out (Figure 7). Then using the band saw, the hexagon was formed.

Figure 6- Self-feed bit.

Figure 7- Drilling with the extension.

Cut fins. Cutting the fins posed another problem, as the Student Shop Staff had G10 as a banned material in the shop due to health hazards from improper ventilation. They were not willing to do the cutting for us, but suggested to use a Dremel instead. With a facemask and safety glasses outdoors, the fins were first cut out to rough dimensions with a cutoff blade (Figure 8). They were then sanded down to the exact dimensions, sporting rounded corners with an almost airfoil shape. This is an excellent shape to have when dealing with aerodynamics, as it has minimal drag associated with it.

Figure 8- Cutting out fins with cutoff blade.

Photographs of the Completed Rocket

Post Flight Analysis

General Flight Characteristics. After careful review of the rocket's flight performance, Team Rally Axe believes that all but one aspect of the design competition was met. The minimum altitude criterion was not met due to an inadequate location for the center of pressure (CP) which resulted in over-stability. Initially, the rocket maintained a stable flight path until just after burnout, when the over-stability caused a severe weather-cocking effect. Because of the high winds, this effect became so extreme that a spiraling motion was imparted on the rocket, substantially increasing the drag and causing a premature apogee. Despite these adverse conditions, the parachute was deployed successfully and the rocket was recovered near the launch pad in flyable condition.

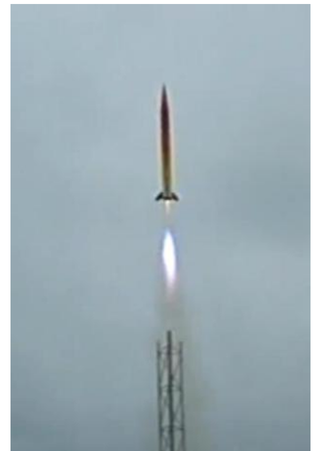


Figure 9- Rally Axe launches successfully.

Official scorecard (Figure 10). All aspects of the competition were met except for minimum height.

SCHOOL: University of Wisconsin-Madison **Team:** Rally Axe

			Predicted	Actual	
1	Operation (determined by RSO or designee)				✓
	Launch				✓
	Parachute deployment				✓
	Recovered				✓
	Determined to be in flyable condition				✓
	Mass of rocket without motor			34.25 lbs	
2	Maximum Altitude	(*ft.*)	1549	653	
3	Peak Acceleration	(G's	9.66	9.2	

Figure 10- Official scorecard.

Comparison of altitudes. Prior calculations anticipated the rocket to reach 1549-feet at apogee, with an achieved value of only 653-feet. Because of the team's inexperience in high-powered rocketry, an appropriate method for determining the location for the CP was not utilized. The only known method for obtaining this key location was through RockSim, because the team was oblivious to the existence of other methods such as Barrowman's equations. After analytically determining the CP using the Barrowman method, it was found that RockSim's location for the CP was more than 3-inches higher on the rocket than the analytical result. Since the location for the center of gravity (CG) is a fixed location, the true CP was nearly two calibers below the CG, resulting in a larger margin and an over-stable flight. With the correct value for the CP, the rocket had a static margin of 1.68 at launch and deteriorated throughout the burn phase until reaching its worst value of 1.89 after burnout. As a check, Space CAD was used to calculate the location for the CP as well, producing similar results.

Comparison of accelerations. After comparing the official acceleration to the predicted value, an error of 5% for the peak value was found. Figure 11 shows the overall trend of the acceleration, which is consistent throughout the flight with only minor discrepancies. The first difference is a heightened acceleration towards the end of the burn phase, probably due to variability between the motor used and the thrust curve provided. The other noticeable difference is that the value for acceleration after burnout is not consistently -1G. This makes sense due to the erratic flight path that occurred.

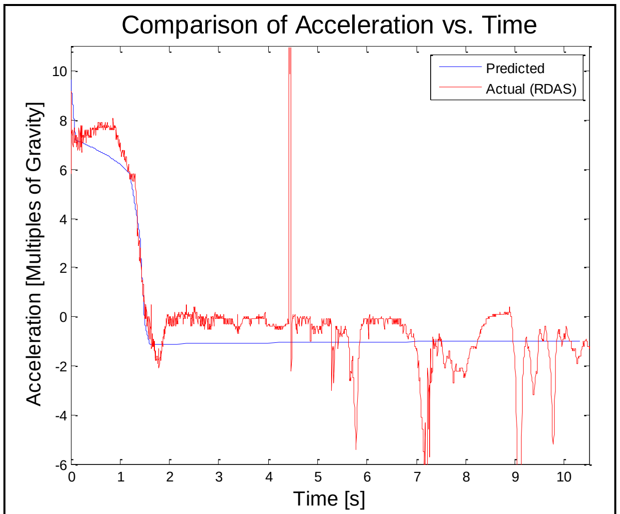


Figure 11- Predicted Versus Actual Acceleration.

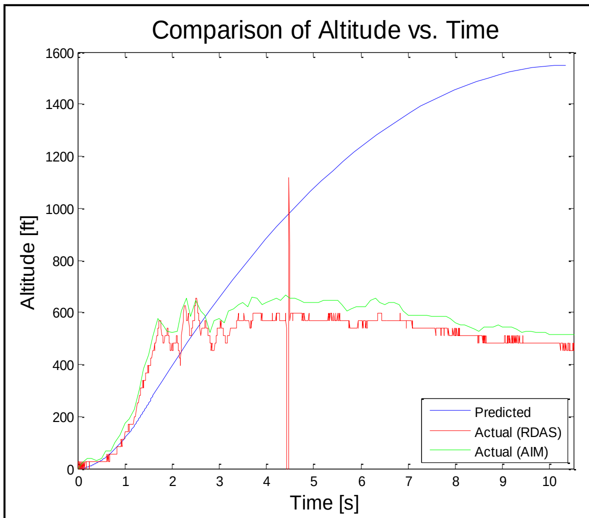


Figure 12: Predicted Versus Actual Altitude.

Comparison of times to apogee. Another issue arose when comparing altitude versus time, in that even with a stable flight, the time to apogee calculated is much greater than what would have been experienced. Figure 12 shows both the predicted and actual altitudes versus time for both altimeters. For the first 2-seconds of flight, the plot shows that the rocket experienced a relatively straight trajectory; however, the slope of the predicted altitude is underestimated. This is a direct result of how the values were calculated using MATLAB's ode45 internal solver. Though very useful, this Runge-Kutta method tends to have a time-shift, which is what caused the under-estimated slope. In the absence of this shift, the projected altitude over time would have compared more favorably to the experienced rate.

Conclusion

The variation between the expected and experienced values of the flight performance was proven to be caused by calculation errors. Most notably, the neglect to analytically derive the location for the center of pressure resulted in the subpar performance in altitude achieved. Team Rally Axe is pleased, however, with all other aspects of the rocket's flight, and is confident that the experience gleaned will benefit them in future competitions.

20th Annual Conference
Part Three

NASA Reduced Gravity Program

Demonstration of Lunar Regolith Handling Techniques
University of Wisconsin Microgravity Team

Contact: Nathan P Wong
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Faculty Advisor: John Santarius

NASA PI: Juan Agui
NASA Glenn

Abstract

In returning humans to the moon, it is critically important to look at how we can utilize the materials there to make our trip easier. One of those materials is the lunar regolith itself. It can be used to extract oxygen for life support or propulsion. In order to increase processing efficiency it is necessary to sort out larger particles of regolith to increase the surface area to volume ratio. Our experiment looked at the efficiency of a one pass and two pass system. Our results were quantitatively inconclusive, but qualitatively we observed that sifting of lunar simulant with a terrestrial sifter is possible in a variable gravity environment.

Introduction

Development of lunar regolith handling technologies for *in-situ* resource utilization (ISRU) has shown the need to sort the size of regolith particles. (Mason, 1992) Processes required include volatiles extraction, lunar oxygen extraction, lunar metals separation, and construction of lunar concrete. (Wilkinson, 2005) It is desirable to find an existing technology that can perform the function of size sorting. Existing processes for separating bulk solids are cyclone separation, sifting, and sieving. It is unknown whether sieve systems manufactured on earth for similar soil size separation behave differently in a lunar gravity environment. It is desired to verify the sorting of a specified amount of JSC-1A in a commercial sieve operating in lunar gravity.
A sieve works by accelerating the surface of a wire mesh rapidly with an unsorted bulk solid lying on top of the wire mesh. This causes particles of sizes smaller than the mesh size to pass while the larger particles remain on top. The proposed experiment will determine if the acceleration provided by the sieving equipment is adequate for lunar gravity. By varying the amplitude and frequency of the vibrator on the sieve and comparing the mass through the mesh, the effectiveness of such a system can be determined.

Purpose

The purpose of this study was to investigate the sieve efficiency in a reduced gravity environment. The design was to drop premeasured amounts of lunar simulant into the sifter and measure the mass flow rate of the system, and then compare that to terrestrial gravitational testing. We also wanted to look at if a two-pass system was more efficient than a single pass system. This was to be accomplished by having one flight day of unsorted simulant, and the other flight day use presorted simulant of particle size under 150 microns. On both days we were sifting to get particles of 75 microns or smaller.

The importance of this study comes from the planned technology needed in returning humans to the moon to stay. In order to create a permanent outpost, we must utilize the materials on the moon to their fullest advantage. One of those materials in the lunar regolith itself, and many chemical processes can be done on it to produce oxygen, hydrogen, silicon, and various metals. Being able to sort out the smaller particles can make these processes more efficient by having a higher surface area to volume ratio.

Experimental Method

In order to collect data for our experiment, individual samples of regolith weighing approximately .25kg were dropped into the sifter, the material was then collected and sealed. This was done 15 times throughout the flight. On the first flight day we were using unsorted JSC-1A and sorting to under 75 microns. On the second flight day we were using presorted JSC-1A that was under 150 microns, and sorting to under 75 microns.

Difficulties

Unfortunately on our first flight day, our experiment was not receiving the correct power from the plane. This caused our sifter to behave in an unexpected, and underpowered manner. On the second flight day we had some mechanical issues with our experiment that, if the first day had gone well we may have been able to catch and fix. Due to these complications, we do not put much weight behind our numerical data collected during the flight, although from the video we collected have do have qualitative data. Our data can be found in the appendix.

Results

Our qualitative data shows that the sifting lunar regolith in a lunar gravity environment is a possibility, even with machines that were design and intended for terrestrial use. We believe this is true for two reasons. The first is that the sifter operates by moving the sifting surface parallel to the ground, and perpendicular to the gravitational acceleration. Therefore the effect of gravity is minimized in the overall efficiency of the sifter itself. The second reason is that many machines are built with a safety factor of at least two. We showed this by performing runs in the hyper gravity environment.

Future Work

We are currently having a particle simulations group on campus look at the same experiment we were doing on the plane. It is our hope that we will be able to correlate our ground tests with simulations, and then alter the simulations to change gravity. This would help give numerical data to our experiment.

Conclusion

From the results of our experiment, we can report that a sifter built for terrestrial applications can be used in a lunar gravity environment. The change in performance was not accurately measured, but from visual data, there did not seem to be much change in performance. If we were to do this experiment over again, the first thing we would do differently is have someone check the power coming out of the plane. We had a unique request for power (220V), so it should not have been assumed that everything would be working correctly. Another aspect of our project we would change is to do more work at the start of the project. It would have been nice to have things built sooner so we could have done some more ground testing.

The results that we got will aid our expansion into the solarsystem. We were able to show that new technology does not need to be developed for the sifting of lunar soil. This work could also translate to Martian and asteroid regolith. The ability to utilize already mature commercial technology can ultimately save millions of dollars in the budget, that can be used towards advancing other technologies that we have yet to come up with.

Acknowledgements

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Investigation of Propellant Sloshing and Zero Gravity Equilibrium for the Orion Service Module Propellant Tanks

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Abstract

We study fluid slosh in the Orion Service Module propellant tanks. Resonant slosh frequencies were measured as a function of tank fill-fraction in a scaled model of the tanks. We carry out both computational and theoretical calculations of resonant slosh frequencies, and find reasonable agreement between experiment and prediction. We measured fluid slosh in $2-g$, $1-g$, Martian gravity ($1/3-g$) and lunar gravity ($1/6-g$). Using the software FLOW-3D, we established free-surface configurations in zero gravity of both the model and the full scale Orion SM tank. In addition, we measured formation times of the equilibrium free surface configuration. FLOW-3D calculations suggest that the zero-g free surface configuration consists of two separated fluid volumes.

Introduction

In fluid dynamics, *slosh* refers to the movement of liquid inside a hollow object. Slosh control of propellant is a significant challenge to spacecraft stability. Mission failure has been attributed to slosh-induced instabilities in several cases [Robinson,1964], [Wade, 2010], [Space Exploration Technologies Corp., 2007]. While propellant masses are highest in the initial phases of a mission (launch and orbital insertion), slosh control is particularly important in the latter stages of the lunar return mission envisioned in the Constellation/Orion

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program.

The Orion capsule serves as the crew launch and return vehicle of the Constellation program and consists of a crew module (CM) and service module (SM). In addition to housing thrusters, propellant and oxidizer for lunar return maneuvers, the SM provides power and life-support services to the Orion spacecraft. In support of its main engine, the Aerojet AJ-10 rocket engine, the SM contains two propellant and two oxidizer tanks with a total launch mass of 8300kg of propellant and oxidizer [NASA, 2010]. The bipropellant system consists of mono-methyl hydrazine (MMH) and the oxidizer N_2O_4 (NTO). As a substantial portion of the initial weight of the SM is propellant/oxidizer, an understanding the slosh dynamics in the SM tanks is critical.

As the propellant level decreases throughout a mission, the effects of sloshing forces on the remaining fuel become more prominent. When the tank is full or nearly so, the fuel lacks the open space to slosh. However in the latter stages of the mission, when most of the fuel has been consumed, the fuel has sufficient volume to slosh and possibly disturb the flight trajectory. This sloshing can ultimately lead to wobble in a spinning spacecraft and self-amplifying oscillations that can result in failure of individual instruments or failure of the entire structure. The dynamics of a fluid that interacts with the walls of its container are complicated and challenging to predict. The effects of sloshing on bodies in motion are significant and in some cases devastating. These effects remain prominent even when the propellant volume represents only 0.3% of the total spacecraft mass [Vreeburg, 2005].

Due to the significance of slosh dynamics, a considerable amount of research has been conducted on this topic over the past sixty years. Graham and Rodriguez conducted the first study specifically related to propellant slosh [Graham, 1952]. This research investigated the effect of fuel slosh in aircraft in response to simple harmonic motion from plane pitching and yawing. The results facilitated a general understanding of propellant slosh dynamics.

In 1964, a study at the Lewis Research Center in Cleveland, Ohio analyzed experimental sloshing characteristics by relating movement of sloshing liquids to an effective pendulum mass [Sumner et al, 1964]. The researchers employed a scaled version of a Centaur liquid oxygen tank, which was a spherical vessel with a cylindrical portion along the major axis of the tank. Three model tanks with varying complexity were tested. The initial setup was a clean or empty tank with no internal structures. The second setup consisted of an unbaffled tank with a thrust barrel, fill pipe, annular spring ring and a vent pipe. The final tank included a baffle near the center of the tank in addition to the internal structures from the second setup. When compared the clean tank, it was found that the fundamental frequencies of the liquid were reduced due to the thrust barrel in the unbaffled tank. This research is relevant to our project as it provided a considerable amount of information in relation to damping slosh dynamics in a $1 - g$ environment. However, research conducted in variable gravity conditions is more pertinent to fluid dynamics in space.

In 1969, Salzman and Masica conducted research that provided data for slosh dynamics under variable low-gravity conditions at the Lewis Research Center [Salzman, 1969]. In particular, the lateral sloshing resonant frequencies in cylindrical tanks were studied as a function of Bond number, a parameter that describes the relationship between gravitational forces and surface tension. The results suggested that for liquid depth ratios (height of the liquid/radius of the tank) less than two, the natural resonant frequency of lateral sloshing is directly proportional to the liquid depth. The study also found that the zero-g liquid equilibrium configuration was reached in less than 50ms for cylinders ranging in radii from 1.59cm to 2.54cm. Because of those results, we conjectured that we could see the equilibrium free surface configuration in our tank within 25s of zero gravity.

We report here the results of an experiment to perform a linear sloshing analysis on a scale model of the SM downstream propellant tanks, to examine the free surface configuration of the same tank in a zero-gravity environment, and to determine the free surface formation times of the liquid in the tank.

Parabolic Flight

Our experiment was conducted aboard a microgravity aircraft commissioned by the NASA Reduced Gravity Office (RGO). In order to simulate a zero-g environment, the aircraft flies a set of parabolic flight maneuvers illustrated in Fig. 1. As the plane crests the top of the parabola, the occupants and experiments begin to experience weightlessness. The aircraft then begins a free fall towards the earth in a path that follows an elliptical orbit and lasts approximately 25s. The payload is subjected to weightlessness because it is falling at the same rate as the plane and experiences no ground reaction force from the body of the aircraft.

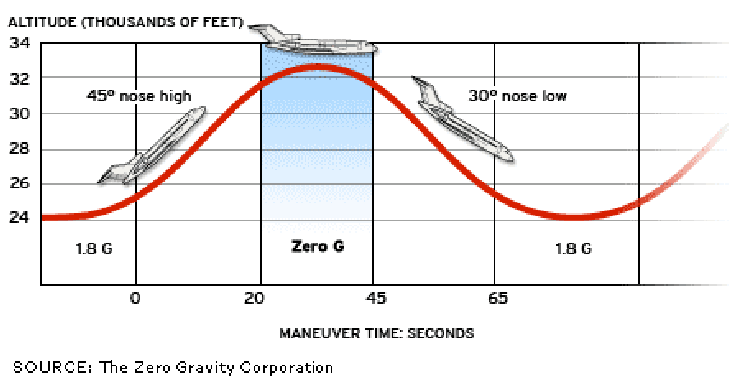

Figure 1: A parabolic flight path indicating the zero-g and high-g phases of the trajectory. The aircraft pitch angle determines the gravity field the payload experiences.

Research Objectives

It is important to understand relevant fluid properties that will be addressed in this paper. The *Bond number* of a liquid confined in a container of characteristic length L is a dimensionless quantity that describes the relationship between gravitational forces and surface tension:

$$B_0 = \frac{\rho g L^2}{\sigma}, \tag{1}$$

where ρ is the density of the liquid, g is the gravitational acceleration experienced by the liquid, and σ is the surface tension of the liquid.

The *contact angle* (θ_c), illustrated in Fig. 2, is the angle at which a liquid meets a solid surface. Contact angle is a function of the cohesive forces within the liquid and the adhesion between the gas and liquid as well as the surface and the liquid. Strong adhesive forces tend to flatten the drop, leading to a smaller contact angle. A contact angle of less than 90 degrees is said to be wetting, and a contact angle of more than 90 degrees is said to be non-wetting. A key research objective is to determine a useful propellant simulant that exhibits the same θ_c as MMH on aluminum.

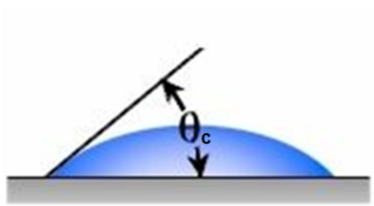

Figure 2: The contact angle of a fluid on a solid surface.

In a zero gravity environment, propellant does not remain at the bottom of the tank, but instead establishes a new configuration within the tank. These *zero-g surface configurations* and their formation times depend on tank geometry and internal structures. If there is an absence of fluid near the intake valve at the bottom of the tank, the spacecraft's engines may fail. To combat the effects of zero gravity on the fluid, the use of reaction control system (RCS) thrusters may be necessary to ensure that fuel is constantly present near the fuel intake valve. In order to properly use the RCS thrusters, the free surface configurations and their formation times for different fill levels must be known. The free surface formation time for a liquid is the time for the fluid surface to obtain its equilibrium shape after a reduction in gravitational acceleration [Dodge, 1967].

The *settling time* of the fluid is an important property and depends on the fluid characteristics, tank design, and Propellant Management Device (PMD) design. The settling time is the amount of time it takes for a liquid to transition from a zero-g surface configuration to the bottom of the tank. The settling time data will determine if the use of RCS thrusters is necessary. More importantly, settling time data will validate current computational models and PMD designs.

Our research objectives were as follows:

1. to carry out a *Linear Sloshing Analysis* to identify frequencies of the fundamental anti-symmetric slosh modes in the Orion SM downstream propellant tanks
2. to establish the zero-g *free-surface configuration* of propellant in the Orion SM downstream propellant tanks
3. to determine forrmation times for free surface configurations.

We examine these questions using standard potential theory, computational modeling and experiment. This report is organized around these research objectives.

Experiment Design

We designed and built a 1/6-linear scale model of the Orion SM Downstream Propellant Tank illustrated in Fig. 3.

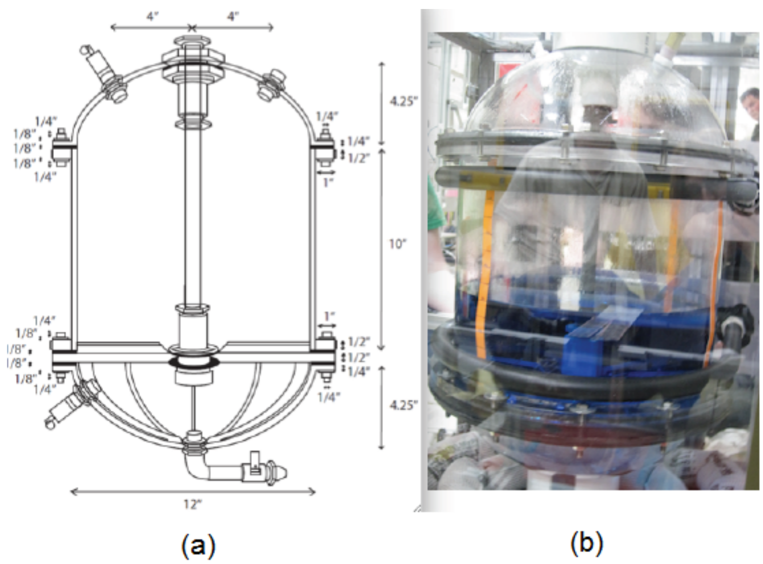

Figure 3: (a) detailed drawing of the internal structures of the model tank; (b) a photograph of the operational tank.

Our model tank consisted of 0.25in thick acrylic cylinder with acrylic domes of similar thickness bolted to each end. The cylinder had a height of 10in and an outer diameter (OD) of 12in. The domes had ellipsoidal vertical cross-sections with a semi-minor axis length of 4.25in (OD). At the bottom of the cylinder, a 0.5in thick circular Lexan plate was bolted between the edge of the cylinder and the bottom dome. The total height of the tank was 19.5in, excluding the fill cap at the top of the tank and the manual drain valve at the bottom.

A high-fidelity model of propellant slosh in a reduced-scale tank should preserve the dynamical properties of the fluid in a full-scale tank. To acheive full dynamical equivalence between the two tanks, a set of scaling parameters representing ratios of critical forces must be preserved from model-scale to full-scale. In addition to the contact angle and the Bond number, full dynamical equivalence preserves the value of the Weber number and the Reynolds number. The latter parameter is the ratio of inertial to viscous forces, while the Weber number is the ratio of the inertial forces to surface tension. Preserving the values of each of the three scaling parameters (Bond, Weber, and Reynolds) and the contact angle is generally impossible, and modelers usually choose a simulant fluid to match a single dynamical property such as inertial response.

In our experiment, it was most important to match contact angle and Bond number. The contact angle of MMH on aluminum is approximately 20°. Ethanol and acrylic exhibit a similar contact angle. However, pure ethanol will crack acrylic, so our experiment utilizes a 60/40 mix of ethanol and water. The Bond numbers of the model and full-scale tank differ by an order of magnitude, but are as close as possible given the range of fluids and tank materials availible to us.

We tested four fill-levels in both the upper and lower compartments of the model tank. Halfway through each of the two flight days, we drained propellant simulant from the upper compartment into the lower compartment via the drain plug at the center of the Lexan plate in order to acheive different fill fill-fractions. The fill fractions are displayed in Fig. 4.

	Day 1		Day 2	
	Pre-Drain	Post-Drain	Pre-Drain	Post-Drain
Upper Compartment	40%	30%	20%	10%
Lower Compartment	2.5%	76.50%	3%	77%

Figure 4: This table shows the tested fill-fractions of each compartment of our model tank. The values are percentages of the total volume of the respective compartment.

We collected our data using three mini-DV cameras; two set on the upper compartment, the other to record the lower compartment. They gathered close to 50 minutes of visual data apiece for two days.

Computational Fluid Dynamics

Computation Fluid Dynamics (CFD) is the study of fluid dynamics in which algorithms and numerical methods are used to investigate and solve fluid flow problems. To further examine our scale model of the SM downstream propellant tanks, we use a CFD software package called FLOW-3D, a program that models complex fluid flows in many different applications. FLOW-3D uses a process know as the volume of fluid (VOF) method to locate and track the free surface of a fluid. In the VOF method, the fluid and tank geometry are discretized on a mesh. Appropriate boundary conditions based on fluid properties and tank geometry are applied, and the Navier-Stokes equations are solved iteravely on the mesh. The numerical calculations can then be transformed into a picture of what the liquid looks like in the tank, illustrated in Fig. 5.

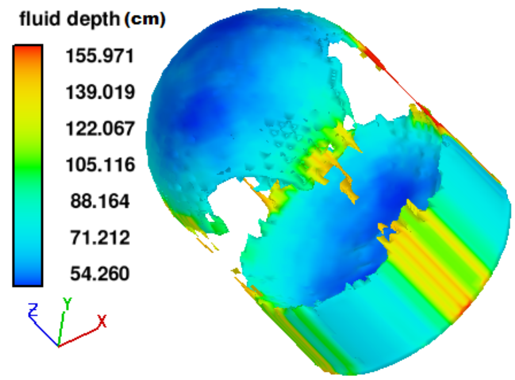

Figure 5: The full-scale tank at 0.8 fill-fraction and 1700 sec. The mesh size is approximately $1cm^3$.

For our purposes, we ran simulations in FLOW-3D to determine the natural resonant frequency of the ethanol at different fill levels, to examine the zero-g free surface configurations for the real and model tanks, and to ascertain the free surface formation time of the fluid.

Linear Slosh Analysis

When an impulse is applied to a tank, the fluid will slosh with harmonic motion at a natural frequency that depends on the gravity environment, the tank geometry, and the properties of the fluid. In our experiment, this impulse occurs during aircraft transitions from low-g to high-g. We measured the natural frequencies as a function of the ratio h/R, where h is the liquid height and R is the tank radius.

The spectrum of resonant slosh frequencies in an upright, cylindrical tank can be derived from a standard flow potential theory [Dodge, 2001]. While the tank geometry supports both symmetric and anti-symmetric slosh modes, the anti-symmetric modes are the lowest in energy, and were most frequently observed in our experiments. We therefore restrict our consideration to these modes. The spectrum of anti-symmetric slosh modes in a cylindrical tank are given by

$$f_{mn}^2 = \frac{1}{4\pi^2}\frac{g\xi_{mn}}{R}\tanh(\xi_{mn}h/R), \quad (2)$$

where g is the acceleration of gravity, ξ_{mn} are the roots of the Bessel function of the first kind (we used ξ_{10}, the lowest non-vanishing solution), h is the height of the liquid, and R is the radius of the tank. Eqn. 2 is derived from the velocity potential for ideal fluids in

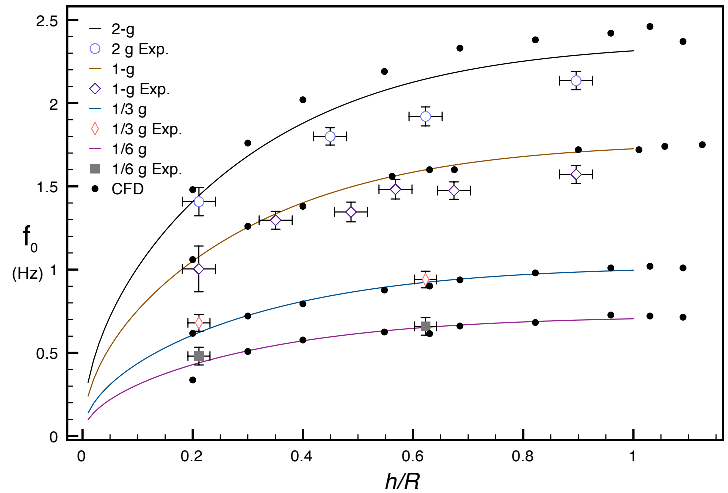

Figure 6: The relationship between natural slosh frequency and fill fraction (h/R) for the lowest andti-symmetric mode. The solid lines are derived from Eqn. 2 at $2-g$, $1-g$, Martian gravity ($1/3-g$) and Lunar gravity ($1/6-g$). The solid points are from FLOW-3D at those fill fractions. The open points are the experimental data measured using the video data. The horizontal error bars indicate uncertainty in height measurement, while the vertical error bars represent standard error in frequency measurements.

cylindrical tanks.

Using the FLOW-3D software, we calculated the natural slosh frequency of the computer generated model tank at the various gravity environments and fill levels. Tank models were generated with and without axial mass gauging probes running the length of the upper compartment of the tank. The presence of the mass gauging probe had no discernible effect on the resonant frequencies. In general, we find congruity between theory, CFD, and experiment.

We looked for the natural frequencies of the anti-symmetric mode because it is a low energy formation and the waves carry the most momentum [Abramson, 1966]. Since it carries the most momentum, the anti-symmetric mode is most likely to disturb a spacecraft trajectory.

Free Surface Configuration and Formation Time

The *formation time* is the time a fluid takes to reach its zero-g surface configuration. In a circular cylindrical tank, the formation time can be calculated using Eqn. 3. Formation times in a cylindrical tank can be estimated from the emperical relation [Dodge, 2001]

$$t_s = \frac{R_0^2}{\nu} \frac{10^B \xi^A + 0.01\alpha^2}{1+\alpha^2} \quad (3)$$

where ν is the kinematic viscosity, R_0 is the radius of the tank,

$$\begin{aligned}
\alpha &= \frac{1-\sin\theta_c}{\cos\theta_c} \\
A &= 0.28 + 2.2\alpha - 1.2\alpha^2 \\
B &= 3.9A - 3.32 \\
\xi &= \nu\sqrt{\frac{\rho}{R_0\sigma\alpha^2\cos\theta_c}}.
\end{aligned}$$

and σ is the surface tension and ρ as the mass density of the fluid.

Full Scale Tank	Model Tank
3400s	110s

Figure 7: The formation time of the liquid in the full-scale tank and the model tank.

Eqn. 3 is valid for contact angles less than 90° [Dodge, 2001]. Formation times are independent of h/R over the range (0.8-1.6), and can be estimated from Eqn. 3 for both full-scale and model tank geometries. Characteristic formation times for both the model and full-scale tanks are shown in Fig. 7.

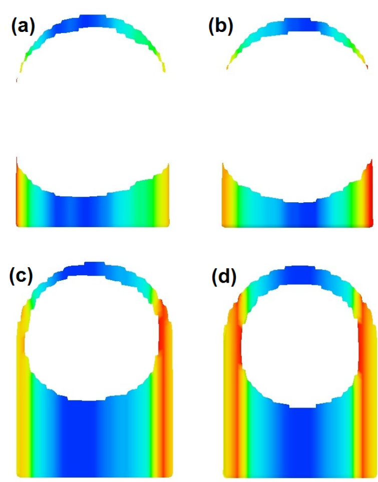

Figure 8: (a) full-scale tank at h/R =0.8; (b) model tank at h/R =0.8; (c) full-scale tank at h/R =1.6; (d) model tank at h/R =1.6.

Since the formation time for the scale tank exceeds 25s, it would have been impossible for us to achieve the zero-g free surface configuration on the zero-g aircraft. Instead, FLOW-3D was used to analyze the zero-g free surface configurations of the liquid in the model tank as well as the full-scale tank.

The zero-g free surface configurations that we observed in our simulations were not what was expected. We expected the fluid to slightly wick-up the sides of the tank and form a spherical depression in the center of the tank. However, the simulation results were drastically different. The fluid in both the model and the full-scale tank formed a zero-g free surface configuration with a "double interface," illustrated in Fig. 8 (a) and (b). This double interface formed at fill levels of less than 1.4. The remaining fill levels exhibited a different configuration. Fig. 8 (c) and (d), depicts a spherical interface at fill levels of 1.4 and 1.6.

Summary and Conclusions

We have performed experimental and numerical investigations of slosh modes and free-surface configurations of propellant simulants in reduced and zero-g environments. Experimental measurements of anti-symmetric slosh modes agree well with both theoretical predictions and computational models using Flow-3D.

Free-surface formation times and configurations were not accessible to experiment due to the limited time period of weightlessness provided by parabolic flights. However, in the context of CFD investigations, we did find a new and unexpected free-surface configuration after a step-wise reduction in gravity from 1-g to zero-g in both full-scale and model tank geometries. This new configuration consists of two, often separated, fluid volumes resident at the top and bottom of the tank. The fluid volumes enclose a roughly spherical void volume. These results may have bearing on mass gauging technologies in cylindrical tanks, and are worthy of further investigation.

Finally, we establish, using CFD, that free-surface formation times in the full-scale Orion down-stream propellant tanks should be on the order of 3400 seconds. This results suggests that there may be considerable time between main-engine cut-off and propellant equilibrium during which the propellant is in a dynamic state.

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20th Annual Conference
Part Four

Senior Design

ECLIPS: Engineered Compact Lunar Interchangeable Power Systems
Alternative Energy Storage Solutions for Lunar Exploration

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Abstract

Team ECLIPS pursued in their research energy systems which would allow long range, manned exploration on the moon once a lunar presence was established. This system would need to be modular, compact, lightweight and have the ability to operate on the majority of the surface of the moon. Such a system would have the ability to extend the range of lunar rovers, as well as act as a power source for a wide variety of applications. Research and experimentation focused on novel concepts where there was little existing researc. A Lunar Regolith filled flywheel concept was chosen and tested using basic tests. Tests conducted using lunar simulant established that feasibility of a loose Regolith filled flywheel lay on both uniformity of the regolith, and the ability of the flywheel components to handle loads caused by the inevitable imbalance of loose lunar dust.

Background

One of the objectives of NASA's Project Constellation is to establish a manned presence on the moon. Exploration from a single permanent base would be limited due to the safety concerns of astronauts traveling beyond their ability to walk back to safety should their rover lose power. This limit, called the walk back limit, was a major factor in reducing the distance that the Apollo astronauts explored. Due to this limit, extended operations would require additional, remote power stations which could be deployed along exploration routs. These would not only produce and store the much need energy for exploration rovers, but would also serve as the power source for small emergency bases, as well as additional equipment that may be deployed in the course of exploration.

The study conducted by team ECLIPS investigated the feasibility of a power source which could act as a power supply for a remote lunar base, or as a supplementary supply for a lunar rover. The system needed to be modular, compact, and capable of producing and storing the required energy for a given application. Preliminary designs were evaluated based upon the relevant criteria, with attention paid to minimizing size and weight, while maximizing energy storage and production. The most promising and undeveloped storage option was found to be a flywheel with auxiliary generation inputs. Research indicated that the most feasible generation methods should include radioisotope thermoelectric generators (RTGs) and a solar photovoltaic array. In addition to these, a rocket powered turbine was also investigated to maximize the versatility of the designed system.

Given the expense of launching material into space, it was proposed that the flywheel shell be sent to the moon and be filled with lunar regolith upon its arrival on the lunar surface. This would allow for a relatively large rotating mass of the wheel while keeping the terrestrial launch mass low. The flywheel design proposed consists of an outer reinforcing ring used to support the

[1] The authors would like to thank WSGC for provided the funding for the construction of the testing apparatus.

rotational body force of the regolith, as well as an enclosed hollow center section that would be filled with the lunar regolith. Through static and dynamic finite element analyses, it was found that to achieve the necessary energy capacity of 10kWhr in a system, a material with a very high specific strength would have to be used such as carbon fiber. It was determined that using a regolith filled flywheel decreased the total energy available in the wheel versus an empty wheel, since the empty wheel could spin at a much higher RPM. However this was also found to be the major advantage of the regolith filled wheel, as the motor generator used in conjunction with the wheel would need to operate of a much smaller range, and the wheel imbalance could also be much larger. This is true as the force of an imbalance is heavily dependent on the angular velocity of the mass.

A solar photovoltaic system was investigated as an option to supply power to the motor during the light cycle of the moon's revolution. Research was conducted to determine efficiency, power output, and size. In addition, a pole mounted solar array could be used to provide shade for the rest of the system, allowing the system to stay cool. It was determined that gallium arsenide solar cells would be the optimal choice, as they are efficient and have been used for space applications in the past. These cells can reach an efficiency of almost 28 percent, however lunar dust may lower this value. The solar insolation present in space and on the lunar surface is a constant 1367 Watts per square meter, which ideally translates into a power output of about 380 Watts for a square meter panel. (Luque & Hegedus, 2003) However, when accounting for temperature degradation and losses due to ultraviolet exposure, micro-meteor damage, and ordinary surface contamination, the final power output would be closer to 320 Watts.

Radioactive power sources are a second type of power system that could be used during either the lunar day or night. NASA has a long history of using radioactive material as a power source. In a family of power systems called radioactive power sources (RPS), the radioisotope thermoelectric generator and its newer cousin the sterling radioisotope generator have the ability to generate thermal and electrical energy in the dead of space, as well as on lunar and Martian surfaces. While both use capsules of decaying Plutonium 238 to produce thermal energy, each produces electrical power through different methods. RTG's use the Seebeck effect to produce a current in dozens of thermocouples, while SRG's use the temperature gradient between the plutonium and the surrounding space to run a Stirling engine. The modern RTG and the SRG outputs are approximately 125 Watts (electric) and 116 Watts (electric) respectively, which is just slightly below the required output for the system of 139 Watts (electric). (DOE, 2008)

Given that both the solar and RTG charging methods have a relatively long charge time for the system, it was determined that an immediate charging method would greatly improve the systems versatility. One of the most promising and original options for a generation system of this type would be a rocket powered turbine, very similar to that of the fuel pumps used on modern rocket engines. One pump that was found to have specifications that met our design criteria very closely was the turbopump from the RL10 rocket engine used by NASA. This pump outputs 80HP and 420inlb of torque at 12,200RPM. The pump would be used to spin the flywheel up to speed rather than as a fuel pump. Due to much of the information about this engine being highly classified, this option has not had exhaustive research done completed at this point.

The Ideal Flywheel Design

A critical part to the design of the power system is the containment structure which consists of the frame, the affixing bearings, and vibration or balancing control systems. The frame should provide a sound structure to ground the flywheel and associated components. The frame should also provide inertial stability to provide the best possible rotation with as little vibration and disturbance as possible. This is important for both the function of filling the flywheel with lunar regolith and operational performance of a full and balanced flywheel. The frame and bearings must be able to safely withstand such additional vibrations to the existing dynamics and continue to provide smooth support for the rotating apparatus. To be optimal for the design the components should operate with as little human interaction and maintenance as possible, and as few losses possible. However, the system must also be able to be assembled on the moon by a standard team of astronauts and operate to specifications.

Any system subjected to high rotational velocities is subject to a phenomenon called whip. Whip is the tendency for the shaft to bend due to an imbalance in the rotating mass. In the case of an imbalanced flywheel, this force can become considerable due to the large mass and radius of the wheel. In the system designed, imbalance will most likely be present due to the proposed filling of the flywheel with lunar regolith. A preliminary study was conducted to determine the force produced by various imbalances.

While many methods of using lunar regolith are possible, the simplest method, and one not previously researched, was chosen. This method was the simple filling of the flywheel with loose regolith. The selection of this method necessitated the investigation the amount of imbalance caused by filling the wheel with loose regolith.

Flywheel Experiment

To test the filling and imbalance of a wheel a small scale test model was constructed. This model consisted of a stand which held the motor as well as the bearings which supported the flywheel itself. The shaft holding the flywheel was supported on only one end of the flywheel. This was done in order to accentuate the effect of imbalances. This cantilever shaft design would allow sensing small imbalances though the use of a sensor on the bottom rim of the flywheel. This sensor sensed the deflection in the shaft. As the deflection of the shaft was the characteristic whip caused by an imbalance, and this deflection was a function of mass imbalance. From this relationship, the equivalent mass imbalance could be found. A mathematical model was created to describe the deflection of the shaft based on probable imbalances the test system would see.

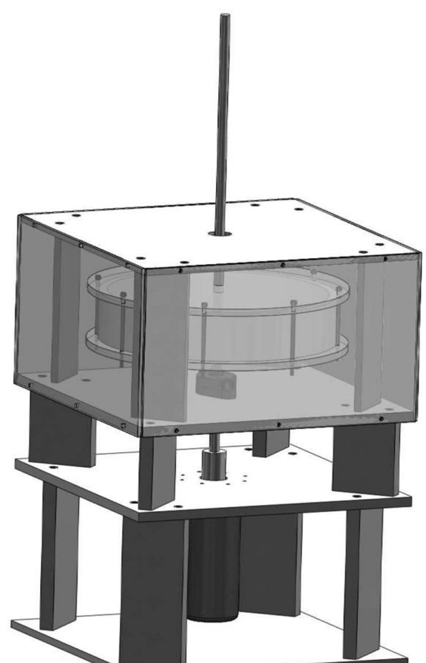

Figure 1: Model of Flywheel Test Stand

Procedure

Testing began by collecting calibration measurements from the setup. This consisted of spinning the empty flywheel to a set speed, and measuring the deflection of the flywheel for two or three revolutions. This was done every 100 RPM from 0 RPM to 700 RPM. This allowed for the establishment of a base line set of deflection. These helped to account for variations in the surface of the wheel, and allowed for the observation of the empty systems behaviors.

Figure 2: Filled Test Stand Before top Attached

Once the empty tests were completed, the flywheel drum was filled with loose Lunar regolith simulant JSC-1. Care was taken not to shake or vibrate the container as the simulant was prone to settling. It was desired that this settling occur while the system was operational. This was to test if the simulant would flow in a way that would have a balancing effect on the system. Additional empty tests were conducted using known imbalances. These were 10g, 20g, and 50g on the outer edge of the flywheel. These know imbalances allowed for a comparison between the measured data and the mathematical prediction model.

Once the flywheel was filled and properly sealed, the flywheel was accelerated to 100 RPM. Here the deflection of the wheel was recorded. Measurements were taken at every one hundred RPM until 700 RPM. This was done twice. The test was repeated once again with half the flywheel.

Results

The filled flywheel tests yielded a number of important results. The most important was that a significant imbalance was present in both full fill trials. Both trials yielded an imbalance of an equivalent of over 150g on the outer edge of the wheel. It was also significant that the imbalance remained in the same place regardless of the wheel's angular velocity. This was important as the reaction of the loose simulant in a spinning flywheel had never been observed. Filled tests showed some settling, and displacement of the simulant from the center of rotation. The partially filled tests showed similar results with greater displacement of the simulant, though the location of the imbalance was not dependant on RPM for these tests either.

The tests showed that loose regolith would most likely cause too much of an imbalance in the system. While bearing selection on the final production design would ultimately determine the acceptable level of imbalance, future research into the use of regolith as a flywheel filler would need to focus on manipulation of the filler as to make the flywheel as balanced as possible. Future work could also investigate the possibility of melting regolith.

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Condensation in Spacecraft

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One of the many concerns when dealing with the exploration of space is how to practically and efficiently create a habitable area in which astronauts can work. One issue of interest is how to account for the large temperature differences that inevitably occur across the outer walls of a spacecraft. Such temperature differences pose problems for keeping the astronauts in a comfortable working environment. More specifically, these large temperature differences can lead to the formation of condensate on the inside surfaces of the living environment.

The formation of condensate can lead to many unwanted effects and conditions. Condensation of water vapor occurs when the vapor in the air is cooled below its dew point, leaving standing water droplets on surfaces that are at or below the dew point. Standing water on the inside walls of a spacecraft has the possibility of promoting the growth of mold or bacteria. Condensate would also be problematic if it were to come into contact with any electrical systems that may be found within the habitable area, rendering those systems inoperable. These possible consequences of condensation lead to undesirable living conditions and are possibly dangerous to the crew aboard a space exploration vessel thus creating a need for an effective method to eliminate the negative effects of condensate formation.

Before any method to eliminate condensate could be developed, it was necessary to first determine the design conditions for the spacecraft under consideration. Once these have been established, the design specifications could be determined. First and foremost, the system had to be capable of dealing with whatever amount of condensate formed. It was decided that the system could accomplish this goal in one of three ways. It could either prevent the formation of condensate altogether, collect the condensate as it forms and store it in a waste tank, or collect the condensate as it forms and recycle the water for some useful purpose. Since water is such a valuable resource the third option was deemed more desirable than the second but either would have met the specification. The second important specification for the system was its mass. In space applications, no physical property is more important than mass because of the large costs associated with launching even a single pound of mass. The mass of the system was set to be no greater than the current method used to eliminate condensation on the walls of spacecraft, using strip heaters to raise the inside wall temperature above the dew point. Two other important desired characteristics of any useful system were passivity and reliability. Ideally, the system

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would be passive to the point that it could be put in place and would work without any interaction from the crew aboard the spacecraft. Also, the device needed to be reliable because if it were to fail, the condensation could accumulate quickly.

Prior to the development of any possible designs, it was necessary to model the heat transfer through the walls of the spacecraft. The spacecraft that was chosen was the lunar lander Altair. Altair was chosen because being a space only vehicle it would presumably have the thinnest wall. The team was fortunate to have, as a NASA contact, an individual with extensive knowledge of Altair. To create a model it was essential to gather information about Altair. Most of the information acquired came directly from a contact working at NASA, Mr. Ryan Stephan. Mr. Stephan was extremely helpful throughout this process and provided large amounts of information including things such as: the composition of the walls of Altair, details about the condition of the air within the cabin of Altair, as well as many other details that were necessary to accurately model the spacecraft. Once all this information was known, a simple one-dimensional heat transfer model was developed. This model was set up in such a manner that it would determine temperatures at various points throughout the wall cross-section based on a wide variety of inputs. The most important piece of information calculated by the model was the inside wall temperature. This is the temperature that, when compared to the dew point, determines whether or not condensate would form on the wall. From the model, it was determined that under worst case conditions, there would be condensate formation on the walls, thus requiring some method to remove the water from the walls.

After it was shown that condensate could potentially form on the walls of Altair, many different removal methods were explored. After a thorough analysis of all the viable methods, it was determined that a system that made use of an air curtain complemented with wicking materials best met the required specifications. Other options included wicking to a collection vent and removing the water with the collection vent and a chemical reaction with the water.

The idea behind the air curtain design is that if the convective heat transfer coefficient is increased enough the amount of heat transfer from the cabin air to the wall can be increased, effectively warming the wall to a temperature higher than the dew point. The air curtain seemed reasonable because the math model predicted that under worst case conditions, the temperature of the wall would only have to be raised by a few Fahrenheit degrees to get above the dew point, meaning the amount of air that needed to be forced over the wall is relatively low. The only drawback to this method is that there are spaces within a spacecraft where the air curtain would not reach. This is where the wicking materials come into play. These materials would be used to transport condensate from one location to another. The idea is that the material can be positioned in such a manner that it pulls water from trouble spots (corners, under cabinetry, etc.) and moves it to a position where the air curtain can reach the wall and eliminate the condensate.

20th Annual Conference
Part Five

Biology/Medical Sciences

Muscle Atrophy Can and Can't Be Prevented Using Passive Stretch

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ABSTRACT

Humans unloaded by microgravity or chronic bedrest exhibit muscle shortening and loss of muscle extensibility within 7 days. Prolonged unloading of the musculoskeletal system means reduced performance and increased susceptibility of muscles to injury when returned to weightbearing activity. Passive stretch is a therapy traditionally thought to preserve range of motion and slow muscle atrophy at the clinical level; however, the cellular mechanism by which stretch exerts its effects is not well understood and its efficacy is questioned. This study uses a tenotomy unloading model to model muscle atrophy and passive stretch in the rat. While 20 minutes of daily passive stretch appears to prevent central core lesions (CCLs), a morphological change associated with chronic muscle shortening, and activate some biosynthetic pathways, it was ultimately unable to prevent the overall shortening of the tenotomized soleus muscle indicating that passive stretch alone is not likely a useful counter to microgravity induced muscle shortening in astronauts.

BACKGROUND AND SIGNIFICANCE

Astronauts/cosmonauts returning to the 1-G gravitational environment of earth often complain of muscle weakness, reduced of range of motion, and delayed-onset muscle soreness following spaceflight. These symptoms are indicative of muscle atrophy and cellular damage which manifest during long exposure to microgravity.

Atrophy can be measured along the transverse or longitudinal plane of the muscle. Transverse, or cross-sectional atrophy, is usually associated with shrinkage in diameter of muscle fibers due to disuse unloading. Atrophy along the longitudinal plane is associated with muscle shortening and the subtraction of sarcomeres (the smallest functional unit of organization in a muscle cell) at the ends of muscle fibers. Muscle held in a shortened position has a reduced average sarcomeric length and is thought to subtract sarcomeres to restore normal resting length to the remaining sarcomeres. After the muscle has adapted to the shortened state and is returned to normal working range, range of motion and force output are reduced. Force falls because of reduced overlap and crossbridge formation between thick filaments (force generating myosin) and thin filaments (actin filaments) [1, 2].

An example of shortening of range of motion can be observed in the ankle joint of astronauts as plantarflexion (downward pointing of the foot) posture in which the resting ankle joint opens from 90º to 100º in astronauts/cosmonauts exposed to as little as 7 days of microgravity [3, 4]. This ankle posture shortens the calf muscles and persists for the duration of spaceflight. Adaptation to this shortened state predisposes the muscles to injury when it is reloaded with the weight of the body upon return to 1-G. The prolonged shortening of the primary antigravity muscle of the lower leg, the soleus, has been shown to produce a significant shortening of length, loss of mass and weakening of muscle fibers in unloaded rat models [5, 6].

In an attempt to reduce muscle atrophy in astronauts during spaceflight, the flight surgeon prescribes ~2.5 hours daily of daily exercise. However, these exercise regimens are time consuming and focus chiefly on preventing the loss of muscle strength (transverse atrophy) rather than muscle shortening (longitudinal atrophy) as loss of range of motion is often less appreciated than loss of muscle mass when discussing muscle atrophy. As a result, the subcellular signaling that drives the shortening or lengthening adaptation of muscle to a new shortened or lengthened state is incompletely understood. Passive stretch, a long standing therapy, is often prescribed to preserve and/or return range of motion in patients suffering from a wide range of neural and musculoskeletal injuries and illnesses and could potentially be used in combination with existing countermeasures to prevent muscle shortening and range of motion loss in astronauts. Despite the widespread use of passive stretch in sports medicine, rehabilitation and physical therapy, it remains unclear exactly how stretch elicits its muscle-preserving effect at the cellular and molecular level. There also exists a growing body of work questioning the efficacy of passive stretch as a clinical intervention for preventing muscle shortening [7-9]. Before passive stretch is integrated into the exercise regimens recommended on orbit, it is important that the effects and efficacy of stretch on a cellular and molecular level be better understood.

RESEARCH EFFORTS AND FINDINGS

Using a tenotomy unloading model, I tested the ability of passive stretch to prevent atrophy and muscle shortening. Tenotomy is the transection of a tendon resulting in a loss of resting tension and shortening in the corresponding muscle or muscle group. This surgical manipulation is used clinically in the treatment of multiple injury and disease states affecting the tendon and muscle imbalance at a joint but is also used as a model that mimics tendon rupture

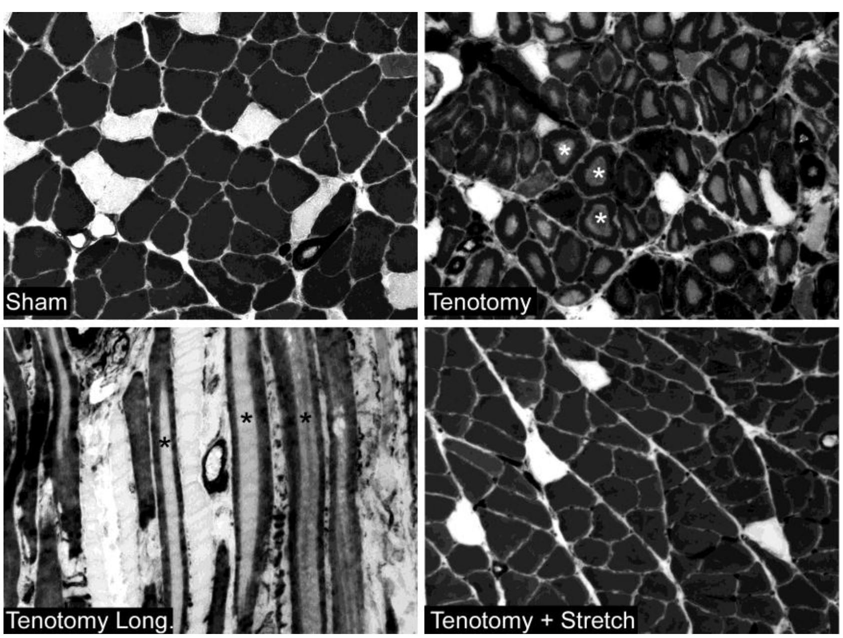

Figure 1: Tenotomy induces the formation of CCLs in slow muscle fibers (dark staining fibers). Sham operated rats had their tendons and muscles perturbed surgically, but the solei tendons were not cut (tenotomized). Tenotomized muscles developed severe CCLs (asterisks) by day 7 which run through the majority of muscle fiber as can be seen in the longitudinal (long.) view of the fiber. 20 minutes of passive stretch applied daily prevented the formation of CCLs in the majority of fibers by day 7.

and subsequent shortening of the muscle [10]. Persistent shortening of the muscle results in rapid contractile protein breakdown, and therefore, tenotomy is an appropriate model for studying atrophy [10].

Briefly, our tenotomy plus stretch protocol is as follows: both legs of a fully anesthetized rat are tenotomized. One leg has an inelastic monofilament line attached to the distal tendon of one soleus. This monofilament line is used to connect the soleus to a force transducer through which passive stretch is applied for 20 minutes daily. The rat is fully anesthetized during this daily stretch in order to eliminate motor nerve impulses and muscle contraction i.e., the result is pure passive stretch.

Prevention of Central Core Lesion (CCL) formation. The morphological consequence of tenotomized soleus muscle develops over a few days and culminates in the formation of CCLs in slow (type I) fibers (figure 1) [11, 12]. These CCLs represent muscle breakdown at the cellular level. Histochemical actomyosin ATPase activity reveals normal activity around the periphery of slow myofibers but light to no activity in the central region of the fiber [11, 13]. By 7 days post tenotomy, CCL formation reaches peak occurrence. With tenotomy alone, 70.0 ± 7.5% of slow fibers exhibited CCLs while with 20 minutes of daily stretch significantly ($p < 0.05$) prevented CCL formation and only 24.8 ± 6.3% of slow fibers exhibited CCLs (figure 1 tenotomy + stretch).

Activation of Protein Synthetic Pathways. Immunoblot analysis of biomarkers of three major signaling pathways linked to protein synthesis revealed some passive stretch-induced activation. The extracellular signal regulated protein kinase (ERK) pathway has been shown to regulate cell survival while the p38 mitogen activated protein kinase (p38) pathway is responsible for regulating the activation of transcription factors which trigger the expression of proteins that make up the contractile elements of muscle. Both ERK and p38 activation have been linked to stretch in other models [14-16]. In our model, daily passive stretch strongly activated ERK (2.4 ± 0.6 fold at 1 day and 4.8 ± 1.0 fold at 7 day by daily stretch) and p38 (16.1 ± 4.6 fold at 1 day and 4.0 ± 0.7 fold at 7 days following daily stretch). The protein kinase B (PKB) pathway is responsible in part for regulating the translation of messenger RNA to proteins and has been shown to be activated during exercise; however, passive stretch did not alter PKB activation at 1 or 7 days in the tenotomized soleus muscle. Passive stretch activates some protein synthetic pathways associated with muscle preservation but not others.

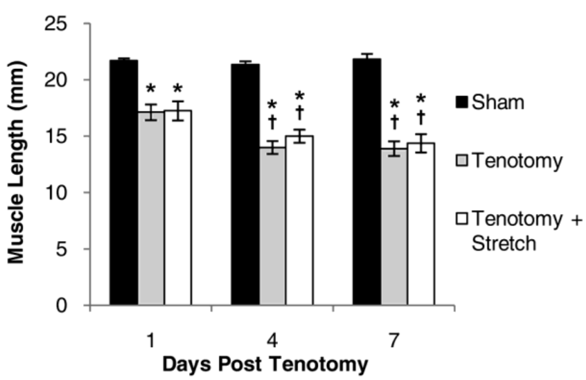

Figure 2: Sham solei length did not differ significantly 4 days or 7 days post-surgery. Tenotomized solei are significantly shorter 1 day after surgery. Passive stretch applied 1 day after tenotomy did not increase soleus resting length. By day 4 post tenotomy, the unloaded solei are shorter compared to day 1. This reduced length persisted through day 7 post-tenotomy. Passive stretch did not prevent the muscle shortening at day 4 or day 7. * = significantly shorter than sham ($p < 0.001$), † = significantly shorter than 1 day tenotomy ($p < 0.05$). Error bars = Standard error.

Muscle Shortening is not Prevented.

Tenotomized soleus is significantly shorter 1 day post-tenotomy (17.1 ± 0.7 mm) than sham (21.7 ± 0.2 mm) (figure 2). By day 4, the length of soleus is further reduced to 14.0 ± 0.7 mm, significantly shorter than day 1 ($p < 0.05$), and persists through day 7 (13.9 ± 0.4 mm). 20 minutes of daily passive stretch did not prevent shortening of tenotomized soleus length which is17.2 ± 0.9 mm at 1 day), 15.0 ± 0.8 mm at 4 days) and 14.4 ± 0.7 mm at 7 days (Figure 2).

IMPLICATIONS AND FUTURE RESEARCH DIRECTIONS

Passive stretch prevents the formation of central core lesions, a dramatic loss of contractile protein at the core of slow muscle fibers which forms in response to chronic muscle shortening, and activates ERK and p38, two biomarkers of muscle cell survival and muscle protein synthesis. However, passive stretch does not activate PKB a biomarker of a pathway generally implicated in muscle growth in response to exercise. Most importantly, 20 minutes of daily stretch did not prevent the muscle shortening adaptation resulting from tenotomy indicating that passive stretch is not likely a useful exercise for astronauts on orbit for use in slowing or preventing the shortening adaptation of their muscles.

Since passive stretch does not appear to prevent muscle shortening, it is possible that contraction is key for preventing range of motion loss. The combination of stretch and stimulation to induce mild contraction for 20 minutes daily in a fully anesthetized rat tenotomy model will demonstrate whether stretch plus contraction can prevent muscle shortening and potentially reveal what signaling pathways are activated in response to stretch plus contraction that are not activated with passive stretch alone. These future experiments will further our understanding of the cellular and molecular understanding of the effect of mechanical stimulation on muscle and aid in the development of more effective countermeasures for preventing atrophy and shortening in astronauts in microgravity.

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Effects of Photobiomodulation in Osteoclast Formation *in vitro*: a Pilot Study

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Abstract

Introduction: Near-Infrared Light Emitting Diode (NIR-LED) photobiomodulation has been found to be effective in improving wound healing, bone regeneration, mitochondrial function, and attenuating cellular oxidative stress. Little is known regarding the use of NIR-LED and osteoclastogenesis associated with building bone. ***Purpose:*** The use of NIR-LED 670nm photobiomodulation may attenuate or amplify osteoclast differentiation in the RAW264.7 cell line. ***Methods:*** RAW264.7 cells were cultured for 24 hours and differentiated into osteoclasts, using cytokine RANKL. Plates were divided into groups according to RANKL dose (0, 2.5, 10, 25, 50 ng/ml), and different energy densities (2.25, 4.5, 45 J/cm²), treated with light either once or on four consecutive days using the WARP™ 75 (Quantum Devices, Barneveld, WI). Osteoclast cells were stained for Tartrate-Resistant Acid Phosphatase (TRAP) and manually cell counted by microscopy. ***Analysis:*** Mean osteoclast well counts and standard deviations were calculated by the sum of TRAP+ osteoclast cells per well surface area. The cell counts of each group were compared. ***Results:*** RANKL-induced osteoclast formation by RAW cells occurred as expected in all experiments. Light-treatment alone had no effects. A single NIR-LED treatment at 4.5 J/cm^2 combined with a RANKL dose of 10, 25, and 50ng/ml amplified osteoclastogenesis by 75%, 137%, and 32%, respectively. At 45 J/cm^2 and a RANKL dose of 2.5ng/ml, a single NIR-LED treatment amplified osteoclastogenesis by 120%, but inhibited osteoclastogenesis by 25% at a RANKL dose of 25ng/ml. Osteoclastogenesis inhibition was equivalent for 2.25 J/cm^2 and 4.5 J/cm^2 single light-treatments, and multiple light-treatments showed greater effectiveness over single treatments. ***Conclusion:*** The effects of the NIR-LED treatment on osteoclastogenesis are RANKL dose and light intensity-specific. We conclude, as hypothesized, that NIR-LED light-treatment may impair RANKL-induced osteoclastogenesis, particularly when using multiple light treatments.

Introduction

Microgravity during space flight simulates complications of muscle and bone loss often experienced by older adults during the process of aging, and after prolonged bed rest during hospitalization. Research in skeletal health problems that develops and validates countermeasures taken during long duration space flights involves interventions and procedures designed to mitigate health and performance hazards present in a space environment (Clement, Bukley, & Paloski, 2007). Some researchers investigating bone loss in microgravity

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environments believe that there is the potential for translational research that could impact the pathology of bone loss in the aging population (Rittweger, 2007). One multidisciplinary approach to study skeletal health in the aging population involves teaming with researchers investigating skeletal health in a microgravity environment. Therefore, collaborative research with the NASA Ames Bone and Signaling Lab may assist in development and utilization of new technologies to mitigate bone loss for the older adult population to prevent fracture (Rittweger, 2007). It is important that innovative technologies for interventions that may improve bone cell function and skeletal health (particularly those that would increase understanding of osteoclast differentiation or bone-resorbing cells) are developed.

One major area of musculoskeletal health research is the study of the pathogenesis of osteoporosis. Osteoporosis is a major public health problem for an estimated 44 million Americans (National Osteoporosis Foundation, 2010) and the prevalence of fall-induced fractures, specifically hip fracture, are a well-documented problem within this population (Lim, Hoeksema, & Sherin, 2009), which has subsequently burdened the health care system (World Health Organization Scientific Group, 2003).

Fifty-five percent of people aged 50 years and older are effected by osteoporosis (National Osteoporosis Foundation, 2010). There has been only a modest decline in the rate of osteoporosis over the past 15 years despite the development of interventions using medications and weight-bearing exercise (National Osteoporosis Foundation, 2010). Complementary interventions need to be investigated. According to the World Health Organization, osteoporosis has the potential to become an epidemic by the middle of the 21st century, from an incidence of 1.7 million in 1990 to a projected 6.3 million by 2050 (World Health Organization, 1999).

It is projected that by the year 2030, the United States (US) population of older adults will double to 71.5 million (U. S. Department of Health and Human Services, 2006). In 2007, data from the U.S. Census Bureau estimated that there are more than 84,000 centenarians in the US and their population is projected to increase sevenfold, by 2040 (US Census Bureau & US Department of Commerce Economics and Statistics Administration, 2007). This aging population is at risk for disability, morbidity, and mortality related to bone loss which is an identified risk factor for fracture resulting from a fall (Hall, Williams, Senior, Goldswain, & Criddle, 2000; Ostir, Ottenbacher, & Markides, 2004).

Briefly, there are two types of cells within mineralized bone that contribute to mineral homeostasis: osteoclasts and osteoblasts. They both are responsible for building and maintaining bone structure. Osteoclasts are bone-resorbing cells that originate from monocyte/macrophages within the hemopoietic lineage. Their activity is regulated by osteoblasts (bone-forming cells), as well as numerous hormones and other growth factors. If bone formation and resorption are not balanced, bone loss occurs (Manolagas & Jilka, 1995). In healthy remodeling tissue of the adult skeleton, 5-10% of existing bone at specific bone sites is replaced every year, but not replaced uniformly throughout the skeleton (World Health Organization Scientific Group, 2003). Bone resorption and formation occur within the same space (resorption lacunae) of the bone so that a bone’s shape is not altered. Bone remodeling occurs in both spongy (cancellous) tissue and dense/compact bone (cortical), which together comprise intact bone. The percentage of cancellous and cortical tissues in a given bone varies according to the type of bone. Vertebrae are particularly rich with cancellous tissue, while the hip and wrist are rich with cortical composites of bone (Wyngaarden, Smith, & Bennett, 1992)

Osteoporosis arises from an imbalance in osteoclast/osteoblast homeostasis (uncoupling) in remodeling bone (Lemaire, Tobin, Greller, Cho, & Suva, 2004; Manolagas & Jilka, 1995). Normal bone remodeling is a coupling process; balance between bone gain and loss, where bone absorption and bone formation is balanced (North American Menopause Society, 2010). Bone remodeling begins with bone resorption in both cortical and cancellous bone by the osteoclasts over a period of a few days. This initial phase is followed by the "reversal phase" where the osteoclasts leave and mononuclear cells line the resorption lacunae. The resorption lacunae is the area where the osteoclasts resorbs the bone and forms a noncalcified bone matrix called osteon in cortical bone and a bone structural unit in cancellous bone. A "cement line" forms between eroded bone and newly formed bone. The mononuclear cells are eventually replaced by osteoprogenitor cells which differentiate into cuboidal-shaped osteoblasts. Osteoblasts lay down a new matrix, called the "organic matrix", that becomes mineralized with calcium and phosphate and fills the resorption lacunae over several months (Mundy, Boyce, Yoneda, Bonewald, & Roodman, 1996).

In the US, osteoporosis causes 1.5 million fractures every year (Lim et al., 2009). Vertebral compression fractures are the most commonly associated osteoporosis bone injury. Unlike vertebral fractures that occur earlier in life, hip and wrist fractures commonly result from cortical composite weakening occurring later in life (Wyngaarden et al., 1992). Ninety percent of osteoporotic-induced fractures, specifically hip fractures among older adults in the US, are caused by falls (Cummings, Kelsey, Nevitt, & O'Dowd, 1985; Grisso et al., 1991). Serious injury occurs in 10-15 percent of falls (Centers for Disease Control and Prevention, 2006). Hip fracture mortality rates have been reported to be three times higher for individuals with hip fracture as opposed to the mortality rate of the general population (Kannegaard, van der Mark, Eiken, & Abrahamsen, 2010). The rate of mortality associated with hip fractures within the first year is estimated to be 20% - 35% (Goldacre, Roberts, & Yeates, 2002; North American Menopause Society, 2010) and is greatest immediately after the fracture (Center, Nguyen, Schneider, Sambrook, & Eisman, 1999). Long-term care is required for approximately 25% of women and 50% have some form of immobility (North American Menopause Society, 2010). Currently, the majority of hip fractures occur in Europe and North America. Over the next 50 years, due to demographic changes in the number of older adults living in developing counties, 75 percent of the world's total hip fractures will occur in developing countries (World Health Organization, 1999).

It has been reported that bone degradation increases risk for fall-induced fractures (Grahn Kronhed, Blomberg, Lofman, Timpka, & Moller, 2006). The World Health Organization reported in 2003 that osteoporosis-induced fractures burden society by depleting available resources (World Health Organization Scientific Group, 2003). In 1992, in the state of California, it was estimated that 62.4 % of expenditures were used for inpatient care, 28.2% for long term care, and 9.4% for outpatient care to treat osteoporotic-induced fractures (Nagley et al., 1992). However, these figures do not take into account indirect costs such as lost wages or the decrease productivity of caregivers and the patient (NIH Consensus Development Panel on Osteoporosis, 2000) Researchers using the 1999-2005 Chronic Conditions Warehouse dataset (Iowa Foundation for Medical Care, 2008) reported that Medicare beneficiaries receiving payments for osteoporotic-induced fracture incurred a cost of $7788 (95% CI, $7550-$8025) for an average wrist fracture. The cost of an average open hip fracture was $31,310 (95% CI,

$31.0073-$31,547) per beneficiary (Kilgore et al., 2009). Due to the cost of treating osteoporotic fall-induced fractures, the development of effective interventions meant to slow the progression or reverse bone loss could be instrumental in decreasing the financial burden of healthcare for the aged, as well as enhancing the quality of life for aging persons by helping them avoid long-term care placement. Implementing a new intervention, such as the use of photobiomodulation (light-treatment), may have the potential to preserve bone density and prevent bone loss.

Photobiomodulation—referred to in the literature as low-level laser therapy, cold-laser therapy, or laser biostimulation—was introduced in the 1980's. Laser "light-treatment" uses light in the infrared to near-infrared region of the absorption spectrum (630-100nm) which is known to effect numerous cell functions that are dependent on the energy production in the mitochondria (Desmet et al., 2006; Karu, Piatibrat, & Kalendo, 1987). It has been postulated that the mechanism of the effect of a low-power laser is at the cellular level due to irradiation of the components of the electron transport chain system within the mitochondria (Karu, 1988). The electron transport system of the cell is directly related to the production of Adenosine triphosphate (ATP), the primary energy compound for the cell.

It is now commonly accepted that free radical oxidative stress is the result of cellular chemical reactions with oxygen (Beckman & Ames, 1998). Specifically, free radicals are unpaired electrons on the electron orbitals or electron shells of a molecule. In this unstable state, these molecule types become highly reactive with other molecules involved in cell metabolism, and these reactions instigate oxidative cell destruction. Because the structure of an oxygen molecule has an unusual placement of electrons within electron orbitals, it prefers to accept one electron at a time, rather than two electrons, which would keep the oxygen molecule in a stable state. When electrons are accepted one at a time, the oxygen molecule becomes unstable; and superoxide (O_2^-) and hydrogen peroxide (H_2O_2) are generated. These reactive oxygen species undergo further biochemical cellular reactions, and the result is that an extremely reactive molecule is produced: hydroxyl radicals (OH^-) (Beckman & Ames, 1998).

Biological aging is associated with oxidative stress and this may induce bone loss (Srinivasan & Avadhani, 2007). It is suggested that mitochondrial dysfunction via oxidative stress may instigate premature apoptosis and alter mechanical signaling in bone (Booth & Criswell, 1997; Hock et al., 2001). In a recent study using the RAW 264.7 cell culture model, without the addition of osteoclast differentiation factors, hypoxia-mediated mitochondrial stress increased reactive oxygen species (increased oxidative stress) which resulted in osteoclastogenesis (the proliferation of bone resorbing cells).

NIR-LED treatment is known to decrease oxidative stress (Desmet et al., 2006; Karu et al., 1987). Light-treatment in numerous studies has been documented to have beneficial cellular level mechanisms that reduce oxidative stress, improve mitochondrial function, and prevent premature apoptosis (programmed cell death) (Desmet et al., 2006; Eells et al., 2004; Karu et al., 1987). NIR-LED (630-1000nm) photobiomodulation—an FDA-approved treatment—has been found to be effective in improving wound healing (Whelan et al., 2003; Whelan et al., 2001), bone regeneration (Pinheiro et al., 2009), mitochondrial function (Eells et al., 2004; Wong-Riley, Bai, Buchmann, & Whelan, 2001), attenuating cellular oxidative stress (Desmet et al., 2006; Eells et al., 2004; Karu et al., 1987), decreasing inflammation and pain, aiding in recovery of ischemic cardiac injury (Oron, 2006; Oron et al., 2001), and attenuating retinal/optic nerve degeneration (Eells et al., 2007; Eells et al., 2004; Liang et al., 2006).

Specifically, NIR-LED treatment, using an absorption spectrum of 670nm, activates the mitochondrial photo acceptor molecule cytochrome c oxidase (CO), specifically, Complex IV (COX IV) of the electron chain transport system (Karu, 1999). If cytochrome c (COX) does not properly function, the cell electron transport system performs poorly, and alters the production of ATP, and premature cell death can occur. Therefore, the use of light as a treatment to improve oxidative metabolism and mitochondrial function in bone tissue may prevent bone demineralization and preserve cell life.

Research has been completed that has increased our understanding of NIR-LED effects with osteoblast cell function (in vitro) (Renno, McDonnell, Parizotto, & Laakso, 2007; Yamada, 1991), bone graft biomaterials (in vivo) (Pinheiro et al., 2008; Pinheiro et al., 2009; Torres, dos Santos, Monteiro, Amorim, & Pinheiro, 2008) and bone formation (in vivo) (Blaya, Guimaraes, Pozza, Weber, & de Oliveira, 2008). In one study that investigated osteoblastogenesis, it was found that low-level laser irradiation in cell culture significantly increased osteoblast proliferation and differentiation (Stein, Benayahu, Maltz, & Oron, 2005) Another study found that photobiomodulation increased bone formation (Torres et al., 2008), increased amount of well-organized bone trabeculi (Pinheiro et al., 2008), and enhanced vertical regeneration of bone (Blaya et al., 2008).

The evidence that NIR-LED increases *osteoblastogenesis* and bone formation is documented in the literature, but little is known regarding the effects of NIR-LED on *osteoclastogenesis*. The activity between osteoclastogenesis and osteoblastogenesis is a complex cellular system. When cellular mechanisms are chronically disrupted, metabolic bone disease occurs (Lemaire et al., 2004), so any intervention that is known to increase osteoblastogenesis must also take into account its effect on osteoclastogenesis. Osteoblastogenesis and osteoclastogenesis need to be coordinated— i.e. achieve “coupling” (Rodan & Martin, 1981) –to attain a healthy balance (homeostasis) between bone gain and bone loss. It is with aging that the “uncoupling” of the bone remodeling cycle occurs and results in increased bone resorption (Kiel, Rosen, & Dempster, 2008). It is documented in the literature that osteoblastogenesis is increased with NIR-LED (Stein et al., 2005). Therefore, in order to develop effective and safe interventions for a vulnerable population, such as older adults, it is imperative to investigate the cellular level effects of NIR-LED to determine if osteoclastogenesis is amplified or suppressed due to uncoupling.

Our primary goal in this study was to determine the effects of NIR-LED treatment on osteoclast cell differentiation (osteoclastogenesis) in cell cultured RAW264.7 cells using the WARP 75 ™ NIR-LED light. Our specific research questions and hypotheses were as follows: **Question 1.** Is there a difference in osteoclast cell count between single light-treated RANKL-induced cell cultures as compared to non-light-treated controls? ***Hypothesis:*** Single light-treatment of RANKL-induced cell cultures will attenuate osteoclastogenesis. **Question 2.** Is there a difference in osteoclast cell count between light-treated RANKL-induced cell cultures treated at different energy densities of light-treatment (2.25, 4.5 and 45 J/cm^2) compared to non-light treated controls? ***Hypothesis:*** Light-treatment of RANKL-induced cell cultures at a higher energy density (45 J/cm^2) will have a greater attenuation of osteoclastogenesis compared to lower energy densities (2.25 and 4.5 J/cm^2). **Question 3.** Is there a difference in osteoclast cell count between single light-treated RANKL-induced cell cultures compared to multiple light-treated RANKL-induced cell cultures? ***Hypothesis:*** Multiple light-treatments of RANKL-induced cell cultures will have a greater attenuation of osteoclastogenesis compared to single light treated RANKL-induced cell cultures.

Materials and Methods

Experiment Timeline. This study is a description of two experiments (e1387, e1390) using the WARP™ 75 light source. RAW 264.7 cells (ATCC) were plated on cell culture Day 0 and then incubated for 24hrs. RANKL is added to cell culture medium on Day 1 at specific experimental doses. Light-treatment began on Day 2 for all experiments regardless if the experiment was testing a single or multiple light-treatments. Experiments that tested multiple light-treatments had repeated exposure on Days 3-5 for a total of 4 light-treatments. Culture medium was changed and fresh RANKL was added to the medium on Day 4 in all experiments. On Day 7 cells were stained for Tartrate-Resistant Acid Phosphatase (TRAP), and were prepared for cell counting.

Experiment e1387 tested only a single light-treatment and e1390 tested multiple and single light-treatments. All experiments tested energy densities of 4.5 and 45 J/cm^2, but e1390 tested an additional energy density of 2.25 J/cm^2 to explore an energy density light-treatment dose response. Lastly, experimental controls were tested for RANKL dose response at 0, 25, & 50ng/ml in all experiments, and experimental controls were tested in e1387 for RANKL dose response at RANKL dose 0, 2.5, 10, 25 and 50ng/ml.

Cell Plating Procedure. On Day 0, RAW 264.7 cells were plated at 2 x 10^4 cells per well (4x10^4 cell/ml) in 15 wells of a 24-well plate (well diameter: 1.77mm) for each experimental condition. The WARP™ 75 (Quantum Devices, Barneveld, WI) illumination surface covered 15 wells (well rows A-C by columns 2-6). Some experimental conditions did not require the full 15 wells; in those cases only 10 wells were used. Plates were divided into experimental treatment groups according to experimental condition: number of light-treatments (1 or 4), energy density (varied by experiment: 2.25, 4.5 or 45 J/cm^2), and RANKL dose (varied by experiment: 0, 2.5, 10, 25, or 50 ng/ml) with respective negative controls. The plates were cultured for 24 hours prior to RANKL induction. At the end of the 24-hour period, RANKL was added to each plate well at the dose of 0, 2.5, 10, 25 or 50ng/ml, according to experimental design.

Light-treatment Procedure. A continuous wave NIR-LED (WARP™ 75) with a wavelength of 670nm, power intensity of 60mw/cm^2 and energy density of 5 J/cm^2 was used in the experiments because it was shown in previous studies to produce positive cellular effects (Desmet et al., 2006; Eells et al., 2007; Eells et al., 2004; Karu, 1988; Liang, Whelan, Eells, & Wong-Riley, 2008; Pinheiro et al., 2002; Whelan et al., 2003; Whelan et al., 2008; Wong-Riley et al., 2001; Wong-Riley et al., 2005). The dosage of light-treatment was determined by applying the following formula: Power (mW/cm^2) x Time (seconds) ÷ 1,000 = Energy Density (J/cm^2) in order to deliver 4.5 J/cm^2 and 45 J/cm^2. In order to ensure delivery of an accurate energy density of 4.5 J/cm^2 and 45 J/cm^2, each light-treatment was timed to 80 seconds to deliver 4.5 J/cm^2 and to 800 seconds to deliver 45 J/cm^2.

Light-treatment began on cell culture Day 2 (Stein et al., 2005; Yamada, 1991) under a sterile laminar hood with the dish lid in place. If one of the objectives of a particular experiment was to test multiple light-treatments vs. single light-treatment, additional light-treatments were performed, one per day on three consecutive days.

Analysis

TRAP staining (SIGMA #387) was the method used for manual osteoclast cell counting (Nakano, Toyosawa, & Takano, 2004; Susa, Luong-Nguyen, Cappellen, Zamurovic, & Gamse, 2004). Using a visual cell counting taxonomy, those multinucleated cells that were stained light pink/purple were identified by light microscopy (inverted microscope, 10 x magnifications; Nikon Eclipse TS100) and counted. Mean osteoclast cell counts per well and standard deviations were calculated by taking the sum of multinucleated TRAP+ osteoclast cells for each well and dividing by the well surface area, expressed as cells per cm^2. To determine light-treatment effects, the difference between osteoclast cell counts in treatment plates and controls was calculated.

Results

A summary of experimental results reported by experimental group according to the number of light-treatments, energy density and RANKL dose with the corresponding result of increased/decreased effect on osteoclastogenesis followed by the percent change between non-light treated control that were found to be at least 25% or greater is presented in **Table 1 and Table 2**. For purposes of this study a change of 40% or greater in osteoclast cell counts compared to controls was considered to be a biological effect.

Table 1*: Summary of Experimental Results Single Light-treatment*

↑ = Amplify Osteoclastogenesis, ↓ = Attenuate Osteoclastogenesis, % = Percent Change,

Experiment Number	Number of Light-treatments	Energy Density J/cm^2			RANKL Dose ng/ml					↑ ↓	%
		2.25	4.5	45	0	2.5	10	25	50		
e1387	1		*				*			↑	75
e1390	1		*					*		↑	137
e1390	1		*						*	↑	32
e1387	1			*		*				↑	120
e1387	1			*				*		↓	25

Table 2: *Summary of Experimental Results Single Light-treatment*

↑ = Amplify Osteoclastogenesis, ↓ = Attenuate Osteoclastogenesis, % = Percent Change

Experiment Number	Number of Light-treatments	Energy Density J/cm^2			RANKL Dose ng/ml					↑ ↓	% --
		2.25	4.5	45	0	2.5	10	25	50		
e1390	4		*		*						--
e1390	4		*					*		↓	43
e1390	4		*						*	↓	36

Results of Experiment e1387. This experiment tested single light-treatments at energy densities of 4.5 J/cm^2 and 45 J/cm^2 at a RANKL dose of 0, 2.5, 10, 25 and 50ng/ml and demonstrated the experimental RANKL dose response curve which resulted in the expected step-wise two-fold increase in biological signal

A single light-treatment at a RANKL dose of 10ng/ml amplified osteoclastogenesis by 75% at an energy density of 4.5 J/cm^2 and no effect was seen at an energy density of 4.5 J/cm^2 in RANKL doses 2.5, 25 and 50ng/ml. At an energy density of 45 J/cm^2 and a RANKL dose of 2.5ng/ml osteoclastogenesis was amplified by 120%. Single light-treatments at an energy density of 45 J/cm^2 and at a RANKL dose of 25ng/ml inhibited osteoclastogenesis by 25%. (see **Table 1**)

Results of Experiment e1390. This experiment tested the effect of single light-treatment on osteoclastogenesis at energy densities of 2.25, 4.5 and 45 J/cm^2 at RANKL doses of 0, 25 and 50ng/ml, as well as compared multiple light-treatments vs. single light-treatment at an energy density of 4.5 J/cm$^{2.}$ A RANKL dose response curve was completed to serve as the experimental control. A biological dose response (an approximate two fold step-wise increase) at a RANKL dose of 25 and 50ng/ml occurred in the 2.25 and 4.5 J/cm^2 treatment groups, however, the single light-treatment (45 J/cm^2) group and the multiple light-treatment (4.5 J/cm^2) group did not yield the expected two fold response.

At an energy density of 4.5 J/cm^2 and a RANKL dose 25 and 50ng/ml, a single light-treatment amplified osteoclastogenesis by 137% and 32%, respectively. (see Table 1) There was no effect of the light-treatment on osteoclastogenesis in RANKL doses of 25 and 50ng/ml at energy densities 2.25 and 45 J/cm^2.

Figure 1 compares the effects of single light-treatment at energy densities of 2.25, 4.5 and 45 J/cm^2. A single light-treatment at an energy density of 4.5 J/cm^2 approximately amplified osteoclastogenesis by a two fold increase compared to both energy densities of 2.25 and 45 J/cm^2 which were found to be equally effective inhibiting osteoclastogenesis. **Figure 2** compares multiple light-treatments and single light-treatment at an energy density 4.5 J/cm^2 and RANKL dose 25 and 50 ng/ml. Multiple light-treatments were more effective than single light-treatment at inhibiting osteoclastogenesis by 43% and 36% at RANKL dose 25 and 50ng/ml, respectively. (see **Table 2**)

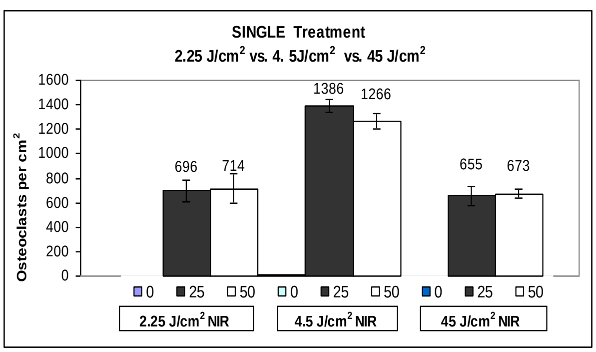

Figure 1. e1390 WARP™ 75:
Single light-treatment
2.25 J/cm^2 vs. 4.5 J/cm^2 vs. 45 J/cm^2
RANKL dose 25ng/ml &50ng/ml

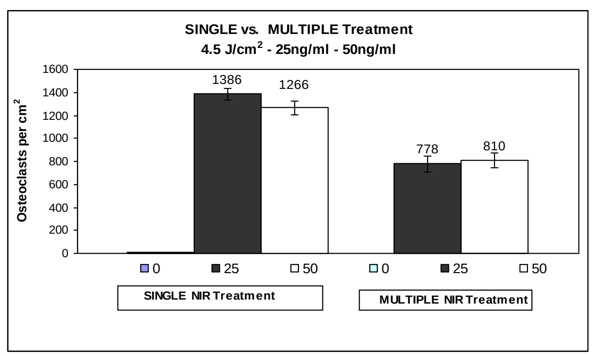

Figure 2. e1390 WARP™ 75:
Single vs. Multiple light-treatment
4.5 J/cm^2
RANKL dose 25ng/ml &50ng/ml

Discussion

Developing interventions to preserve bone density, and prevent or reverse bone loss in osteoporosis, is important because osteoporosis is a major public health problem estimated to affect 44 million Americans (National Osteoporosis Foundation, 2010). The US population of older adults will be approaching 70 million by 2020; the financial burden to treat osteoporosis in older adults and osteoporotic-induced fractures will be cost prohibitive and burdensome to the health care system (World Health Organization Scientific Group, 2003). Prevention must occur earlier in life because the incidence of bone loss is seen at a younger age, rather than only pathology associated with the aged.

We investigated the effects of NIR-LED light-treatment using the WARP 75™ on osteoclastogenesis in the RAW 264.7 cell line. The purpose of this study was to pilot test a new protocol designed to answer the broad research question: Does NIR-LED photobiomodulation affect RANKL-induced osteoclastogenesis in a cell culture model? RANKL-induced osteoclast formation by RAW cells occurred as expected in all experiments and in all experiments using light-treatment without the induction of RANKL at these doses and regimes, no effect was measured on osteoclast formation.

Our first hypothesis predicted that a single light-treatment of RANKL-induced cell cultures would inhibit osteoclastogenesis, however, only one out of 19 **single light-treatment** experimental groups actually inhibited osteoclastogenesis—and then only modestly (less than a 40% biological effect) (see **Table 1**). In fact, four out of the 19 single light-treatment experimental groups *increased* osteoclastogenesis. Three of these four experimental groups showed a significant biological effect of 40% and the fourth showed a modest effect (less than a 40% biological effect) (see **Table 1**). The remaining 14 experimental groups showed no effect from light-treatment.

Our second hypothesis predicted that light-treatment at a higher energy density would inhibit osteoclastogenesis more than at lower energy densities; however it was found that osteoclastogenesis at the highest and lowest energy density level were equally effective in inhibiting osteoclastogenesis (see **Figure 1**).

Our third hypothesis predicted that multiple light treatments would decrease osteoclastogenesis more than single light-treatments. It was found that multiple light-treatments inhibited osteoclastogenesis more than single light-treatment in two out of the three experimental groups; one showed a significant biological effect of 40% or greater, and the other showed a modest effect (less than a 40% biological effect) (See **Figure 2**).

After an extensive review of the literature, we did not find any experimental models studying osteoclastogenesis using NIR-LED light treatment. Two experimental cell culture models (Stein et al., 2005; Yamada, 1991) and two animal models (Blaya et al., 2008; Torres et al., 2008) were found studying the effects of near infrared light treatment. The two cell culture models were designed to study osteoblastogenesis, rather than osteoclastogenesis, using a helium neon (He-LE) laser light treatment in the near-infrared light spectrum. The two animal studies which investigated bone as a living tissue and histologically identified osteoblast and osteoclast activity collectively, found that near-infrared light treatment enhanced bone formation (Torres et al., 2008) and bone architecture (Blaya et al., 2008).

Yamada and colleagues studied the clonal osteoblastic MC3T3-E1 cell line using a continuous wave 632.8nm, power intensity of 3.03mW/cm^2 He-Le laser at energy densities 0.01, 0.1, and 1.0J/cm^2 administered on cell culture day 2, as compared to our continuous wave 670nm, power intensity of 50mW/cm^2 NIR-LED light at an energy density of 2.25, 4.5, and 45 cm^2 administered on cell culture day 2. They found a significant increase in osteoblastogenesis ($p<0.05$) at energy densities of 0.01 to 1.0 J/cm^2 (Yamada, 1991). Stein and colleagues used human osteoblast cells for cell culture. Light treatment was administered on cell culture day 2 and 3 with a 632nm, power intensity 180mW/ cm^2 He-Le laser, at energy densities 0.14, 0.43, and 1.43 J/cm^2 and also found a significant increase in osteoblastogenesis ($p < 0.05$) (Stein et al., 2005). Both of these studies used low energy densities suggesting that lower energy densities had a biological effect on osteoblastogenesis, thus, we tested an energy density of 2.5 J/cm^2.

We chose to test higher energy densities than in the osteoblastogenesis studies because they were comparable to successful 670 nm NIR-LED light treatment studies used in a human model (Whelan et al., 2001) and in a neuronal cell culture model (Wong-Riley et al., 2001; Wong-Riley et al., 2005). Further, these studies by Whelan (Whelan et al., 2001) and Wong-Riley (Wong-Riley et al., 2001; Wong-Riley et al., 2005) used the same NIR-LED light source manufacture (Quantum Devices, Barneveld, WI) as ours. However, our NIR-LED light source was a commercial product rather than the scientific grade NIR-LED.

Bone loss occurs rapidly during early menopause; osteoclastogenesis is, thus, proportionally greater than osteoblastogenesis (Eriksen et al., 1990; Jilka, Weinstein, Takahashi, Parfitt, & Manolagas, 1996) followed by an age-related steady continuous loss of bone till the end of the life-span (Parfitt, 1990). Loss of estrogen in women results in rapid trabecular bone loss by 20-30% and in cortical bone loss by 5-10% (Khosla & Riggs, 2005; Parfitt, 1990). However, it has been hypothesized that it may not be the mismatch of osteoclastogenesis/osteoblastogenesis, but a decrease in the number of stromal/osteoblastic cells (Manolagas & Jilka, 1995),

In a study (Jilka et al., 1996) investigating the validity of a senescence-accelerated osteopenic mouse model for the study of metabolic bone disease, reported a correlation between low bone mineral density and impaired osteoblastogenesis due to a low number of stromal/osteoblastic cells. The impairment of osteoblast formation resulted in a secondary impairment of osteoclastogenesis. When adding exogenous stromal/osteoblast cells from neonate mouse clavaria cells to the aging and osteopenic ex vivo marrow cell cultures, osteoclastogenesis was restored (Jilka et al., 1996). This may suggest that the imbalance between osteoblast/osteoclast activities may be due to the number of bone cells.

If osteoclastogenesis activity is greater than osteoblastogenesis during the aging process, then NIR-LED treatment increasing osteoblastogenesis activity without affecting osteoclastogenesis would be beneficial to returning the bone remodeling cycle to homeostasis (coupled). However, it is not known if the use of NIR-LED increases or decreases osteoclastogenesis. The literature suggests that osteoblastogenesis is increased with light treatment. Therefore, if osteoblastogenesis and osteoclastogenesis both increase equally from light treatment and the bone remodeling cycle is already “uncoupled”, imbalanced due to aging, NIR-LED treatment could result in the same disrupted bone remodeling process seen before treatment.

In this study we investigated the effects of NIR-LED treatment solely on osteoclastogenesis, but it would be useful to investigate both osteoblastogenesis and osteoclastogenesis under the same experimental conditions to compare their rates of amplification or inhibition with NIR-LED treatment. After the effects of NIR-LED light- treatment are determined by testing each cell type in culture, the next step would be to investigate the effects of NIR-LED light-treatment on the bone remodeling process, because the biological effects of NIR-LED light-treatment on a system of homeostasis may be different than the biological response found in separate osteoclast and osteoblast cell cultures.

The long-range goal of this program of research is to discover and test interventions that may increase bone strength and integrity in the older adult population to prevent bone fracture (specifically hip fractures) and improve skeletal health. There is not sufficient evidence to draw a firm conclusion regarding the effects of NIR-LED light-treatments on osteoclastogenesis since attenuation and amplification of osteoclastogenesis were found with the use of NIR-LED treatment in these pilot experiments. Furthermore, these data must be interpreted with caution since it is pilot data and meant to assist us in designing other experiments. Several limitations to this study are discussed below and include: the use of a commercial light source rather than a scientific grade light source, the possibility of cell culture heat shock, and investigator subjectivity in manual osteoclast cell counting.

Commercial NIR-LED Light Source: Both light sources used in these experiments are commercial grade and approximately calibrated for energy density, wavelength, and light intensity from the factory. The scientific grade light source has the advantage of controls for fine-tuning these variables. The commercial grade light source used in the experiments automatically turned off every 80sec, requiring manual restarting of the light during the 45 J/cm² experiments. This may have resulted in measurable effects on osteoclast formation similar to pulsing light-treatment (Karu, 1992). The manual restarting of the light-treatment (WARP™ 75) caused a brief temperature surge in testing during development of the protocol, but the cell culture medium never rose above 37°C. Temperature surges could be considered pulsing light-treatment which have been shown in the literature to give a greater biological effect than continuous wave light-treatment (Karu, 1992). Given the existence of temperature surges, heat shock cannot be ruled out; if heat shock did occur, the cultured cells may have been stressed by the abrupt change in temperature resulting in an effect that was not brought about by the light-treatment. What is needed to control for these possible confounding variables is a light source with a built-in timing mechanism, allowing for any length of light-treatment and the capability to manually tune for specific energy densities and light intensities. This would give the investigator greater control to test specific irradiation wavelengths, energy densities and light intensities, and to prevent heat shock by using consistent low radiation intensity (670nm) (Karu, 1992; Letokhov, 1991). In future experiments, obtaining a scientific grade continuous wave NIR-LED would be necessary for ensuring reliable results.

Manual Cell Counting: Lastly, the manual cell counting technique is a subjective process relying on visual interpretation of color and identification of nuclei based on an osteoclast identifying-taxonomy. Consistently applying this taxonomy over a lengthy period of time is necessary to ensure data reliability and validity. Alternative methods for osteoclast quantification are described in the literature: computer-imaging software that quantifies osteoclasts by color, shape, and nuclei; and by a TRAP5b assay. The computer software captures multiple images within specific boundaries demarcated by a gridded disk in the cell culture well, and counts osteoclasts based upon these specifications. The TRAP5b is an ELIZA assay that quantifies the amount of secreted TRAP5b by spectroscopy from collected cell culture medium. This method of quantifying osteoclastogenesis is less time consuming than manual cell counting.

However, it is clear that the effects of the light on osteoclastogenesis are RANKL dose and light intensity-specific. We conclude at this time that NIR-LED light-treatment may impair RANKL-induced osteoclastogenesis, particularly when using multiple light treatments. The use of NIR-

LED light therapy may be a beneficial intervention to return the bone remodeling process to homeostasis and preserve bone integrity.

It remains unknown how NIR-LED light therapy affects the intricate physiological signaling between osteoblasts and osteoclasts, as well as what effects it may have on bone remodeling and absorption. NIR-LED may decrease oxidative stress, preventing premature apoptosis, which is known to occur with aging.

Continued experiments are planned with the use of a scientific-grade NIR-LED light source that will allow for greater control of energy density and light intensity. Repeated experiments will produce a larger sample size and enable full statistical analysis. Understanding that aging impairs osteogenesis (bone remodeling) due to an imbalance or "uncoupling" of osteoclastic/osteoblast activity, interventions aimed at correcting this pathogenesis will further the science to provide knowledge in reaching the goal to develop an intervention that may restore physiological function, preserve or improve bone quality, improve bone mineralization with the hope of preventing bone fragility and fracture, and ultimately improve the bone architecture to withstand mechanical insult such as a fall.

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20th Annual Conference
Part Six

Atmospheric Sciences

Implications of Boundary Layer Connectivity between the Great Lakes and Synoptic Cyclones

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ABSTRACT

Operational meteorologists forecasting for the Great Lakes have long struggled with the unclear interactions between synoptic-scale cyclones and turbulent heat fluxes from the Great Lakes. The coupling of the complex moist processes which are integral to winter storms and the warm, moist air from the water surface convectively mixed in the boundary layer is not well understood. As the polar air of winter freezes the water surface of the Great Lakes into pack ice, the sensible heat flux is altered, adding to the complications for wintertime weather forecasting in the Great Lakes region.

This paper investigates how the water temperature of the Great Lakes—or ice concentration—impacts the evolution of synoptic-scale winter storms over the Midwest. The CIMSS Regional Assimilation System (CRAS) is used to determine how changes in the Great Lakes skin surface alter the track and development of the severe winter storm and blizzard of 8 and 9 December 2009. Model output from the two cases compared to the control indicated that changing the properties of the Great Lakes did not seriously alter the direction and nature of the storm, though there were some minor changes to the surface pressure field and precipitation output.

Introduction

A critical component of Great Lakes weather prediction during the late fall and winter months is snowfall coverage, intensity, and accumulation. Heavy snows traditionally result from two predominant mechanisms. First, synoptic-scale disturbances can impact the Great Lakes region in various flow regimes with differing support from upper levels of the troposphere. Most disturbances on this horizontal scale have vertical components through the depth of the troposphere which contribute to the general dynamics of the system. Though mesoscale banding is possible, synoptic-scale disturbances generally produce swaths of snowfall over large areas (beyond 100 kilometers, for example) with a gradual distribution. Contrarily, flow regimes containing cold, polar air over relatively warm, substantial bodies of Great Lakes water can produce heavy snowfall downwind on an unpredictable and generally smaller spatial and temporal scale (Figure 1). Furthermore, the thermodynamic processes most influential on lake snows, namely those contributing to strong diabatic forcing resulting from convection, are confined to the boundary layer.

The Great Lakes are a unique feature in the earth's environment in that their middle latitude position subjects them to substantial, seasonal air mass changes. These changes also influence the water temperature, especially at the water surface, where land-sea interactions are particularly common. These changes require a response in the boundary layer (BL). In the spring and summer months, the result is traditionally a sea breeze, because the water temperature, particularly during the day, is colder than the air temperature, and much colder than the nearby land surface temperature. During the winter, the warmer water temperature compared to the air temperature is sufficient to result in upward vertical motion and a moistening of the BL. Depending on the background BL conditions (state without modification), significant precipitation (typically snow) over and downwind from these warm water bodies may result.

Using mass conservation principles, there are pragmatic assumptions about the nature of the surface pressure field in these situations. During the spring and summer months, the subsident air over the cooler lakes relative to the air leads to a high pressure anomaly within the marine boundary layer (MBL) compared to the over-land BL. During the winter months, the warmer lakes induce upward vertical motion and result in decreased pressure within the MBL. Due to the vast coverage of Great Lakes water surface, these anomalies have a near synoptic scale in the horizontal, but height anomalies on pressure surfaces in the lower levels of the troposphere are not as profound, and are traditionally confined to the BL.

Previous Studies

The literature surrounding the combined impact of the Great Lakes on weather systems beyond the mesoscale is limited and inconclusive. This has led to continuing confusion among operational meteorologists about how to expect synoptic-scale weather systems to evolve in the presence of various lake states, predominantly modulated by temperature and ice coverage. Cox (1917) was the first to propose connectivity between synoptic scale weather disturbance evolution and the collective effect of the Great Lakes, suggesting that the Great Lakes “attracted” cyclones through both altering the track and intensifying the core (deepening the cyclone through moist processes). It was not until Petterssen et al. (1959) that the pressure weakening effect of 6 to 7 hPa at sea level was actually quantified. Danard et al. (1972) and Boudra (1981) performed simulations with and without the Great Lakes, concluding that the Great Lakes reduced surface pressure by 5 hPa and increased temperatures at the 850 hPa pressure level by 5 degrees Celsius, a suspect result because the increase in air temperature would decrease instability, and thus moisture transport, between the sea surface and 850 hPa.. There was no determinable influence on cyclone track, however. Sousounis et al. (1994) examined simulations of weak synoptic disturbances interacting with the Great Lakes and did find deviations in track as well as deepening of the center surface pressure.

The BL is the atmospheric couple between the water surface and the free atmosphere supporting these synoptic weather systems. Unfortunately, the winter MBL is ill-studied and real-time observations of skin temperature and near-surface atmospheric properties over the water are consistently lacking in spatial coverage. The preliminary investigation conducted here postulates about the sensitivities of a synoptic-scale cyclone in the free atmosphere to the Great Lakes water temperature and ice concentration based on peer-reviewed literature. The water temperature and ice concentration play a significant role on the latent and sensible heat fluxes at the bottom of the BL. A case study model simulation where the Great Lakes water temperature was increased and decreased ahead of a significant winter storm is also presented.

In this study, only the influences of pack ice on the turbulent heat fluxes are considered. Changes in surface roughness are not considered, because ice formation over the lakes is uncommon during periods where seas are rough and wave laden. The wind acts to dissipate the ice and likely increase the sensible heat flux indirectly because more water is upwelled and directly exposed to the atmosphere between the ice floes. While this negation is not ideal, in some situations, the roughness over water and ice is nearly the same, particularly when winds are light, and likely never as complex as hilly terrain, vegetation, and urban areas.

Some early, unpublished studies were conducted using the Weather Research and Forecast (WRF) model which showed that modifications of the Great Lakes skin surface temperatures during the spring months did not notably influence the over-land temperature or pressure field. One likely reason for this is a strong inversion that typically develops near the surface in the spring and summer, inhibiting strong and deep mixing with the air aloft, while during the winter months, the profile is unstable. During the winter, this exchange is convective through a sizable depth of the BL. Published findings from Kristovich et al. (1998) suggest that lake surface temperatures influence the location of cloud development in the MBL, indicating that heterogeneities in the lake-atmosphere temperature differences can alter the rate of the air-sea heat exchange and nature of the convective BL. This result was confirmed by LaCasse et al. (2008) in experimental WRF simulations run after enhancing the gradients in the sea surface temperatures in the coastal waters off eastern Florida. In LaCasse, the location of summertime thunderstorm development relative to the Gulf Stream changed based on the skin surface temperature gradients.

While spring and summertime temperature gradients across the Great Lakes can be particularly intense, this is generally not true during the winter months, particularly in late winter, because the generic water temperature of the Great Lakes is 4 degrees Celsius or colder. Ice usually forms in shallower areas near the shore, and sometimes over vast open water areas of the northern Great Lakes. There is no reason to expect intricacies which influence the MBL during the winter months, except in cases of ice decay during the early spring.

Gerbush et al. (2008) uncovered that operational numerical weather prediction models do not have sophisticated parameterizations to deal with lake ice. Furthermore, observation methods for areal coverage and depth of ice pack are predominantly confined to satellite and produced at the National Ice Center. The North American Mesoscale (NAM) model, with a spatial grid resolution of 12 kilometers, assumes grid boxes with less than 50% ice concentration to be completely void of ice, while for areas where ice concentration is above 50%, it assumes complete one-meter ice coverage (Gerbush 2008).

Great Lakes Ice Cover-Atmospheric Flux (GLICAF)

Gerbush et al. (2008) focused on the Great Lakes Ice Cover-Atmospheric Flux (GLICAF) experiment, which was conducted to intensively study the ice concentration over Lake Erie in February 2004. For the field campaign, the predominant method of observation was via University of Wyoming King Air with a downward pointing Heimann KT-19.85 pyrometer with an adjacent digital video camera. During the experiment, observations of pack ice concentration and turbulent heat fluxes were obtained over Lake Erie at frequencies of 1 and 25 Hz at flight distances of 80 m and 3 m, respectively (Gerbush).

Turbulent heat fluxes (latent and sensible) are contingent on characteristics of the atmospheric properties and thermodynamics near the land-sea interface. The pack ice plays a role in attenuating the sensible heat flux, but Gerbush (2008) found that this relationship is nonlinear and poorly correlated. For latent heat flux, the linear correlation from Gerbush is even lower. Fortunately, sensible heat fluxes are an important characteristic in determining the nature of lake effect snow. For pack ice concentrations less than 70%, turbulent fluxes were very similar to those for no ice cover (Gerbush). If numerical weather prediction models continue to employ linear ice-flux relationships, there is a risk of underestimating the heating of the atmosphere over parts of lakes where the there is a substantial and notable ice pack. The pack ice is also important for influencing the mesoscale variations in temperature and moisture within the MBL

(Gerbush), though the impact of near-surface temperature and moisture on numerical weather prediction models is difficult to quantify because remote sensing of these variables from space is not possible with current instruments, and in-situ measurements are sparse.

Lake Modification of Synoptic Scale Features

Gallus (1999) demonstrates the two methods through which a lake large enough to influence the synoptic scale could augment the dynamics of a frontal passage. The first method is for the lake to lessen the frontal temperature gradient through an alteration of the thermal fluxes compared to those over land. The second method is for the lake's flat surface to modify friction through a decrease in surface roughness and increase in near-surface thermal stratification. Cool water clearly retards the upward heat flux as well as the formation of a convective boundary layer (stable stratification results when the temperature increases with height) which effectively reduces the frictional effect, so the two methods are somewhat interlinked. The lack of friction increases the strength of cold air advection post-frontal, sharpens the convergence boundary from its back (away from the direction of propagation), and subsequently, in the region of the lake, produces a stronger, faster-propagating temperature gradient. Gallus (1999) effectively demonstrated this in a case from 9 March 1992, where a modulated evening cold front pushing across Lake Michigan dropped the air temperature at Chicago Midway Airport (KMDW) from 62 degrees Fahrenheit to 41 degrees Fahrenheit in one hour, and 34 degrees Fahrenheit in two hours, per hourly records, a net drop of 28 degrees.

Gallus concludes that the 9 March 1992 frontal passage was relatively shallow in vertical depth and behaved similar to a density current, which was supported by the enhanced horizontal temperature gradient. Also emphasized was the cause for the acceleration: the flow had strong northerly components and the source region contained copious, unobstructed cold air. In addition, Gallus notes that strong warm-sector winds may also have played a role in increasing the temperature gradient, though the fetch across extremely cold Lake Michigan waters may have allowed this to play only a secondary role.

During the summer months, the water temperature of the Great Lakes continues to warm. Thus, over-lake convergence boundaries are likely weaker (based on the cross-front temperature difference) during the late summer compared to the early spring. However, the southern Great Lakes warm faster than the northern Great Lakes. Particularly, Lake Superior is relatively cool throughout the summer, only able to warm significantly during the month of August, after the entire lake has reached four degrees Celsius (the temperature at which water is its densest and overturning ends). In contrast, Lake Erie is relatively shallow and can start substantial warming months earlier. This is also in part due to its more southern geographic position.

Even over land, many summertime frontal passages in the Upper Midwest have little in terms of significant temperature gradients. More often, the frontal passages have a relatively strong gradient in moisture, where the air is notably drier behind the front than ahead of it. As these fronts transgress Lake Superior, they advect warm, moist air ahead of it through turning winds southerly, with somewhat drier air behind under northerly flow. With lake water temperatures quite low, the near-surface air temperatures are similar, and the air behind the front is closer to saturation than over land. A stronger temperature gradient is likely to be present over water than on land despite the lack of a sizable differential horizontal heat flux at the surface across the boundary in either place (except between urban areas and dense vegetation). This is due to strong stable stratification immediately above water level which has been theorized to demote vertical mixing at the base of the boundary layer. Despite this, the low-friction water surface compared to land will promote higher winds over water and near shore than well inland.

Compared to the 9 March 1992 case, the main factors with the passage of a summertime front, are the strength of the warm air advection across the lake to increase the temperature gradient and the lake-modified cool, relatively moist air behind the front accelerated in a lesser-friction environment. In addition, there is a substantial lake breeze apt to form post-frontally with a continued differential heat flux across the land-sea interface. Ahead of the front, this process is liable to be disturbed under synoptic flow, at least in the upwind region of the lake. It is hypothesized that Lake Superior's role in serving as a reservoir for cold air is critical for the enhancement of frontal passages and pneumonia fronts later in the spring.

Zwack-Okossi and Surface Pressure Tendency
In an attempt to determine the impact of sensible heat fluxes from idealized lakes on the MBL and the ambient flow influencing synoptic-scale cyclones, Chuang et al. (2002) applied the Zwack-Okossi (ZO) equation,

$$\frac{\partial \xi_{gl}}{\partial t} = \mathrm{Pd}\int_{p_t}^{p_l} -\mathbf{V}\cdot\nabla\xi_{\alpha}\,dp + \mathrm{Pd}\int_{p_t}^{p_l} \mathbf{k}\cdot\nabla\times F\,dp - \mathrm{Pd}\int_{p_t}^{p_l}\left[\frac{R}{f}\int_{p}^{p_l}\nabla^2(-\mathbf{V}\cdot\nabla T + \dot{Q} + S\omega)\frac{dp}{p}\right]dp, \quad (1)$$

in order to analyze the influence of vorticity advection, friction, temperature advection, diabatic heating, and adiabatic heating, respectively, on surface pressure tendency, such that

$$\frac{\partial \xi_{gl}}{\partial t} = \frac{1}{\rho f}\nabla^2\frac{\partial p_s}{\partial t}. \quad (2)$$

This method is popular because the parameters forcing the solution are distinct and integrated through the depth of the atmosphere. However, the full ZO equation also contains other, smaller terms which are neglected here, predominantly accounting for ageostrophic vorticity tendency, vertical vorticity advection, the tilting effect, and divergence effect. The diabatic heating term accounts for solar and terrestrial radiation, stable and convective latent heat release, and evaporative cooling, while the sensible heating term used in the ZO equation is parameterized such that the sensible heat flux decreases linearly with height to zero, such that there is there is no sensible heat flux resulting from surface effects above 850 hPa.

Chuang et al. (2002) performed a series of ideal numerical simulations to determine how four, uniform circular, idealized lakes on the meso-beta-scale impact flow regimes. Three cases representing different flow patterns were run with the lakes: zonal flow, a single trough, and a continuous sinusoidal wave pattern. Based on the results from the experiments, the idealized settings did not produce any new synoptic scale cyclones without the presence of an external dynamical forcing. There was the genesis of closed lows on the synoptic scale, however. These closed lows were weaker in terms of scale and generated much less precipitation, consistent with their characteristic behavior. Further, Chuang found that "pre-conditioning" from the positive amplification in the wave was significant for further development of the synoptic-scale cyclone.

Chuang et al. also found that the idealized lakes helped to induce a warm front. Increased sensible heating from the lakes collectively helped to heat the warm side of the front and intensify the differential diabatic heating gradient, and thus the temperature gradient. Based on the findings in Gerbush (2008), it is possible that an appreciable ice concentration (over 50%) could greatly misrepresent atmospheric conditions which actually favor cyclone development and intensification. The effect of the sensible heat flux on the cold front trailing the low pressure center was less. Like the warm front, the front was enhanced by the differential diabatic heating, but an opposing frictional effect from the lakes veers the flow to the right, decreasing frontal convergence.

Using the ZO pressure surface tendency equation, Chuang (2008) found that the only term which contributed to an increase in the surface pressure was adiabatic cooling. Vorticity advection, temperature advection, and diabatic processes all helped to deepen the low, as well as the residual terms, which contributed to the deepening pressure tendency likely because of the strong convergence at the center of the cyclone (Chuang).

Case Study: 8-9 December 2009

An attempt was made to replicate the results of Chuang using a realistic situation. The Cooperative Institute for Meteorological Satellite Studies (CIMSS) Regional Assimilation System (CRAS) is a numerical weather prediction model that has been in development for over a decade, guided by validation and input from data obtained from satellites, predominantly the Geostationary Operational Environment Satellites (GOES). For this study, we assume that the dynamics and parameterizations are adequate to resolve the atmospheric phenomena here, a mid-latitude cyclone, and that this behavior does not significantly deviate from other operational models running at this spatial resolution; there is no verification performed with respect to this case to assure the fluxes were as observed, primarily because this data is not available. There are no in-situ near-surface or water temperature measurements taken over open water in the winter.

The CRAS (http://cimss.ssec.wisc.edu/cras) was initialized with initial and boundary conditions from the Global Forecast System (GFS), modified with moisture assimilation from the GOES Sounder in at 12-hour spin-up preceding the model initialization. A 60-hour simulation was run at a grid scale resolution of 45 kilometers. The model was initialized at 12:00 UTC on 7 December 2009 (Figure 2), approximately 48 to 60 hours before the cyclone neared and crossed the Great Lakes. This time range was sought in order to allow the Great Lakes to "pre-condition" the preceding ridge as was a surmised to enhance development in Chuang.

The severe winter storm and blizzard of 8 and 9 December 2009 was a substantial mid-latitude cyclone with a pronounced moisture feed from the tropics and strong support in the upper levels of the troposphere from a jet streak riding in the parent longwave trough. Days ahead of the event, numerical output from the operational weather models suggested a surface track from central Illinois through northern Indiana and into central Lower Michigan (Craven 2010). The observed result was somewhat different with the surface low progressing from the St. Louis, Missouri, area to near Milwaukee, Wisconsin, and continuing north-northeastward over Lake Michigan. This led some forecasters to surmise that the Great Lakes are producing a systematic bias in numerical weather prediction output.

The choice to use the CRAS for this simulation resulted from desirable model performance of the control run compared against the other members of the short-range ensembles produced at the National Centers for Environmental Prediction (NCEP), as well as assimilation of important moisture information which may impact the diabatic processes at the core of the mid-latitude cyclone. In addition, the intent of the study was not to measure the accuracy of the surface low track compared to other models; it was to determine the impact of the lake surface temperature on the synoptic scale evolution. There were three runs: the control run, where all of the Great Lakes exhibited a standard and observed winter water surface temperature value of roughly 4 degrees Celsius, the ice run, where all the of the Great Lakes were assumed to be covered with ice, and the hot run, where all of the Great Lakes were assumed to be 5 degrees Celsius warmer at the skin layer compared to the control. The ice run did not limit the heat flux through the ice, and the skin water temperature is static throughout the entire model simulation.

Results. A comparison of the experimental runs to the control shows little impact. Most notably, the Great Lakes did not seemingly influence the track of the surface low in the least, nor was there any prominent shift in the 500-millibar pattern between the control and the experimental runs. Based on the horizontal scale arguments, this is a reasonable result. One area of deviation between the control and the hot experimental run was the lowering of the 850-hPa heights over northern Lake Michigan as the system slowed over the water in the hot run at the end of the simulation. Residence time of the lakes appears to have a factor in contributing to development. Figures 2 through 4 compare surface pressure, BL (1000 to 850 hPa) thickness, and precipitation 60 hours after initialization. Sea level pressure between experiment and control runs changed less than 2 hPa near the low center; precipitation increased in the hot run by less than 0.2 inches.

The results that show the ice run and the control run were nearly identical gives credence to the Gerbush (2008) result that ice cover does not significantly attenuate the sensible heat fluxes. It is important to note that most wintertime ice-cover studies are performed over the Arctic, where extremely cold temperatures promote long-term and deep ice growth. Such conditions are relatively rare over the Great Lakes. Severe cold outbreaks traditionally last for days instead of weeks, and an amplified pattern can result in some super-freezing days which interrupt ice growth. Furthermore, the Great Lakes exhibit much more significant warming during the Northern Hemisphere summer. This warming requires significant, prolonged cooling for ice production, especially over the voluminous lakes of Lake Michigan, Lake Michigan, and Lake Huron, where lakes must uniformly cool to 4 degrees Celsius before top-down cooling to near freezing can occur due to density overturning. Some winters result in little ice coverage across the Great Lakes outside of the shallow bays. In 2010, true color imagery from the MODerate resolution Imaging Spectroradiometer (MODIS) instrument aboard polar-orbiting satellites Aqua and Terra showed partial ice coverage only over Lake Erie by March.

Conclusions

This investigation sheds some new light on how ice concentration on large lakes impacts the development and track of mid-latitude cyclones. Further investigations should focus on the development of a northwest flow Alberta clipper system as it passes over Lake Superior and Lake Huron in northwest flow. That northwesterly flow regime would traditionally put the surface low over water for the longest period of time. For models with horizontal resolutions of 45 kilometers, ice pack concentrations must vary on at least that scale to expect a positive impact result. Based on the scale of mid-latitude cyclones, the heterogeneities probably do not matter much; the ice concentration of each individual lake could be set by averaging the ice concentration from the various parts. However, there are underlying thermodynamical forcings in the BL which contribute to amounts in Great Lakes synoptic-scale snowfalls through lake-enhanced snow, where increased moisture in the BL is converted into snowfall with help of the dynamical upward vertical velocities associated with the warm air and vorticity advection (via the omega equation). For higher resolution model simulations, equally high resolution ice coverage data may matter for those scenarios. Regardless, this study underscores the importance of understanding how turbulent heat fluxes modify the BL and contribute to the development of the lower levels of synoptic storms, whether on a bulk scale or mesoscale.

It should be stressed that the residence time and large air-sea temperature differences are probably the two largest variables impacting BL contribution the synoptic scale storm dynamics. Storm scale is a contributing factor. Large storms can be easily overrun with moisture transport from other sources, such as the Gulf of Mexico, which contributes to intensification via diabatic processes at the center of the storm, driving development and track. For smaller, meso-beta-scale storms, moisture impacts and the Great Lakes may be more significant.

For these reasons, satellite data assimilation projects remain a valuable asset for studying these types of problems. Satellite observations are the predominant source of total precipitable water and other moisture data on high spatial scales and play a significant impact on precipitation amounts. In a similar fashion, strong temperature gradients over the lakes, which are much better resolved via remote sensing techniques than with limited in-situ observations, redistribute the BL air through dynamics resulting in sea breezes, cloud condensation, and lake-effect precipitation. There is little question that remote observation systems such as GOES and MODIS are the only way to confront the initial condition problems of the future as spatial numerical weather prediction model resolutions continue to approach and surpass one kilometer.

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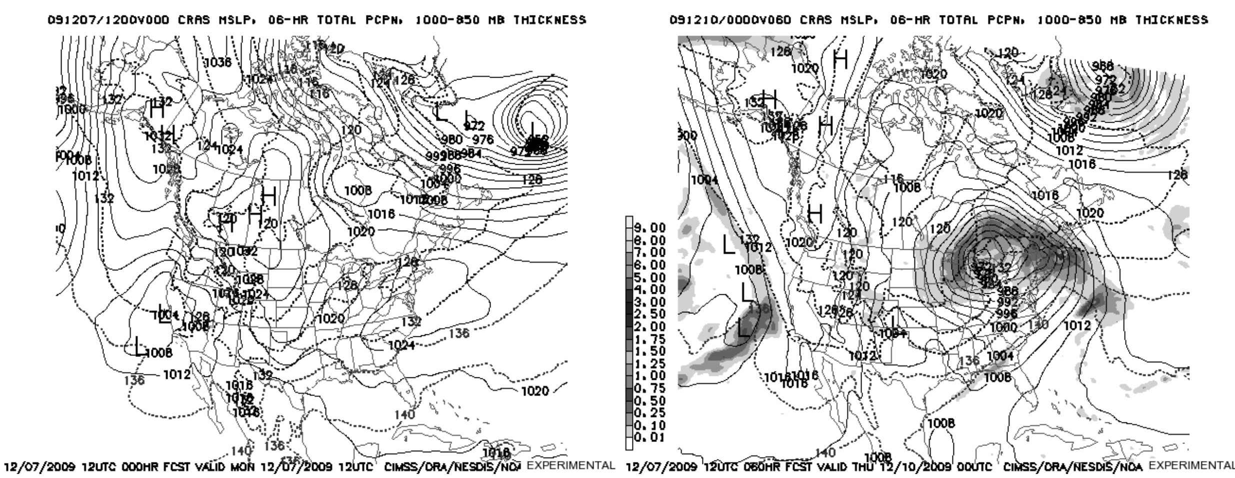
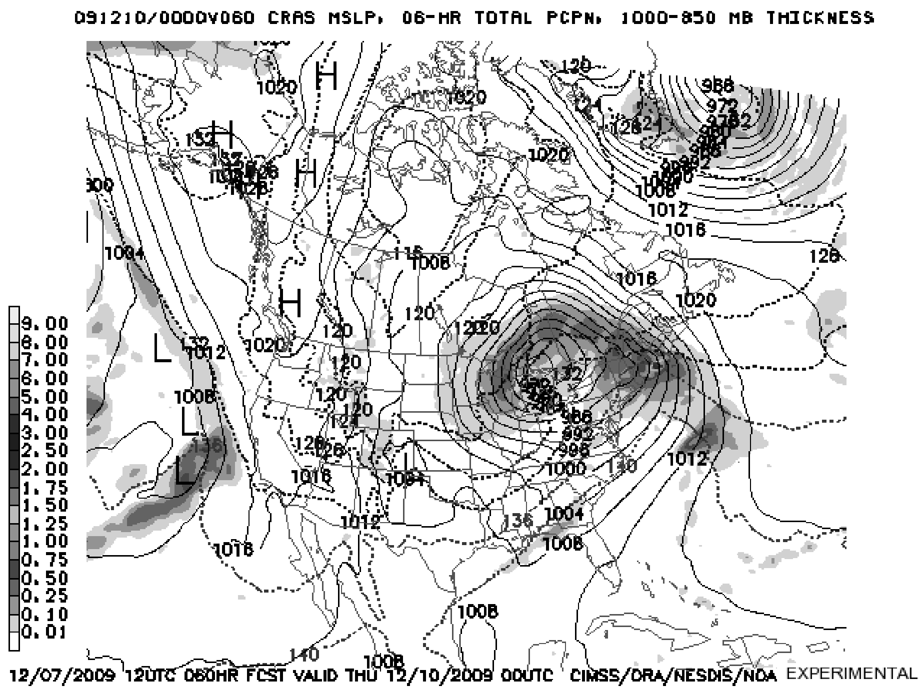
Figures

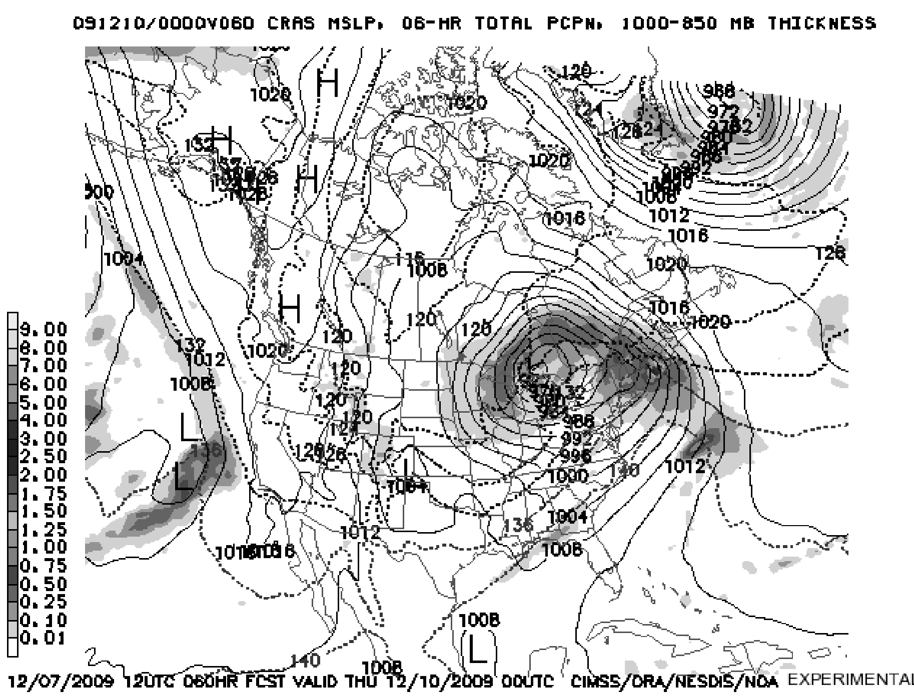
1. This MODerate resolution Imaging Spectroradiometer (MODIS) true color image from 11 December 2009 shows convective boundary layer cloudiness in the wake of a winter storm. There is no ice cover over the western Great Lakes. Wisconsin is snow-covered. Much of central and southern Illinois is free of snow.



2. Model output from the control run of the 12 UTC 7 December 2009 CIMSS Regional Assimilation System (CRAS) showing mean sea level pressure (hPa), 6-hour accumulated precipitation (inches), and 1000-850 hPa thickness (dm) at time of initialization (left) and 60 hours after initialization (right).



3. Model output from the hot run of the 12 UTC 7 December 2009 CRAS showing mean sea level pressure (hPa), 6-hour accumulated precipitation (inches), and 1000-850 hPa thickness (dm) at 60 hours after initialization. Note slightly deeper surface pressures, decreased thickness, and increased precipitation over and near the western Great Lakes. However, the position of the surface low pressure system is unchanged compared to the control run.



4. Model output from the ice run of the 12 UTC 7 December 2009 CRAS showing mean sea level pressure (hPa), 6-hour accumulated precipitation (inches), and 1000-850 hPa thickness (dm) at 60 hours after initialization. Note relatively few changes compared to the control run, including the position of the surface low pressure system.

20th Annual Conference
Part Seven

Engineering

Regenerative Fuel Cell Systems Round Trip Efficiency Capability

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Abstract

This research identifies the key parameters of a Regenerative Fuel Cell System (RFCS) that allow for round trip efficiency improvement. Current RFCS models and running RFCS systems exploit round trip efficiencies around 35% excluding parasitic power losses. A design and modeling of a low power, continuous output RFCS demonstrates that round trip efficiencies are capable as being as high as 50% (Bents, Chang, Garcia, 2005).

Introduction

A Regenerative Fuel Cell System (RFCS) consists of three main system components and 2 different power cycles all while supplying a continuous power output. The main components consist of a solar array, a fuel cell stack, and an electrolyzer stack. The two different power cycles of a RFCS are the Charge cycle, and discharge cycle. During the charge cycle, the solar array supplies power to provide the continuous power output needed, and to the electrolyzer stack where solar energy is then stored as hydrogen and oxygen to power the fuel cell stack. During the Discharge cycle the hydrogen and oxygen stored during the Charge cycle are consumed by the fuel cell stack to supply power for the continuous power requirements and parasitic system components such as pumps, sensors, and controls (Bents, Chang, Garcia, 2005)(Revenkar,2006).

Nomenclature

C_p	Specific Heat(constant Pressure)
C_v	Specific Heat(constant Volume)
e_t	total specific energy (J/mol)
F	Faradays constant(98645)
G	Solar Irradiation (W)
$\Delta H_{R,T}$	reaction energy (J)
h	specific enthalpy (J/mol)
I	current (A)
i	current density(A.cm2)
k	nozzle flow rate coeff. (mol/s Pa)
kb	boltzmann's constant
k_{conv}	heat transfer coefficient (W/K)
m	mass (kg)
N	number of cells
n	number of moles
$\dot{n}$	molar flow (mol/s)
P	Power density (W/cm2)
p	Pressure (Pa)
q	charge (C)
R	universal gas const. (8.314 J/mol K)
T	Temperature (K)
x	mole fraction

Greek

η	efficiency
ρ	density (kg/m3)
$\bar{\rho}$	molar density (mol/m3)

Contributors: Wisconsin Space Grant Consortium & MSOE.

subscripts		∞	ambient condition
act	activation	m	membrane
an	anode	o	initial condition
ca	cathode	oc	open circuit
diff	diffusion	ref	reference value
FC	fuel cell	rxn	reaction
EZ	electrolyzer	sc	short circuit

Key Parameter Identification

The parameters of the RFCS were investigated to identify what system components most adversely affected the round trip efficiency. Figure 1 illustrates the power/energy distribution of the system during the charge cycle and discharge cycle.

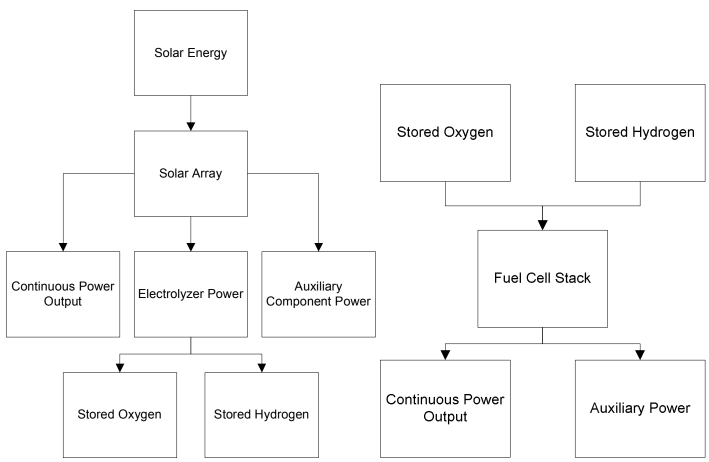

Figure 1: Charge Cycle Power Energy/distribution & Discharge Energy/power distribution

The primary concern of improving the round trip efficiency can be identified as the auxiliary power consumption or otherwise known as the parasitic power consumption. The round trip efficiency of the RFCS is defined as illustrated in equation (1) (Bents, Chang, Garcia, 2005).

$$round\ \ trip\ \ efficiency = \eta = \frac{(P_{output})(t_{total})}{(P_{input})(t_{charge})} \quad (1)$$

Where P_{output} is the continuous power output from the system, t_{total} is the total cycle time, P_{input} is the power input of the system from the charge cycle, and t_{charge} is the time duration of the charge cycle.

Minimizing the input power that isn't supplied to the electrolyzer and continuous power output or reducing auxiliary power consumption improves the overall system efficiency. The main power consumer in the auxiliary components of a RFCS is pumps that store the oxygen and hydrogen created from the electrolyzer. System efficiency can be improved by identifying the optimal operational parameters of the fuel cell and electrolyzer (aka: pressures required for optimal FC stack performance), and the space available for the system. This can be turned into an optimization problem between the system space available and minimizing pump power requirements while fulfilling operating pressures of the FC stack (Barbir & Dalton, 2005).

RFCS Modeling

Fuel cell modeling

The PEM fuel cell stack is governed by mass, energy and momentum where a combination of continuity, energy, heat transfer, and electrochemical equations were used to develop a numerical iterative model of the FC stack using MATLAB.

The continuity equation of the FC that uses a mass balance and can be used for any control volume is illustrated in equation (2). Equation (2) is expanded using system properties and balances of hydrogen, oxygen, and water as illustrated in equation (4)(Spiegel,2006)(Spiegel,2007)(Revankar,2006).

$$\frac{\partial}{\partial t}\iiint_{CV} \rho dV + \oint\!\!\!\oint_{CS} \rho\left(\bar{V} \bullet \bar{n}\right) dS = 0 \tag{2}$$

Equation (3) describes the energy balance used in the system where heat transfer and power production are factored into the model. This energy balance was used to model the system response of the FC stack (Barbir, 2005)(Spiegel,2006)(Spiegel,2007)(Revankar,2006).

$$\frac{\partial}{\partial t}\iiint_{CV} \bar{\rho} e_t dV + \oint\!\!\!\oint_{CS} \bar{\rho} h\left(\bar{V} \bullet \bar{n}\right) dS = \frac{dQ}{dt} + \frac{dW}{dt} \tag{3}$$

The continuity in the anode of the FC stack considering the hydrogen entering, exiting, and being consumed is illustrated in equation (4). Similarly, an equation for the cathode considers the same for oxygen entering, exiting, and being consumed in the FC stack.

$$\frac{\partial}{\partial t}\left(n_{H_2,An}\right) = x_{H_2 in}\dot{n}_{in,an} - x_{H_2 an}\dot{n}_{out,an} - \dot{n}_{H_2 RXN} \tag{4}$$

Equation (5) describes the molar fraction of hydrogen gas in the system and is integrated into the continuity hydrogen equation described in equation (8).

$$x_{H_2} = \frac{n}{n_{H_2} + n_{H_2O}} \tag{5}$$

Also, the rate of moles entering the anode in the fuel cell stack is described in equation (6) and also is included in the continuity hydrogen equation in equation (8).

$$\dot{n}_{in,an} = k_{in,an}\left(P_{inlet} - P_{an}\right) \tag{6}$$

The rate of hydrogen consumption in the FC stack is described in equation (7) by the Nernst equation which is also used to describe the consumption of oxygen and production of water in the FC stack the respective values of n=4 in the cathode.

$$\dot{n}_{H_2RXN} = \frac{Ni}{2F} \tag{7}$$

The continuity hydrogen equation of the system is described below in equation (8), which combines equation (4) – (7).

$$\frac{\partial}{\partial t}\left(n_{H_2,an}\right) = \left(\frac{n_{H_2}}{n_{H_2} + n_{H_2O}}\right)_{in} k_{in,an}\left(P_{inlet} - P_{an}\right) - \left(\frac{n_{H_2}}{n_{H_2} + n_{H_2O}}\right)_{an} k_{out,an}\left(P_{an} - P_{outlet}\right) - \frac{Ni}{2F} \tag{8}$$

From equation (3) the energy balance is governed by Newton’s law of cooling simply functions of temperature in the FC stack. Equation (9) illustrates the total energy in the anode.

$$\iiint_{AN} \overline{\rho} e_t dV = [x_{H_2,an} c_{v,H_2} + (1 - x_{H_2}) c_{v,H_2O}] n_{an} T_{an} \tag{9}$$

Factoring in the energy in the cathode, anode, and the energy in the body of the FC stack while including Newton’s law of cooling, heat transfer and electrical work done by the FC stack concludes the entire energy balance which is illustrated in equation (10)(Gomatom, 2003)(Revankar, 2006).

$$\frac{dQ_{body}}{dt} = k_{conv,an}(T_{an} - T_{body}) + k_{conv,ca}(T_{ca} - T_{body}) + k_{conv,\infty}(T_{\infty} - T_{body}) + \Delta H_{R,T} \dot{n}_{H_2rxn} \tag{10}$$

Equation (10) also is used to model the response of the fuel cell stack as illustrated in figure 3 which is mainly a function of temperature and the current drawn from the stack (Pathapati, Stefanipoulou, Peng, 2002)(Spiegel, 2006)(Spiegel, 2007)(Revankar, 2006)(Xiaguo, 2006)

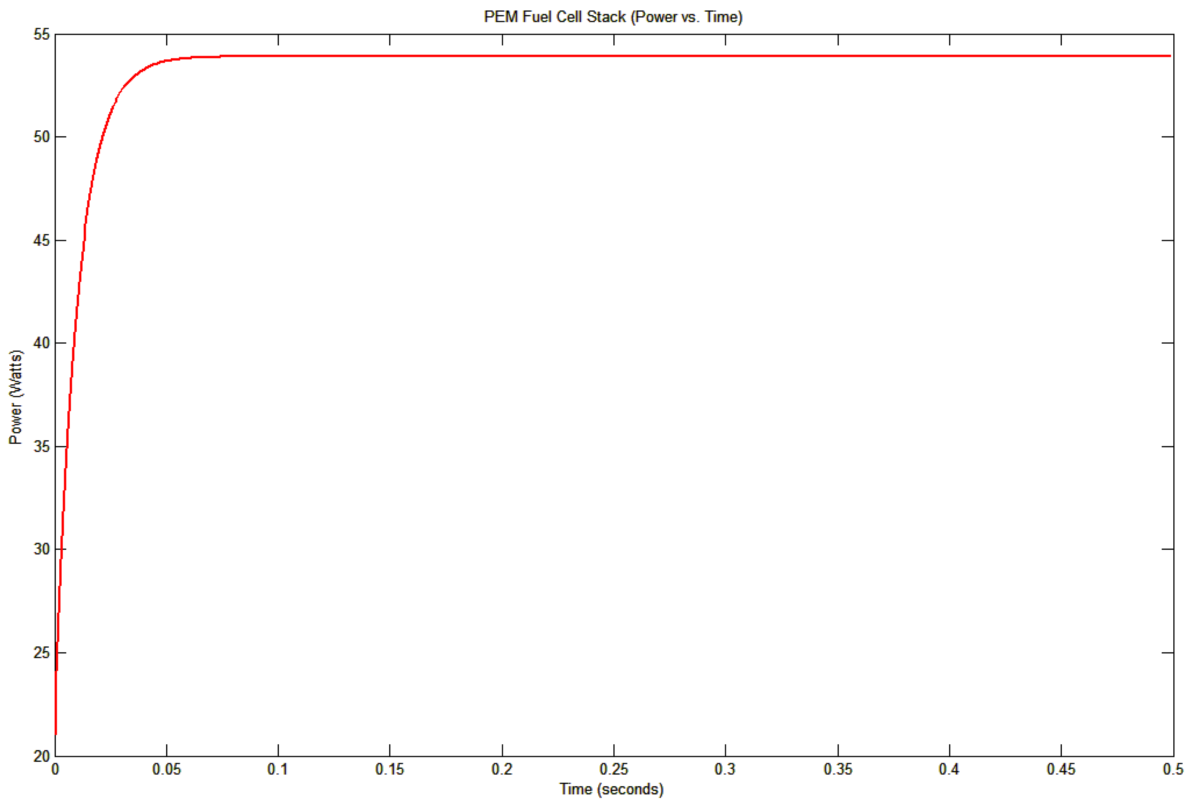

Figure 3: FC stack Response (Power vs. Time)

Electrolyzer Modeling

Like the FC stack, the PEM electrolyzer uses the same governing equations and variations to numerically model the production of the hydrogen, oxygen, the system response once power is applied and the steady state properties of the stack. The equations used are illustrated in (2)-(10) where the signs of the reactions and electrical work done are reversed as described in equation (11) as compared to equation (3)(Revankar, 2006).

$$\frac{\partial}{\partial t}\iiint_{CV}\bar{\rho}e_t dV+\oiint_{CS}\bar{\rho}h\left(\bar{V}\bullet\vec{n}\right)dS=\frac{dQ}{dt}-\frac{dW}{dt} \tag{11}$$

The response of the electrolyzer stack is similar to figure 2 since most of the thermal properties and parameters are the same.

Solar array modeling

When modeling the solar array of the RFCS, the solar energy available is assumed to be sinusoidal and consistent. The current in each cell is a function of the temperature, which is a function of the solar flux. The current of the cell is described by equation (12) where it's between the short circuit current and the reverse current or dark current (Revankar, 2006).

$$i = i_{sc} - i_o[\exp\left(\frac{qV_{oc}}{K_b T}\right) - 1] \tag{12}$$

Equation (13) illustrates the short circuit current which is a function of the sinusoidal solar flux.

$$i_{sc} = \frac{i_{sc}}{G_o} G \tag{13}$$

The cell operating temperature is described as function of the solar flux and the ambient temperature around the cell as shown in equation (14)

$$T(G) = T_{\infty} + \frac{T_{ref} - T_{\infty,ref}}{G_{ref}} \frac{dG}{dt} \tag{14}$$

Equation (15) describes the open circuit potential in each of the cells which like the current is also a function of the cell temperature.

$$V_{oc} = V_{oc,0} + C_1(T - T_o) \tag{15}$$

The power produced by the solar array is illustrated in equation (16)

$$Power = (i * cell\_area)V_{oc} \tag{16}$$

Values of solar flux used in the model were a running average of the sinusoidal solar flux at the in the month of June over the years of 2007 and 2008.

RFCS model

The RFCS model is governed by the models of each system component where there cycle initiation is determined by the continuous power supply needed by the system. The model was made for the designed system with a continuous power output of approximately 47 watts. Parasitic power consumption was factored in by assumptions made in the experimental design of a system to verify the RFCS model. Assumptions made included: 3W of continuous power allocated to storage to power the closed loop control system and its instrumentation, 5W of continuous power for each of the two micro diaphragm pumps that were selected for the system.

The power distribution of the RFCS over the span of 2 twenty four hour cycles was modeled as well as the molar consumption of hydrogen, and volumetric consumption of hydrogen gas. The power distribution of the RFCS is illustrated in figure 4.

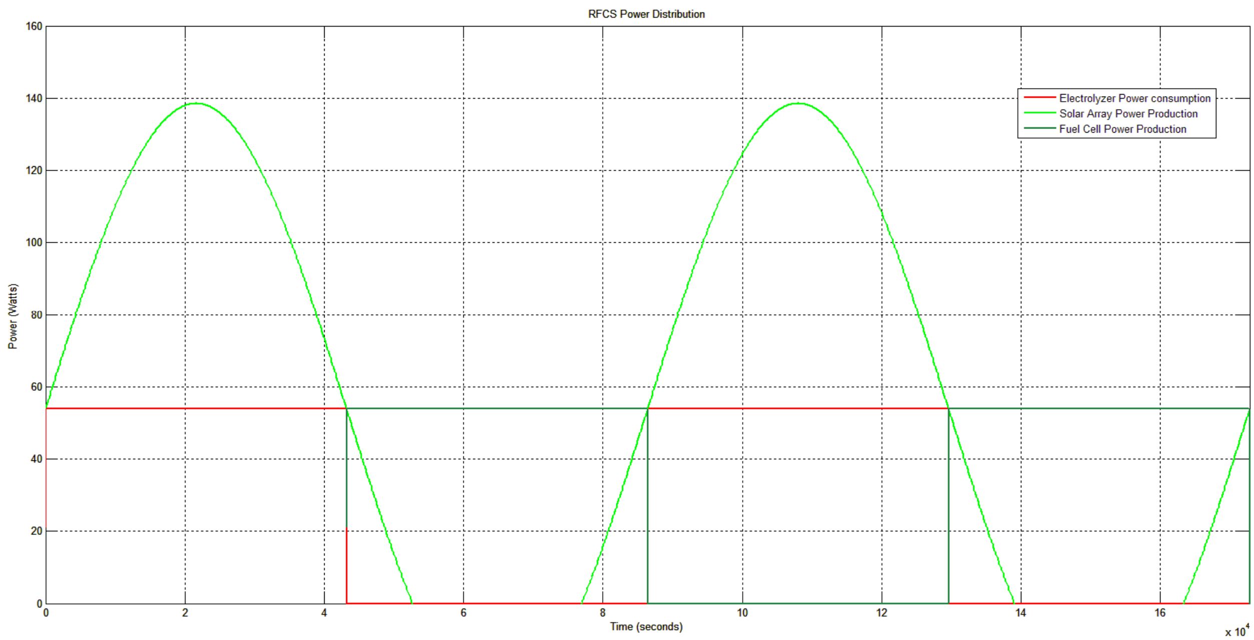

Figure 4: RFCS power distribution.

Figure 5 illustrates the molar consumption and production in the RFCS by the electrolyzer and the fuel cell stack as a function of time over the two twenty four hour cycles.

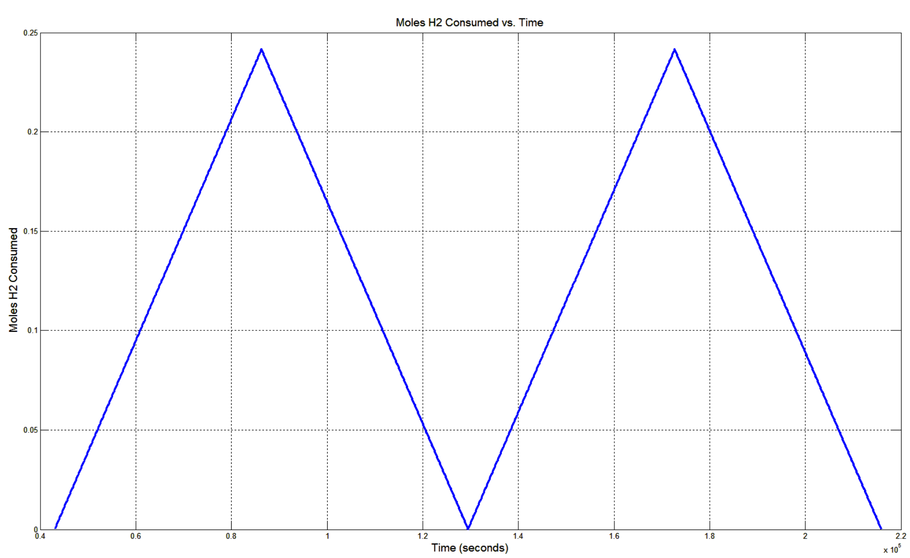

Figure 5: Hydrogen molar consumption and production.

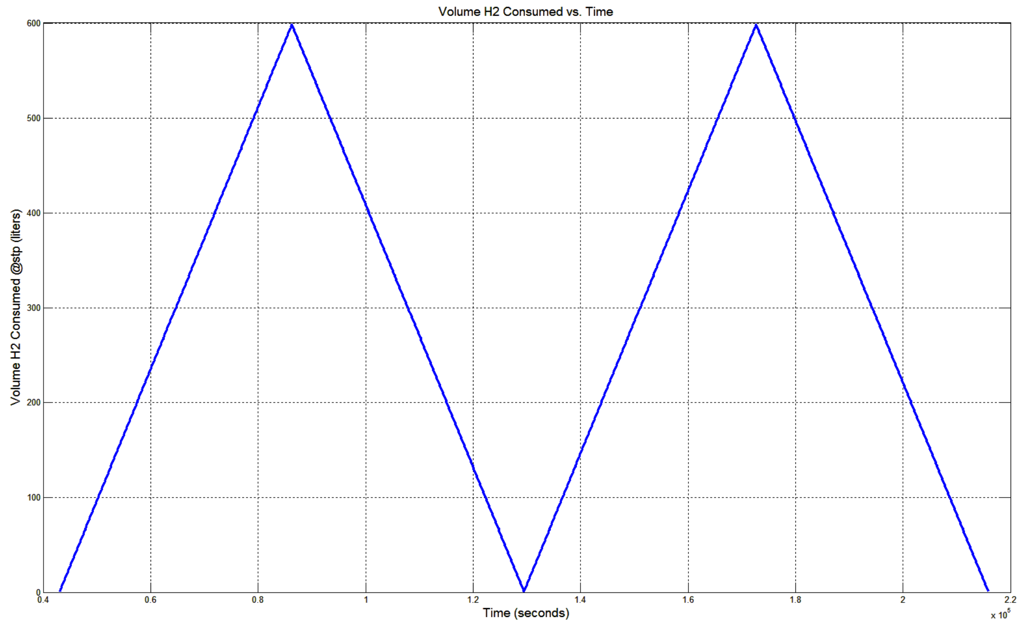

Figure 6: Hydrogen volumetric consumption and production.

Conclusions

The RFCS model was used to design and verify the effectiveness of the model and validate whether or not it is correct. Current RFCS models have roughly 35% round trip efficiency while given the system designed using the model with a continuous power output of approximately 47 watts is expected to have an round trip efficiency 42.5%-53% round trip efficiency. The main focus when designing the system was aimed at keeping the parasitic power consumption as low as possible. The RFCS designed is still undergoing construction to verify these results (Bents, Chang, Garcia, 2005)(Revankar, 2006).

In order to keep the parasitic power consumption low, alternative methods of hydrogen and oxygen gas storage methods must be used due to the large amounts of energy needed to store gases at higher pressures. Developing alternative methods of fuel storage while still being able to supply pressurized fuel to the FC stack should be a main focus for improving RFCS.

Future research should also aim towards validating the current model for the round trip efficiencies of a RFCS stated. Such efficiencies could lead to more promising uses in aerospace, power distribution, and eventual commercial applications.

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Decomposition of Noise Contributions in QDOGFET Single-Photon Detectors

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Abstract: We report on the noise characteristics of a quantum dot, optically gated, field-effect transistor (QDOGFET) that uses self-assembled semiconductor quantum dots embedded in a high-electron-mobility transistor to detect individual photons of light. Paramount to the operation of the device is differentiating weak, photo-induced signals from random fluctuations associated with electrical noise. To date, studies of the noise and the photoresponse of QDOGFETs have only been performed at sample temperatures of 4 K and 77 K. Here, we study noise spectra of QDOGFETS for sample temperatures ranging from 11-77 K. Observed in the noise spectra are Lorentzian-shaped noise features riding on top of the fundamental $1/f$ noise of the device. We find that the Lorentzian noise features exhibit Arrhenius Law behavior.

Introduction

The ability to detect and count individual photons of light is of intense interest given today's growing interest in quantum information technologies. Single-photon detectors that can operate at high detection rates and with high detection efficiency are needed to extend the link lengths and data transmission rates of ultrasecure communication systems based on quantum-key distribution (QKD) [1] as well as in future interplanetary and deep-space communication systems [2-4]. Such detectors are also important components in the areas of medical diagnosis and imaging, light detection and ranging (LIDAR) [5], and astronomy. Furthermore, other applications require detectors that are not only sensitive to single photons but that can also resolve the *number* of incident photons that arrive simultaneously. Photon-number-resolving (PNR) detectors are a key enabling technology for linear optics quantum computing [6], impact the security of quantum communications [7], and are crucial measurement tools for studying the quantum nature of light [8-12].

While detectors based on avalanche gain [13, 14] and low-temperature superconducting materials [15, 16] are drawing a tremendous amount of research interest, we are investigating an entirely different method of detection that makes use of self-assembled semiconductor quantum dots (QDs). In these devices, referred to as QDOGFETs (quantum dot optically gated field-effect transistors), QDs are embedded in a specially designed high-electron-mobility transistor (HEMT). The structure consists of alternating layers of GaAs and AlGaAs with a single layer of InGaAs QDs positioned at the GaAs/AlGaAs interface, as shown in Figure 1. A thin layer of material that is doped with Si (denoted as δ-doping) provides excess electrons to the conduction band (CB) forming a two-dimensional electron gas (2DEG) at the GaAs/AlGaAs interface adjacent to the QDs. The detector is fabricated by depositing ohmic contacts, denoted as the source and drain, on the semiconductor structure; by etching a mesa between the contacts; and by depositing a semitransparent platinum (Pt) Schottky barrier gate across the mesa. The active area of the detector is defined by the gated portion of the mesa, which is typically about 4 μm^2 in size and encompasses about 2000 QDs.

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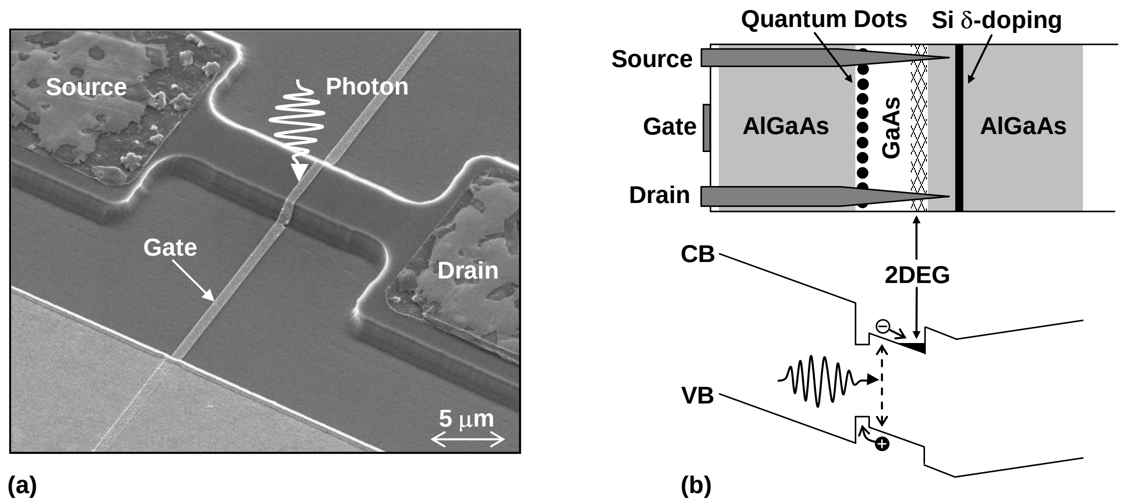

Figure 1. (a) Scanning electron microscope image and (b) schematic diagram of the composition and band structure of the QDOGFET. CB and VB denote the conduction band and valence bands, respectively.

The principles of operation of the QDOGFET are shown in the context of the band diagram of the structure in Figure 1(b). The device is designed to efficiently detect photons absorbed in the GaAs layer separating the 2DEG and the QDs. Key to detecting photons with this structure is that the conductivity of the 2DEG depends strongly on the electric field produced by the gate. When a photon is absorbed in the GaAs absorption layer, it excites an electron from the valence band (VB) to the CB leaving behind an empty state, or hole. With a reverse bias applied to the gate, the hole is swept by the internal electric field toward the QD layer, where it is trapped by a dot, while the excited electron is swept in the opposite direction, where it joins the 2DEG. Confined to a QD, the positively charged hole screens the internal field produced by the gate contact, subsequently changing the amount of current flowing in the 2DEG, as dictated by the transconductance, g_m, of the transistor. This change persists for as long as the hole is trapped in the dot. In the small-signal limit, the increase in the channel current (I_{ds}) caused by the trapping of N photogenerated holes in the QD layer is given by

$$\Delta I_{ds} = g_m \frac{eW}{\varepsilon' A} N , \qquad [1]$$

where e is the elementary charge, W is the distance between the Pt gate and the QD layer, ε' is the electric permittivity, and A is the active area. Over time, the charging of the QDs caused by the capture of even a single photo-generated hole results in a large change in the cumulative charge transferred in the 2DEG. The *photoconductive gain* [17] associated with this process provides the detector with single-photon sensitivity. Moreover, because ΔI_{ds} is proportional to N, the channel response provides a direct measure of the number of detected photons.

Previously, we demonstrated that the QDOGFET can discriminate between the detection of 0, 1, 2, and 3 photons with 83% fidelity [18]; however, these studies represent only the first steps to developing practical PNR detectors and address only part of the potential functionality of these nanostructures. For instance, these initial measurements were performed at an operating temperature of 4 K. For practical applications, much higher operating temperatures desired.

Paramount to detecting individual photons of light is differentiating weak, photo-induced signals from random fluctuations associated with electrical noise (*i.e.* the random fluctuation in the transistor current). In recent work [19], we investigate the spectral content of the noise from cooled QDOGFETs at two fixed temperatures (4 K and 77 K) and presented a mathematical framework for single-photon detectors based on photoconductive gain. In this work, we showed that the performance of such detectors can be determined through purely electrical measurements of their noise spectra.

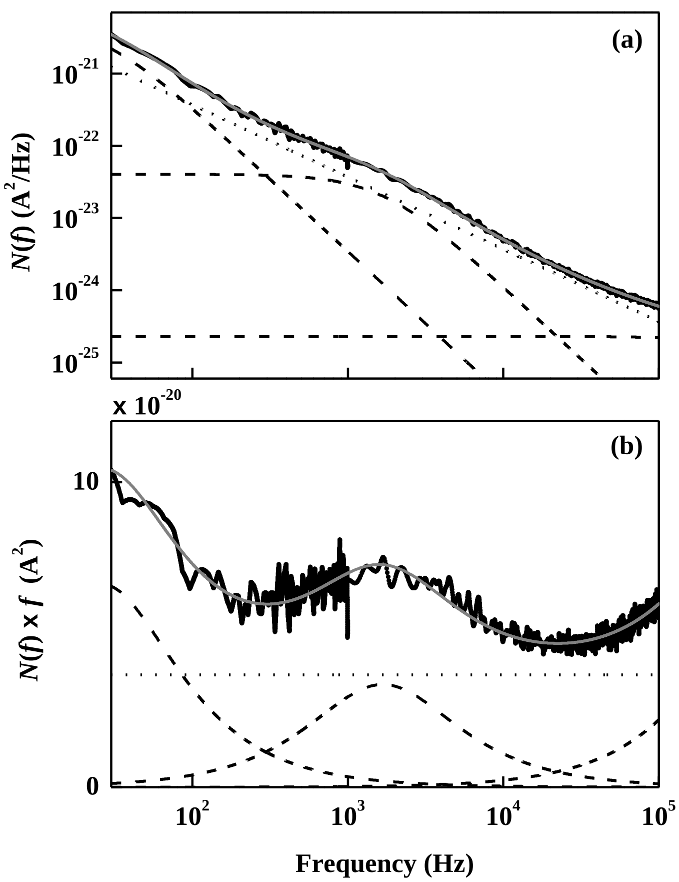

Figure 2. (a) Power spectral density, $N(f)$, of the noise in the QDOGFET current for a sample temperature of 13.5 K and a gate bias of 0 V. (b) $N(f)$ multiplied by the frequency. The solid gray line in each panel is a multiparameter fit to the data based on the functional form shown in Equation [2]. The Lorentzian and $1/f$ contributions are represented as dashed and dotted lines, respectively.

Here, we extend our previous investigations of the noise in QDOGFETs by studying how the noise of these devices varies with temperature. The noise in GaAs/AlGaAs two-dimensional electron systems has been studied extensively [e.g. Ref 20 and references therein] due to its impact on the performance of many semiconductor devices, such as HEMTs and Hall-bar structures. In these previous reports, noise spectra characterized by Lorentzian-shaped noise superimposed on a $1/f$ background has been reported and various noise mechanisms discussed. The features observed in the noise spectra have been shown to depend strongly on the dimensions of the structure, the sample temperature, and applied gate fields. In regard to QDOGFET detectors, it is important to identify the noise mechanism in order to engineer better performing devices and to determine the performance trade-offs involved with operating the devices at temperatures higher than 4 K. In this work, we present noise spectra of QDOGFETS for sample temperatures ranging from 11-77 K. We show the existence of Lorentzian noise features riding on top of the fundamental 1/*f* noise of the transistor current. We create Arrhenius plots for the Lorentzian features and show that they are characteristic of thermally activated noise sources.

Experimental Results

We performed our noise studies with the QDOGFET connected to biasing and amplification circuitry appropriate for operating it as a single-photon detector. The device was housed in a liquid helium cryostat on a temperature tunable stage. The output of the QDOGFET was amplified by a two-stage amplifier. The first stage of the amplifier was placed in close proximity to the QDOGFET and was cooled to the same temperature as the sample. The second amplifier stage was positioned outside the cryostat and was held at room temperature. Under dark conditions, the amplified signal was measured using a real-time spectrum analyzer. At each sample temperature, the amplification and noise spectra of the amplifiers were obtained. This allowed us to subtract the amplifier noise from the total noise present in the system, revealing the noise spectrum characteristic of the biased QDOGFET.

Figure 2(a) shows a sample of our measurements, where the power spectral density, *N*(*f*), of the noise exhibited by the QDOGFET channel current is shown for a sample temperature of 13.5 K with an external gate bias of 0 V. Also show in the figure, is the result of a multiparameter fit to the data, where the functional form of the noise spectral density is given by

$$N(f) = \frac{A}{f} + \frac{B}{\left(f/f_B \right)^2 + 1} + \frac{C}{\left(f/f_C \right)^2 + 1} + \frac{D}{\left(f/f_D \right)^2 + 1}. \qquad [2]$$

Here, the first term represents the 1/*f* noise, while the three subsequent terms represent Lorentzian contributions with independent amplitudes and characteristic frequencies (f_i), where $i=B$, C, or D. The individual contributions of these four terms are represented by dotted and dashed lines in Figure 2. The data exhibits, to a high degree, a 1/*f* dependence; however, some subtle “knees” in the data characteristic of Lorentzian contributions are present. These Lorentzian features are more easily viewed in Figure 2(b), where *N*(*f*) is multiplied by the frequency. In this representation, the 1/*f* contribution results in a constant offset while each Lorentzian component produces a peak in the data, centered at its characteristic frequency. Portions of three Lorentzian features are observed in the data – one at a very low frequency, one at ~1.7 kHz, and one a frequency higher than 100 kHz.

In Figure 3, noise spectra are shown for a series of sample temperatures. In the figure, black and gray arrows are used to highlight the temperature dependence of two independent Lorentzian peaks. Notice that these features systematically move to higher frequencies with increasing temperature. This tendency is consistent with the behavior of thermally activated noise mechanisms.

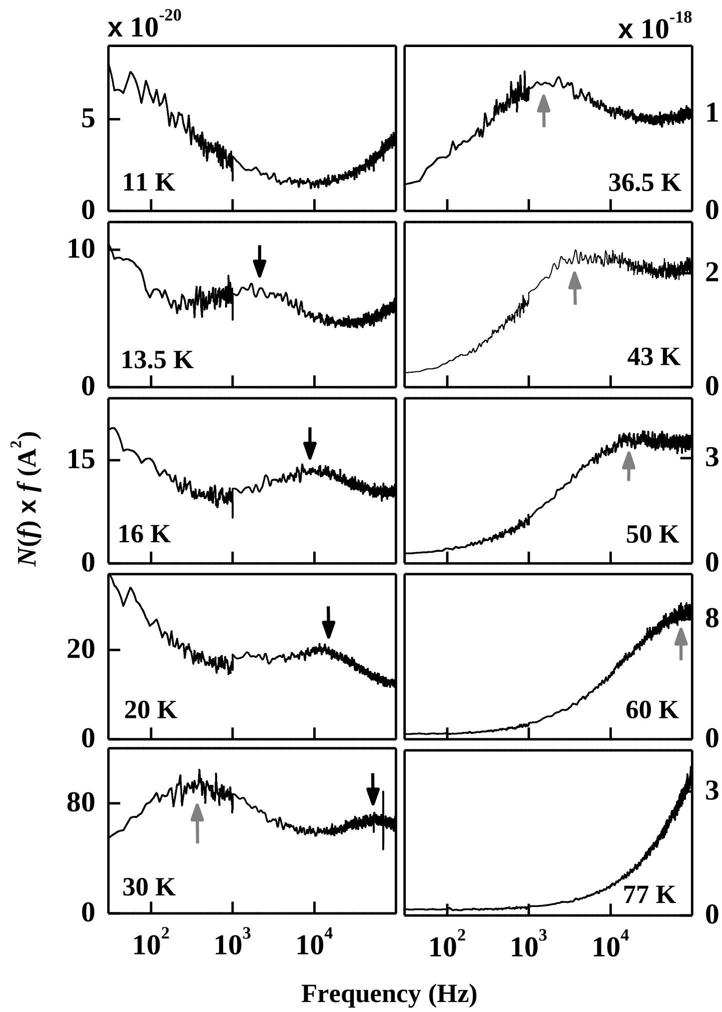

Figure 3. Noise spectra at selected temperatures for a gate bias of 0 V. Black and gray arrows highlight the temperature dependence of two independent Lorentzan noise features.

In the simple case that the noise is caused by thermally activated switching between two levels, the characteristic frequency follows the well-known Arrhenius Law

$$f_i = f_o(T)\exp\left(-E_a / k_B T\right), \qquad [3]$$

where, T is temperature, E_a is the activation energy, $f_o(T)$ is the attempt frequency, and k_B is the Boltzmann constant. How f_o varies with temperature depends on the dynamics of the particular noise source. In the literature, models have been proposed that result in temperature dependences that include, $f_o{\sim}T^2$ [21, 22] and $f_o{\sim}T^{1/2}$ [23]. More simplified models assume that f_o is independent of temperature [20, 24]. Following the models presented in Refs [21, 22], Figure 4 shows Arrhenius plots of the two Lorentzian features highlighted by arrows in Figure 3. Here, the gray and black data points correspond to the peaks indicated by the gray and black arrows, respectively. Consistent with the simple Arrhenius Law expression, $f_i \times T^{-2}$ exhibits a linear dependence on $1/T$ for each of the two systems when plotted on a logarithmic scale. The activation energy for each system can subsequently be determined from the slope of its linear character. The gray data are characteristic of an activation energy of E_a = 14±1 meV, while E_a = 4±1 meV is obtained for the black data.

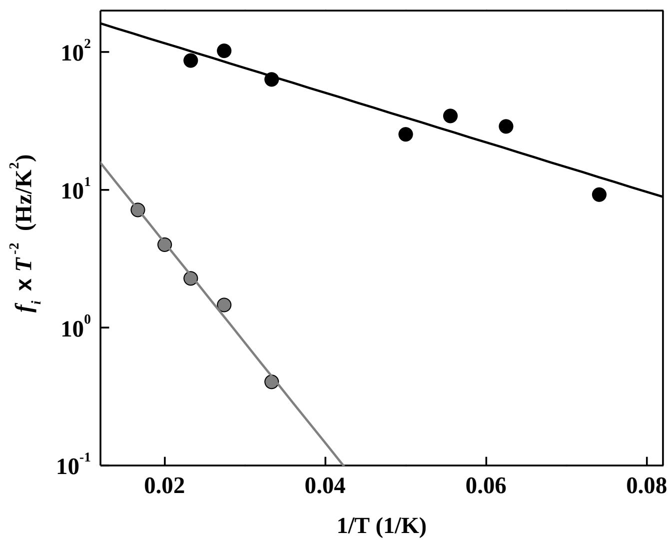

Figure 4. Arrhenius plot of Lorentzian noise features. The gray and black data points correspond to the features highlighted in Figure 3 by gray and black arrows, respectively. The lines are the results of fits to the data using Equation [3] where $f_o \sim T^2$.

Conclusions

We have performed a systematic study of the noise exhibited by QDOGETs as a function of operating temperature. In this work, we discussed the properties of noise spectra for sample temperatures ranging from 11-77 K. The data exhibit Lorentzian noise features riding on top of the fundamental 1/*f* noise. We created Arrhenius plots for the Lorentzian features and showed that they behave in accordance with Arrhenius Law for thermally activated noise sources.

The results of this work will be used to deduce the operational limitations of QDOGFET detectors and to engineer better performing devices. Previous studies of two-dimensional-electron systems point to a variety of different sources that can contribute noise. Further analysis of the data presented in this work will help ascertain which mechanisms contribute for our specific device makeup and geometry. Persistent photoconductivity in HEMTs has been observed at temperatures as high as 150 K [25]. Consequently, it should be the noise characteristics that ultimately limit the operating temperature of QDOGFET detectors. Among the top performing PNR detectors are those based on low-temperature superconducting materials [15, 16]. The stringent cooling requirements of these detectors are highly undesirable for practical applications. As a result, this work may demonstrate an advantage of QDOGFETs over competing technologies.

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Solid Rocket Motor Thrust Oscillation with Inhibitors due to Vortex Shedding

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The problem of identifying and attributing vortex shedding to certain causes (inhibitors, propellant cavities, etc) has been a long debated topic in the scientific community. Pressure oscillations within the motor are of increasing concern as it has been discovered that for certain motors the frequency of oscillation is nearing the harmonic frequency of the motor's structure and in some cases the human body. Thrust oscillations can result in guidance and thrust vector control complications and in worst case scenarios these oscillations can result in motor structural failures or severe bodily harm to astronauts. The decision was made to use schlieren photography to view vortex shedding over various inhibitors, through a simulated section of a motor, to develop a relationship between inhibitor size, shape, and placement with pressure oscillations. Although no correlation could be determined, the concept for this experiment lays the groundwork for future research that will help increase the efficiency of the motor, eliminate vortex shedding, and move the aerospace community forward.

I. Introduction

Thrust oscillations have been a source of debate and concern over the last 50 years during the development of solid rocket motors. When these oscillations match the motors inherent oscillation modes the amplitude of these oscillations increases drastically. In the case of the Space Shuttle Reusable Solid Rocket Motor (RSRM) a one psi pressure oscillation results in a 33,000 lbf thrust oscillation which results in large vibration loads on both the shuttle's payload and crew.[1] In the case for the Ares I, thrust oscillations were identified as a major risk to the Ares project and were assigned a four by five on NASA's risk matrix.[2] Several methods have been proposed to prevent the oscillations from affecting the crew and payload; however, most methods attempt to dampen the effects rather than then prevent the occurrence of the oscillations. This experiment set out to determine a correlation between pressure oscillations and the vortices generated by combustion gases flowing over the inhibitors. A thurst trace and frequency plot for a simulated motor are shown in Fig 1a and 1b, respectively.

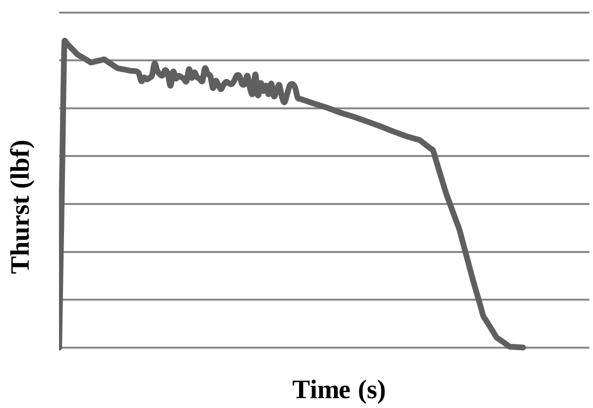

Figure 1a: Thurs vs. Time Plot for Simulated SRM

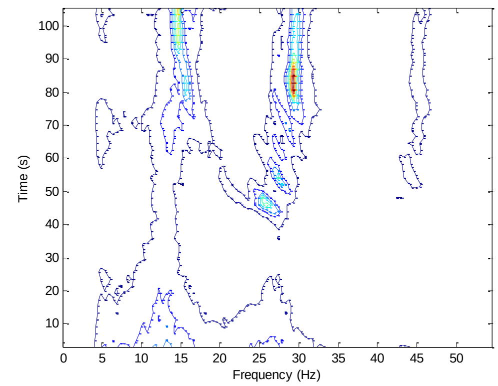

Figure 1b: Frequency vs. Time Plot for Solid Rocket Motor

Multiple studies have been conducted and many models, utilizing both CFD programs as well as other forms of empirical mathematical modeling, have been developed. The Flandro Model was based on the assumption that instead of instability due to combustion, shock waves are the dominant source of nonlinear losses.[3] In a paper written specifically relating to the Solid Rocket Motor Upgrade (SRMU), a motor without inhibitors designed for the Titan IV, the acoustic feedback model was examined by K.W. Dotson et al, trying to explain how a vortex moves through a SRM. The theories presented show that the length of vortices (regardless of their source) are not of constant length (increases with distance from origin) and that nearby vortices can combine to form a larger single vortex. Using PV-Ware (empirical) to solve equations and then running the results through NASTRAN and an FFT, D.R. Mason et al, were able to show that indeed the highest amplitude pressure oscillations occurred on the acoustic modes (1L, 2L, 3L, etc) the first number being their harmonic number. Using CFD, it was shown how the vortices progressed through the ETM-3 and the Shuttle RSRM motors. With the use of weak parameters the simulated data matched field data; however, it contained a significant amount of error. This led to the firm definition of three known sources of vortices; wall layer interaction, inhibitor interaction, and flow over propellant cavities.[4] An example of the vortex shedding phenomena is shown below in Fig. 2.

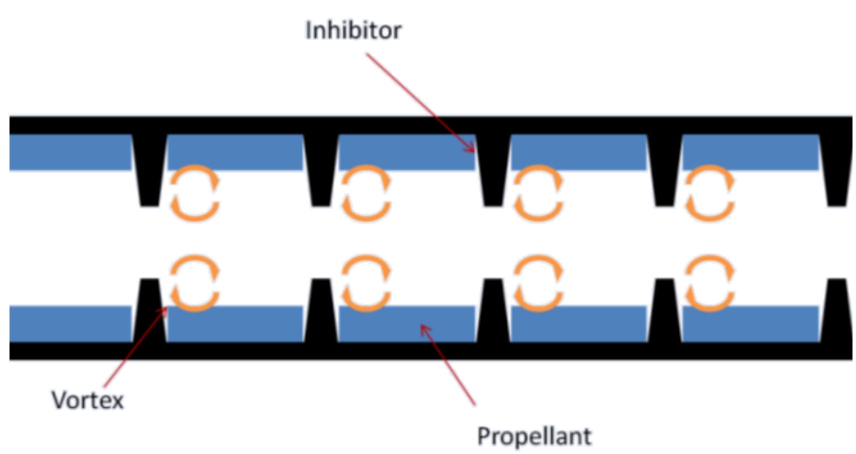

Figure 2: Simulated Vortex Shedding in a Solid Rocket Motor

II. Background

Although schlieren photography has been around since the 17th century, the 19th and 20th centuries brought about its aerospace applications. The applications of schlieren in wind tunnels include visualizing subsonic and supersonic flows, examining turbulent flows over vehicles, and a basis the beginning of computational fluid dynamics. However, schlieren photography is only available in 2-D and it is not in true color. Despite these disadvantages this technology can be utilized to view vortices in a modeled SRM cavity.

Schlieren photography and shadowgrams utilize a phenomenon where light passing through materials of different density, thus different refractive indices, is refracted. The angle of refraction is directly related to the refractive index of the medium. For both setups both mirrors and lenses can be used to obtain results, however as a result of chromatic abrasions resulting from light passing through the glass of a lens, mirrors are often preferred. Despite being closely related, shadowgraphs vary from schlieren in two distinct ways. Shadowgrams are not focused images, but a shadow of the object being observed. Schlieren systems use a series of optics to focus the image to obtain a precise representation of the object of interest. Second, schlieren setups require a knife-edge or filter to cut off refracted light rays. The resulting image from this method is more sensitive than the one obtained from a shadowgram. Shadowgram and schlieren arrangements are shown in Fig. 3 and 4,[5] respectively. In interest of higher sensitivity a schlieren arrangement was chosen for this experiment.

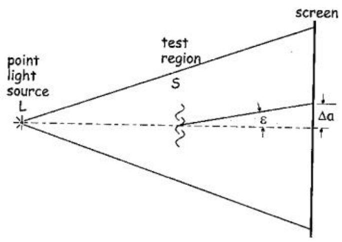

Figure 3: Early Shadowgraph Setup

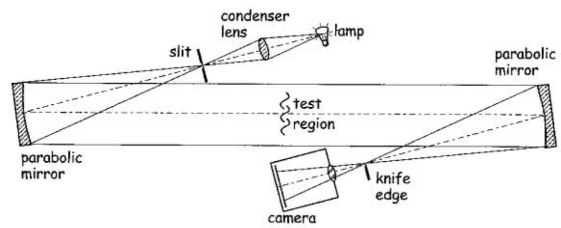

Figure 4: Z-Schlieren Setup with Razor Blade Cutoff

The knife-edge cut off characteristic of schlieren photography is shown in Fig. 4. Light diffracted by the field of interest will not be parallel with the non-diffracted light; therefore, it will not condense to the same point after being reflected by the second mirror. By placing a cut-off at the focal point of the second mirror the diffracted rays will be removed, resulting in a more sensitive image. Typically a razor blade is used as a cutoff, which can either be oriented vertically or horizontally. It was determined that by positioning the blade horizontally a more detailed image was obtainable for our setup. The process by which the knife-edge removes diffracted rays is shown in Fig. 5.

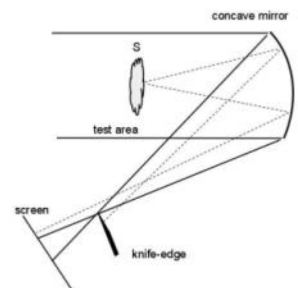

Figure 5: Knife-Edge Cut-Off

III. Methodology

To achieve the objective of this experiment, three milestones were initially identified as:

1) Visualize vortex-shedding resulting from inhibitors using schlieren photography
2) Correlate video of vortex-shedding with pressure frequency traces
3) Determine a relationship between various heights and placement of inhibitors and their affect on vortex formation

The following details the development of several tools necessary to accomplish these milestones.

A. Schlieren Setup

In order to obtain a point source of light, a 12-volt automotive head lamp was used. This type of bulb was selected since it contained a short straight filament which could be approximated as a point source. The bulb was placed inside a metallic electrical box which had a hole drilled in the front. An adjustable diameter iris was placed over this hole which was located directly in front of the bulb. A variable voltage DC power supply was used in attempt to supply a constant current to the lamp. Adjustable optics stands and towers were used to create a permanent set up and were used to adjust the positioning of the optics and light source to obtain a precise image. Fig. 6 displays the experimental set up used.

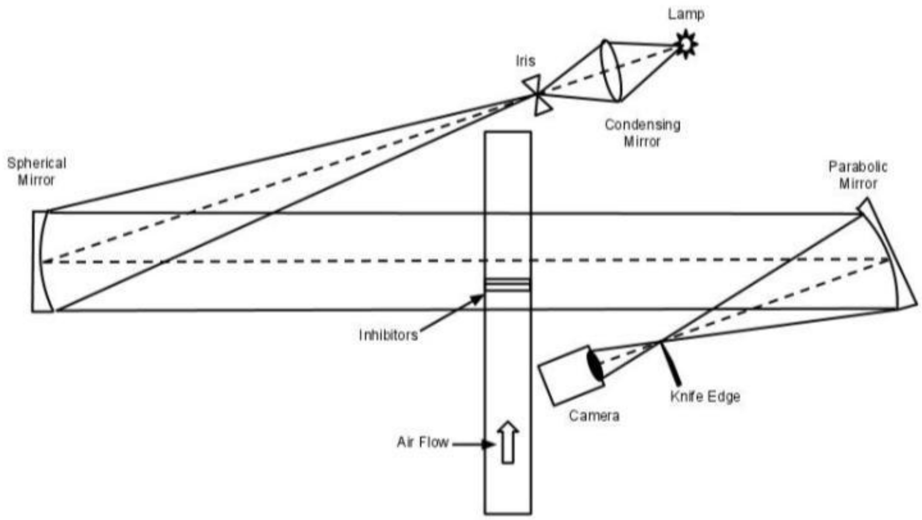

Figure 6: Experimental Setup Diagram

Two different types of mirrors were used (one spherical, one parabolic) due to spatial constraints of the optics table. Parabolic mirrors are generally preferred for use in schlieren photography because they are ideal for focusing parallel light rays to an exact point and creating parallel rays from a point source. However, since the focal ratio for the spherical mirror was greater than 10, the errors resulting from this mirror are negligible. The focal lengths of the spherical and parabolic mirrors used are 50-in and 18-in, respectively. The spherical mirror was incorporated for reflecting the light source first since the large focal point collimates the light better due to its increased length. The parabolic mirror was added so that its small focal point allowed it to receive the light and bring it to a point so the camera and razor could fit between it and the test chamber. This allowed the entire test arrangement to fit within the limits of the optics table (8X4 feet). A picture displaying this setup is shown below in Fig. 7:

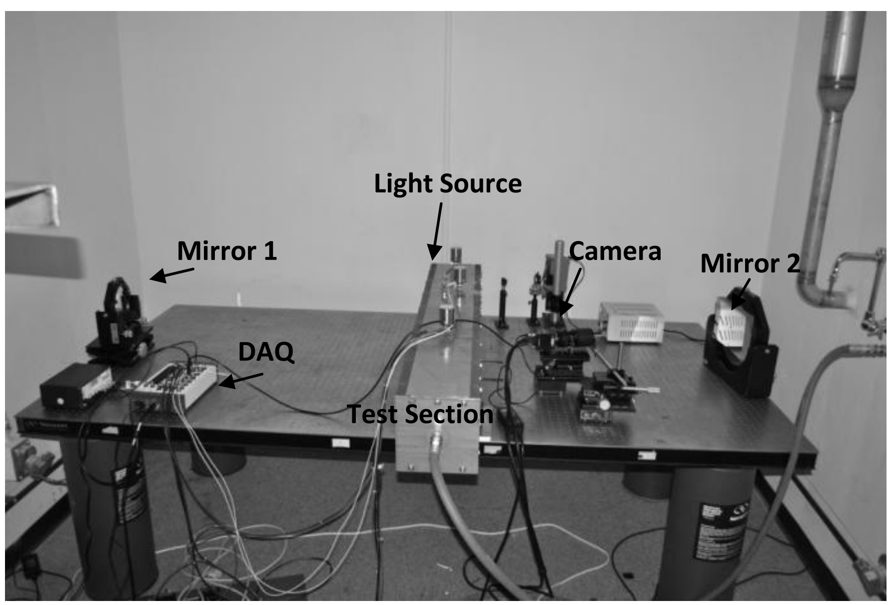

Figure 7: Experimental Setup

The z-type arrangement chosen for this experiment results in off-axis aberrations called coma and astigmatism. Coma occurs when the point source of light is off axis of the mirror. The light source is intentionally off axis of the mirror such hat it will not be in the field of interest. However, the resulting light rays refracted by the mirror will not be perfectly parallel. Likewise when light contacts the second mirror the rays will not be perfectly focused to a point, resulting from the second mirror being positioned to focus light off axis as well. An astigmatism results since the distance from the point source to the mirror is not constant for any point on the mirrors surface. This aberration can be minimized by using selecting large f-value mirrors and minimizing the angle of offset angle. However, the extent that the angle of offset could be reduced was limited by the position of the test chamber on the table. As a result the angle of offset was larger than desired. For future experiments the alignment of the optics with respect to the test chamber should be taken into greater consideration.

B. Test Chamber

To simulate on a small scale the inner workings of a SRM, a rectangular test section was designed. The test section consisted of a top and bottom constructed of aluminum, and two clear acrylic sides. Aluminum inhibitors were placed inside the test section to act as flow-tripping devices. A nozzle was simulated using a fixed steel plate on the aft end shown in Fig. 8.a. Compressed air at 125 psig is flown through the inlet of the SRM mock assembly where the schlieren photographs are taken. The cold flow enters in a custom inlet (shown in Fig. 8) which was designed to spread the flow the full cross sectional area of the test apparatus such that it would be fully expanded before contacting the mock inhibitor. To diffuse the inflowing air a porous polyethylene tube was placed over inlet hole. The complete test chamber is shown in Fig. 9.

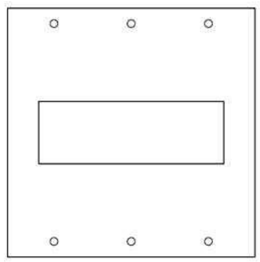

Figure 8.a: Test Section Nozzle

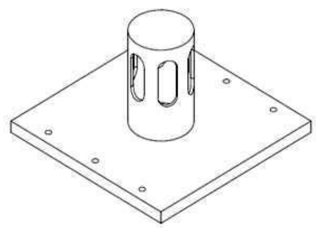

Figure 8.b: Cold Flow Inlet

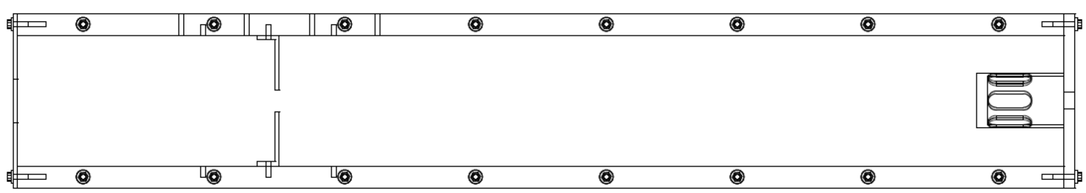

Figure 9: Test Section

C. Pressure Measurements

To obtain pressure data, four pressure transducers and two dynamic pressure transducers, or microphones, were utilized. Pressure transducers were placed half-way between the inlet and the inhibitor, before and after the top inhibitor, and before the nozzle. The microphones were placed before and after the inhibitor located on the top of the chamber.

The LABVIEW code used to record and write pressure data was modified from an existing block diagram generated for a similar cold flow experiment. Modifications were made to the code so that a trigger would be sent to the high speed camera so the recording of the camera and pressure sensors would begin simultaneously. Data was initially collected at a frequency of 1,000 Hz, allowing frequencies to be calculated up to 500 Hz using FFTs. MATLAB was utilized for data analysis of the dynamic pressure sensors. The code written was designed to perform two forms of analysis. The first form was a 2-D frequency plot across the entire time range. This plot gave an overview of all of the frequencies present in the sample. The second analysis was a time-based one-sided FFT designed to show any variations in frequency with respect to time. To perform this analysis, the sample data was separated into 30 equal time divisions. An FFT was performed on each of these divisions and the resulting frequencies were correlated with the average time for the sample. These calculations are presented as both a 3D waterfall and a contour plot. These graphical methods were chosen to allow for an easy visual analysis to determine any change in the frequency spectrum over a given time span.

IV. Results

A. Schlieren Results

This experiment proved that the airflow across the inhibitor can be illustrated by the schlieren apparatus. The vortex shedding across the inhibitor was not clearly visible primarily due to the low pressure of the test chamber, which created small, diffused vortices. These vortices had a small curve in their movement, but did not have a dedicated spiral in their path as expected. The turbulence was displayed by a MATLAB program, which removed the background image, leaving only the moving air in the visual frame. Regardless, the schlieren photography was sensitive enough to see the heat coming off a hand, and was able to produce several clear images of heat from a match and soldering iron.

Additionally, the 125 psig hose allowed direct image capture of supersonic flow containing mach diamonds. This proved that the schlieren apparatus itself was not primarily to blame for the difficulty in visualizing vortex shedding but rather the test chamber. The reasoning for this statement is that several different tests were run using the apparatus and all clearly illustrated the density change of the air. A clear image of a soldering iron's heat was seen through the glass and so the image was not distorted enough through the acrylic to be a concern. Thus, the only remaining factor was the apparatus in which its airflow was not sufficient to create a stable vortex generation. Photographs taken to demonstrate the functionality of the schlieren system are shown in Fig. 10a and 10b:

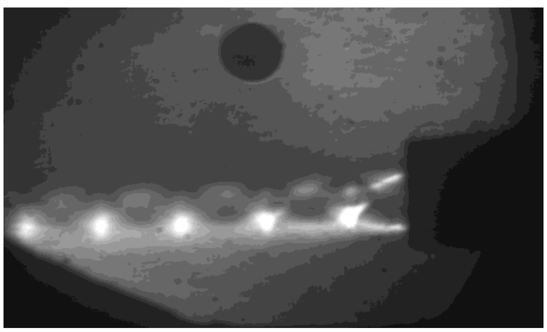

Figure 10a: Air Jet From Low Pressure Inlet

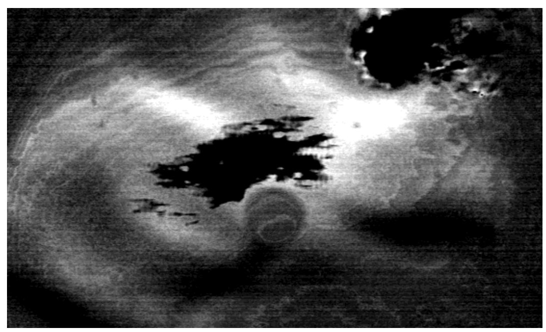

Figure 10b: Vortex Shedding

B. Pressure Results

The acquisition of pressure data was faced with several technical problems throughout the duration of cold flow experimentation. Initially, the signal conditioner which was connected between the microphones and the DAQ system was one source of complication. It was noticed that the voltage being received from the generator was exponentially declining after first being turned on. Through referencing technical support it was determined that this decline was a result of the capacitance in the signal conditioner – microphone circuit. After experimentally determining the time constant (20 seconds), it was decided to allow five time constants, to pass to allow the signal to reach steady state, prior to the acquisition of data.

After processing the first batch of pressure data though the MATLAB script it was discovered that all samples contained white noise across the entire frequency spectrum with a spike at approximately 0 Hz and 340 Hz. These results for one sample are shown in Fig. 11a and 11b:

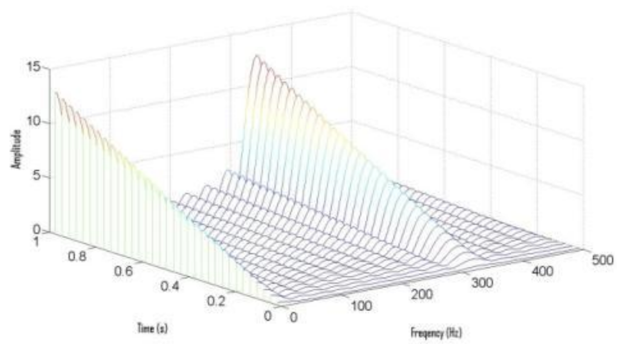

Figure 11a: Waterfall Plot of Frequency Spectrum

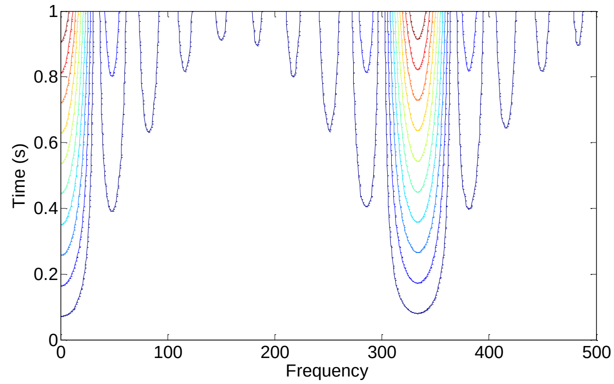

Figure 11b: Contour Frequency Plot

Based on expected results, an error in the analysis was immediately suspected. An attempt was made to determine if the error was a result of the algorithm used by MATLAB in the FFT calculations. Several sample sets of data were generated which incorporated various frequencies sampled at 1,000 Hz. These sets were analyzed with the software and yielded expected results. Based on these results the error was identified as originating prior to the FFT analysis. Additional samples of data were collected at a frequency of 10,000 Hz, which likewise yielded similar results to the first sample set. Finally, to determine the whether the microphones were functioning properly a speaker was placed inside the test chamber which produced a tone at a constant frequency. The resulting FFT analysis showed a spike at that frequency, proving that the microphones were operating properly.

Based on the experiments proving the proper operation of the microphones, DAQ system, and MATLAB code, it was determined that the lack of a distinguished frequency was a result of the test chamber not oscillating at any set frequency.

V. Conclusion

The concept of using Schlieren photography is a viable option to visualize vortex shedding off of inhibitors. If more time were available, further progress could have been made to find a direct correlation between vortex generation rates and pressure oscillations. With this correlation developed, research in different inhibitor shapes, sizes, and locations could be tested to discover their impact on vortex shedding which could potentially reduce these pressure oscillations drastically. A few improvements to the design could include:

A. Test Chamber Improvements

As testing progressed and air flow was visualized through the test apparatus, several faults in the experimental design were discovered. As flow tripped over the inhibitor, it was apparent that the air was not completely laminar when reaching the inhibitors. It was determined that a narrower, longer test chamber would have allowed the air to fully expand, and serve the needs of the experiment better. This would lead to a complete redesign of the test apparatus, but not the schlieren photography arrangement. The problems with the flow were attributed to several other factors that would need to be addressed in a redesign. In a wind tunnel, flow is straightened twice, once horizontally (accomplished using the porous polyurethane wall material) and longitudinally usually with some type of honeycomb structure or screen. These types of structures would establish laminar flow within the test chamber. The same material from the inlet could be used as a screen to help stabilize the flow. To observe the vortices, a higher mass flow is needed. A greater mass flow rate can be achieved either by increasing the inlet pressure, or by decreasing the cross sectional area of the test chamber. These are all ideas that should be adequately addressed should experiments of this kind continue.

B. Schlieren Improvements

Improvements on the schlieren apparatus would be to incorporate two similarly shaped mirrors (as opposed to the current spherical/parabolic arrangement) so that the light reflected is not bent unusually. To accomplish this, larger mirrors with greater focal lengths would be desired which would require a larger test facility. This would create improved collimation of light resulting in less distortion. It was also observed that the intensity of the point source was oscillating when high frame rates were used. This is a result of the power source used in the experiment not receiving constant current. A battery used as a replacement would allow the current to be constant enough to generate a steady light.

Acknowledgments

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Life Support Systems/Particulate Matter and Lunar Dust Filtration

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An integral part of the life support systems on board the International Space Station and on future space vehicles is the filtration system. It is critical to understand the dynamics of the fluid flow throughout the living and working quarters in order to effectively control the particulate concentration so that humans and equipment can work without the risk of harmful effects. Furthermore, it is beneficial to continue to improve the current filtration systems so that they can become more cost and time efficient. The focus of this internship is on two coupled projects which work toward improving fluid flow models of aerosolized particulates and on developing and improving regenerable filtration systems for use in future long term space missions.

Nomenclature

C_1	=	Particle volumetric concentration inside cabin (mg/m^3)
C_2	=	Particle volumetric concentration after filter (mg/m^3)
	=	Particle flux inside cabin (mg/min)
	=	Particle flux after filter (mg/min)
P_s	=	Standard pressure (101,312 Pa)
Q	=	Volumetric flow rate (m^3/min, cfm)
	=	Source particle generation (mg/min)
η	=	Filter efficiency
φ	=	Permissible exposure limit (mg/m^3)

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Background and Importance of Filtration

The mitigation of Lunar or Martian dust is one of the primary challenges to future manned missions to the Moon or Mars. In spacecraft cabins, mitigation of internally generated dust as well as intrusive space dust from extra-vehicular activities (EVAs) is critical. The systems must be designed to sustain high efficiency without constant maintenance or replacement during the long missions. Cabin dust, particularly Lunar dust, poses several different potential problems. First, Lunar dust can have both short and long-term effects on the crew's health from eye and throat irritation to more serious problems like iron blood poisoning. Secondly, dust can reduce the nominal performance of sensitive equipment and instrumentation. Lunar dust, especially, has a tendency to adhere to many smooth surfaces, and can scratch these surfaces during its removal due to its jagged, silicate-type structure. Additionally, properties of the lunar dust affect the sensitivity and durability of spacecraft equipment by reducing the efficiency and straining the instrumentation. Given these challenges, effective infiltration barriers and particulate removal technologies geared toward the filtration of lunar dust is of the upmost importance.

Particulate filtration will most likely serve as a primary means of removing particles from the circulating air in the cabin for Lunar or Martian surface exploratory missions as well as long-term space missions. Filters will remove both internally generated dust and intruding Lunar or surface dust from the spacecraft. The filtration systems needed to support future missions and maintain an acceptable level of air cleanliness will need to be able to handle the load of Lunar dust particles and provide longer service life while being efficient, robust, and low-maintenance.

Lunar Dust Loading Model

During future manned lunar surface missions lasting more than just a few days, filtration systems are of key importance. To better design and develop suitable filtration systems, it is important to understand dust generation and intrusion models. Often dust models predict intrusion and generation rates that cannot be handled by current filtration methods. New models have been developed which consider both steady state and transient particle generation within a vehicle cabin. These theoretical models are further supported by computer models of the fluid flow and particle movement within the simulated cabin.[1] This project involves developing these CFD models.

Steady State Models. In a closed cabin environment, such as on the International Space Station (ISS), a level of dust is generated internally, and needs to be filtered from the air. Thus, a model is created to simulate the dust generation and mitigation through fluid flow analysis. For the models, the dust, either internally generated or from intrusion, is assumed to be from a single point source within the cabin, from which particles are rapidly circulated and dispersed throughout the entire cabin volume by ventilation flows. Figure 1 shows a schematic of the parameters within a closed cabin.   is the particle

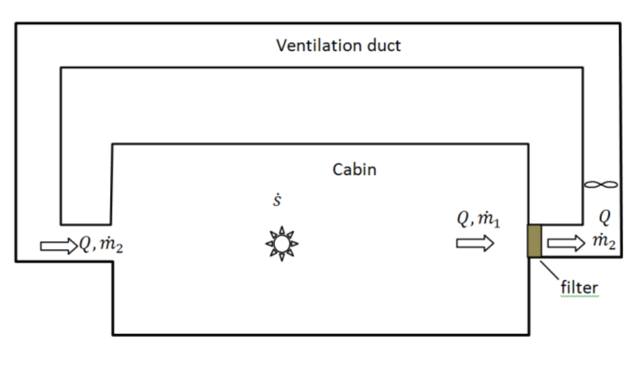


Figure 1. Cabin Model Schematic for Filtration

generation or intrusion rate, is the particle flux inside the cabin, is the particle flux after the filter, and Q is volumetric flow rate of air through the cabin. For each of the steady state models, a 100% efficient filter is assumed, such that the mass flow rate of particles after the filter is zero. This, however, is not a bad assumption considering most standard high-efficiency particulate air (HEPA) filters are efficient in the range of 99.97% in removing particles larger than 0.3 micrometers from the air.

The first steady state model looks at only internally generated dust and it is assumed to be generated at a rate of 0.1227 mg/min per person in the cabin.[2] Secondly, the acceptable level of internally generated dust is an exposure limit of φ=0.2 mg/m^3 based on the ISS requirements of permissible limits of particulate matter. At standard atmospheric pressure, P_s=101,312 Pa, the required air flow rate to meet these standards is determined to be 86.7 scfm.[1] This flow rate was verified using Ansys Fluent and a generic cabin model with a volume comparable to a Lunar lander.

The second steady state model is very similar, though the source of the dust is through intrusion from an airlock. All previous assumptions hold true, while the dust intrusion rate is assumed to be 22.22 mg/min for a two person EVA per day. This intrusion rate assumes that 7% of the dust from a typical EVA becomes airborne and intrudes into the cabin. The other 93% of the dust is assumed to be collected by other means such as shaking and brushing, or through the airlock filtration and vacuuming system. In this case, the necessary flow rate to bring the dust down to an appropriate level is determined to be 8861 scfm.[1] The flow rate was, again, verified using the Fluent software. This flow rate is unrealistic for filter systems to achieve on limited power, and would not be biologically feasible to subject astronauts to. This means that the barrier between the airlock and cabin must be able to retain a larger percentage of dust after an EVA, and not allow it to intrude into the cabin.

Transient Models. Three transient models are developed to consider dust mitigation in the same generic cabin model as in the steady state cases. The first two transient models consider the slow release of extraterrestrial dust into the cabin air while the third assumes the dust is instantaneously released and evenly dispersed throughout the entire cabin. For all three models, it is assumed that there is an even distribution of dust particles ranging from 0.1 micrometers to 10 micrometers.

The first transient model looks at the intrusion of dust over the course of a 24 hour period, distributed evenly throughout the entire cabin. To simulate an even particle distribution throughout the cabin, dust particles are released from 27 discrete points, spread evenly throughout the cabin. The initial particle concentration, C_1, is set to zero. In this model, the filter efficiency is set at η =98%, meaning that , the mass flow rate of particles after the filter, and C_2, the particle concentration downstream, are no longer zero. These escaped particles will re-enter the cabin at the inlet. The variable in this case is the airflow rate which was set at discrete values of 200 cfm, 4200 cfm, 8200 cfm, 12200 cfm, and 16200 cfm. These values span a wide range in order to show the strong correlation between airflow rate and necessary filtration time to reach steady state conditions. Ansys Fluent is used to model the particle concentrations within the cabin over time for the varying flow rates.

A typical flow rate in a filtration system of 200 cfm cannot effectively control the dust concentration levels within the cabin under these circumstances. At that flow rate, the steady state particle concentration is reached after a period of 20 minutes and is a concentration of almost 4 mg/m^3, which is 80 times the maximum allowable exposure limit. Only the very high flow rate of 16200 cfm was able to reach a steady state particle concentration level below the required 0.05 mg/m^3 exposure. The theoretical model predicts that a flow rate of 15695 cfm[1] is necessary to reach a steady state particle concentration level of exactly 0.05 mg/m^3. As in the steady state model; this flow rate is much too high to be considered feasible.

The second transient model considers a constant flow rate of 15695 cfm, the necessary flow rate determined in the first model. This time, the filter efficiency is varied in the model at 80%, 85%, 90%, 95%, and 100%. Ansys Fluent is again used to verify the steady state particle concentration and transient time. Only the 100% efficient filter reaches a steady state value at or below the maximum acceptable exposure limit. Fortunately, a standard HEPA filter has an efficiency of nearly 100%.

The final transient model considers the dissipation of an initial dust intrusion. It is assumed that the entire transient load quickly and uniformly is distributed throughout the cabin. To simulate this assumption in the Fluent model, an even distribution of particles is injected into every cell of the mesh with a total mass of 32,000 mg (for a 2 person EVA in a 20 m^3 cabin.) Reasonable filtration system flow rates, in the hundreds of cubic feet per minute, are used in the simulation to determine the transient time for the particle concentration to reach an acceptable level. Figure 2 shows particle concentrations within the generic cabin over time at a flow rate of 200 cfm.

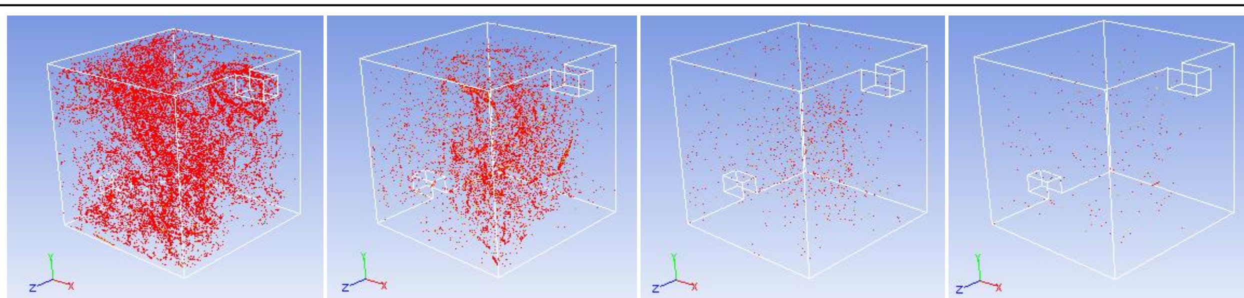
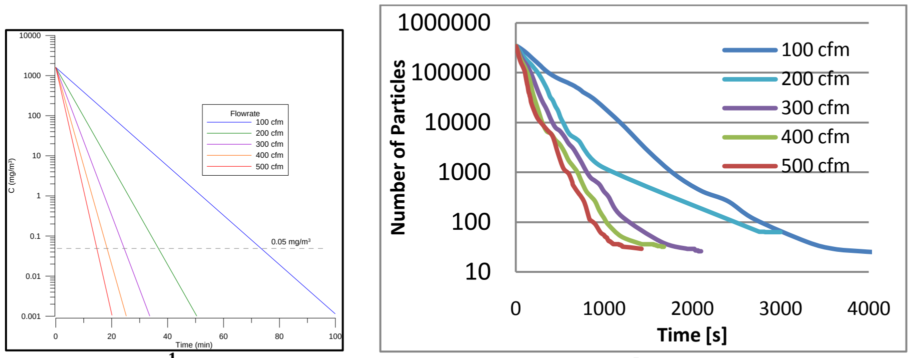


Figure 2. Particle Concentration Over Time at 20 0cfm (t = 60 s, 120 s, 180 s, 240 s)

Filtration times are determined for models at flow rates of 100 cfm, 200 cfm, 300 cfm, 400 cfm, and 500 cfm. These particle dissipation models (Figure 3b) were indirectly compared to the theoretical dissipation model (Figure 3a.) To reach the required particle exposure limits, fewer than 15 particles could remain in the model. Due to the placement of the inlet and outlet ports on the generic model, areas of stagnant air were produced in some corners. A small amount of simulated dust became trapped in these areas, never allowing the cabin to reach the desired concentration levels. This factor produced errors when compared to the theoretical models. The fluid flow analysis, however, was the same up to a concentration of 0.4 mg/m^3.



(a)[1] **(b)**

Figure 3. Theoretical Particle Concentrations for Varying Flow Rates

Regenerable Filtration System for Long Duration Space Missions

In addition to modeling fluid flow rates necessary to properly clean cabin air, it is also important to develop next-generation filtration systems to reduce overall cost. Current filtration systems on the ISS and shuttle are comprised mainly of HEPA filters. The filters, which are replaced regularly, take up some known volume of storage space aboard the craft and require astronaut interaction for replacement. The ultimate goal of this project is to extend the life of the HEPA filters so that fewer replacement filters need to be stowed and less maintenance is required. To reach this goal, the scope of this project is to develop and test a regenerable filtration system.

As part of the Facilitated Access to the Space Environment for Technology (FAST) program, a new filtration system, described below, will be tested on a Zero-G flight. Experiments on the flight will help to determine if the implementation costs (added mass and complexity) of the regenerable cycle are outweighed by the benefits (reduced volume and maintenance) it provides.

Design. The focus of the regenerable filtration system is increasing the life of the primary HEPA filter by reducing the number of particles incident on it. This goal in mind, the regenerable filtration system, diagrammed in Figure 4, was developed to be built and tested. These tests will be conducted under ambient, reduced-gravity, and microgravity conditions. The experiment consists of three primary flow paths including the main test chamber flow path, the particle generation loop, and the regeneration loop.

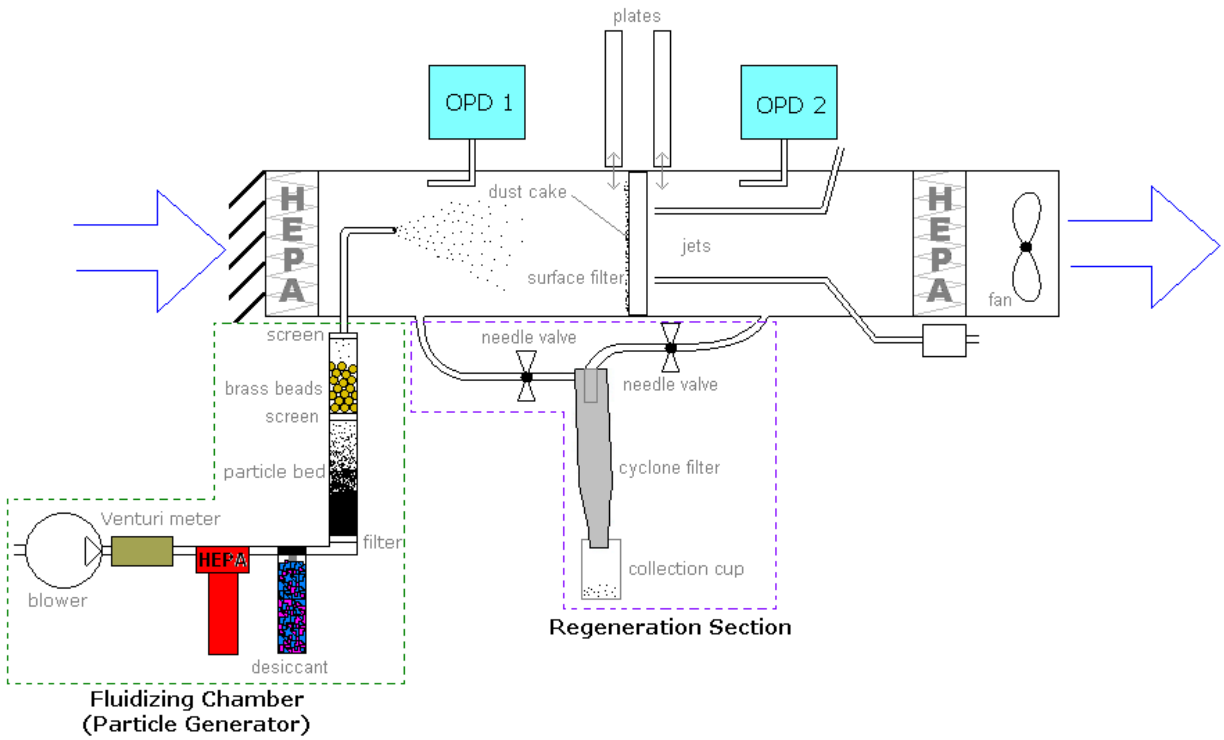


Figure 4. FAST Experiment Schematic

One principal goal of the experiment is to examine the collection efficiency and pressure drops across several components of the regenerable air filtration system, primarily the surface filter and cyclone filter. The second main goal of the experiment is to simply demonstrate the regenerability and the reliability of the system. Because there are only a few minutes of accumulated time in the reduced gravity environment, it will be difficult to measure the direct life extension of the primary HEPA filter through regeneration.

Main Flow Path. The primary test chamber has a 24 cm by 24 cm square cross-section and runs the length of the test rig, 76 cm. Four double bladed fans at one end of the chamber drive the air flow through the chamber. There is a HEPA filter at each end of the chamber to keep intrusive particles from the ambient air from entering the test chamber. The down-stream HEPA filter is considered the primary HEPA, as referenced previously. The purpose of the experiment is to extend the life of this filter, though life extension will not be directly measured.

Also in the primary test chamber, an interchangeable pre-filter is loaded for testing. This pre-filter can initially be clean or pre-loaded with a dust cake. Both types will be used during flight experiments.

Fluidizing Chamber (Particle Generator). A ShopVac blower produces the flow that aerosolizes the particles into the test chamber. The air first passes through a HEPA filter to remove any foreign contaminants. Then is passes through a desiccant dryer before entering the fluidizing stack. Lunar or Martian simulant and common dust are the types of particles that will be aerosolized during the experiment. Beds of these powders will be located near the base of the stack, directly on top of a paper filter, which keeps the particles from flowing backwards into the air dryer. The air flow pushes dust particles through a bed of bronze beads which breaks up agglomerates. The flow passes through a final screen to keep the brass beads from entering the test chamber, and provides a steady stream of dust to the test chamber.

Regeneration Section. The ShopVac blower is used in the back-flow loop to break up the dust-cake which is formed on the pre-filter. The flow is pushed through jets on the downstream side. Plates block the airflow through the main test chamber, and two valves are opened to allow airflow to pass through the cyclonic filter, allowing the dust to be collected in the collection bin. The purpose of using a pre-filter in the main flow loop, as opposed to using only the cyclonic separator is a matter of efficiency. The pre-filter is better suited to remove the small particles during normal filtration processes, while the cyclonic filter easily removes particle agglomerates from the broken up dust cake. Additionally, and perhaps more importantly, the pre-filter produces a lower pressure drop than the cyclone filter. The cyclone separation process is discussed in more detail in the following section.

Cyclone Filter Modeling. As discussed, a cyclone filter is used in the regeneration loop to filter out the particles released from the dust cake on the pre-filter. A cyclonic filter, or separator, uses cyclonic action to separate dust particles from a gas stream. The dirty gas stream enters the separator at an angle and rotates around the chamber. The centrifugal force created by the circular flow pushes the particles toward the wall of the cyclone. After striking the wall, the particles fall into a collection bin below. The clean air escapes through the top of the chamber. A diagram of this process is shown in Figure 5. In zero-gravity conditions, the inertia is capable of sending the particles into the collection bin; however, another particle retention apparatus may be necessary to keep the particles from bouncing out of the collection cup.

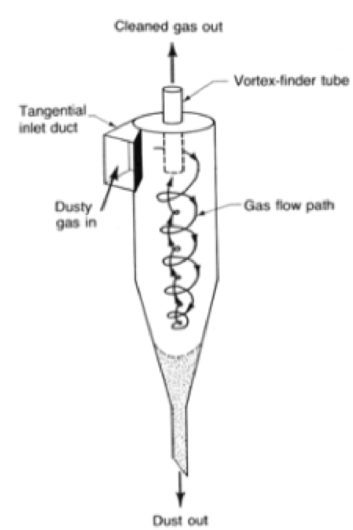


Figure 5. Cyclone Filter Schematic

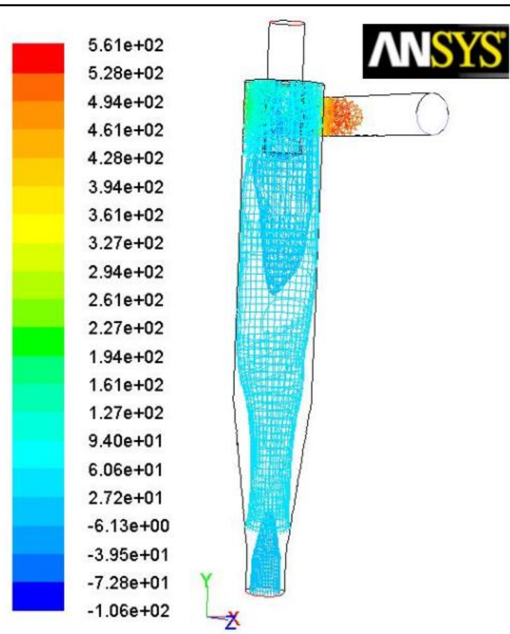


Figure 6. Pressure Gradient in Cyclone Filter

Modeling of the cyclonic filter was important for two reasons. First, the model was used to determine the predicted pressure drop across the cyclonic separator. The four double-bladed fans from the main test chamber will be driving the air flow across the cyclone, so it is critical to confirm that they can handle the pressure drop. The modeled pressure gradient within the cyclone filter is shown in Figure 6 on the following page.

Secondly, this type of filter has not yet been used in zero-gravity environments. The model predicted that the particle inertia alone is enough to drive the particles into the dust collection bin, as described above, and gravity is not necessary for the separator to function. This prediction will be demonstrated and verified during the test flight.

Fabrication. Once specific fluid conditioning components were selected for the experiment, a test rig needed to be built for the flight, allowing time for systems to be tested prior to flight day. Figure 7 shows a CAD model of the primary sections of the proposed test rig, which fits within the flight size restrictions.[3] The main frame for the test rig is made from 1.5 inch 80/20 aluminum extrusions. Secondary frame components are constructed using 1 inch 80/20 aluminum extrusions.

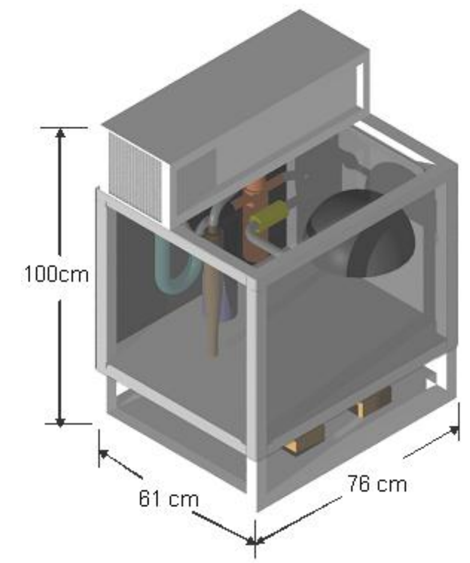


Figure 7. CAD Model of Test Rig

The particle generation loop, as mentioned before, consists of a ShopVac blower, a Venturi flow meter, a HEPA cartridge filter, a desiccant air dryer, and the fluidizing stack constructed from vacuum parts. Within the fluidizing stack, there is one paper filter, two fine screens, dust or simulant, and bronze beads. The regeneration cycle consists of the same ShopVac blower, multiple reverse flow jets, and a cyclone particle separator. The main test chamber includes two HEPA filter, four double-bladed fans, a pre-filter, and two sliding plates.

In addition to the components described above, instrumentation will also be added to the test rig to collect data. Pressure and temperature transducers will be integrated into the main test chamber. Particle counters will also be part of the instrumentation to measure particle concentration up and down stream of the pre-filter and cyclone filter stages. Additionally, a high speed video camera will focus on capturing the dynamics of the dust cake break-up.

Testing. Many of the subsystems can, and have been, tested prior to being installed on the final test rig. The first unit built and tested was the particle generator. The series was assembled on a temporary test unit, and a Lunar simulant, JSC1a, was put into the particle generation stack. On start-up, there was a visible surge of particles out of the nozzle. The particle spray was viewed by using a low-power laser to scatter light in an otherwise dark room. A video camera was used to capture the process. After a few seconds, the number of particulates in the air dropped significantly. The theory as to why this surge occurs is the fact that the initial pulse of air creates somewhat of a free-flow air path through the bronze beads for a few seconds, after which this free-flow path collapses and the particle surge stops. To reduce the chance of this occurring, the amount of bronze beads in the particle generation stack was doubled in hopes of creating a layer so thick and heavy, that the initial surge of air could not create a resistance free path through the bronze beads. The initial dust surge problem has not occurred again, and steady flows of dust particles are viewed.

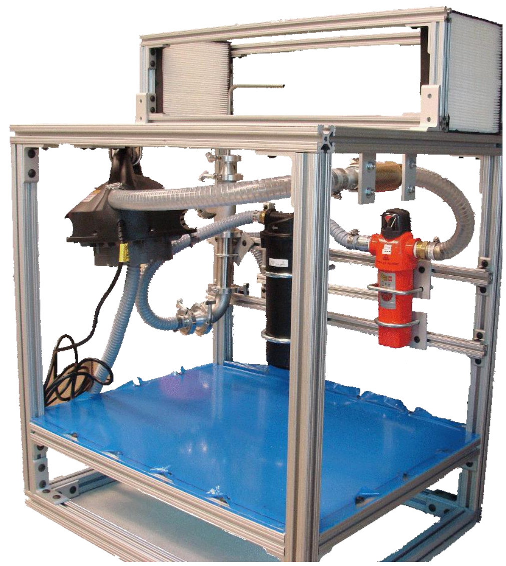


Figure 8. Test Rig

The second partial system built and tested is that of the main flow test chamber. A duct was constructed from clear acrylic sheets. At one end of the chamber, the four double-bladed fans were installed so that they could pull the air through the chamber to meet experimental needs. Preliminary tests show that the fans were able to produce enough flow through the chamber. Additional tests will be done using a second set of fans that are slightly smaller.

The third system that will have to be built and tested prior to installation is the back-flow jets. In order to break up the dust-cake on the pre-filter, sufficient air velocity from the jets is required. Valves in the overall system will allow flow from the ShopVac through the particle generation loop to be switched to pass through the back-flow jets. The tube diameter of the jet pipes must be reduced significantly from the 1 inch inlet hose in order to increase the flow velocity leaving the jets, and reduce the down-stream volume consumed by the intruding jets.

After these tests are completed, the entire test rig will be assembled and instrumentation added. The construction of the rig to date is shown in Figure 8. Before the rig is shipped to the flight location, the entire system will be tested to ensure everything is ready for flight day.

Test Flight. The experimental test flight will occur at the end of September this year (2010). The flight team, consisting of four members, will fly approximately 30 parabolas each day for four days aboard a Zero G aircraft. The aircraft is capable of performing parabolas that simulate zero-g, lunar-g, and Martian gravity levels. The experiments will be run during these reduced gravity situations. The time in between the reduced-gravity time periods will be used to switch out pre-filters, upload data, adjust flow rate, and take other various measurements.

Conclusion

Though dust is not often considered a critical issue, it can in fact play a major role in the successes (or failures) of both short and long term space missions. For this reason, dust mitigation and control within habitation modules is crucial. The instrumentation, the equipment, and the crew depend heavily on the proper control of dust, which comes from two sources: internally generated and intrusions from external activities. To maintain appropriate and safe air conditions, air filtration systems are necessary.

To better predict the necessary flow rates, filtration times, and required filter efficiencies, it is beneficial to create a simple CFD model of a cabin volume and vary the particle parameters such as particle intrusion rates, particle sizes, intrusion sources and location, etc. These models can later be updated to reflect the actual filtration system, cabin size, and cabin geometry to determine the filtration time necessary to reach acceptable contamination levels.

Secondly, it is also beneficial to create new-generation filtration systems that require less overall volume and human interaction than traditional systems. One such regenerable system uses a back-flow cleaning method for a pre-filter in conjunction with a cyclone separator. This system was designed, built, and will be tested in Lunar environments to determine pressure drop requirements and demonstrate a level of reliability. It is likely that this type of a system will be included in future filtration systems for long term space flight.

Acknowledgments

I'd first like to thank my principal investigator Dr. Juan Agui for his support and guidance during my internship as well as mentor Dr. Jeff Mackey for all of his help. I would like to thank NASA and NASA Glenn Research Center for this amazing opportunity. I would also like to thank the Wisconsin Space Grant Consortium (WSGC) for their financial support of this internship. Finally, I'd like to thank those who made this experience possible including: Ron Turba, Dr. M. David Kankam, Bernice Beznoska, Dr. Vince Prantil, Paul Michael, and my fellow Glenn Academy interns.

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20th Annual Conference
Part Eight

Chemistry

Space and Earth Carbon Research*

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Introduction

In the past this research award focused on Carbon-Based Astronaut Advanced Life Support concepts that included extremophile plant research that would shape the moon and Mars in support of colonization. Our pyrogenic carbon (C_{pyr}) is made by high-temperature reduced oxygenated wood biomass. Experimental C_{pyr} is filtered to <9mm by fraction (C_{pyr9}). To ensure consistent experimental carbon data C_{pyr9} is distributed to Space and Earth Carbon Research Environmental Team members (www.secretorg@gmx.com). Other research organizations can order C_{pyr9} for $100/gallon. C_{pyr9} is currently used in extremophile plant research at El Paso Community College, high-altitude crop research in Divide, Colorado, and toxic filtration experiments in Green Bay, Wisconsin. Our team has expanded to citrus research at the University Central Florida, in Orlando and grassland carbon sequestration at Sinte Gleska University, Rosebud Sioux Indian Reservation, Mission, South Dakota. Future research is planned for carbon-filtering oil and gas hydraulic fracturing (fracking) fluids and gases.

C_{pyr} is the main ingredient of Amazon Black Earth (ABE) an ancient sustainable agricultural method. In the literature ABE is well known yet is not understood. *ABE is independent of climate and soil type;* it is this tenet for which carbon-based extra terrestrial research was first started; meaning that ABE could be created on the moon and Mars thus creating sustainable agriculture on another planetary body. Our research suggests that C_{pyr} be amended to extra terrestrial in situ regolith media to grow sustainable crops in support of colonization regardless of conditions.

Carbon is one of the most important extra terrestrial elements because carbon forms four bonds and the carbon-hydrogen bond is considered the backbone of organic chemistry and life. The unique qualities of carbon increase our research capabilities to other astronaut advanced life support ideologies. Herein the rest of this paper focuses on alternative space and earth carbon research.

Pyrogenic Carbon Filter

There is concern that extra terrestrial colonization such as moon mining would result in, in situ pollution such as hydraulic fluid and oil spills; carbon chemical adsorption can filter pollutants. Melted lunar ice will need to be filtered before distillation for human consumption. Herein, C_{pyr} is a *tuned* activated carbon filter that could be used for many colonization purposes such as radiation hot cell filtration to minimize radioactive contamination, biological filtration to minimize bacterial exposure and transmission, and purifying deadly ubiquitous nano-phase iron lunar dust particles to keep astronauts safe.

Carbon Filter History. The British SBR gas mask was first used in WWI and incorporated activated carbon and alkaline perm agnate filtration (Berens, 1942). Today carbon filters are readily used as point source water and air purifiers. As mentioned, carbon can be activated in different ways; tuned to filter desired contaminants. As an example unknown terrestrial biologics could be filtered with carbon-KDF (Kinetic Degradation Fluxion) however in situ copper and zinc are not found in the quantities needed on the moon. We plan to research lunar chemical amended carbon filters to determine the possible activation methods and their specific filtration qualities.

JSC-1A Oil Experiment: Removing Oil from Lunar Regolith Simulant. In an interview with David Dunlop (Hawk, 2010a) Dunlop mentioned that India is very serious about mining the moon. Specifically, they have a 40-year moon mining plan because they understand they cannot keep building coal-fired plants. Therefore, India is taking space exploration very seriously. The writing is on the wall; sometime in the near future we will be mining the moon. Inevitably we will contaminate the lunar surface with hydrocarbons such as a hydraulic fluid leak.

The JSC-1A oil experiment simulates contaminated lunar mare. In this experiment SNAP® hydraulic jack oil is soaked into Orbitec JSC-1A lunar regolith simulant whereby C_{pyr9} and water are added. After mechanically mixing, the contaminated regolith, water, and C_{pyr9} the oil is chemically adsorbed to the C_{pyr9} forming three separation layers; regolith simulant, oil-coated C_{pyr9}, and water. The oil-coated C_{pyr9} is skimmed off. C_{pyr9} is added, agitated, and skimmed until the regolith is restored.

The results of this experiment suggest that hydrocarbon contamination on the lunar surface could be mitigated using C_{pyr}. The contaminated high-BTU C_{pyr} can be further mitigated by non-edible bio-mining plants such as extremophile cacti.

Deepwater Horizon Experiment: Removing Oil from Water and Sand. On April 20, 2010 the BP Deepwater Horizon oil rig exploded in the Gulf of Mexico killing 11 workers and creating a seafloor oil gusher. The amount of oil spilled into the Gulf is debatable however what is not debatable is that the oil slick and plume have caused serious economic and ecological devastation that may never be fully realized. From this disaster three carbon filtration experiments were set up and subsequently placed on www.youtube.com.

C_{pyr} Filter. The significance of removing oil from water by carbon filtration is that the carbon becomes oil laden. C_{pyr} chemically adsorbs oil and it appears that it does not matter the oil composition. C_{pyr} can easily be ignited demonstrating its higher obtain BTU value from the oil. Oil filtered C_{pyr} appears to have similar ignition qualities of Kingsford Match Light® charcoal. This quality is clearly demonstrated on the oil mitigation video (Hawk, 2010b).

The significance of removing oil from soil media cannot be underestimated. The oiled-sand video (Hawk, 2010c) demonstrates how raw C_{pyr} is mixed into a prepared oil-sand mixture whereby the C_{pyr} chemically adsorbs the oil. The C_{pyr} visibly becomes oil laden and again ignites similarly to Kingsford Match Light® however; it was experimentally observed that the oil was sparsely and unevenly distributed on the C_{pyr} causing abnormal ignition. Abnormal ignition is also demonstrated on the oiled-sand video (Hawk, 2010c). Therefore, in order to thoroughly restore the oil-sand mixture a better cleaning process is needed. And, that brings us to the third experiment below.

Oil-laden South Carolina beach sand was mixed with water and C_{pyr9} and mechanically agitated. Within a few minutes several separation layers are clearly visible. The top layer is primarily C_{pyr9}-oil, the middle layer C_{pyr9}-oil-water, and the bottom layer sand-oil-water-and C_{pyr9}. Over time the separation layers become clear and distinct. As the sand is cleaned the oil-laden C_{pyr9} is skimmed, the remaining sand-oil-water-C_{pyr9} mixture is again agitated. After skimming the oil-laden $C_{pyr9,}$ the mixture is again agitated then skimmed and filtered, until the sand appeared to be restored. This is demonstrated on the S.C. beach sand video (Hawk, 2010d).

Assorted Tree Bark Filter. John Schmitt called regarding the Gulf oil spill and requested that our team replicate a tree bark experiment (Hawk, 2010e). Schmitt knew that Norway had used pine bark to mitigate oil spills (Norway used pine tree bark because it is abundant). An assortment of tree bark was gathered and placed through a hammer mill. Subsequently an oil-water solution was poured through the shredded bark filter. At first glance the tree bark filtered oil from water with greater efficiency than C_{pyr} however; we used C_{pyr9} or raw C_{pyr} that was not pulverized. Had the C_{pyr} been pulverized increasing the surface to volume ratio, we most likely would have observed higher oil chemical adsorption. Nonetheless assorted tree bark appears to remove oil from water effectively. This can be demonstrated on the tree bark video (Hawk, 2010f).

CO_2 Climate Change Mitigation. What are the implications of these three experiments? Before we can answer this question we must look at the importance of using pyrogenic carbon. Carbon dioxide is a known greenhouse gas. For every ton of solid carbon sequestered 3.6667 tons of carbon dioxide is sequestered. Bark beetles such as the Emerald Ash Borer (EAB), Southern Pine Beetle, and the Mountain Pine Beetle (MPB) have killed millions of trees over vast areas. Currently the MPB is attacking the Canadian boreal forest estimated to be 3.1 million km^2. Considering that a dead tree is no longer a carbon sink but a carbon source. Below we estimate the atmospheric CO_2 equivalent based on one boreal Jack Pine tree to be ~47lbs per year.

> ***Atm CO_2=.25(d)2(h)(1.20root system)(72.5%dry weight)(.5amount of C in tree)(.25temperate climate factor)(3.6667C:CO_2 ratio)/(age of tree)+.25(d)2(h)(1.20root system)(72.5% dry weight)(72.5%lignin factor)(.5amount of C in tree)(.25temperate climate factor)(3.6667 C to CO_2 ratio)/(time of deterioration).***
>
> ***Where; d=12 inches, h=60 feet, age of tree = 25years, time of deterioration = 50 years. How much CO_2 would remain in the atmosphere if the Canadian boreal forest would succumb to the bark beetles by the year 2070?***
>
> ***(555trees/ha)(310,000,000ha in Canada boreal forest)=1.72x1011 trees***
> ***(1.72x1011 trees)(47lbs CO_2/year)=4.043billion tons Canadian boreal forest CO_2/year***

There are currently few commercial products for dead beetle-killed trees which mean that the great majority of trees will die in place; dead standing trees are called *snags*. The U.S. Forest Service estimates that 100,000 snags will fall every day; they will fall on houses, power lines, and on people and people will die (Miller, 2010). The dead trees pose several other severe risks such as high fire danger and hypoxic conditions that kill Sockeye salmon. In another twist, dead trees no longer absorb rainfall; the forest floor is subsequently inundated with rain causing hydraulic changes that lead to flooding, and river temperature increase which also kills Sockeye salmon (Porter, 2000). The mitigation of beetles is just as important as mitigating dead trees. And here is where our NASA and pyrogenic carbon research is important.

Carbon Mitigation Examples.

1. Each carbonized tree yields ~55lbs of solid carbon or 200lbs of CO_2. For every 10 trees you can sequester ~1ton of CO_2. Approximately 25% the Rosebud Sioux Indian Reservation grasslands are degraded. We estimate that 45Mt of CO_2 is needed to restore soil organic carbon (SOC) to 100% therefore it would take ~ 450million trees to revitalize the grasslands on the Rosebud Indian Reservation in South Dakota.

2. One gram of C_{pyr} has a surface to volume ratio of ~500m^2. An oil slick from 10,000 tonnes (74,000barrels) of crude ~.2mm thick, covering 58km^2 could be mitigated by ~116kg (255lbs) of carbon or five trees.

3. To help mitigate beetle-kill we combined two known insecticides; C_{pyr} and diatomaceous earth to form a proprietary long-lasting non-toxic insecticide; known as C_{pyr}-DE insecticide.

Salton Sea Experiment: Removing Salt from Water. The Imperial Valley, Salton Sea, California is well known for agricultural production; in 2008 it was close to $2billion. The formation of the Salton Sea is an incredible story. The Salton Sea is the largest California Lake which lies at 227feet below sea level. The Salton Sea is an important flyway for hundreds of migratory birds and animals. Unfortunately, the land-locked sea is succumbing to combinations of toxic farm runoff, and high-salinity mountain runoff.

Indeed, On July 17, 2010 we took water samples and NIR photography from the closed Bombay Beach. There were few birds and a lot of dead fish on shore. The air was filled with rotting fish.

In a previous saline experiment we filtered 200mmol through C_{pyr9}. Only 40mmol of salt remained. The significance of this experiment suggests that C_{pyr} could be used to lower the salt concentration of the Salton Sea which is now at 44parts per thousand (ppt), ~25% greater than that of the ocean. Annual lake inflow is ~1,300,00acre-feet which carries with it ~4Mt of dissolved salt and is estimated to contain 500Mt of total salt. We suggest that C_{pyr} can filter salt and unwanted toxic farm runoff that is killing fish and animals.

Twenty two grams of sea salt was added to 500ml of water in a follow up saline experiment. The solution was filtered through 1gm of pulverized C_{pyr}. There was no significant desalination. This could be because there was not enough C_{pyr} or perhaps the surface to volume ration was too high.

This experiment suggests that more saline experiments are needed to verify consistent desalination processes.

Because of conflicting saline experimental data the amount of C_{pyr} needed to desalinate the Salton Sea to ocean levels cannot be predicted. However, a simplified plan of filtering run off from dry washes along with attacking the main body of water would seem to be the best approach; effectively limiting lake inflow toxins while purifying lake water in situ.

Winogradsky Lunar Agricultural Carbon Battery

There is much literature on bacterial batteries. Our research observation shows that plants use carbon as an insulator, conductor, and even a superconductor. We know from our carbon bacterial experiments show that bacteria are carbon-loving. We further believe that the Lunar Agricultural Experiment at the Controlled Environment Agricultural Center (CEAC) at the University of Arizona can provide sufficient compost to produce electricity from a Winogradsky bacterial battery.

Implications of a Lunar Agricultural Battery. When we return to the moon, we will stay for awhile. Plants will eventually feed colonists and disposable biomass can be pyrolyzed. The C_{pyr} can be used to create sustainable agriculture similar to Amazon dark earths. In addition to filters, C_{pyr} can be used to create electron producing bacteria; microbial fuel cell (MFC) that could further supply electricity to the lunar settlement. Indeed, graphite (an allotrope of carbon) is now being used as an anode in a dirt battery that is being tested by Lebone Solutions Inc (www.lebone.org) in Africa. Furthermore, the Apollo 16 brought back high-iron electron rich minerals (Heiken, 1991) and closer to home JSC-1A regolith simulant can be mixed into the lunar agriculture compost to produce electricity; JSC-1A is characterized (Rickman, 2007) to have almost 16% by weight Fe^{3+}. Herein, we believe the Lebone battery anode could be replaced with a cheap ubiquitous C_{pyr} anode which may be the economical answer to supplying 500million people off the grid inexpensive easy to get electrical power.

Research Conclusion

Earlier we positively demonstrated that C_{pyr} amended soils produce extraordinary agricultural results. The greatest example of this was the lunar cycling experiment called Eureka. Eureka a garden variety cactus (*Mammillaria rhodantha pringlei*) was subjected to vacuum under water, temperature and lunar cycling. Carbon dioxide starved; Eureka's ability to transpire and off-gas oxygen was due to its ability to uptake carbon from soil amended C_{pyr} through the roots. An even earlier experiment EXP-3, an anti-desertification experiment showed that just 7.94% C_{pyr} (by volume) amended to plain sand doubled plant mass. It is easy to imagine the importance of mitigating deadly expanding deserts by using just a "little bit" of carbon; simply by not allowing wood fires to burn to ash creates an effective way to combat desertification. It is education and not money that will save hundreds of thousands of people from becoming starved desert refugees.

Our ability to survive on earth should be a priority. Herein, we convey that the amount of trees that have been killed or will be killed; dead and dying from bark beetles and diseases, will significantly increase atmospheric CO_2 levels by 2070. Thus it is important to carbonize and sequester dead and dying beetle-killed trees. We observe that earth does not have any environmental tipping points however, human beings regardless of our technology, might not be able to save our current way of life. Space exploration may help alleviate earth's growing pains and thus our motto is to "Extend Carbon-Life to There".

To conclude based on our research C_{pyr} amended lunar regolith would create near-sustainable extra terrestrial agriculture plant media. Plant biomass can further be pyrolyzed for filters or composted to create Winogradsky electricity in support of lunar settlement.

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Photos

Photo 1. Author (Co-PI) performing research at Bombay Beach, Salton Sea, California, (photo by Judy Cornelius).

Photo 2. Left hand is showing raw pyrogenic carbon (Cpyr) and right hand is showing Cpyr9.

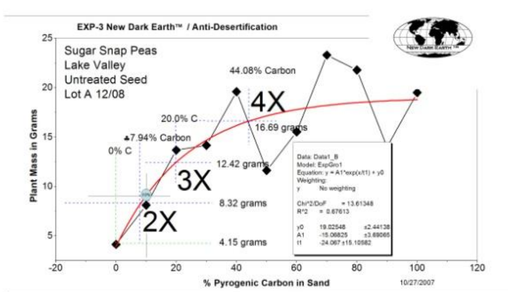

Photo 3. EXP-3, Anti-Desertification Experiment showing Cpyr needed to double, triple, and quadruple plant mass in plain sand.

Photo 4. Eureka in vacuum underwater, in refrigerator for lunar cycling.

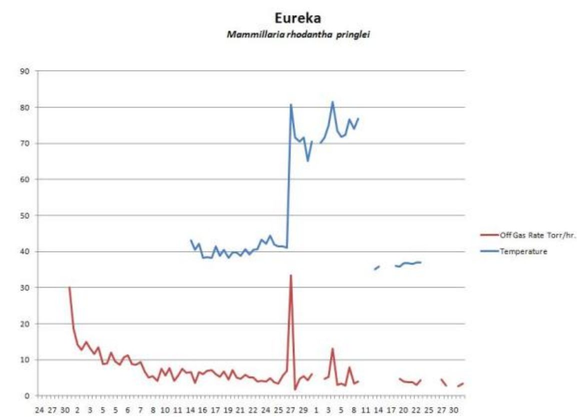

Photo 5. Eureka off-gassing rate in Torr/hr.

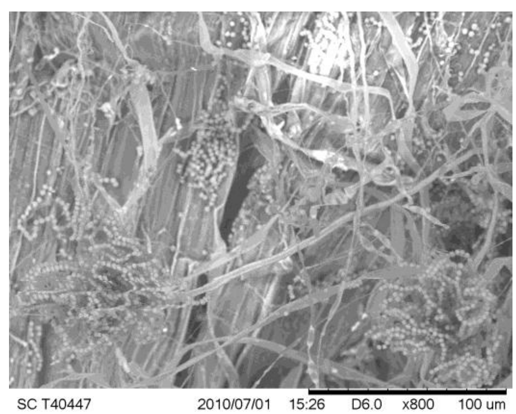

Photo 6. SEM Cactus roots grown in nitrogen atmosphere showing penicillium fungi, (Co-PI, Dr. Gertrud Konings-Dudin).

Photo 7. Mountain Pine Beetle-Kill.

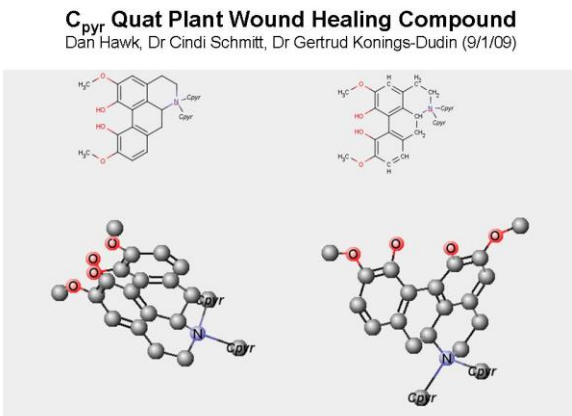

Photo 8. Cpyr amended Dragon's Blood used to create new plant wound healing compound.

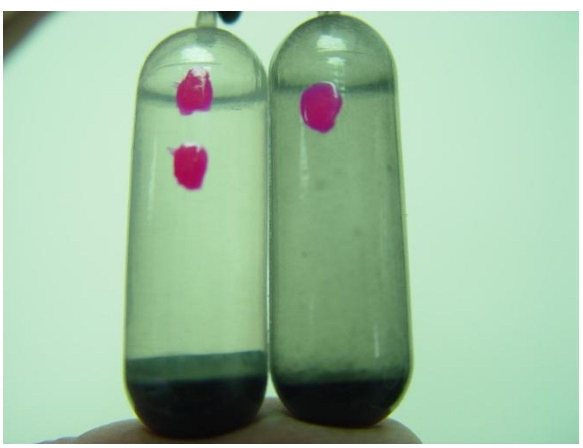

Photo 9. Cpyr-DE insecticide on left. (Co-PI, Dr. Cindi Schmitt collaborator).

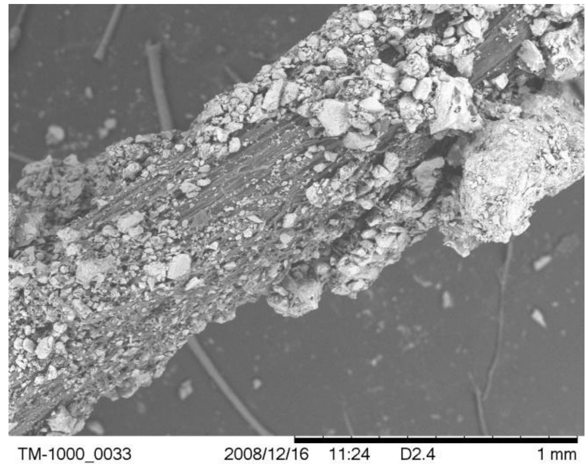

Photo 10. SEM cactus root covered with Cpyr amended JSC-1A lunar regolith simulant, (Co-PI, Dr. Gertrud Konings-Dudin).

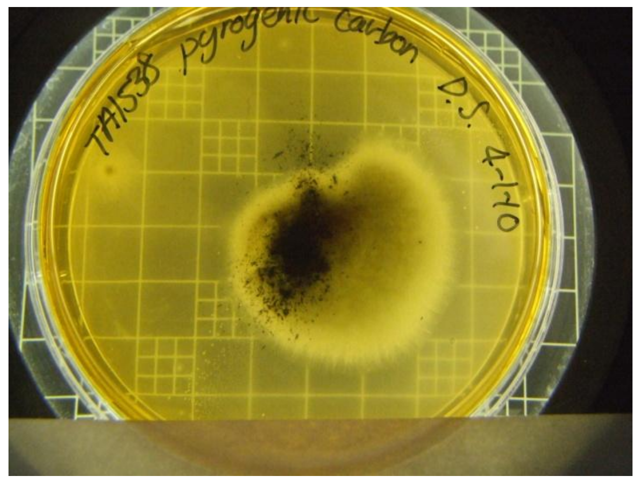

Photo 11. Sample TA1538 Cpyr-loving bacteria.

Photo 12. NIR dead fish, Salton Sea (2010).

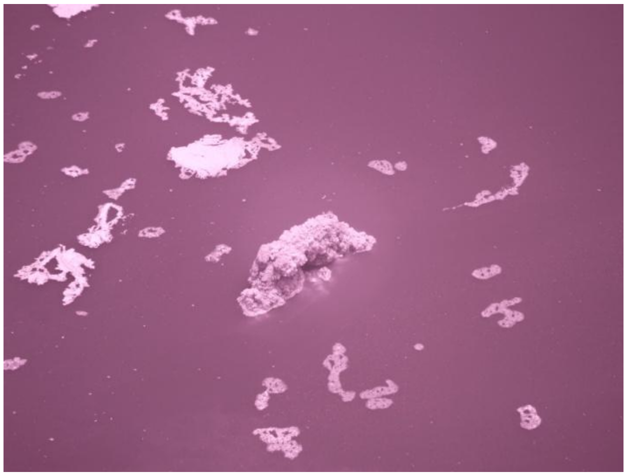

Photo 13. Bombay Beach NIR land-locked boat ramp showing surface algae bloom, Salton Sea, California.

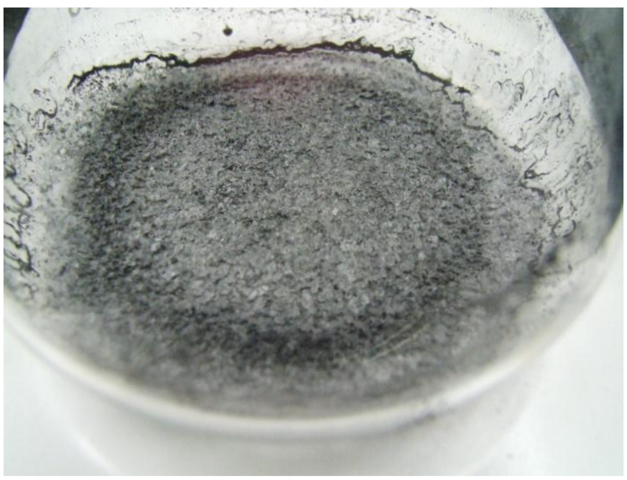

Photo 14. Saline experiment results; 40mmol of Cpyr-salt.

Photo 15. CEAC.

Photo 16. Author collecting carbon slash-n-burn from wheat field in El Centro, California, (photo by Judy Cornelius).

Photo 17. Cpyr-oil mitigation separation layers.

Photo 18. Restored S.C. beach sand with oxygen bubbles. Water has thin residue oil layer.

20th Annual Conference
Part Nine

Physics & Astronomy

Characterizing Magnetohydrodynamic Turbulence in the ISM

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Abstract: Magnetohydrodyamic turbulence is immensely important to interstellar processes such as magnetic reconnection, cosmic ray transports, star formation and galaxy evolution. However, in its astrophysical context it is very difficult to study. In this on going study we seek to develop new tools to study ISM turbulence via statistical studies linking theoretical predictions, numerical studies and observations. In these proceedings I briefly review the problem and our work up to date as well as future papers

Magnetohydrodynamic (MHD) turbulence is a critical ingredient in understanding most astrophysical processes, as it influences scales ranging from clusters of galaxies down to AU. Although turbulence is of obvious importance to
gaining insight into the IGM, ISM and star formation process, it is not so easily studied. Observationally, several techniques exist to study ISM turbulence. Many of these hinge on either density fluctuations, via scintillation in ionized media. Radio position-position-velocity data (PPV) and column density maps exist in plenty for studies of neutral media. Radio spectroscopic observations are also useful when considering centroids of spectral lines and line widths. The advantage of spectroscopic data is that it contains information about the turbulent velocity field as well as the density fluctuations. However this type of data can be difficult to study in its own ways. Projection effects due to not having the full 3D density information of clouds can hamper observer's understanding of turbulence in an object. Doppler shifted spectral lines contain insight about the turbulent velocities but because they contain density and velocity information entangled together the results are often difficult to interpret.

In general, the most promising methods of studying turbulence lie in a statistical description. Indeed, a statistical description of turbulence is necessary in any situation where the subject arises as it allows one to study the underlying regularities of the fluid motion. The advantage of using statistical techniques is that they extract patterns in the flow and reject incidental details. For astrophysical settings in particular, statistical studies have found their uses in the comparison of observations with models of turbulence. In order to get the most information and use out of the wealth of astronomical data available, many new tools have been recently tested, which generally provide information on sonic and Alfvenic Mach number as well as topology and nature of the turbulence cascade. These statistics include probability density functions (PDFs), wavelets, the principal component analysis, higher order moments, Tsallis statistics, spectrum and bispectrum, Velocity Coordinate Spectrum (VCS), and Velocity Channel Analysis (VCA), to name just a few.

My research hinges on the precept that the most effective way to use these tools is a synergetic one. By using multiple tools simultaneously with the aid of numerical simulations, we can get the most reliable information on turbulence in a particular medium. This is the approach that I used for the analysis of HI column densities in the SMC (Burkhart et al. 2010a), a near by dwarf galaxy. In this study we applied several statistics known to shed light on gas compressibility to the neutral hydrogen column density data. These included bispectrum (higher order spectrum), statistics moments, and power spectrum. It is very encouraging that the different tools used in this study, e.g. higher order

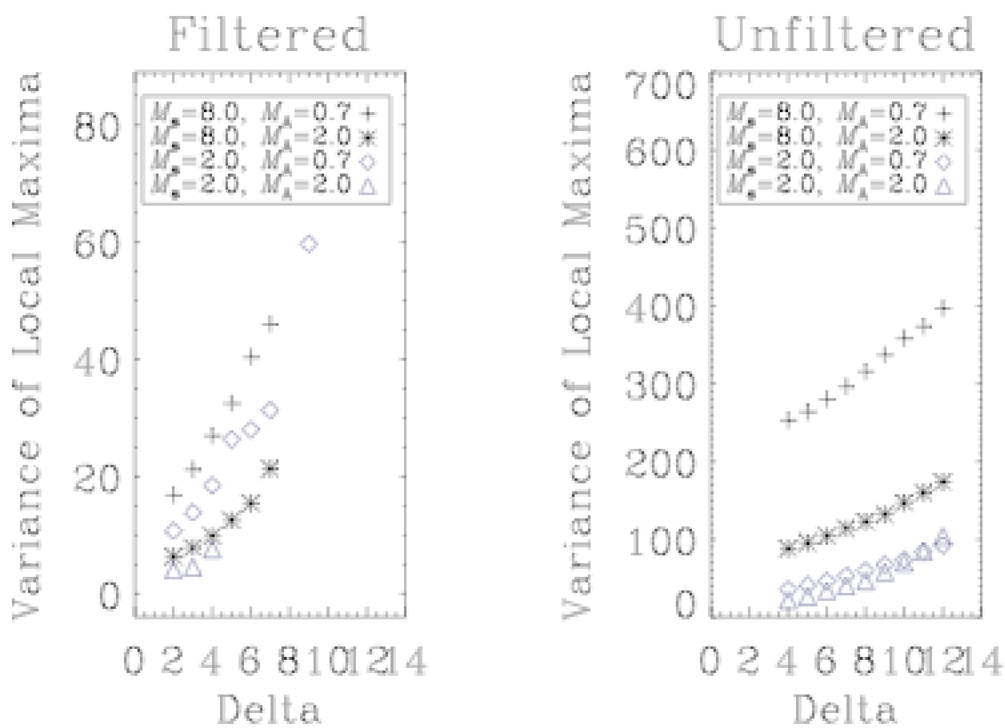

Figure 1: Variance of hierarchical tree diagram (dendrogram) distribution for four different MHD synthetic spectroscopic data. The dendrogram shows strong preference to the strength of the magnetic field and the gas compressibility.

moments, density power spectrum, and bispectrum, provide consistent values for the degrees of compressibility of turbulence. In addition, using the higher order moments dependency on the compressibility of column density (see Burkhart et al. 2009) we were able to make a 30' resolution map of the spatial distribution of turbulence, which highlighted shearing flows in the direction of the LMC as well as confirmed observational results that the HI in the SMC is dominated by warm gas.

In addition to compressibility, many astronomers are also interested in gaining insight into the role magnetization plays in the dynamics of the ISM. A hierarchical tree diagram tool known as a dendrogram has shown great promise in this direction on synthetic spectroscopic data cubes. The distribution of local maximum of emission is directly correlated to the magnitude of the magnetic field and strength of the shocks. In Figure 1 we demonstrate that the variance of the distribution of dominate emission as found by the dendrogram shows strong preference to magnetic field strength. The dendrogram is highly complimentary to other tools used on spectroscopic data. A paper outlining these results is in preparation to be submitted April 2010 (Burkhart et al. 2010b).

This work is significant in that, because MHD turbulence spans a wide range of astrophysical scales and phenomena, we expect to have a broad impact. The leaps in data quality made possible by modern instrumentation call for a complimentary advance in data analysis techniques. Ultimately, statistical studies combining high quality observations with numerical simulations will give new insights into ISM processes, star formation, and galactic evolution.

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The Development of a Transition-Edge Hot-Electron Microbolometer for Observation of the Cosmic Microwave Background

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Abstract: Future NASA missions to probe the Cosmic Microwave Background polarization will need sensitive detectors provided by arrays of 1000s of bolometers. We are developing a Transition-Edge Hot-Electron Microbolometer to fill this need.

I. Introduction

My research focuses on the development of a sensitive detector, called a Transition-Edge Hot-Electron Microbolometer (THM). The THM detector is optimized to take precision measurements of the Cosmic Microwave Background (CMB). Arrays of 1000s of these THM detectors would meet the sensitivity level required to measure the faint B-mode polarization signal in the CMB, a remnant of gravitational waves from the inflation era, and tell us about what happened in the earliest moments of the universe [1].

A bolometer is a detector that absorbs incident photons and converts their energy into heat. It consists of three parts: an absorber, thermometer, and cold bath (see Figure 1 below). Incoming photons thermalize in the absorber, and heat leaves the absorber via a weak link to the cold bath. The power of incident radiation is measured by monitoring the temperature of the absorber.

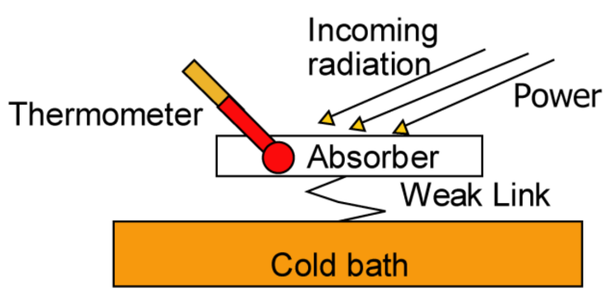

Figure 1: The components to a bolometeric detector.

An important component to the operation of bolometers is the thermal link between the detector and the cold bath. Common TES bolometers make use of micro-machined isolation structures, to precisely control the thermal conductance of the link. This thermal conductance affects the noise, time response, saturation level and other characteristics of the detector. These membrane structures are fragile and present both fabrication and design complexities[2]. The Transition-Edge Hot-Electron Microbolometer (THM) makes use of a different type of thermal isolation, one that is controlled by the weak coupling between electrons and phonons (quantized vibrational states of the crystal lattice) in the detector at low temperatures and within small volumes [3].

To measure small differences in incident power a sensitive thermometer is necessary. The THM employs an extremely sensitive thermometer called a Transition-Edge Sensor (TES). A TES is a superconductor which exhibits a transition between a normal and superconducting state. At this transition its resistance drops to zero and there is a sensitive dependence of resistance on temperature.

The noise of the detector for a bolometer is dominated by thermal fluctuation noise which is proportional to the thermal conductance of the bolometer thermal link [2]. This thermal conductance is directly proportional to the device volume. To obtain noise levels below the background noise of a telescope observing from the ground of from space the optimal design for the THM detector is a detector on the micron size scale.

In addition to the electron-phonon effect dominating on these small scales a lateral superconducting effect also becomes important in the TES. In order to operate the TES it is voltage biased in the transition region via superconducting bias leads. When the lead to lead distance across the TES is small the superconducting affect from the leads can 'leak' into the TES dramatically changing the TES transition behavior. In previous molybdenum/gold bilayer TES devices the bulk transition temperature of the TES shifted from 200mK to 7K due to this lateral proximity effect for 3μm wide devices [4].

In the recent measurements described below, I present measurements of the transition behavior of a non-bilayer gold TES in THM test devices. This gold TES was designed with the hope of using the lateral proximity effect as the superconducting mechanism of the detector. I also present measurements of the thermal conductance and noise of these micron-sized THM devices.

II. Recent Measurements

The THM test devices consist of a gold TES with niobium superconducting leads, and with an overlapping normal bismuth absorber. An optical image of a THM device is shown in Figure 2. The THM absorber terminates a superconducting niobium microstrip line which couples to a slot antenna for optical coupling to a microwave source. The niobium DC leads to the TES are also part of a niobium microwave structure that provides for the termination of microwave power in the absorber

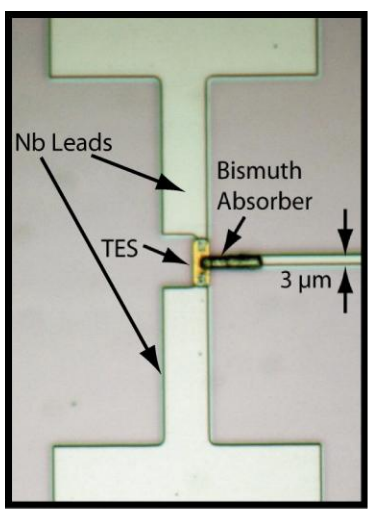

Figure 2: An optical image of a THM device. Incoming power terminates on the device via a niobium microstripline (from the right). The niobium microwave termination structure (only partly visible) also serves as the DC bias leads for the TES.

The test devices were cooled in a cryostat with a adiabatic demagnetization refrigerator down to 150 mK. 4-wire resistance versus temperature measurements were taken for each of the devices while sweeping the bath temperature. The lateral proximity effect due to the superconducting niobium leads in these gold TES devices was minimal. None of TES devices transitioned to zero resistance at temperatures above 150 mK. This may be due to a large contact resistance between the TES and leads impeding the lateral proximity effect.

To measure the thermal conductance the 4-wire resistance of each TES was measured at a fixed bath temperature while DC power was applied directly across the absorber via a separate absorber bias lead. Thermal conductance measurements of these devices showed a power-law dependence on TES temperature consistent to that predicted by theory for a electron-phonon dominated thermal link. For two 3μm wide devices thermal conductance values of of $2\text{-}3\times10^{-11}$ W/K were measured for a 50 mK bath temperature. This thermal conductance predicts detector noise of $6\text{-}7\times10^{-18}$ W/Hz$^{1/2}$. This is near background limited levels for CMB observing (a background noise of 5×10^{-18} W/Hz$^{1/2}$ is predicted from a CMB telescope in space).

III. Conclusions

The recent thermal conductance measurements are very promising for achieving low noise detectors capable of CMB observing. However, further investigation into the lateral proximity effect is still necessary in order to design micron-sized THM devices with transition temperatures between 50-300 mK. Recently, new test devices with different contact schemes between the gold TES and niobium leads have been fabricated. We are hopeful that these will provide more insight into THM design options.

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Millimeter-wave Bolometric Interferometer

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Abstract
The Cosmic Microwave Background is instrumental in furthering our understanding of the early universe. Observing the temperature and polarization anisotropies, NASA's WMAP mission has constrained the age of the universe and other important characteristics. The Einstein Inflation Probe, an upcoming NASA mission, will map the polarization of light from the CMB to search for evidence for inflation. In order to accomplish this, more compact and refined microwave instruments are needed to minimize weight and maximize signal. Advanced microwave phase modulators are needed to provide lock-in detection of small signals. These are being tested for use in the Millimeter-wave Bolometric Interferometer (MBI), which is itself a test-bed for technology for the Einstein Inflation Probe.

1. ***Project objectives:*** The cosmic microwave background (CMB) results from a period called recombination. At that time in the universe's early history, about 379,000 years after the big bang, photons are no longer tied to matter [4]. This allows hot radiation to escape from this surface of last scattering. This radiation, first observed by Pensias and Wilson [13] and more recently by WMAP [2], is observed as microwave photons with a temperature of 2.7K. Although the CMB is the best black body ever observed, there are anisotropies in the observed temperature. These anisotropies over the entire sky have been mapped by COBE [1] and WMAP. Using statistics of these maps, angular power spectra have been produced. These results give us a better understanding of the geometry and age of the universe, and make cosmology a data-rich branch of astrophysics.

The next step is to investigate the polarization of light from the CMB. For many areas of astrophysics, polarization often relates information that can be measured through no other method. That is also the case for the CMB. Polarization of light from the CMB results from density (scalar) perturbations, gravitational waves from inflation (tensor perturbations), and gravitational lensing by large-scale structures (which converts scalar perturbations to tensor). These scalar and tensor perturbations are characterized by two components of the polarization, called E-modes and B-modes respectively. The E-mode is a gradient decom-position of the polarization, while the B-mode is a curl decomposition. Both these polarization components are expected to be measurable at magnitudes below the temperature anisotropy. DASI [11] and WMAP have detected E-mode polarization at a level of a few microkelvin. B-modes, which are of great interest, will be observed at a level smaller yet than the E-modes. The relative amplitudes of these signals are included in Figure 1 [14]. Detecting B–mode polarization will require highly sensitive detectors whose systematic errors are well defined. If we can observe the B- mode signal, we will be able to probe the Universe at times earlier than with any other method. This can be very powerful. Since the density of matter in the early universe was very high, light could not escape until the optical depth fell at the time of last scattering. Gravitational waves from the inflationary epoch (when space expanded exponentially for a short time after the Big Bang) should imprint the light escaping from the last scattering surface with B-mode polar-

[1] Funded in part by the Wisconsin Space Grant Consortium

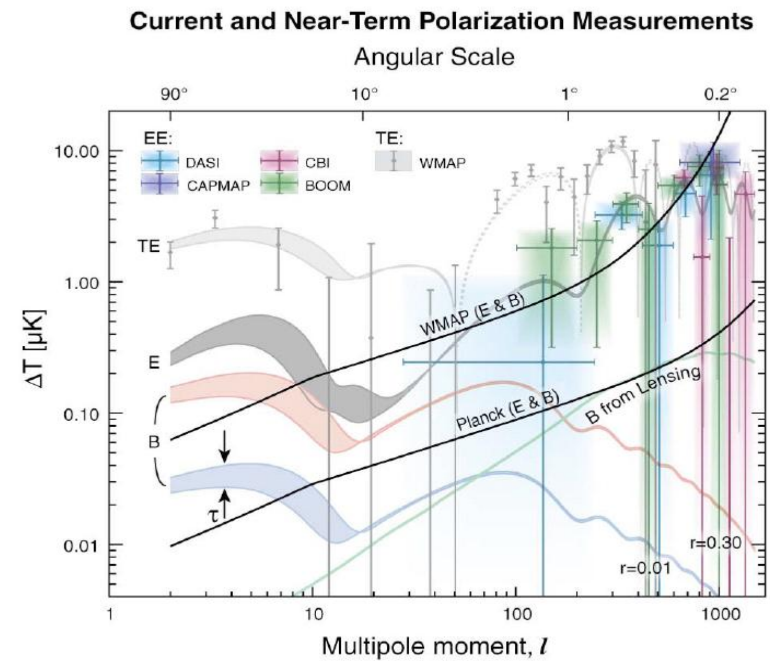


Figure 1- Power spectra for E-mode polarization (EE), B-mode polarization (BB), and temperature- E-mode polarization correlation (TE), along with observation by several recent experiments. Black Lines illustrate the sensitivity limits of WMAP and the future Planck mission. T (not shown here), TE, and EE power spectra have already been detected [2, 11, 12] and await full characterization.

ization, allowing us to access times near 10^{-37} seconds. The amplitude of the signal from the B-mode polarization is thus linked to the energy scale of inflation. This contribution to the B-mode polarization should be seen for large angular scales, while the gravitational lensing contribution (from much more recent times) will be seen on smaller angular scales. If ten percent of the fluctuation of the CMB polarization is due to tensors that would imply that inflation occurs at the GUT scale (10^{24}eV). Therefore, measurements of the B-mode polarization would provide a strong consistency check for inflation.

2.*Millimeter-wave Bolometric Interferometer:* Our project centers on demonstrating the potential and relevance of bolometric interferometry for CMB observations, both on the ground and in space. This goal requires innovative microwave technology to provide phase modulation without moving parts. We intend to map galactic foregrounds and search for the E and B-mode polarization in the CMB. Our collaboration is building the Millimeter-wave Bolometric Interferometer (MBI) [10], a groundbased prototype for a satellite, NASA's Einstein Inflation probe, which will map the polarization of the CMB. The initial version of this, MBI-4, utilizes an array of four corrugated feedhorn antennas arranged as an interferometer with a quasi-optical Fizeau beam combiner. Figure 2 shows the MBI cyrostat. Sixteen cold bolometers act as detectors. MBI is expected to demonstrate the advantages of millimeter-wave interferometry for control of systematic effects.

2.1. *Interferometry:* An interferometer was chosen for this project to make use of several main advantages for high- sensitivity observations over direct sky imaging systems with a single dish.

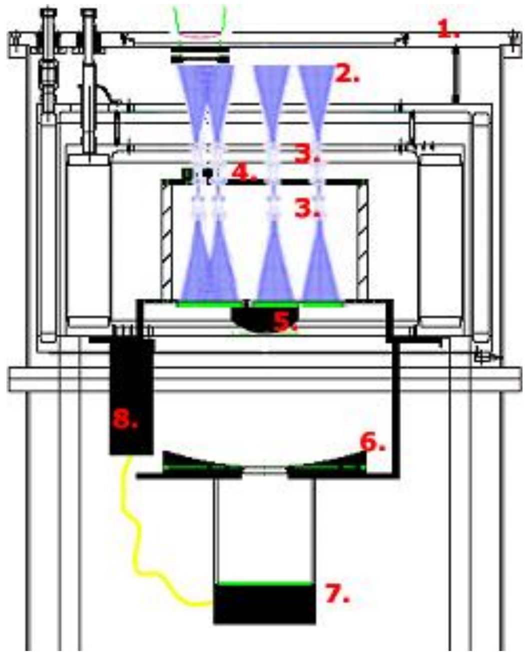


Figure 2:Schematic of the MBI-4 Cryostat:1. Cryostat; 2. Sky antennas; 3. Circular to rectangular transitions; 4. Phase modulators; 5. Secondary mirror; 6. Primary mirror; 7. Bolometer unit; 8. Helium fridge.

These advantages include: ***1.Ability to measure the power spectrum of the sky directly***. This occurs because the fringes within the beam pattern of the interferometer sample the sky with positive and negative weighting. The fringes only depend on the baseline between a pair of antennas, so MBI-4 will be able to sample instantaneously from six baselines. These fringes will provide information about the spectrum of the E and B-modes. 2.***Higher angular resolution at lower cost.*** It is difficult and expensive to manufacture a large, accurate mirror but constructing many accurate feed horns a few inches in size is no more difficult than constructing one. This lowers the cost significantly when future interferometers observing the CMB could include 1000s of antennas. ***3.Clean optics.*** The mirrors and lenses of optical systems introduce extraneous polarization signals from reflections and can add aberrations. MBI-4 will only utilize mirrors and lenses behind the optics observing the sky, causing some loss of signal without introducing additional polarization. MBI-64 can be designed to utilize neither of these, so the optical system would not introduce either problem. ***4. No field of view (FOV) limit.*** Both on-axis and off-axis optical systems, such as COMPASS [5] and WMAP respectively, have limits on their field of view due to the limited range over which images are focused in their focal plane. Interferometers, on the other hand, have no such intrinsic limit. Thus, their FOV is only determined by the beamwidth of the antennas and can reach much larger values. (MBI has a FOV of 7 degrees.)

The largest problems for interferometers are their complexity and possible losses within the microwave parts. Difficulties from these can be minimized by designing test “telescopes” such as MBI. Recently, interferometers (DASI and CBI [12]) successfully measured CMB polarization but they have been limited to a small number of receivers.

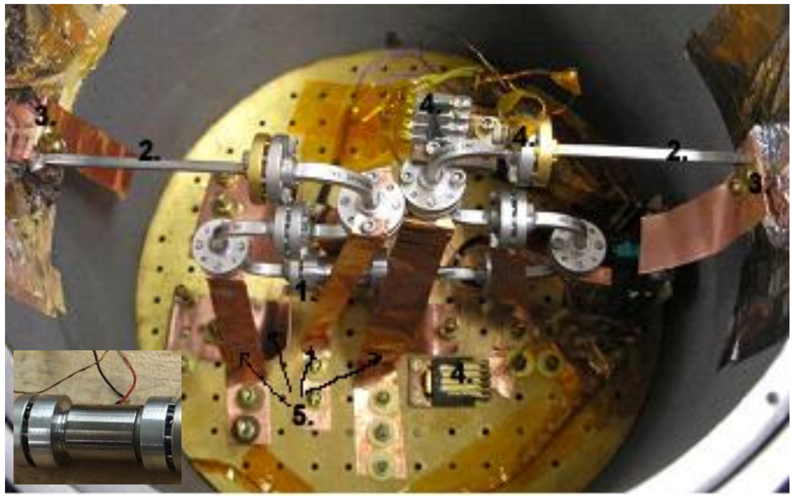


Figure 3- Looking into the test dewar. 1 and inset: Phase modulator. 2: Input waveguides. 3: Small copper blocks. 4: Thermometers. 5: Copper heat straps.

2.2. ***Bolometers:*** We choose to use cooled bolometers for MBI because they are the most sensitive detectors across the 30-300 GHz range relevant to the CMB. When cooled below 0.1K, bolometers achieve the background-limited sensitivity necessary for CMB observations. Bolometers will allow us to use a multiplexing readout. This means that each bolometer receives a phase-modulated signal from each antenna. The detector then produces a superposition of signals. A lock-in detector can then separate out each signal based on the beat frequency of the specific baseline. We are designing a Butler combiner [3] as well as an optical combiner to accomplish this multiplexing scheme. Figure 2 shows the optical combiner, which consists of primary and secondary mirrors. This method of utilizing bolometers should remove the limit of interferometers to small numbers of antennas.

2.3. ***Status:*** MBI-4 has observed a calibration source for two seasons. Observations have been made from Pine Bluff, Wisconsin. Data analysis is ongoing, and MBI is undergoing modifications and repairs in anticipation future technologic tests.

3.*Microwave instrumentation.*

3.1. ***Faraday effect phase modulator:*** I have been focusing on testing the phase modulators that will allow for lock-in detection of the CMB polarization signal. One of these devices will be placed at the back of each antenna (see Figure 2). Noise is reduced in this scheme since we can lock into the modulation frequency of incoming signals, allowing us to throw out unmodulated signals from motor noise, instrumental drifts, and 1/f noise. Since MBI is an interferometer, phase modulation also allows us to pick out signals from individual baselines on the detectors. Our current phase modulators are Faraday rotators [7] that have been constructed at the University of California- San Diego, who have constructed similar modulators for use in BICEP[6] .

The Faraday modulators consist of rectangular waveguide flanges on each end that couple to a ferrite rod centered inside a circular waveguide surrounded by a super-conducting coil. As the polarized signal enters the ferrite, the polarization is split into left- circular and right-circular polarizations, which propagate at different speeds within the ferrite. The outgoing signal is then

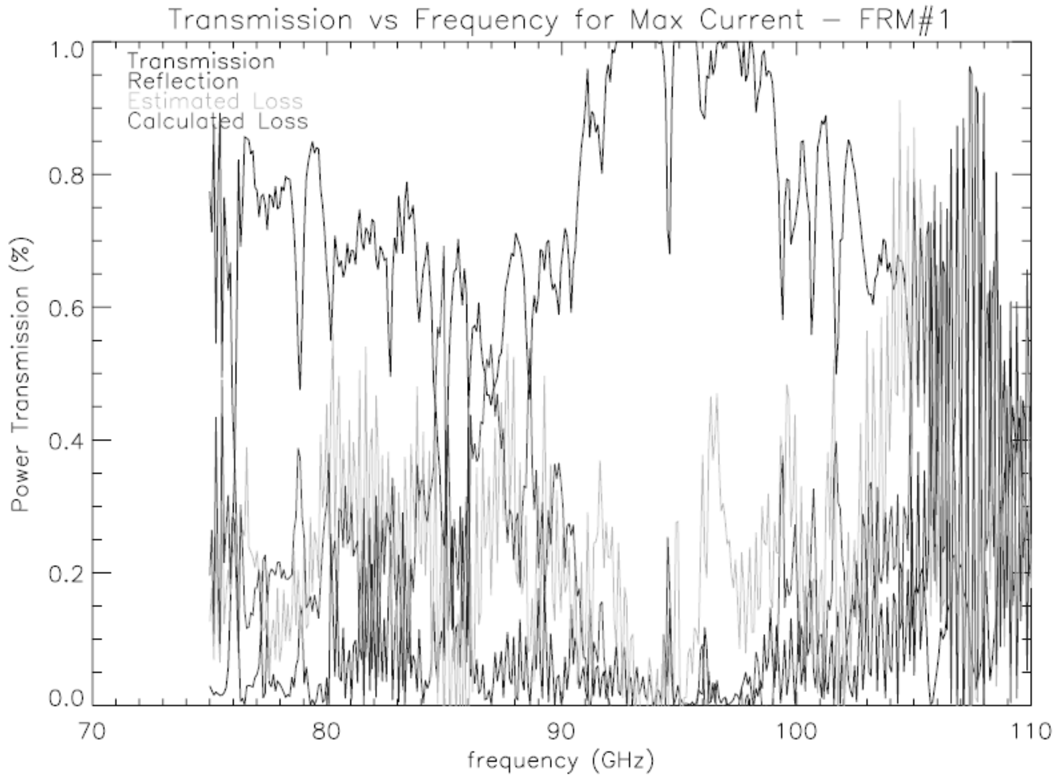
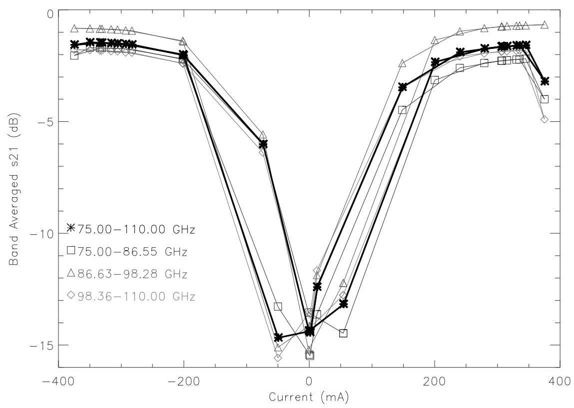


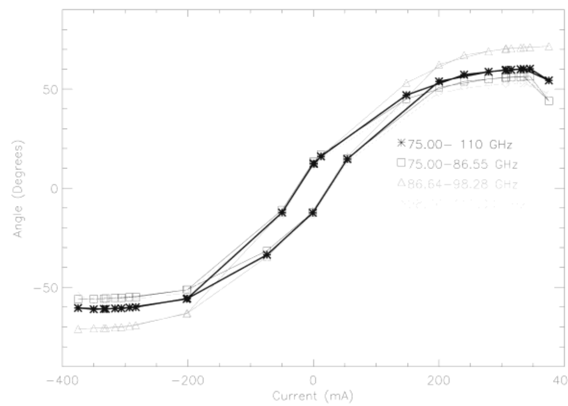
Figure 4: Transmission, Reflection, and Ferrite Loss Percentages for FRM #1

phase shifted based on how much one polarization is retarded with respect to the other while traversing the ferrite. The amount of phase shift depends on the strength of the magnetic field produced by the surrounding coil, which depends on the current through the wires. Modulating the signal thus only requires changing the current supplied to the phase modulator. This allows for reliable modulation without any moving parts. Previous tests on modulators with circular waveguides at UCSD show a rotation of approximately 75 degrees for input currents of a maximum of 340 mA. Since MBI will require phase rotations of 0 and 180 degrees, the rectangular waveguides on our modulators are set perpendicular to each other. Any phase shift obtained will be projected onto a 90-degree phase shift with excess loss.

These phase modulators require cryogenic temperatures to operate properly. In order to test this phase modulator, I have outfitted a test Dewar with appropriate waveguide plumbing and taken measures to thoroughly heat sink the test device. Without proper heat sinking, the device will heat up too rapidly from the input current, which will raise the resistance in the superconducting wires and, thus, limit the amount of phase shift possible. The dewar also would warm up too quickly for all the desired measurements to be taken. These time constraints also made it difficult to have enough time for calibrating the testing instrument, a 100 GHz Agilent 8510C Vector Network Analyzer (VNA), available to us through the department of electrical and computer engineering (ECE) at the University of Wisconsin-Madison. The heat sinking became a major issue to overcome before reliable tests could be made. The solution, after several attempts, turned out to be soldering a small copper block onto the steel input waveguide, as seen in Figure 3, and connecting it solidly to the liquid nitrogen cold plate. This diverted incoming heat away from the liquid helium tank, allowing for hold times over twenty-four hours.



a. Transmission for FRM#1 binned by frequency



b. Phase Shift for FRM #1 binned by frequency

Figure 5: Hysteresis curves of transmission and resultant phase shift versus current for FRM#1.

Tests of the four phase modulators needed for MBI are complete. Each was tested using the VNA using the setup seen in Figure 3. The VNA allows us to measure the reflection and transmission coefficients for the device. In order to determine the phase rotation achieved for a given input current we assume all loss in transmission is due to incomplete rotation to 90 degrees. The loss we see is actually a result of many different components, which must be corrected for before determining the rotation angle. These losses result from other aspects of the test setup and include losses in the waveguide plumbing, in the waveguide to coaxial adapters, and within the phase modulator itself. These losses due to the waveguide and the adapters are found independently by taking baseline measurements with the phase modulator replaced by a straight section of waveguide. Losses within the phase modulator are estimated by looking at a preliminary plot of current verses phase rotation and looking at the reflection measurement at a current with approximately zero phase shift. This loss can also be calculated by subtracting the transmission and reflection percentages from 1.0. All of these parameters can be seen in Figure 4. A definitive variation in the transmission through the device with frequency implies that the amount of phase shift will also depend on frequency. These corrections are all applied before averaging the coefficients over the entire frequency band of the measurements (75-110GHz) or over smaller bands. The corrected transmission and reflection coefficients can then be used to calculate a value for the rotation angle since the ratio of the coefficients varies with the sine of the angle. The resulting hysteresis curve for phase modulator #1 can be seen in Figure 5a and b.

We have obtained a phase rotation comparable to that seen by our collaborators at UCSD. For a maximum current input of 350mA, they report a phase shift of 80 degrees. For our modulators that reached that current value, we see a shift of about 85-90 degrees. This amount of phase shift will minimize loss due to the modulation scheme. These phase modulators have now been installed in the MBI-4 cryostat.

Frequency (x8 GHz)	Current (mA)	Temperature 1 (K)	Temperature 3 (K)	Boil-off Rate (l/min)
11.25	227.96		4.440	2.24
13.75	227.96		4.392	1.96
no RF	199	4.260	4.358	2.20
10.00	199	4.263	4.374	2.60
11.25	199	4.267	4.424	1.96
13.75	199	4.268	4.370	2.20
no RF	165.52	4.266	4.327	1.96
10.00	165.52	4.266	4.351	1.80
13.75	165.52	4.265	4.352	1.90
11.25	165.52	4.266	4.403	2.00
10.00*	165.52	4.266	4.348	2.20
11.25	165.52	4.266	4.401	1.80
13.75	165.52	4.266	4.351	2.00
no RF	138.47		4.313	1.96
13.75	138.47	4.264	4.338	1.88
11.25	138.47	4.264	4.338	1.90
10.00	138.47	4.264	4.336	1.88
no RF	138.47	4.264	4.314	1.90
no RF	no Current	4.257	4.280	1.80

Table 1: Boil Off Rates

I have also begun to evaluate the thermal properties of the faraday modulators. The thermal response and liquid cryogen (helium) boil off rates are summarized in Table 1 for each of the recent testing situations. There does not seem to be any clear trend to the rate of Helium boil-off with frequency. Rates do seem slightly higher for higher input currents on average, which would be expected since more power is being dissipated within the system.

3.2. ***Modulation Control Board:*** The control board has been designed by others to manage the current modulation for all four of the Faraday modulators. Much time has been spent attempting to optimize the time constant for the transition of the square-wave current signal in order to maintain the superconductivity of the modulators while they are in operation. Tests have been completed on two of the faraday modulators. Figure 6 shows the approximate square wave modulation pattern provided by the control board to the Faraday modulator (red line) along with the transmission for a 100GHz signal (black line). Spikes in the current modulation are due to ringing since the superconducting solenoid in the Faraday modulator is essentially an inductor. Another important aspect of these tests is to analyze the signal transmitted through the modulator while it is operating. Since the Faraday modulators have a transmission which varies with frequency, I have taken measurements at several frequencies over the operating range of 75-110 GHz. It can be seen that it can be seen that the spikes in the transmission correspond to times when the current is switching from a positive to negative sense. This is true for all frequencies tested. Both modulators that were tested show no significant difference in their response to the modulated input current.

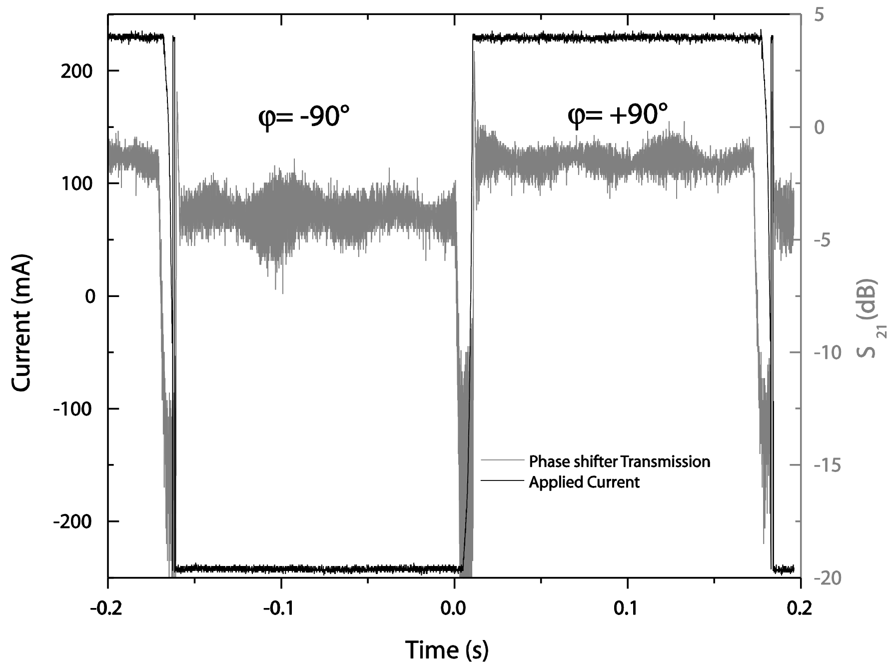


Figure 6: Black: Current modulation at 3 Hz and 228mA. Grey: 100GHz transmission amplitude through the system while current modulation is active.

4. ***MBI Observations:*** Over two seasons, MBI made observations of a polarized 3mm wavelength radiation source mounted on a tower in the mid-field of the instrument. Observations were made in a raster pattern to fully map out the beam pattern of each of the horns and to map out the interference patterns of pairs of horns. Observations of the sun and a patch of sky were also made. Figure 7 shows the positions of the telescope relative to the tower and the orientation of the source polarization relative to the polarization of each horn. As shown in the figure, the MBI input plate was rotated such that the polarizations of all of the horns are oriented at a 45 degree angle with respect to the source polarization. This keeps the input signal amplitude equal for each horn.

Maps have been made of the interference patterns between most pairs of horns for each bolometer, as seen in Figure 8a. Comparing this with a simulation of the interference pattern we expect based on the optics of the telescope, seen in Figure 8b, shows how well the optics are performing. The spacing and orientation of the fringes match very well, with low residuals when taking a difference between the maps.

Two of the four faraday effect phase modulators used in MBI did not work properly and were removed during the second season. This limited which pairs of horns could be used for single baseline observations and eliminated the possibility to make observations with all four horns open to the source at the same time. This is due to the requirement for each horn to have an independent modulation frequency in order to reconstruct the individual baselines during the data analysis process.

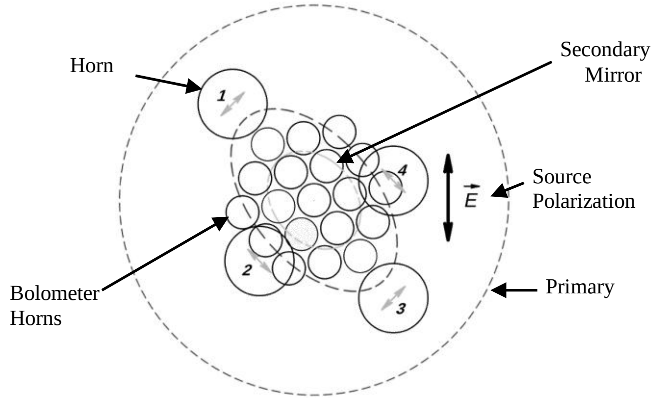
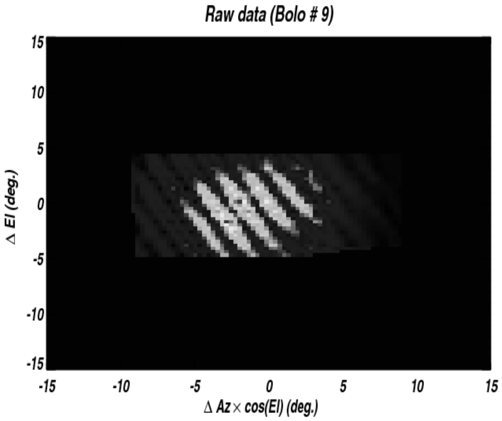


Figure 7: Relative Positions of Horns, Bolometers, and Microwave Source During MBI Observations

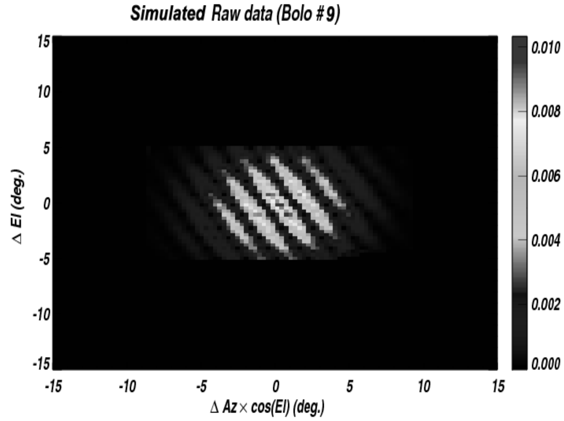
Work is still being conducted to evaluate how to effectivley compare signals from the various bolometers. A method of calibrating the bolometers based on simulations of the telescope is being explored as is a method using on and off source measurements. No direct means of internally calibarting the detectors was included in MBI's design. This calibration difficulty is being taken into consideration in anticipation of designs for a next generation telescope based on MBI's design.

5. ***Conclusion:*** MBI has succesfully made interference measurements of a millimeter-wave source. The faraday effect phase modulators have been found to not be sufficient for future large arrays as there is great variation between each device and the time for transition limits the speed of modulation possible. Plans for a next generation telescope based on the technology used in MBI are underway.

Advances in millimeter-wave phase modulators will allow for improvement in CMB experiments, such as the Millimeter-wave Bolometric Interferometer and it's successor. Phase modulators are required for chopping the signal to reduce sensitivity to drifts and 1/f noise. MBI's successor will allow us to characterize foreground polarization from nearby objects, which is essential for future CMB polarization observations to be successful as well as making observations of the CMB polarization. Additionally, the detection of the low level B-mode polarization of the CMB would provide us further evidence for inflation.



a. **Map of the signal amplitude received at a single bolometer from horns 2 and 3**



b. **Simulated mapping of the signal amplitude using a model of the telescope**

Figure 8: MBI Observed Fringes from Scan of 3mm Source

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Hydrodynamic Simulations of Double-Bent Radio Sources

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Abstract: Using three-dimensional hydrodynamic modeling code, we have simulated and studied the development of Active Galactic Nuclei (AGN) in galaxy groups and clusters, with an emphasis on the reciprocal relationship between AGN and cluster as well as the use of jet curvature as a density probe of the Intergalactic Medium (IGM).

I. Introduction

Active Galactic Nuclei are among the most powerful and spectacular phenomena ever observed. Consequently, the jet trails left behind a mobile AGN serve as highly visible, enormously vast beacons of potential knowledge. Our focus will primarily be on AGN in the relatively high-density regions found inside galaxy groups and clusters, which produce more pronounced effects on these radio sources.

II. Background Information

An AGN emits bipolar relativistic jets, which become swept backward relative to the host galaxy by drag forces produced by their own motion through the IGM. By studying the curvature of these double-bent radio tails, we can use the measurable parameters of power and velocity of the AGN in order to infer the density of the IGM using the equation[1]

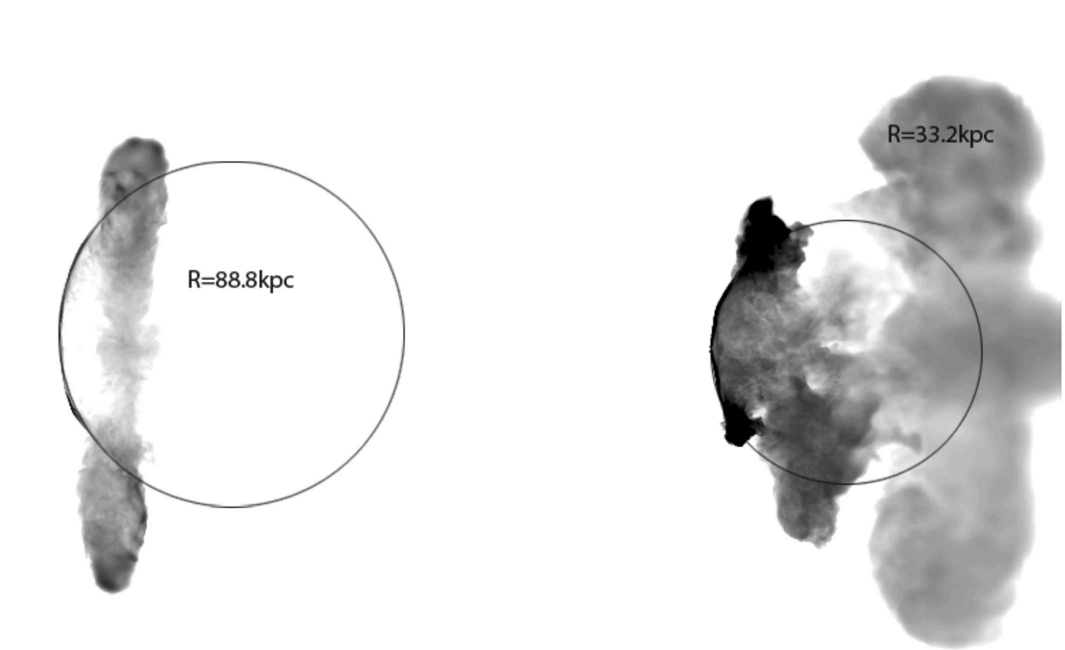
$$\frac{\rho_{\mathrm{IGM}} v_{\mathrm{gal}}^2}{h} = \frac{\mathrm{w}\Gamma^2 \beta^2}{R}, \qquad (1)$$

III. Methods

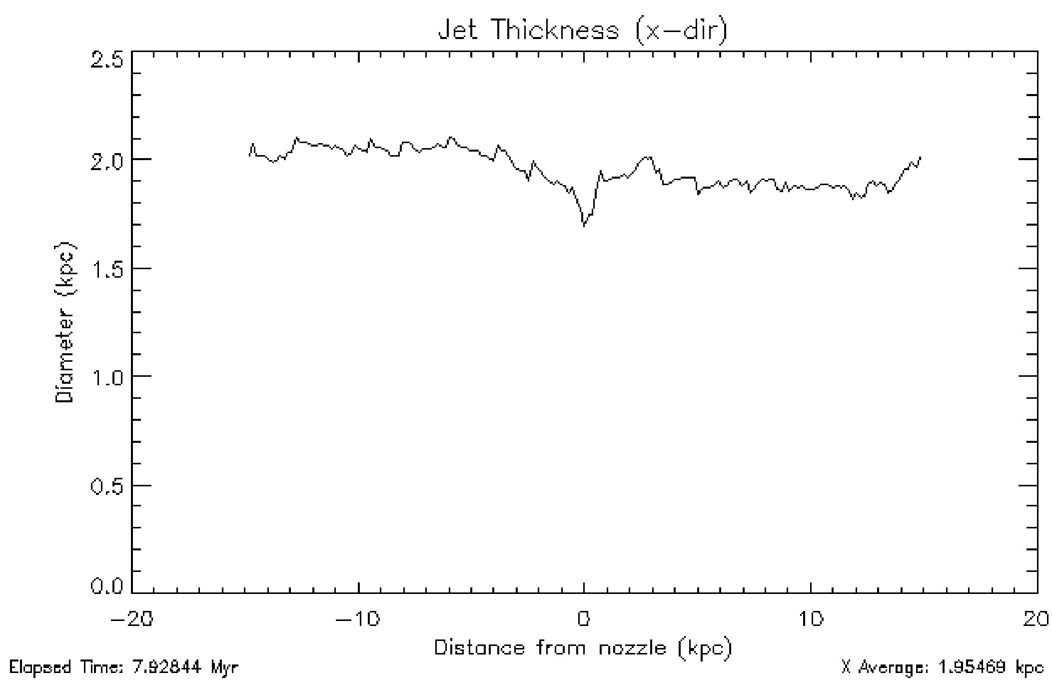
Using the FLASH hydrodynamic simulator, we carry out a series of simulations, varying parameters one by one in order to see how the morphology of the jet reacts. Independent variables include AGN velocity, IGM density, jet power, jet velocity, nozzle diameter, and Mach number. For each parameter, we run several simulations and attempt to empirically determine the relationship between that parameter and our dependent variables, which include jet thickness, radius of curvature, and feedback into the cluster medium as a form of heating.

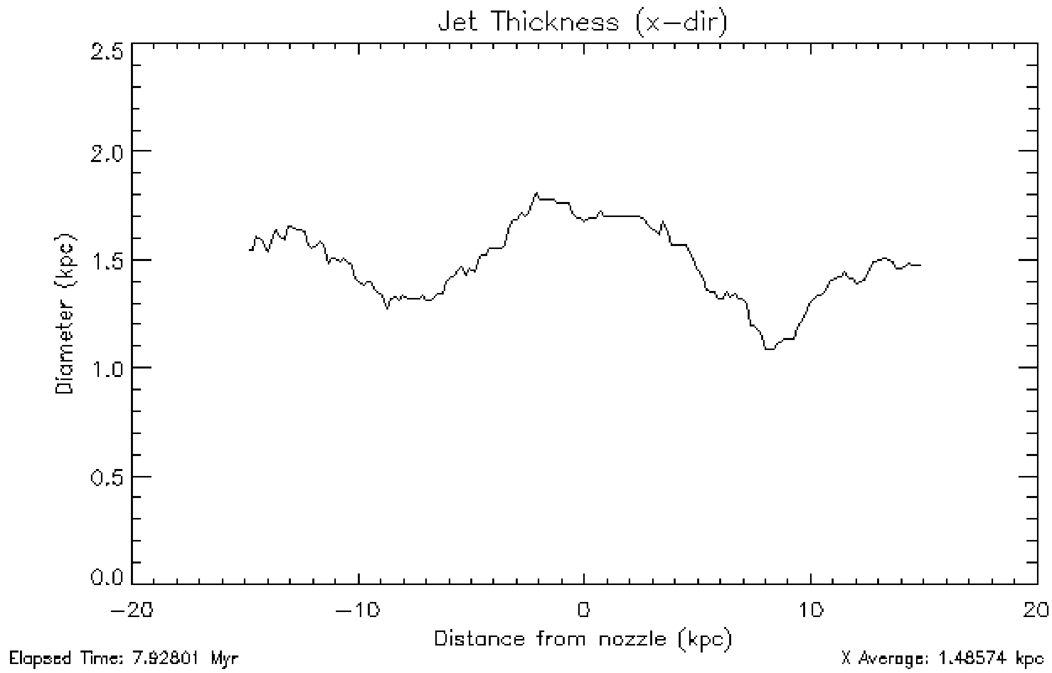
IV. Data

Preliminary data indicates good agreement with theoretical predictions. In the following example case, we see that the baseline compares well with a second simulation using quadruple the standard IGM density.



Radius of curvature is expected to scale inversely with IGM density, yet we see here a four-fold increase in density producing a radius ~0.37 times the original. The explanation for this discrepancy is that the increased IGM density produces a narrower, more collimated jet, which helps to offset some of the expected change in radius, as illustrated by the following plots of again the standard case followed by quadruple density





Taking this extra factor into account brings the corrected effective radius to ~0.28 times the original, which is in close agreement with the expected factor of 0.25

V. Future Projections

Our primary future goal is to finish collecting data by measuring the results of additional parameter adjustments. We also aim to automate the curve fitting process, allowing an easy method to extract the average radius of curvature from a simulation and simultaneously provide a measure of variability over time as the jet evolves.

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[1] Freeland, Cardoso, & Wilcots. 2008. arXiv:0806.3971v1

Big Bang Blackbody Simulator

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University of Wisconsin – Madison

ABSTRACT

The Cosmic Microwave Background (CMB) is a remnant glow from the Big Bang, and as such it provides us with a direct view into the early universe. By mapping out the CMB we are able to view the universe as it appeared when it was only 400,000 years old. The CMB radiates as an almost perfect blackbody at a temperature of 2.7 Kelvin. It is necessary to be able to simulate the CMB as a blackbody source in order to allow us to test instrumentation intended for CMB observation. The purpose of the Big Bang Blackbody Simulator is to construct a blackbody 'cold load' to measure the microwave response of superconducting Transition-Edge Hot-Electron Microbolometers. These detectors will allow us to measure the faint polarization signals in the CMB that are expected to be the result of gravitational waves generated in the very first moments of the universe.

Introduction

Around 400,000 years after the Big Bang, during an era termed 'recombination' the universe had cooled to a point where the photons could no longer scatter with the surrounding baryons. These photons were then allowed to travel freely through space and are what we observe as the Cosmic Microwave Background (CMB) today. The CMB radiates as a nearly perfect blackbody at 2.7 Kelvin. The CMB also contains very faint temperature and polarization inhomogeneities. Around 10^{-34} seconds after the Big Bang a period of rapid expansion occurred. This rapid expansion period, called inflation, produced gravitational waves which would have left an imprint on the polarization of the CMB (Bock et al 2005).

The focus of the Big Bang Blackbody Simulator (BBS) is to create a calibrated source of microwave photons that simulate the CMB as observed from space or the ground in order to measure the response of superconducting the Transition-Edge Hot-Electron Microbolometer (THM). These THM detectors are specifically optimized to take measurements of the CMB. Arrays of 1000's of THM detectors would be sensitive enough to measure the very faint B-mode polarizations in the CMB, the imprint left by gravitational waves.

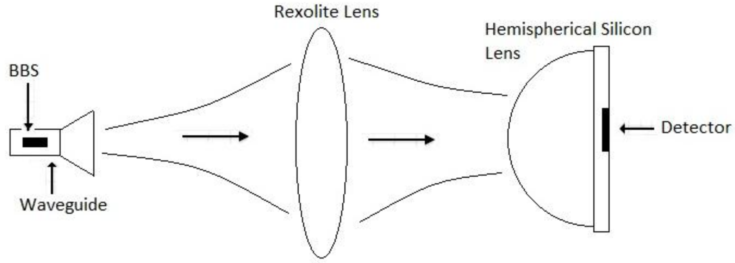

Figure 1: The BBS radiation will be coupled to the THM detector through multiple lenses.

Acknowledgements:

Special thanks to Peter Timbie, Emily Barrentine, and Eric Katzelnick, also to Wisconsin Space Grant Consortium for financial support.

Figure 1 shows how the BBS will be used to test the THM detector. The radiation produced by the BBS will be coupled to the detector through a series of lenses. This entire set up will be then be placed in a cryostat with the left side being cooled to 4 Kelvin and the right to approximately 100 mKelvin to reduce noise.

Construction

The BBS was originally based on the design presented in McGrath et al. (1986) but has since been drastically altered. The BBS consists primarily of a 100 Ohm chip resistor and a copper finline structure, shown in figure 2. When heated, the chip resistor emits thermal radiation which is then coupled into a copper waveguide by the microwave circuit created by the copper finline structure. The copper finline structure is the placed between two pieces of Kapton to electrically and thermally isolate the structure as well as provide mechanical stability.

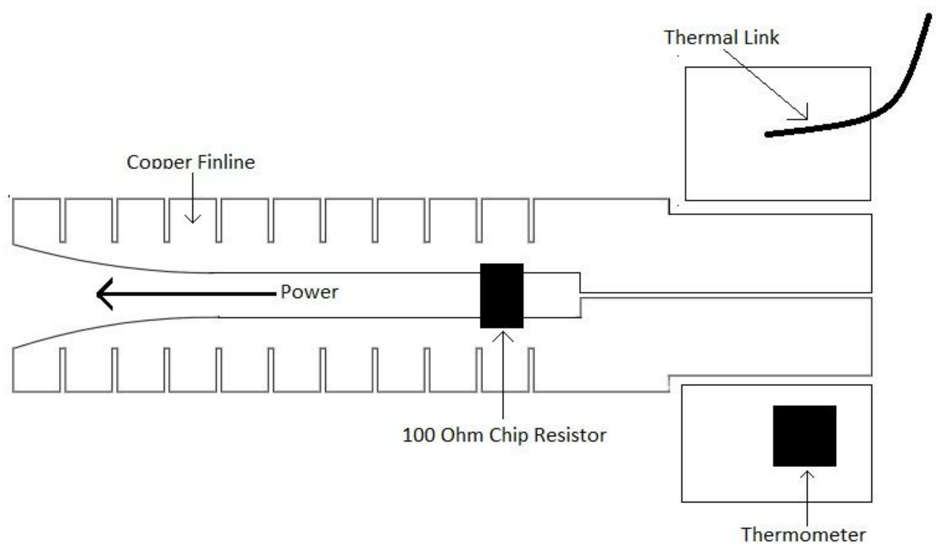

Figure 2: The structure of the BBS.

A Ruthenium Oxide thermistor is used to monitor the temperature of the BBS. A thick copper wire also acts as a thermal think between the BBS and the cold stage, which is used to control how quickly the BBS can be heated and cooled.

Requirements of the Big Bang Blackbody Simulator

In order for the BBS to be effective it must meet a few basic requirements. The first is that it simulates an almost perfect blackbody with an emissivity of 90% or greater. It also needs to emit at the peak of the CMB spectrum, 75 to 110 GHz or approximately 3 mm. Next we must be able to heat the BBS to the desired temperature using low power, 10 mWatts or less. The desired temperature for CMB simulation is 4 to 20 Kelvin. This process of heating and cooling must also happen very quickly in order to viable for laboratory experiments, on the order of one second. To achieve this, the BBS must have low heat capacity and an optimal thermal conductance.

Results

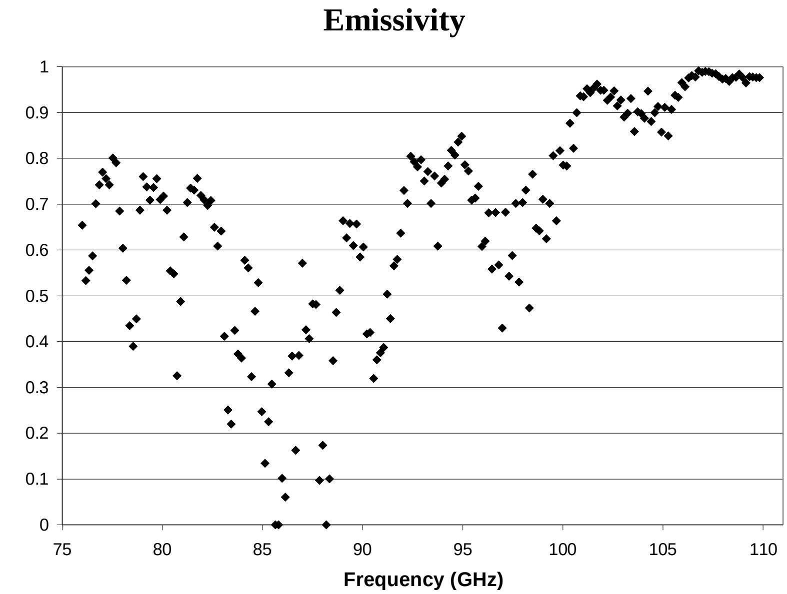

Figure 3: Plot of the emissivity of the BBS versus frequency

Figure 2 shows the emissivity of the BBS as a function of frequency. The emissivity of the BBS peaks around 98% with average emissivity of 69%, which is near the desired level.

To measure the time constant of the BBS, the BBS was placed in a copper waveguide block and then attached to the cold stage in a cryostat cooled with liquid helium to 4 Kelvin. The BBS was then heated to a maximum of 20 Kelvin using Joule power. Figure 4 shows the rise and fall of the temperature of the BBS. Joule power was applied until the temperature stabilized, then the power was shut off and the BBS was allowed to cool.

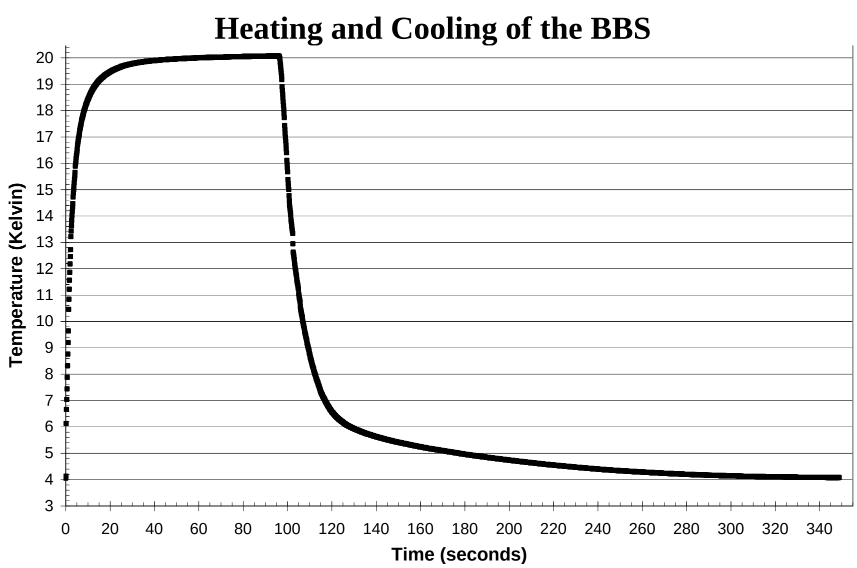

Figure 3: The BBS reaches a maximum temperature of 20 Kelvin when 34 mWatts power applied.

Fitting the temperature versus time curve to an exponential gives a time constant of 3.3 seconds. Varying amounts of power were applied to the BBS to reach maximum temperatures between 12 and 20 Kelvin. Using the power versus temperature graph, figure 4, the thermal conductance, G, was determined by fitting the line to the equation

$$P=C*(T^n-4^n)$$

Then,

$$G= {}^{dP}/_{dT} = n*C*T^{(n-1)}$$

Using these equations, the thermal conductance of the BBS was found to be $2.9\text{x}10^{-3}\ {}^{W}/_{K}$. The heat capacity, the product of the time constant and thermal conductance, was determined to be $9.7\text{x}10^{-3}\ {}^{J}/_{K}$.

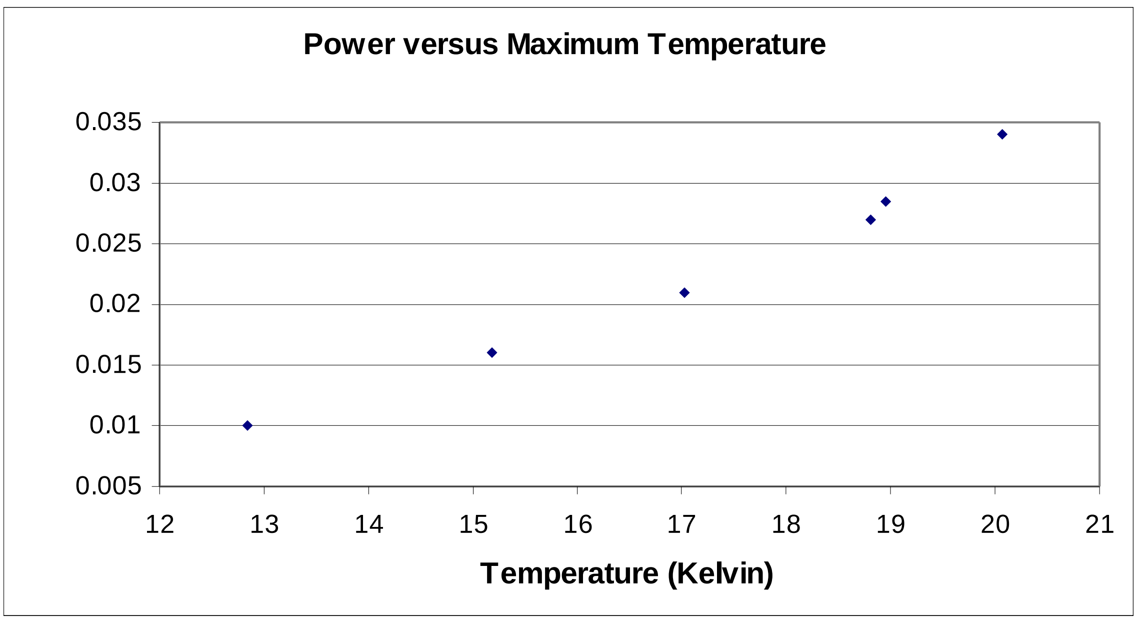

Figure 4: Plotting the power needed to heat the BBS to each maximum temperature gives a thermal conductance of $2.9\text{x}10^{-3}\ {}^{W}/_{K}$.

Conclusions

The initial thermal requirements placed on the BBS, a short time constant and low power usage have been satisfied. The time constant to heat or cool the BBS is approximately 3 seconds, and a maximum of 35 mWatts of power was used, both of which are in the desired range. While the emissivity of the BBS is reasonable, there is some room for improvement. Future work will use two chip resistors in the place of the current one, as preliminary simulations have shown higher emissivity when this resistive area is better distributed in the finline structure.

Next, the Big Bang Blackbody Simulator will be used to test the microwave sensitivity of Transition-Edge Hot-Electron Microbolometer detectors. If successful, these detectors may be used in NASA's CMBPol mission at the end of the decade.

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20th Annual Conference
Part Ten

Education and Public Outreach

A Celebration of Life!

An African American Ethnic Academy & BioPharmaceutical Technology Center Institute Science Outreach Partnership

Barbara Bielec

BioPharmaceutical Technology Center Institute

Abstract

The primary goal of "*A Celebration of Life"* is to support the continued development of African American and other students' interest in science, and to assist in providing them with the tools for success in school. A long-term goal is to increase the number of minority students who successfully complete high school science courses and who choose to pursue STEM careers. In partnership with the African American Ethnic Academy, Inc. (AAEA), a Madison non-profit organization, the BioPharmaceutical Technology Center Institute (BTC Institute) offered *"A Celebration of Life XIV: Let's Fly!"* during summer 2009 and *"A Celebration of Life XV: Healthy Planet"* during summer 2010. Two week sessions for elementary and middle school students were held weekday mornings at the BioPharmaceutical Technology Center, in Madison, Wisconsin. These programs represent a 15-year collaboration between AAEA and the BTC Institute that prioritizes offering a rich range of hands-on science activities for students.

Introduction

The primary goal of "*A Celebration of Life"* is to support the continued development of African American and other students' interest in science, and to help provide them with the tools for success in school. A long-term goal continues to be increasing the number of minority students who successfully complete high school science courses, and who may eventually choose to pursue science, technology, engineering and math (STEM) careers. Extensive efforts are made to ensure participation of students from economically challenged families through the provision of scholarships and transportation.

Program Details

The program themes were *Let's Fly!* and *Healthy Planet!* (focus: water), for 2009 and 2010, respectively. For all sessions, content was selected to emphasize how each content area related to life on earth and to space exploration. Program activities reflect the Wisconsin Model Academic Standards for Science, which follow the form and content of the National Science Education Standards. Over 95% of the student participants were African American. Many received scholarships and transportation to facilitate their participation in the program. A total of fifty-seven students, evenly split between boys and girls, participated in developmentally appropriate learning.

The BTC Institute is pleased to acknowledge the Wisconsin Space Grant Consortium Special Initiatives Program for their financial support.

Table 1: Gender of Participants in *A Celebration of Life!* Summers 2009 & 2010

Program	**Total Participants**	**Girls**	**Boys**
Let’s Fly! 2009 Elementary	14	4	10
Let’s Fly! 2009 Middle School	13	9	4
Healthy Planet 2010 Elementary	18	10	8
Healthy Planet 2010 Middle School	12	5	7
Total	57	28	29

The 2009 *Let’s Fly!* sessions included:

- Discussing African American STEM Professionals, including aviators, astronauts and other NASA employees. Related science activities were also conducted that emphasized and reinforced the accomplishments of these STEM role models.
- Taking Field Trips to the EAA AirVenture Museum in Oshkosh, and to Truax Field in Madison.
- Constructing and testing airfoils, airplanes, kites, parachutes and rockets made out of a variety of materials
- Conducting experiments demonstrating air movement, airplane movement, and the four forces of flight
- Learning about the parts of an airplane and the symbols included in the NASA logo

On the final day of each session, students demonstrated and explained aviation activities in the laboratory to family members and friends. They also shared their posters of African American STEM Professionals. The program was covered by *The Wisconsin State Journal*,*The Madison Times* and *UMOJA* magazine.

The 2010 *Healthy Planet!* sessions included:

- Discussing African American STEM Professionals, including a NASA Engineer who designs water filtration systems for space vehicles. Related science activities were also conducted that emphasized and reinforced the accomplishments of these STEM role models

- Taking Field Trips to the Aldo Leopold Nature Center in Monona, Wisconsin
- Constructing and testing water filtration systems, desalination systems, and models of oil spills and aquifers
- Exploring characteristics of water including: density, pH, and surface tension.
- Making daily observations related to the water cycle (rain gauges, terrariums)
- Learning about daily water usage in the United States compared to other countries
- To-scale modeling of the usable fresh water on earth
- Interacting with Meja Maka, a Financial Assistance Specialist for water and sewerage projects throughout the state for the Wisconsin Department of Natural Resources, who came to the U.S. from Tanzania

On the final day of each session, students demonstrated and explained activities in the laboratory to family members and friends, also sharing their posters of African American STEM Professionals. The program was covered by *The Madison Times* and *UMOJA* magazine.

Results

Pretests and post-tests are administered as part of each program as one indicator of students' learning. Overall, both elementary and middle school students showed an increased knowledge of aviation (2009), water (2010) and African American STEM professionals (both years).

Scientific content knowledge can be measured by the pre- and post-tests, providing information regarding one aspect of program assessment. Another key indication of success is the number of students who had participated in previous AAEA/BTC Institute programs, or who had family members who were previous participants.

Of the 14 elementary students in 2009, 6 had attended previous AAEA/BTC Institute summer sessions. Of the remaining 8 students, 7 of them were in their first year of eligibility for the program (entering 3rd grade in Fall 2009). This "return rate" to the elementary program is less than that of previous years, (67% in 2008 and 57% in 2007[1]) however, it does not include the 6 former elementary students who returned to join the middle school program (as entering 6th grade students), and it is also offset by the many first time 3rd grade students. ([1]B.Bielec, K. Borgh, *Report of activities – Special Initiatives Program*, 5 Sept 08; and B. Bielec, K. Borgh, *Report of activities - Aerospace Outreach Program*, 12 Sept 07)

In 2009, 10 of the 13 middle school students had attended previous AAEA/BTC Institute summer sessions. This return rate of 77% exceeds that of previous years, (67% in 2008 and 57% in 2007[2]). Of those middle school students, 8 of 13 (62%) had participated in the summer program at least three times. ([2]B.Bielec, K. Borgh, *Report of activities – Special Initiatives Program*, 5 Sept 08; and B. Bielec, K. Borgh, *Report of activities - Aerospace Outreach Program*, 12 Sept 07).

Of the 18 elementary students in 2010, 8 had attended previous summer sessions (44%), 3 were in their first year of eligibility for the program, and 6 had family members who were previous participants in the program.

In 2010, 8 of the 12 middle school students (66%) had participated in at least two previous summer programs. When students return for the third, fourth, or fifth time, it is a strong indication of their interest in science programming. In addition, two of the young women who have participated for five years and are now headed to high school have expressed interest in coming back next year to be assistants with the elementary program.

Table 2: Participants in *A Celebration of Life!* Summers 2009 & 2010

Program	**Total Participants**	**Participants in Previous Programs**	**First Year of Eligibility (Grade 3)**
Let's Fly! 2009 Elementary	14	6	7
Let's Fly! 2009 Middle School	13	10	NA
Healthy Planet 2010 Elementary	18	8	3
Healthy Planet 2010 Middle School	12	8	NA
Total	57	32	10

Conclusion

In a 2009 National Science Foundation (NSF) report, entitled *Women, Minorities, and Persons with Disabilities in Science and Engineering,* it was found that: "Underrepresented minorities (blacks, Hispanics, and American Indians/Alaska Natives) increased their share of S & E [Science and Engineering] graduate students somewhat from 1996 to 2006 (from 9% to 11%), but their overall participation remained low. Only in psychology and the social sciences did underrepresented minorities' participation exceed 10% in either year. Participation rates in other fields ranged from a low of 5.8% in earth, atmospheric & ocean sciences to a high of 9.5% in the biological sciences. These graduate study participation rates are well below the 17% share of

S & E baccalaureate degrees earned by underrepresented minorities in 2006." Supporting African American educational opportunities in science is essential to helping increase the number of African American students who will ultimately go into baccalaureate and graduate programs in science. (NSF, *Women, Minorities, and Persons with Disabilities in Science and Engineering: 2009)*

The exploration opportunities provided by "*A Celebration of Life*" enrich and enhance students' scientific knowledge and associated skills. Generating interest in science is crucial to creating a diverse work force of problem solvers, scientists, inventors and engineers for the future. It is also essential for students to see themselves in those roles. Learning about historic and contemporary African American STEM professionals and interacting with African American STEM professionals from the community ensures that they do so.

Finally, this approach is in alignment with the goals and objectives of the National Space Grant College and Fellowship Program:

- "**Mission Statement #1:** Using our national network of scientists, engineers, and educators, enable the development of a diverse workforce of future scientists, engineers, technology professionals, and educators. **Goal #3**: Model diversity in Space Grant leadership, programs, and activities." AAEA/BTC Institute students learned about historic and contemporary African American Science, Technology, Engineering & Math (STEM) Professionals, featuring many who work for NASA.
- "**Mission Statement #3:** Cultivate a nationwide network of partners from universities, industry, museums, science centers, state and local agencies, to pursue state and national aerospace research, education, and economic development goals. **Goal #5**: Establish Space Grant as a viable state/national resource and catalyst for aerospace research, education, and economic development." The BTC Institute has continued to collaborate with AAEA to encourage interest in aerospace education and careers in an underrepresented group, including representatives of many of the above-listed partners as volunteer instructors.
- **Mission Statement #6:** Serve the general public by contributing to scientific literacy. **Goal #11**: Develop Earth, Air, and Space programs to enhance public scientific literacy and to complement community needs. **Goal #12**: Engage in all facets of the community in the excitement of scientific discovery using Science, Math, Engineering and Technology; (Edutainment, Process of Discovery)*."* (National Space Grant College and Fellowship Program Strategic Plan 2002-2006 Executive Summary) The AAEA/BTC Institute science programs were founded, in part, by the great need for quality scientific programming that can engage minority students and strengthen their learning in STEM content. They include sharing this information with family members and others in the community.

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FLY GIRLS
JUNE 2009 AND JUNE 2010

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Abstract

The Fly Girls program introduces high school females to the aviation and aerospace world by bringing together female role models to give young females a foretaste of what this industry can offer to young women. Through this introductory day, girls will understand the importance of continuing to take classes in science, technology, engineering and math (STEM) to better prepare themselves for their future careers.

Program Goals

In 2009 this daylong aerospace workshop involved a partnership with the Aviation Heritage Center of Sheboygan County and the Milwaukee School of Engineering (MSOE). After the success of the 2009 event, it was decided to try and expand the program in 2010. Waukesha County Airport (Crites Field) was chosen as the expansion airport because of the enthusiasm and support from the airport manager and fixed base operator (FBO) on that field.

New partnerships with MSOE developed in 2010 which enabled both programs to become a reality. In Waukesha, the airport manager donated space to host the program, Atlantic Aviation Services, the FBO, donated the lunch and snacks and Stein Aircraft Services made a financial contribution to the event. In Sheboygan a grant was written and received from the Sheboygan Service Club to offset the cost of the rental of the facility.

Milwaukee School of Engineering has been working to promote females in the STEM fields for almost five years. The programs enable young females to broaden their horizons and encourage them to seek out nontraditional careers in their future. Fly Girls is one of these programs. Before September 11th many small airports were open to individuals to explore the world of aviation. Since that time gates have been constructed and access cards are needed for everyone to enter the facilities which limit the opportunity to explore aviation careers. Fly Girls provides the opportunity for females to explore the myriad of career opportunities that are available to them at not only the local airports but the entire aviation and aerospace industry.

Funding supplied by NASA, Wisconsin Space Grant Consortium and Milwaukee School of Engineering
Funding supplied by the Sheboygan Service Club and Stein Aircraft Services
In Kind donations by Atlantic Aviation Services and Waukesha County Airport

Female role models are a vital part of this program. Recruiting female speakers, mentors and pilots is the most challenging aspect of this program. The aerospace/aviation industry is a traditionally male field and females are difficult to find to fill these rolls. However, everyone in the aviation industry is so passionate about their field that they are extremely helpful and willing to participate in these types of program. Once a person experiences a passion for aviation sharing it with others comes naturally

The 2009 Sheboygan program had the Experimental Aircraft Association (EAA) Young Eagles program as the finale for the day. The pilots gave instructions on preflighting an aircraft and taught the attendees about the controls and instruments in the airplane while in flight. Each pilot brought with them a different type of aircraft as well as a different level of flying experience so the girls were able to gain other perspectives regarding aviation. Young Eagle pilots are required to be members of the EAA so that the program is covered under the insurance of the EAA Young Eagles program. Permission slips are needed from the parents in order to participate in that portion of the program.

In 2010 the EAA would not allow Fly Girls to have the flight portion of the program. By their rules, Young Eagles flights are required to be free. A small fee for this program is charged for two reasons. The girls need to take ownership of the program to make sure that they attend and to cover for the cost of the give-away for the program. EAA will not grant an exception to these rules, even though the cost for the program could be justified. In Sheboygan, the Young Eagles rally was publicize as a separate event which was to be held on the same day after the Fly Girl program. Weather, however, did not permit the Young Eagles Rally to take place that day and the attendees were told an alternate day would be set up for the event. In Waukesha, a Young Eagles Rally was being held the following weekend and attendees were given all of the information they needed to come back and have a flight experience at a different time. Many of the girls took advantage of the Young Eagle flights at that time.

Program

Fly Girls 2009 was held at the Aviation Heritage Center in Sheboygan on June 24th with 29 attendees. The enrollment was limited to 30. The opening speaker was a young 16 year old female that has built her own airplane and has been flying since she was nine years old. The attendees were amazed at her knowledge of aviation and her ability to accomplish so much in the aviation field at such a young age.

A behind the scenes tour of the Sheboygan airport introduced these students to the many career possibilities that are available in the aviation and aerospace industry in their own hometown. One of the highlights of the tour was meeting a pilot who flew Air Force One. The girls enjoyed his stories about flying Air Force One and how he was able to achieve that position. Other stops on the tour included learning the responsibilities and services that a fixed base operator has to the aviation community at the airport and touring a business that does aerial photography.

Sessions on aerodynamics, weather and flight planning were also given by female pilots from the Wisconsin Department of Transportation-Bureau of Aeronautics, the 99ers, an international women's pilot group and female flight instructors from Fox Valley Technical College. Many of these individuals were able to mentor females during the lunch portion of the day and answer specific questions regarding their education, careers and aviation.

Each pilot that was doing the Young Eagles flight went through a pre-flight of their aircraft with the students. The students were shown how the subjects they were learning about during the day transferred to the actual flight. Since each airplane held only one or two girls, stations were set up during that time to continue the learning experience for those not flying. A portable flight simulator was brought in to teach the girls about the flight instruments that they would find in the cockpit and how to use them. Flight simulators are a valuable tool in the aviation world and are used at all levels of flight instruction.

The 2010 Fly Girls programs at both facilities were similarly structured but were also completely different because each airport is unique as are presenters at each program. The Waukesha Fly Girl program was completely embraced by the Airport Manager and others at the airport terminal. The conference room was reserved and plans were underway immediately with many offers of help to facilitate the program. The facility where the program was held was smaller so the number of girls was limited to a maximum of 25 with 20-22 a more comfortable number.

Funds for the Fly Girl program were extremely limited this year so email was used to send out the brochure instead of printing the brochure for the Waukesha program. The lists came from previously held MSOE female programs, the science and math teachers at schools in Waukesha County and youth serving organizations in Waukesha County. This proved to be an effective way to inform the community about the program as registration was successful within a couple of weeks. Twenty-two high school females successfully registered for the program which was a perfect number for the size room that was at the facility for our use.

The day started with a guest speaker who had a wonderful passion for aviation and shared her story of how she ended up owning an aircraft services company which also has a flight school. The airport tour started with a short history lesson about the history of aviation in Waukesha County as well as an introduction to the vocabulary of aviation. The FBO showed the attendees the duties and responsibilities of their job and the facilities available for pilots to use. The person who gave the museum tour also showed the girls the hanger where the Waukesha Flying Club airplane is kept and explained many of the aviation instruments in the cockpit to them.

A highlight of the tour was being able to go into the airport control tower. The students had a firsthand look at the job of an air traffic controller, the computer system in a control tower as well as being able to watch as airplanes received permission to land and take off at the airport.

Aviation weather, flight planning and aerodynamics were taught by female pilots from the FAA, the 99'ers and a female mechanic that worked on the field. The presenters were dynamic and were able to capture the attention of the girls by sharing their personal stories as well as providing hands on activities for the girls. There were numerous other mentors from the 99's organization, retired air traffic controllers, as well as flight instructors from the field that answered questions from the girls during the hands on sessions as well as lunch.

Since having the Young Eagle flight was not a part of this program, several pilots brought their aircraft over for a session on how to pre-flight an airplane. The attendees were shown not only how to pre flight an aircraft but the importance behind the procedures. The pilots fielded many questions from the girls during this time.

The final highlight of this program was a tour of the Wisconsin Flight for Life operations which is based at the Waukesha Airport. The tour was most interesting for the girls to see not only the facility but to be able to talk to the pilot and the emergency personnel that worked in this area. The helicopter was quite interesting to see the engineering involved in not only the helicopter itself but also the interior where patients ride and personnel work to keep individuals stable while they are transported to the hospital. As the tour was ending, the crew received an emergency call so the girls were able to watch the speed at which the helicopter was prepared for flight.

2010 was the third year for the Sheboygan Fly Girl program and we knew that we would have repeat attendees the program needed to have some changes. Our guest speaker and one of the presenters for the program was a dynamic female pilot who has won many awards as a flight instructor including flight instructor of the year in Wisconsin. She graciously gave of her day to tell the girls her story and passion for aviation as well as teaching a session on flight planning.

The Sheboygan Aviation Heritage Center is large enough to set up stations for the attendees to rotate through. With 30 females in attendance, the girls were divided in small groups. Some of the stations this year included blade blending and using a sturdy beauticians chair to teach about vertigo. Blade blending is a skill that was taught by National Guard personnel to keep the engine blades safe and free of abrasions.   The girls used files and sandpaper to take out some of the rough spots on the blades. Experiencing vertigo was a little frightening at first for some of the girls. It was taught to teach the attendees that you can't always rely on your senses and must depend on your instruments when flying.

One of the highlights of the airport tour in 2010 was seeing the inside of a new corporate jet which has the ability to fly nonstop between Sheboygan and Beijing. It was quite a thrill for them to see up close the glass control panel in the cockpit of the aircraft and also to see how different the interior is in a commercial jet and a well appointed corporate jet. They were also told that the company needed to have a third pilot come on the trip as a relief pilot to let each pilot have time to rest during a long overseas flight.

Since EAA informed us that we the program was not allowed to combine a Young Eagle rally with the Fly Girl program, the Sheboygan EAA said they would sponsor a Young Eagle rally after our program on the same day. Single engine flying is extremely weather dependent and our scheduled date was not the day to take the girls up in a small airplane. The Young Eagle rally was cancelled due to crosswinds on the field. The girls were disappointed but safety has to be the main concern when making these decisions.

Program Evaluation

Since this is the third year for this project, we have some interesting data from the Fly Girl program. Pre and post assessments were done each year which looked at the attendees' knowledge of the aviation and aerospace field as well as their career interest in the STEM fields along with an evaluation of the workshop.

When answering the statement "I am interested in a STEM career" during the pre-assessment, it was consistently between forty-two and fifty percent of the attendees that responded positively to the statement. Answering the same statement during the post assessment, the responses barely changed. However, asking the attendees whether they were interested in a career in aviation /aerospace the numbers were significantly different. During the pre-assessment between eighteen and twenty-two percent responded positively to the statement. After the workshop, the interest in aviation and aerospace jumped to between sixty-eight and ninety-three percent. This indicated that the attendees gained valuable knowledge and interest in the career possibilities and insight to the world of aviation. Providing this type of programming has given the attendees another aspect of the STEM fields for them to consider as a vocation or an avocation. We have been made aware of three attendees who are in the process of earning their private pilot's license and one of the females is beginning her second year in college as an aviation major, Another will be applying for admission to the Air Force Academy. Providing attendees with positive female role models and mentors has been part of the success of this program.

One of the goals of the Women in Technology program at MSOE has been to encourage continued attendance at STEM programs as the students advance in school. We have found it encouraging seeing some of the same attendees at other programs that MSOE has been involved with and also found it encouraging that sixty-six percent indicated they would return to attend the workshop if it were offered again. We realize that networking and collaborating with female pilots and females interested in other aspects of the aviation world are important to continue to bring fresh and new ideas to young girls to continue this interest.

One goal that has been difficult for us to meet has been to encourage underrepresented female minorities to attend this program. Less than 1% of the attendees in 2009 and 2010 were from this population. We would like to see this population targeted next year for this program if it is funded again. Another goal of the program is to offer a Young Eagles rally on the same day as the Fly Girl program so that the attendees could experience this aspect of aviation. Expanding and changing the curriculum for the program is another aspect that we are looking into for next year as well as the continuing and expanding the collaboration we have begun this year so ensure that the program can continue.

I have been asked to expand this program to a third airport and I am looking into that as an option for the coming year. The aviation and aerospace industry will continue to grow and will need highly trained individuals to work in the many fields that are in this industry. Aerospace is one of the most diverse industries when it comes to career opportunities. Wherever one's talents or interests lie, there are opportunities in the aerospace industry. Continuing to expose young females to the amazing career options that are available to them in their future is a reachable goal for this program.

Science Outreach for Spanish Speakers

Dr. Jim Lattis
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UW Space Place Madison, WI

Abstract
The goal of the Science Outreach for Spanish Speakers program was to start addressing the science achievement discrepancy at an early age by providing fun and stimulating science workshops for Spanish speaking elementary school-aged students and their parents.

There is a great lack of science-related extracurricular activities in Spanish, both in South Madison and across the country. The benefits from participating in these programs were intended for both children and parents. Children explore science in an informal way, have fun while doing it, and increase their interest in science. Parents gain greater understanding of what their children are learning in school, leading to greater involvement in the children's education. This program can be used as a model for other organizations and communities.

A long term goal was to generate interest and enthusiasm in science, particularly astronomy and space science, of underrepresented students. An interest and curiosity about science will make it more likely for these Spanish speaking children to enroll in and successfully complete high school science courses. As a result, they may eventually choose to pursue scientific careers, including those in space-related science and technology.

Background
The Hispanic population in Wisconsin increased from 195,000 in 2000 to 272,000 in 2007, a 41% increase according to the U.S. Census Bureau. Hispanic student K-12 public school enrollment projections in Wisconsin indicate that the number will almost triple between 2006 and 2016. In Wisconsin, the percentage of students with a proficient and advanced achievement in science is significantly higher in White (81%) than Hispanic (53%) students.

For the past 20 years, UW Space Place has provided school children, teachers, and the general public with interesting and unique science programs including stargazing nights, public lectures, workshops for school groups, after school programs, etc. By providing programs in Spanish, we proposed to add to our diverse educational opportunities offered and address the need to provide opportunities for the underrepresented Hispanic community, especially those living in South Madison, where Space Place is located.

Beginning in 2008, we offered public Saturday morning science workshops and stargazing nights in Spanish. To publicize the events, we ran an ad in a local Spanish newspaper "La Comunidad" and sent fliers out to local bilingual schools and classrooms. The response that we received from those attending was very positive but tended to be families whose native language was English and who wanted to learn or improve their Spanish.

With a grant from the WSGC, we were able to assess ways of promoting our programs more effectively to reach intended audiences and increase our collaborations with other science outreach groups on the UW-Madison campus.

Procedures and Outcomes

Through the network of UW-Madison outreach groups, we planned a science event for families called "Explorando las Ciencias (Exploring the Sciences)". This was patterned after an annual event on the Madison campus called "Science Expeditions" which features hands-on activities, demonstrations and science shows on the Madison campus.

Explorando las Ciencias used the same format but on a smaller scale. Space Place staff and other campus outreach groups including SPICE (Students Participating in Chemical Education), Biology Outreach Club, MicroExplorers (Biochemistry) and IceCube (neutrino astronomy) participated in the planning. More than 130 people attended the event, which took place on Sunday, November 15, 2009 from noon-4:00. Student volunteers from the outreach groups staffed over a dozen hands-on activity stations and each station had a Spanish translator/volunteer. The translator/volunteers helped with the translation of any printed materials at each station. Translators were also available for the two Science Spectacular Shows - the Wonders of Physics and Fusion Science Theater (Chemistry).

One of the organizers later remarked that this was one of the most diverse events she had ever seen run by outreach groups. Through surveys in both English and Spanish that were given to people, we found that 26 of 45 families had not visited Space Place before and many of those expressed an interest in other bilingual programming. Fifteen families attended because it was a bilingual event and 3 of those families spoke only Spanish.

Our survey also included a question on how they had heard about the event. This was an important piece of information for us since a large portion of our planning and resources and had gone into promotion. In order to publicize the event, we designed bilingual fliers/posters to go out to elementary and middle schools in the neighborhoods surrounding Space Place, a bilingual school in the Madison School District, local Spanish bakeries and restaurants, and a multicultural center located in south Madison. The event was also promoted on a bilingual radio program and we made personal visits to several Spanish organizations.

From the results of our survey, it was clear that friend and family networks were key to marketing and brought in the most people. We found that partnerships with Spanish organizations also brought in a number of other families who spoke only Spanish. Other feedback from participants included comments such as "event totally exceeded our expectations" and "we would love to come to more of these".

Following Explorando las Ciencias, we continued our Spanish programming at Space Place with a number of other events. A bilingual storyteller and singer presented a public program at Space Place in collaboration with the South Madison Public Library and our annual New Year's Eve program (US Bank Eve) featured the same entertainer with stories in Spanish and English about the night sky.

In January 2010 we hosted another event similar to Explorando las Ciencias. Planned Parenthood of Dane County was offering cancer screening for Latino women and wanted to provide childcare during the screening. Since Planned Parenthood did not have facilities for the children, Space Place offered the use of our space and brought in many of the same hands-on stations, activities and shows that we had used previously. Most of the groups had the same bilingual materials that they had used before so preparation time and planning was minimal to recreate the program.

We were also asked to promote our Spanish events by Wright Middle School, one of the schools in which we had handed out fliers and is located in south Madison near Space Place. We attended a science night organized by the school's resource teachers and gave a presentation in Spanish and English for parents encouraging families to visit Space Place.

Lessons Learned and Future Work

Sustained partnerships are clearly the key to successful science outreach for Spanish speakers. This includes a wide range of partners. Through previous contacts with other outreach groups on the UW-Madison campus, we were able to provide a variety of science activities and programs. These outreach groups could bring in students from their own departments who spoke Spanish and had a background in science. This partnership provided us with both a wide variety of science topics and a group of bilingual presenters.

Partnering with Spanish groups and organization was another very effective way of promoting our events. By providing programming during childcare, we gave children and parents a sampling of some of our science programming and hopefully encouraged their attendance at future events.

Our plan for the future is to make Explorando las Ciencias an annual event and we are currently in the process of organizing the 2010 event. Through funding from the WSGC we have a better understanding of ways to promote and market our events and create partnerships to carry us into future programming.

To the Moon and Beyond: Lunar Expedition

Chrissy Paape
Space Explorers, Inc.*

Aerospace Outreach Program 2009-2010

Synopsis:

Space Explorers, Inc. facilitated a one day workshop "To the Moon and Beyond: Lunar Expedition" on a Saturday, November 14, 2009. The workshop provided K-12 teachers with personalized training, better preparing them to teach various science concepts in their respective schools.

Space Explorers developed this workshop and programming to improve the quality of science instruction in Northeastern Wisconsin. The teachers attending the workshop received a set of classroom activities which they were trained to use with their students throughout the school year.

To assist schools in implementing their new curriculum resources, each participating teacher received access to Space Explorers universal program. The universal program includes access to Lunar Expedition, Mission: Mars, Asteroid Encounter, Suborbital Sojourn, Orbital Laboratory®, and K-3 Space®. Schools ran Mars Explorer and the team-based simulations, implemented inquiry-based interactive applets, and explored Space Library®. While the workshop primarily focused on the Lunar Expedition program, all of these resources were provided.

Program Details:

Founded in 1994, Space Explorers has established itself within the educational community as an innovative company with the goal of connecting K-12 students with space exploration. The organization accomplishes this by bringing the excitement of space exploration into classrooms across the country. One of the tools Space Explorers uses to promote space exploration is providing professional development opportunities for science educators.

Lunar Expedition is Space Explorers' lunar education module that was designed by teachers for teachers. This program provides educators with the tools they need to prepare and inspire students. Lunar Expedition allows students to simulate the roles of scientists and engineers as they send a spacecraft to the Moon. Teams of students work together to accomplish specific goals as their spacecraft navigates to the Moon. The mission is an authentic experience that gives students a unique perspective on what goes into a mission, and allows students to become active participants in a simulation based on an actual NASA mission. Preparation and follow-up activities are important components

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* Space Explorers, Inc. would like to extend special thanks and acknowledgement to the Wisconsin Space Grant Consortium (Aerospace Outreach Program) for their generous financial support for this project.

of the mission simulation experience. Lesson plans are available for teachers to prepare their students for the missions. Lunar Expedition also includes access to the Space Library and Interactive Applets programs to assist teachers in mission preparation. The inquiry-based applets allow students to visualize and test various scenarios demonstrating the physics behind launching and maneuvering a spacecraft and the Space Library provides information on what is known about the Moon to date. The programming has been developed and tested as a medium to connect the school's technology resources with the curriculum being used in science classrooms.

Our hands-on approach to learning strengthens students' core competencies, affords classrooms the opportunity to work together as a team, promotes problem solving and decision making, and encourages students to think outside the box in order to achieve positive results. As a result, teachers report students' interest in science increases as a result of involvement with Space Explorers. This project aligned with several of NASA's education goals:

- **Objective 1.2 Student Support (Educate)** Provide NASA competency-building education and research opportunities to individuals to develop qualified undergraduate and graduate students who are prepared for employment in STEM disciplines at NASA, industry, and higher education.
- **Objective 2.1 Educator Professional Development (Engage)** Provide short duration professional development and training opportunities to educators, equipping them with the skills and knowledge to attract and retain students in STEM disciplines.
- **Objective 2.4 Student Involvement, K-12 (Engage)** Provide K-12 students with authentic first-hand opportunities to participate in NASA mission activities, thus inspiring interest in STEM disciplines and careers, as well as provide opportunities for family involvement in K-12 student learning in STEM areas.
- **Objective 3.2 Professional Development for Information Education Providers (Engage)** Provide opportunities to improve the competency and qualifications of STEM informal educators, enabling them to effectively and accurately communicate information about NASA activities and access NASA data for programs and exhibits.

Space Explorers Lunar Expedition program is also aligned to meet a variety of the required national science standards. (See Appendix A for complete listing of standards met.)

Results:

Wisconsin Science Network eBlast e-mailed the workshop announcement to their listserv of teachers. Green Bay school district promoted the workshop in their professional development My Learning Plan website. As an extra incentive, Green Bay School District teachers received credit for their time at the workshop. In addition, Space Explorers, Inc. staff called and e-mailed schools throughout Northeastern Wisconsin, informing educators of the workshop.

Attendance in the workshop was concentrated within the schools in Northeastern Wisconsin yet included schools throughout the state. Participating schools included Our Lady of Lourdes, St. John the Baptist, NEW International School, Richland Center High School, Wausau, Lombardi Middle School, King Elementary School, and Red Smith Elementary School. Between one to five teachers from each school attended the workshop.

Evaluation

In response to the statement: “The workshop raised my level of exposure and interest in space, aerospace, and space related science, design, or technology and its potential benefits.” All but one answered “strongly agree.” The one participating teacher who answered differently answered “agree” and wrote “I was already interested.”

All the activities covered received high remarks. The favorite activity was the Interactive Applets, followed by the Moonlink® Simulation. Suggestions for improvement included:

- Have computers all face Smart Board.
- It was great. It kept me engaged on a Saturday!
- Website is great, appreciate the offers of follow-up support.

Conclusion:

Space Explorers is thankful for the opportunity to partner with the Wisconsin Space Grant Consortium to conduct teacher training in the Northeast Wisconsin. Workshops like these provide teachers with new activities and ideas they can use in their own classrooms. These activities then inspire their students who begin to feed off their teachers’ excitement and seek out learning more about the field of aerospace and technology. The end result is a cohort of students who see a future for themselves in the areas of science, technology, and mathematics. By supporting these teachers, the Wisconsin Space Grant Consortium is investing in future scientists, engineers, and related professionals. It is the future students in Wisconsin colleges and universities that will continue to shape Wisconsin into a global leader in aerospace and space science research.

Appendix A

Lunar Expedition National Standards Matrix

Lesson*	1	2	3	4	5	6	7	8	9	10	11	12	13	14
UNIFYING CONCEPTS AND PROCESSES														
Systems, order, and organization					✓	✓								
Evidence, models, and explanation			✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Change, constancy, and measurement												✓		
Evolution and equilibrium														
Form and function	✓													
SCIENCE AS INQUIRY														
Abilities necessary to do scientific inquiry												✓		
Understandings about scientific inquiry												✓		
PHYSICAL SCIENCE														
Properties and changes of properties in matter			✓	✓	✓			✓				✓		✓
Motion and forces	✓		✓		✓	✓			✓	✓	✓	✓	✓	
Transfer of energy				✓		✓			✓		✓		✓	✓
LIFE SCIENCE														
Structure and function in living systems														
Reproduction and heredity														
Regulation and behavior														
Populations and ecosystems														
Diversity and adaptations of organisms														
EARTH AND SPACE SCIENCE														
Structure of the earth system												✓		
Earth's history									✓					
Earth in the solar system	✓		✓		✓	✓		✓	✓	✓	✓		✓	
SCIENCE AND TECHNOLOGY														
Abilities of technological design	✓	✓		✓			✓	✓		✓			✓	✓
Understandings about science and technology	✓	✓		✓			✓	✓						
SCIENCE IN PERSONAL AND SOCIAL PERSPECTIVES														
Personal health														
Populations, resources, and environments														
Natural hazards														
Risks and benefits							✓	✓				✓		
Science and technology in society				✓			✓	✓		✓				
HISTORY AND NATURE OF SCIENCE														
Science as a human endeavor				✓			✓	✓	✓	✓				
Nature of science							✓	✓	✓		✓		✓	✓
History of science							✓	✓	✓					

***** Lesson numbers = 1-Mission Patch, 2-Choosing Position, 3-Moon Introduction, 4-Prospector Spacecraft, 5-Rotation/Revolution, 6-Phases, 7-Exploration History, 8-Apollo, 9-Moon's History, 10-Rocketry, 11-Gravity, 12-Impact Craters, 13-Magnetism, & 14-Electromagnetic Spectrum

ELEMENTARY ROCKETS FOR SCHOOLS

JUDY SCHIEBLE ELEMENTARY CHAIR MAY 2010

Synopsis

The Elementary Rocket Launch Program (ERLP) proposes to stimulate an academic interests in Science, Math, and Technology (SMT) and reinforce the student's knowledge in the areas as it applies to the aerospace field. Through hands-on activity of rocket construction, 4th and 5th grade students will develop teamwork, critical thinking, Science, Math and Technology skills.

Goals and Value of Project

The Elementary Rocket Launch Program is designed to stimulate an academic interest in Science, Math and Technology and to aid the student and public of future aerospace pursuits. This event provides an opportunity for students to participate in hands-on environment in aerospace technology through rocket construction, rocket launches, and educational activities.

Background

The Elementary Rocket Launch started with 4th &5th graders of the Sheboygan County filling out an application with a ten entry fee. The students were given a launch time, so they knew when to arrive and launch their rocket. This was the format for a few years. The students would come from the public, parochial, and Charter Schools, as well as Home-schooled Children. These students were recruited through the schools and the internet. The Hmong and Spanish students were contacted through the corresponding ELL program in their Elementary School. Applications were written in their language, so they could understand the purpose of the program. To be eligible, students needed to submit a completed application for with a ten-dollar entry fee. Students were selected on a first-come-basis.

To increase the creativity of the program, the introduction of two different rocket kits for the each grade -level. A smaller rocket kit for the 4th graders and larger rocket kit for the 5th graders. This method kept the student's interest up, because there was an increase in the number of participants in the next three years. The maximum number of participants was reached for the two years in a row. The students did their own public relations from year to year.

The need to enhance the interest and challenge in Science and the Technology field, another component had to add to the program. The program needed to keep all of the previous elements to still reach all levels of interests, skills, and creativity.

Procedure

After talking with elementary teachers from other elementary schools and science organizations, their usage of plastic bottle rockets in the classrooms was a positive experience for the teacher and the students. Adding this to this element to the elementary rocket launch program would be a positive experience for 4th and 5th graders.

Further discussion was held with a few Elementary teachers of Oostburg Elementary School to clarify the written description of the options and how each student· could choose their option to meet their level of skill, creativity and interest. Critical and creative thinking processes are in combination of abilities, knowledge, values, and attitudes. Critical thinking can be self-directed as scientific thinking and critical inquiry.

The current website for Rockets for Schools for the elementary launch was updated by the Space Explorers staff with in-time of the event. From the website, the student and parent could find the need the options descriptions, application forms and contact information. This allowed 4th & 5th graders of the Sheboygan County from either Public, Parochial and Charter Schools, with additional participants from Home School environment to partake in the event.

Boys and girls between the ages of 7-11 years show evidence for organized and logical thinking process. An added element to the program was to offer the students two different paths of technology in the Science and Math fields. The student could choose one or both options. The first option was the traditional path to put together a level 1 rocket kit The second option was for students to construct a 2-liter plastic bottle rocket with instructions given and many ways to vary it.

The boys and girls of the ages 7-11 have the ability to perform multiple classification tasks, order objects in a logical sequence and capable of concrete problem-solving. With the construction of the rocket kit, the variations had its limits. Those students who choose the plastic bottle rocket option, many of them were doing this for the first time. Those students who choose this option, a few also chose to build the rocket kit. The problem that rose was getting these students to attend the different sessions for building both of their rockets. This was hard to schedule for some parents, because of the other activities the family was a part of. If the student and parent family could not make both building sessions separately, the student had a hard time finishing the plastic bottle rocket at one building session. The student was allowed to take the plastic bottle rocket home, finish it, also make any alterations to their rocket. On the launch day, bring their rocket to the event at their scheduled launch time.

At the elementary launch event we had two launch areas, one for the model rockets and the other for the plastic bottle rocket. The launch started with the launching of the model rockets. The launching of the plastic bottle rockets started later and ran longer giving the students as many times they wanted to launch their rocket. Plus, those students who choose to do the model rocket kit, would launch this and proceed to the plastic bottle rocket launch area. An option to the students launching their bottle rocket, was to add water. The students who experimented with this variable, along with adding various amounts of psi provided opportunities for higher levels of critical thinking and further learning.

Results *I* Outcomes

With the new options added to this year's Elementary Rocket Launch there was a positive showing to the program. Students' first-time attending the program tried more than one option. A few students tried just the new option (2 -liter plastic bottle rocket), while most students stayed to the traditional model rocket kit. There were a few students who tried a combination of both options: rocket kit and plastic bottle rocket. The students that made the plastic bottle rocket enjoyed the challenge. The parent(s) also saw a different path of learning Science and Math in Technology.

The project did comprise of working with 5th graders at Oostburg Elementary where the teachers engaged in this project implementing it in the Physical Science curriculum. Worksheets were created by the teacher to support the application, analysis, and extensions to the student for higher critical thinking and provide opportunities for further learning. Students were able to make conclusions based on their findings they collected on their data sheet. The group work of the student's demonstrated teamwork, generating new ideas and further analysis of the project.

There was separate building session for the Plastic Bottle Rocket, as well as for the building session of the rocket kit. This is a 'must' because a student could not make both the rocket kit and the plastic bottle rocket in one two-hour building session. For a few students & parents found it difficult to do both -some parents had scheduling problems because of other family commitments-they could take their plastic bottle rocket home to finish it.

The results of the 'returned' surveys indicated that the students enjoyed the 'new' item added to the Elementary Rocket Launch. There was a 'target' area placed on the field for the students in the plastic bottle rocket launch for them to land their rocket. Many students came in 'reachable' distance of the target.

Conclusions

Knowing that the Elementary Rocket Launch Program needed a new direction, to keep the students interested in rocketry and to have fun doing it; this a positive move. Working with students for many years, I knew that not all students would choose this new option. I could see that the students were more interested in doing this new option. Some students who never did any construction in rocketry, did the plastic bottle rocket and enjoyed it very much. The students took an interest in their rocket, whether it was the kit or the plastic bottle rocket.

There will minor changes in the written description of each of the options for the students and parents for clarity to make things 'run' smoother. There will be a separate designated building sessions for both the rocket kit and 2-liter plastic bottle rocket. This will be written in the description of option. This will allow better planning for the family of the student(s).

Minor adjustments will be made to the plastic bottle launcher, so the student(s) so it will be easier for them to use it and launch. Thus giving the student(s) better results in their launch, increasing the experience of learning and having fun doing it.

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Combining Writing Across the Curriculum Strategies in Community-Based Programs: Teaching Core Concepts in Science

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Abstract: Persistent achievement gaps affect many Wisconsin school districts. Correlations between income and achievement greatly increase the challenges facing local schools. A recent Harvard Family Research Project study demonstrates that learning support systems outside of school hours are a critical element in long-term student success. Many communities now recognize that partnerships with community-based non-profit groups are essential. The Simpson Street Free Press is a solid academic program, with outstanding community support, and a proven record of success. For 18 years the Simpson Street Free Press has successfully demonstrated that academic success is attainable for all kids. Our student reporters, ages 11-18, learn practical academic and vocational skills through an elaborate process of writing and publishing. We use proven writing across the curriculum strategies to produce thoughtful, well-researched articles on topics ranging from the latest NASA missions to ancient civilizations; from plate tectonics and climate change. We also write extensively about Wisconsin's changing economy and encourage young people to explore careers in science and technology. We use proven methods and nationally recognized best practices to develop lesson plans that work for kids. Our programs help bridge the achievement gap in the communities we serve. 90% of our students increase their core GPA within two semesters and 92% of program graduates go on to college.

1) Organization History and Mission

Wisconsin's own Simpson Street Free Press is now officially designated "one of America's best youth programs." The prestigious 2008 national Coming Up Taller Award was recently presented to our organization at a White House ceremony in Washington, D.C. The award was presented by the President's Committee on the Arts and Humanities, the National Endowment for the Arts, and the National Endowment for the Humanities. Committee members closely examined SSFP curriculum methods and cited our organization for "a thoroughly innovative approach to fostering academic achievement" and "pioneering new and exciting strategies to integrate core subject curriculum into community-based youth programs."

Across the country, communities search for innovative ways to promote achievement and engage young people in civic life. We do just that. Our student reporters, ages 11-18, learn practical academic and vocational skills. They learn to conduct research and use technology. The skills practiced in our newsroom are easily transferred to the classroom. In turn, the publications produced by our hardworking students reach thousands of their peers with powerful messages of achievement and success. It is this multi- mission approach that makes our programs so efficient and so effective. Simpson Street Free Press, Inc. is an organization built on ideas and innovation. We have honed an approach to community-based academics that really works. In turn, our publications influence young readers on a mass scale. Our core curriculum approach builds academic self-confidence, in particular for students from low-income backgrounds. The work our students produce is widely read and very popular. Our student reporters produce a thoughtful and well-researched space science section. Our newspapers also include sections on science and technology, the biological science, and natural history. This sort of coverage draws young readers into academic subjects in new and interesting ways. With print circulation at 23,000 and the addition of a new online version in 2010, the Simpson Street Free Press reaches thousands of young people with very powerful messages of academic achievement. The students of the Simpson Street Free Press are role models in the truest and most accurate meaning of that oft-used term.

Our organization has two missions:
Mission #1: Provide a challenging academic experience for our teen writing staff.
Simpson Street Free Press students pursue their craft in a challenging and authentic newsroom atmosphere. Intensive academic lesson plans are the backbone of all Simpson Street Free Press programs. These lesson plans are developed and executed by an experienced, professional teaching staff. We teach young writers to pull out main ideas, write good lead sentences, and organize their writing effectively. Our core strategy is to teach across the curriculum. Students learn science, geography, and history while practicing the basics: writing, reading, researching, critical thinking, and using computers. Simpson Street Free Press students acquire practical academic skills, and quickly learn to apply these skills in the classroom. Our writers are required to revise each article many times prior to publication. The assignments are challenging and the work demanding, but the rewards are tangible and practical. Tomorrow's community leaders are training today at the Simpson Street Free Press.

Mission #2: Spread a positive message of youth achievement, academic success, and community service throughout Madison and the surrounding area.
The student writers of the Simpson Street Free Press are well known and very influential among their peers. They are role models in the truest sense of the term. There's no achievement gap in the Free Press newsroom and our students send that message, in very clear terms, to thousands of local kids. Our reporters write clearly and poignantly about achievement and success. It is symbolically important that this influential publication is written and produced in south Madison – largely by south Madison kids. The messages of the Simpson Street Free Press are clear: drugs, alcohol, and smoking are bad; core academics, science and geography are cool. Achievement can be, and is, for all kids. These messages resonate with our young readers. Free Press writers are effective role models because they are real and because they are local. They seem "just like us" to kids who read the paper. In our southside newsroom, tomorrow's community leaders are spreading positive and timely messages today.

2) Program/project description

Simpson Street Free Press Program Description
Solid coverage of core academic subjects is the trademark of the Simpson Street Free Press. The 45 students who work at the Simpson Street Free Press receive a valuable academic experience that is unduplicated anywhere. Subjects like science, history, and geography come to life on the pages of our award-winning newspaper. Our programs are designed to complement school curriculum and support student performance. Recent research provides evidence that achievement gaps and writing proficiency are related. And writing has taken on new importance

since 2005 when a writing section was added to SAT college entrance tests. A 2007 report by the National Center for Educational Statistics cites modest national gains in writing proficiency. But the study also reported a consistent achievement gap: a 20-point gap between students of color and their white counterparts. The report also recognized significant gains in school districts that increased their reliance on writing across the curriculum strategies.

This is exactly what we do at the Simpson Street Free Press. And it is why our Space Science and other science sections are such effective learning tools for our students. All Free Press lesson plans are constructed around our core, writing across the curriculum philosophy. Through writing-based lesson plans our students explore core subject areas and polish practical skills. Through writing our students learn to think critically, act decisively, conduct research and work as a team. Through writing our students gain critical academic self-confidence. We conduct trimester student evaluations and track report cards to monitor each student's progress. Our success rate is consistently high.

3) A Focus on Core Science Curriculum

The work our students produce is widely read and very popular. Our student reporters produce thoughtful, well-researched articles on a range of science topics. Our science sections anchor each new issue. The Space Science section focuses primarily in two content areas: New discoveries and current research, and the opportunities that exist for students interested in pursuing science careers.

Simpson Street Free Press student writers explore and discover the fascinating world of science through a series of writing-based lesson plans. Working with our professional teaching staff, our students (and their readers) learn to think critically about a range of science-related topics. Using current research and local professionals as resources, these young science reporters explore our environment, our planet, our solar system, and the fascinating fields of science.

In turn, young readers of the Simpson Street Free Press embark on explorations of their own. Simpson Street Free Press science coverage is designed to complement the Madison Metropolitan School District's school curriculum. Science-focused curriculum guides, produced by our teaching staff, complement each publication of the Simpson Street Free Press and facilitate its use as a classroom teaching tool. Our students make regular community and media appearances, reading samples of their science writing work. Their work is also regularly published in The Capital Times, Wisconsin State Journal, and other area publications.

4) Expanding our Message and Vision

With print circulation at 23,000, the Simpson Street Free Press now prints more pages, more often, and reaches more young readers than ever before. In an effort to include more students, the Simpson Street Free Press is expanding. We recently launched an entirely new online publication. New online publications now allow us to include more students in our programs and reach thousands of additional young readers with stories that engage and educate. Expanding our menu of programs and lesson plans is an investment in proven strategies. Planning is already underway to expand our science content. New online publications will operate in concert with our print versions. Using online technology enhances our award-winning approach to science learning and community-based academics. Young readers across the state are now able to freely access topics that interest them and browse the extensive Free Press archives.

These expansion efforts will allow more students than ever to polish practical academic and real-life work skills. A newsroom is an excellent place to gain practical experience. And it is an excellent place to foster a love of science. The Free Press newsroom is a dynamic cauldron of learning. Because our reporters focus their research and writing efforts in the core subject areas, they acquire skill sets that really matter.

The Simpson Street Free Press would like to thank Wisconsin Space Grant for its ongoing support of our program.

Journey to Planet Earth: A Public Outreach and Teacher Training Course

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ABSTRACT

In the spring of 2010 in Antigo, Wisconsin, a series of "Journey to Planet Earth" meetings were held, including a public lecture series and star party (at the public library and outdoor training center), teacher training workshops (at the middle and high schools), and a new freshman orientation session. Public attendance was in the hundreds, and the teacher workshops included six teachers each. Eleven students self-selected for the orientation session. The topics covered cosmic structure, star and planet formation, habitable realms in the universe, and changing relationship between life and the Earth. These topics were united under specific themes: (1) the universe is a network of relationships, not a collection of objects, (2) life is a lens through which those relationships can be viewed, and (3) every component of the universe is important to life in some way. In particular, a claim was made that every image could be viewed by the participants as having some profound significance to life in the universe. Examples of this perspective were given throughout the talks and star party.

Introduction

In northern Wisconsin, citizens have few opportunities for interaction with scientists and engineers, especially those who work in space-related fields. In the winter of 2007, Turnbull visited her hometown of Antigo and gave a public lecture on astronomy at the Antigo Public Library. Based on the high attendance and local media coverage of that event in spite of abnormally bitter cold temperatures, in 2009 the Global Science Institute (recently founded in Antigo) collaborated with the Antigo Public Library and Unified School District of Antigo to propose a lecture series based on life in the universe and life on Earth. At the same time, the PBS television series entitled "Journey to Planet Earth" became available on DVD, and this was deemed a useful teaching companion for the themes explored in the public lecture series. The Wisconsin Space Grant Consortium awarded funds both to purchase the DVDs and carry out public talks in the spring of 2010.

The goals of the "Journey" program were (1) to raise public awareness and understanding of relationships between the Earth, the universe, and ourselves, and (2) help community members use this scientific knowledge as a springboard toward community projects that tangibly improve the sustainability and quality of life in Antigo. Through training of teachers and public presentations, students were especially targeted to demonstrate how science can and should be used to create a community that is healthy, happy, and wise.

Procedure

Public lectures. Four public lectures plus an outdoor star party were held in March and April of 2010. The lectures each began with stating a "Take Home Point" (THP). For example, Lecture 1 began with the THP: The universe is not a collection of objects. A

[1]The Global Science Institute thanks the Wisconsin Space Grant Consortium as the primary source of funding for this outreach project.

slide was then shown depicting an aspect of the universe as a collection of objects (as in Figure 1, the Solar System), and the audience was given the opportunity to point out flaws in the picture based on their own understanding. From this basic list of corrections (including incorrect relative sizes, incorrect spacing of objects, missing moons, etc), other less appreciated aspects were filled in by the lecturer (including families of minor planets, solar activity cycles, tidal forces between planets) and a more accurate rendering was presented (as in Figure 2). In this way, a more dynamic and interconnected picture of the universe's constituents was built, until participants could begin to see relationships playing out on grander scales (for example, as in Figure 3, the dynamics and diversity of stars and dust within an entire galaxy, including possible habitable neighborhoods for life).

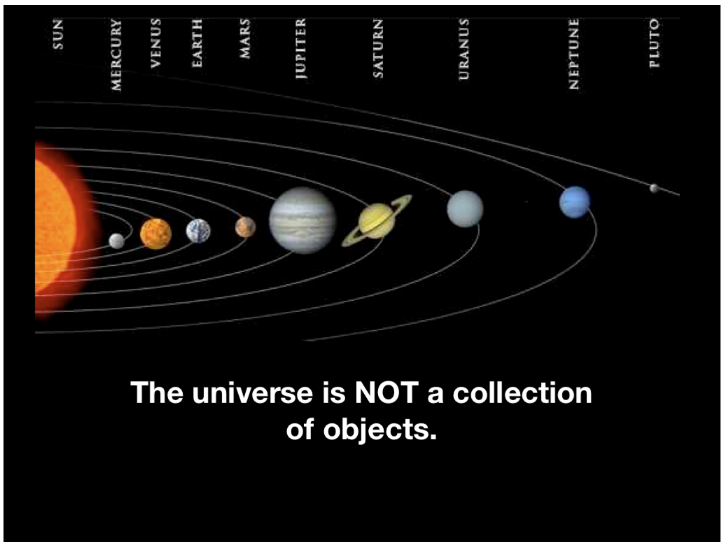

Figure 1. A highly flawed, but useful for discussion, depiction of the solar system.

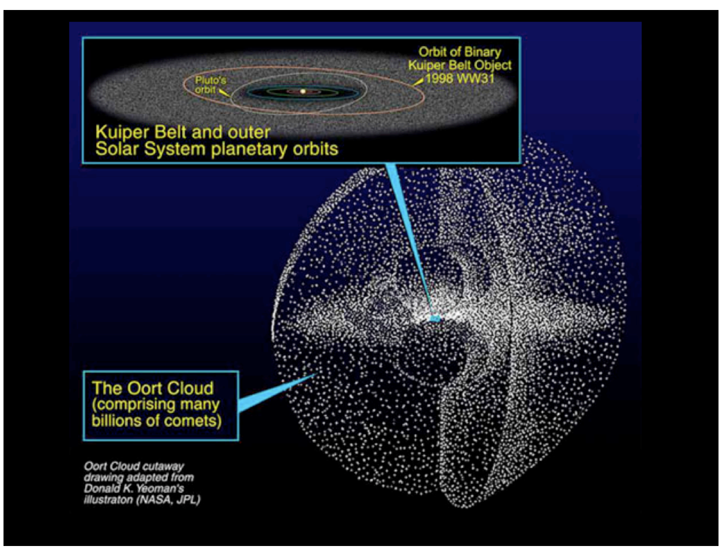

Figure 2. A more accurate rendering of the solar system, including appropriate scales and families of minor planets.

[1]The Global Science Institute thanks the Wisconsin Space Grant Consortium as the primary source of funding for this outreach project.

Figure 3. The Andromeda galaxy, a discussion piece for habitable neighborhoods on galactic and stellar scales.

Teacher workshops. Teacher workshops were held at the High School and Middle School in order to present a shortened version of the public lectures and to point out certain online resources that can be useful for classroom instruction or tools for exploration. A key THP for these workshops was that student comprehension is context (or, relationship) based. If the universe can be presented to students as a very large network of relationships, not only is the depiction more accurate than a simple list of object names and sizes, but the material is more interesting, relevant and memorable.

Of the online resources discussed (including solar imaging and video from SOHO and various other mission pages [1,2,3]), two tools were explored in greater depth. The 3-D JPL orbit simulator for minor planets was used to plot orbits for Kuiper belt objects, asteroids, and comets [4]. Teachers were asked, based on orbital information alone, to identify which family the object in question was a member of. By allowing the simulator to advance the positions of these objects through many years of orbits, teachers could "feel" the difference between the families see their relative motions. Students, then, could be assigned the task of researching and finding the names of objects from these different categories, presenting their orbits to the class using the JPL simulator, and allow other students to determine to which families the objects belong.

The second, and equally impressive, online tool explored during the workshops was the iridium flare prediction page [5]. This page allows students, using accurate coordinates for their own location, to find out when strong reflections of sunlight are likely to occur from satellite solar panels, and to verify those predictions with their own eyes. "Playing" with this tool involves thinking and learning about coordinates, time zones, different types of satellite orbits, reflection geometries, the magnitude brightness system, and the sheer number of man-made objects currently in space.

[1]The Global Science Institute thanks the Wisconsin Space Grant Consortium as the primary source of funding for this outreach project.

Freshman orientation. In the summer of 2010, incoming freshman to Antigo High School attended orientation sessions. During this time, they were allowed to choose as an elective to spend lunchtime with the "Journey" PI and explore science themes rather as an alternative to regular lunch in the cafeteria. Eleven students opted for a science lunch, and after being presented with a few of these same ideas they asked many questions about space exploration, the process of becoming a scientist, and whether the USA will revive its human space flight program. The THP for these students was that they, too, have an essential role to play in the story of life in the universe, and that their primary job for the next four years is to learn everything they can in order to push humanity's frontiers forward.

Outcomes

In January 2010 prior to the "Journey" lectures, Turnbull worked with students at the Antigo High School to pursue a separate grant opportunity to help lower energy costs and produce more local food through (1) planting fruit and shade trees throughout town and (2) harvesting syrup from the mature maple trees in Antigo's City Park. The last of the public "Journey" lectures dove-tailed with this theme and focused primarily on discussing the future of life on Earth, the reasons for changing weather patterns, and the possibilities for increasing the sustainability of the Antigo area. Several of the attendees of the "Journey" lecture series went on to promote sustainability in Antigo through participating in the tree planting program as well. Members from the Langlade County Boys' and Girls' clubs, the Antigo Garden Club, and several other individuals with forestry expertise worked to teach the community about tree care and to plant and distribute about 500 fruit and shade trees to local residences, day care centers, the Humane Society, and a new community garden.

Certainly much more remains to be done both in (1) creating channels for the general public to develop a mature understanding of the universe as a whole and (2) learning as a community how to manage the footprint of our daily lives on Earth. In this lecture series, the two goals were combined, with the result that participants began to be able to see the relevance of astronomical images to life in the universe and were willing to lend a hand in a project to help preserve the network of life on Earth.

References

[1] Solar and Heliospheric Observatory, http://sohowww.nascom.nasa.gov/

[2] The Kepler Mission, A Search for Habitable Planets, http://kepler.nasa.gov/

[3] NASA "Current Missions" page, http://www.nasa.gov/missions/current/index.html

[4] JPL 3-D orbit visualization tool, http://neo.jpl.nasa.gov/orbits/

[5] Heavens-above satellite prediction tool, http://www.heavens-above.com/

[1]The Global Science Institute thanks the Wisconsin Space Grant Consortium as the primary source of funding for this outreach project.

Biotechnology Teacher Training

Barbara Bielec

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Abstract

An integral part of enhancing science education is training teachers in current content and techniques and biotechnology is one of the technologies that will be needed to maintain living systems in space. The BioPharmaceutical Technology Center Institute (BTC Institute) offered two graduate education courses in biotechnology for teachers during summer 2009 and summer 2010. Each weeklong course was held at the BioPharmaceutical Technology Center. *Biotechnology: The Basics* and *Biotechnology: Beyond the Basics* were designed and presented to provide teachers with training, background and curriculum materials so that they may implement hands-on biotechnology in their classrooms. Teachers of a wide variety of subjects with varied levels of experience were active participants in lab-based training.

Introduction

Biotechnology: The Basics and *Biotechnology: Beyond the Basics* are week long summer courses that were offered by the Biotechnology Technology Center Institute (BTC Institute) in summer 2009 and summer 2010. The primary goal of *Biotechnology: The Basics* and *Biotechnology: Beyond the Basics*, is to provide middle school and high school teachers with the training essential to implementation of a laboratory-based biotechnology curriculum. This goal served as the guide in designing and implementing each activity, as well as in structuring each course. Both courses were offered for graduate education credits through Viterbo University and Edgewood College. All three course instructors are experienced teachers of biotechnology at the secondary level.

The NASA Directorate for Space Operations is to: “Extend the duration and boundaries of human space flight to create new opportunities for exploration and discovery.”[1] NASA wisely recognizes the need for training throughout many scientific disciplines, and as plans are made for humans to travel and someday live in space, biotechnology joins other technologies to support these efforts. Often students and teachers in the life sciences do not fully realize how these areas relate to the goals NASA. Another goal of this project is to highlight how biotechnology is and will be used in space exploration. Biotechnology, along with other Science, Technology, Engineering and Math training is needed to help the secondary teachers who directly influence the Science, Technology, Engineering and Math (STEM) Professionals of tomorrow.

The BTC Institute is pleased to acknowledge the Wisconsin Space Grant Consortium (Aerospace Outreach Program) for their financial support of these courses in 2009 and 2010. In addition the 2010 courses received support from the Workforce Development Board of South Central Wisconsin as part of a WIRED Cross Sector Youth Project grant.

Program Details

Both *Biotechnology: The Basics* and *Biotechnology: Beyond the Basics* were offered in summer 2009 and summer 2010. Representing rural, urban, and suburban school districts, the attendees were teachers of a variety of subjects, including: middle school science, biology, biotechnology, agriculture, chemistry, and forensics. Currently there is a strong encouragement from the state of Wisconsin for agricultural educators to receive more science training. They are teaching many of the Biotechnology courses throughout the state, and about one-fourth of our attendees are agriculture teachers.

Most participants are high school teachers in Wisconsin, but three are from Illinois, and two are middle school teachers, one from each of these states. *Biotechnology: The Basics* 2009 had 6 attendees (5 women & 1 man) and *Biotechnology: Beyond the Basics* 2009 had 5 attendees (2 women & 3 men). *Biotechnology: The Basics* 2010 had 13 attendees (8 women & 5 men) and *Biotechnology: Beyond the Basics* 2010 had 15 attendees (11 women & 4 men). As evidence of how teachers value these courses, 10 of the teachers who took courses in 2009 & 2010 were participants in both courses (including 4 teachers who took one of the courses previously in 2008). Class participants included teachers who were former research scientists looking for ways to implement their hands-on experience with students, as well as very experienced secondary teachers looking to update their knowledge of scientific content and techniques. Some of the teachers currently teach an independent Biotechnology course; others incorporate biotechnology curricula within other life science classes. Several teachers were looking for information to help them design and implement a Biotechnology course for the first time.

Table 1: Participants in *Biotechnology: The Basics* and
Biotechnology: Beyond the Basics Summers 2009 & 2010

Teacher Course	**Total Participants**	**High School Science Teachers**	**Agriculture Teachers**	**Middle School Science Teachers**
Biotechnology: The Basics 2009	6	3	2	1
Biotechnology: Beyond The Basics 2009	5	5	0	0
Biotechnology: The Basics 2010	13	9	3	1
Biotechnology: Beyond The Basics 2010	15	11	4	0

The significant increase in attendees for the 2010 courses is due in large part to funding provided by a WIRED Cross Sector Youth Project grant, administered by the Workforce Development

Board of South Central Wisconsin. Reflecting a partnership between the Dane County School Consortium and the BTC Institute, this grant was utilized by 14 districts throughout South Central Wisconsin, covering course fees for 24 teachers.

Barbara Bielec (K-12 Program Coordinator, BTC Institute, Peter Kritsch (Teacher, Oregon High School), and Kathryn Eilert (Teacher, Middleton-Cross Plains High School) worked together to plan and implement the courses. All three are experienced teachers of biotechnology at the secondary level. The BTC Institute course fee was $400 in 2009 and $500 in 2010. Both courses were offered for graduate education credits through Viterbo University (3 graduate credits for $270) and Edgewood College (1-3 graduate credits for $150/credit).

Topics and laboratory activities for *Biotechnology: The Basics* included:

- Basic Lab Techniques
- DNA Isolation & Detection
- Restriction Enzyme Digests
- Polymerase Chain Reaction
- Bacterial Transformation
- Bioethics
- Genetic Counseling
- Biofuels and the Great Lakes Bioenergy Research Center
- Developing Coordinated and Integrated Lab Activities
- Teacher Resources
- NASA & Biotechnology

Topics and laboratory activities for *Biotechnology: Beyond the Basics* included:

- Recombinant DNA and Transformation
- Genetic Identity Testing
- Protein Purification and Detection
- Stem Cells
- Epigenetics
- Microarrays
- Bioethics Biofuels and the Great Lakes Bioenergy Research Center
- Developing Coordinated and Integrated Lab Activities
- Teacher Resources
- NASA & Biotechnology

Implementation was consistently emphasized. How would teachers apply what they learned in their own classrooms? Resources included:

- A comprehensive course binder for each teacher
- Laboratory protocols, classroom activities and power point presentations on a flash drive for each teacher
- Special discounts and offers from Fisher Science Education, Promega, Fotodyne, Global GeneTechs, and Gilson, Inc.
- Research Center outreach programs, and the Fotodyne/BTC Institute Equipment Loan Program

- Daily discussion and review of course topics
- Discussion of funding sources and tips for successful grant writing
- Through the WIRED grant, Biotechnology equipment packages, valued at $1000, for 20 teachers, representing 17 high schools (schools were limited to 2 sets per school)

Each day teachers wrote a reflection detailing how they would integrate material into their curriculum and the challenges that they might face, including the resources they would need. These reflections were discussed the next day with the entire group. Additionally, as a final project, each teacher had to design and present a detailed and personalized curricular unit (lesson plan) for teaching the content learned. Many of the teachers expanded this assignment to include entire course outlines.

Results

Course evaluations were extremely positive. For *Biotechnology: the Basics* teachers wrote:

- "This was well organized and exciting…The instruction was very one-to-one and NOT intimidating. Keep the same instructors and format – this was a wonderful experience!"
- "Thanks! Someday I would love teach a course like this for teachers."
- "Everything was very well done – the prethought on all of the materials was outstanding."
- "I want to take the 2nd course!...The large variety of backgrounds of the participants was very valuable to the discussions."
- "Great course – so helpful and relevant. Best science workshop I have attended."
- "Well done, well organized, and ultimately a very successful class as the training will help train students."

For *Biotechnology: Beyond the Basics*, teachers wrote:

- "I found all workshops informative, interesting and useful."
- "The organized binder and electronic copies are extremely helpful! Thanks."
- "Everything was presented in a logical sequence, explained very well. Instructors gave great tips in how to present to our students."
- "This workshop was extremely beneficial not only to my own professional development but also in ways to teach biotechnology."
- "I learned a variety of ways to take some challenging concepts and make them real for my students. I enjoyed being able to do the labs."
- "Great course—one of the most if not most useful courses I have taken for continued education."

Additionally, results from an independent Viterbo University course evaluation, taken by teacher participants registered for Viterbo credit for the 2010 courses, were very positive. All items, except one, were given the maximum score of "strongly agree" by all of the teachers who completed the evaluations.

Table 2: Results of Viterbo Course evaluations for
Biotechnology: The Basics and *Biotechnology: Beyond the Basics* Summer 2010

Item Analysis	*Biotechnology: The Basics* Participants who gave the maximum response of "Strongly Agree"	*Biotechnology: Beyond the Basics* Participants who gave the maximum response of "Strongly Agree"
I used opportunities to communicate with the instructor.	100% (9/9)	100% (12/12)
I took time to think in depth about this subject.	100%	100%
I came to class prepared.	100%	100%
I cared about my learning in this course.	100%	100%
I was punctual in coming to class.	100%	100%
I turned in my complete assignments when they were due.	100%	100%
I used the textbook, course activities and requirements to meet the objectives of the course.	100%	92% (11/12)
Overall, I rate myself as a motivated learner in this course.	100%	100%
The syllabus for this course clearly communicated objectives, requirements and evaluation methods.	100%	100%
This course caused me to think in depth about this subject.	100%	100%
The content of the assignments contributed to my understanding of the subject.	100%	100%
I had opportunities to ask questions in and out of class.	100%	100%
The instructor cared about my learning.	100%	100%
The instructor demonstrated knowledge of the subject matter.	100%	100%
The instructor conducted class in an organized and clear manner.	100%	100%
The instructor started class on time.	100%	100%
The instructor ended class on time.	100%	100%
The instructor provided useful feedback on student progress.	100%	100%
Overall, I would rate this instructor as an effective teacher.	100%	100%
I would recommend this course to others.	100%	100%

For both courses, teacher participants were recruited through a mailing to the BTC Institute's teacher list; posting in the Wisconsin Society of Science Teachers (WSST) newsletter (print and online); electronic posting and emailing through the Wisconsin Educators Association Council (WEAC) and the Illinois Science Teachers Association (ISTA); posting on the Wisconsin Science Network (WSN) and the BioLink websites; flyers distributed at WSST and Wisconsin

Association of Agricultural Educators (WAAE) conferences; email from the Wisconsin Association of Agriculture Educators (WAAE) electronic network; direct contact at the National Science Teacher Association (NSTA) regional conference; electronic posting by the Wisconsin Department of Public Instruction (DPI); email to Science Department Heads in the Badger School Conference; direct recommendation from UW-River Falls Agriculture Education Professor Timothy Buttles; and, course listings in the Viterbo University and Edgewood College summer catalogs. In 2010, courses were also advertised through the Dane County School Consortium WIRED grant network; on the Education Communication Board's online STEM calendar; and, a district-wide email from Timothy Peterson, Science Coordinator, Madison Metropolitan School District.

We plan to offer both courses in summer 2011, and are seeking grant opportunities that will enable us to fund teacher course fees. As always, we will utilize previous course evaluations to improve our courses. In 2010 our addition of a NASA Human Investigator to speak about the importance of biotechnology to NASA research was a great way to demonstrate the relevance of biotechnology content and techniques beyond the classroom. We will continue to include a NASA & Biotechnology module in future courses.

Conclusion

The enthusiasm demonstrated by our attendees is always inspiring. It consistently and clearly demonstrates the need for high quality graduate education courses that have immediate relevance to the classroom. As stated in a National Science Teachers Association (NSTA) Position Statement: "To be prepared for the 21st century it is critical that all students have sufficient knowledge of and skills in science. Studies suggest that high-quality teaching can make a significant difference in student learning…a high-quality science teacher workforce requires meaningful, ongoing professional development." [2]

The support provided by the Wisconsin Space Grant Consortium to design and implement these courses is greatly appreciated. As indicated above, the 2010 courses also received funding from the Workforce Development Board of South Central Wisconsin as part of a WIRED Cross Sector Youth Project grant. Each year, the donations of instructor time and materials from Fotodyne, WiCell, Promega, Global GeneTechs and Fisher Science Education are also key to our success. These partnerships, along with the options to receive graduate education credits through Viterbo University and Edgewood College, ensure the continuation of these essential opportunities for professional development.

References

1. NASA Directorate for Space Operations, http://education.nasa.gov/about/nasaent/, 2010
2. NSTA Position Statement, Professional Development in Science Education, http://www.nsta.org/about/positions/profdev.aspx, adopted May, 2006

Spaceflight Academy for CESA District #2

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Synopsis: Spaceflight Academy for CESA District #2 was a teacher workshop[1] that focused on the history, math, science, and technology of spaceflight. This workshop offered a unique approach to teaching by incorporating "real world" applications into the classroom.

Goals and Project Value: How does an orbit work? How did our astronauts get to the Moon? How does a spacecraft safely reenter the atmosphere? How does a spacecraft rendezvous with the International Space Station? In this day and age of modern spaceflight, these are just a few of the fundamental questions that students may ask an instructor regarding space. Can teachers comfortably field these and other questions without dispensing any misconceptions? Spaceflight Academy for CESA District #2 was a one-day workshop that accurately answered these and many more questions while focusing on STEM (Science, Technology, Engineering, and Math) related topics for spaceflight. The course offered a unique approach to teaching and answering the age old question "Why do I have to learn this?" by elegantly incorporating "real world" applications into the classroom. Instructors experienced a unique approach to teaching math, science, and technology standards by tackling real world issues in inspiring classroom experiences. Spaceflight Academy for CESA District #2 utilized award-winning approaches to advance an educator's knowledge base by employing a fun, hands-on approach to learning.

For this year's workshop, the Madison area schools (Cooperative Educational Service Agency #2 district) were the target audience. The workshop was setup to provide 20 instructors with a full day of instruction and over $50 per person in materials and resources to take back to their respective classrooms. A lunch was also provided to all participants. After advertising extensively for this 3-12 workshop, a total of 15 instructors pre-registered for it. Twenty percent were elementary instructors, thirty three percent were middle level instructors while forty seven percent were high school instructors.

Due to the broad range of teaching levels present for this workshop, the workshop was broken into three basic segment/components - elementary, middle, and high school level topics. The workshop was co-facilitated. The AM sessions were devoted to elementary and middle level discussions while the PM session was devoted to high school topics. During these sessions the following topics/activities were covered: perception / paradigm shifts; center of gravity; Bernoulli implications; Newton's universal law of gravitation; various orbital shapes (conic sections); circular orbits; geosynchrous orbits; elliptical orbits; spaceflight mathematics; history of human space exploration; and technologies of space exploration.

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[1] The main financial support for this workshop was provided by the Wisconsin Space Grant Consortium. Additional support was provided by the following sponsors: Spaceflight Fundamentals, LLC; Science Kit & Boreal Labs; and the Wisconsin Education Association Council.

Evaluation Results: At the conclusion of this workshop, the following questions were asked on an evaluation form. The results, of this evaluation, are based on a 100-point scoring system with 100% = strongly agreeing with the provided statement, 80% = agreeing with the statement, and so on.

1-My exposure to this project has increased my knowledge/understanding in space, aerospace, space-related science, design, and technology. Score = 86%.
2-Student exposure to this project should increase an interest in space, aerospace, space-related science, design, and technology. Score = 78%..
3-This project has the potential to increase secondary (pre-college) student recruitment, experience and training in the pursuit of a space or aerospace related science, design, or technology profession. Score = 82%.
4-The project has self-sustaining/replicable qualities due to the fact that the participants are trained and supplied with the basic materials to go out and duplicate in their classrooms the work that was incorporated in this workshop. Score = 89%.
5-The project meets the goal of Teacher Training which is defined as successfully educating, training, and exciting teachers about the math, science, technology, and history pertaining to spaceflight. Score = 84%.
6-This project has the ability to expose and prepare the next generation of scientists to aerospace related fields. Score = 89%.
7-I have a better understanding of how our spacecraft and flight support work together. Score = 87%.
8-The instructors were knowledgeable about the subject matter that was being taught. Score = 100%.
9-The workshop was well organized. Score = 98%.
10-The instructors' presentation style was well suited for the audience in attendance. Score = 86%.
11-As a workshop participant, I feel significant professional growth by having attended this workshop. Score = 83%.
12-The pacing of the workshop was well suited for the audience in attendance. Score = 86%.
13-I am pleased with the information and materials that I received as part of this workshop. Score = 96%.
14-What is the total number of students that you teach per day?
*Based on the number of instructors present and their teaching assignments, a total of 809 students will be positively impacted by this workshop.
15-How do you plan to implement this material into your classroom curriculum?
*The following are highlights of responses to this question: This will augment units on Newton's laws of motion, forces and energy. Using it in space curriculum. The hands-on materials will be implemented into my space unit this year.
16-Please express any additional comments regarding the workshop and/or instructors.
*The following are highlights of responses to this request: Thank you for the free materials!! Thank you! I appreciated the opportunity to learn more about space and hope to share this information with my students. Thank you for sharing your ideas and projects with us.

Evaluation Analysis: Based upon the positive evaluations and comments of these grades 3-12 teachers, there should be a definite increase for interest in space, aerospace, space-related science, design, technology, and its potential benefits for their students in the Madison area. Invariably, based on our evaluations, this project should allow secondary (pre-college) students the opportunity to increase their interest, recruitment, experience and training in the pursuit of space or aerospace related science, design, or technology in the Madison area.

The project has self-sustaining/replicable qualities due to the fact that the instructors that were trained were supplied the basic materials to go out and duplicate the work that we incorporated in our workshop. The goal is for teachers to go back to their classroom and replicate this work to their students – The "multiplier effect" is then engaged. Through this effect, each teacher is able to provide their students with exposure to this exciting curricular approach. For the 2010-2011 school year, 1109 students will have the opportunity to be exposed to this worthwhile curriculum. Based upon the amount of grant money received from the Wisconsin Space Grant Consortium (WSGC) and the number of students each registered instructor has, it only cost WSGC an average of $2.43 per student to run this workshop – This is an amazing investment!

The goal for this pilot program is to have it offered in various regions around the state. Based upon the workshop's evaluations, the project certainly met this year's specific goal of Teacher Training. The whole purpose of the project is to educate, train, and excite teachers about the math, science, technology, and history pertaining to spaceflight – This workshop definitely and successfully accomplished this feat.

Alignment With NASA Directorate, Center Goals, and/or Educational Standards Science Mission Directorate: The scientific investigation of the Earth, Moon, Mars and beyond with emphasis on understanding the history of the solar system, searching for evidence of habitats for life on Mars, and preparing for future human exploration. This workshop definitely exposes and prepares the next generation of scientists to aerospace related fields. As we prepare for future human exploration, we will need many new scientists and engineers to accomplish this endeavor. Our project's goal was to train teachers who in turn can train these future scientists and engineers. Our proposal, therefore, provided assistance in this area.

Space Operations Mission Directorate: The three themes – The International Space Station, Space Shuttle Program and Flight Support provide critical enabling capabilities that make possible the science, research and exploration achievements for the rest of NASA. This workshop provided as part of its focus the ISS, Space Shuttle program and required Flight Support. This focus allowed the participants to better understand how they work together and provided enabling capabilities as a whole.

Educational Standards: The National Research Council's (NRC) Science Education Standards were addressed throughout the workshop. Special emphasis was put on the following Standards areas: The Teaching Standards: Guiding and Facilitating Learning & Building Learning Communities; The Professional Development Standards: Learning Science Content, Learning To Teach Science, & Learning To Learn; and The Content Standards: Scientific Inquiry, Technological Design, & Science and Technology.

Participants: The workshop was limited to 20 science and/or math instructors. It was made available on a first come, first serve basis. Once the 20 slots were filled, two additional registrations would also be accepted. Spaceflight Fundamentals, LLC fully complies with the

Americans with Disabilities Act of 1990 (ADA), Section 504 of the Rehabilitation Act of 1973, and its amendments, all of which prohibit discrimination on the basis of disability in the admission, access to, or participation in programs or activities.

Location of Project: The workshop was advertised to science/math (Grades 3-12) teachers in the CESA #2 district (Madison area). The workshop was located at the WEAC (Wisconsin Education Association Council) building, 33 Nob Hill Road, Madison, WI. We coordinated the workshop advertisement with school districts in the Madison / CESA #2 area. The target audience was science / math classroom instructors (Grades 3 –12). Based upon future funding, follow-up (Part 2) workshops and additional initial (Part 1) workshops could be set around the state.

Work Plan: Our work plan involved an eight-hour workshop. In those eight hours, we focused on the concept of spaceflight via a variety of hands-on activities (labs, simulations, computations, etc.) and discussions. High emphasis was placed on cooperative work and constructivistic approaches being fueled through facilitator lead Socratic dialogue. The goal was to allow the instructors to have the chance to infuse their new knowledge of Part 1 into their respective curriculums with the hopes that a follow-up workshop can be funded in order to further our focus.

General Information: Spaceflight Fundamentals, LLC is a small but dedicated company to the advancement of aerospace in the classroom. For the past nine years, our company has been authoring and publishing educational materials on aerospace education in the state of Wisconsin. Also, in those nine years, we have had the opportunity to organize and instruct several teacher graduate course workshops. The workshops have always been well received and have made definite positive impacts in our state's classrooms. With that said, our hope is that workshops like these will allow further opportunities to educate and motivate the current and next generation of instructors/students on aerospace education in the state of Wisconsin. We look forward to creating future proposals / activities for teacher aerospace workshops and further broadening our ability to work with other state organizations with the same goals. We feel that the state of Wisconsin has benefited from our activities, and that we hope to continue being a positive force in the WSGC's community outreach efforts while helping to nurture and grow the aerospace industry in our state.

A Taste of the Solar System

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Abstract:
With support from a National Space Grant Foundation mini-grant, I designed and taught a professional development course for in-service and pre-service elementary teachers on the subject of the solar system using Aerospace Education Services Project toolkits and other active-learning strategies. Teams of students in the course presented and evaluated lessons in Ripon area schools.

Introduction
Thanks to notices sent out by the Wisconsin Space Grant Consortium office, I became aware of mini-grants from the National space Grant Foundation (NSGF) for which space grant institutions could apply. These grants were set up specifically to support the development or redesign of professional development courses for in-service and pre-service teachers of science, technology, engineering, and/or mathematics (STEM) who teach grades levels K-12. The central topic of these courses would be some aspect of the solar system. Ripon College applied for and received one of the mini-grants—2009-AESP05—to develop and offer a new course, Physics 200: *Exploring, Learning, and Teaching the Solar System.*

Course Design, Goal, and Objectives:
I designed the course for in-service elementary teachers and pre-service teachers (Ripon College students intending to teach) with particular interest in teaching grades preK-5. As specified in WSGF guidelines, the course was scheduled to meet for a total of 30 hours—8 three-hour evening classes plus a six-hour Saturday workshop—with extra time to be spent doing in-school presentations in the classrooms of the in-service teachers.

In addition to doing the activities I chose from AESP toolkits and other appropriate astronomy education resources, students in the course also participated in activities presented by the Physics Fun Force (PFF). PFF is the community service group organized and supported by the Physics Department at Ripon College. PFF members visit area elementary schools and encourage children to explore the fun of physics through non-fiction books about science and astronomy followed by sessions of inquiry-based activities. I am the faculty advisor of the group.

Students in the *Exploring, Learning, and Teaching the Solar System* course also corresponded with teachers in primary schools in Wales (UK) to gain insight into similarities and differences in science-teaching strategies in another country and share activity ideas. The three schools in North Wales have been collaborating with Ripon College and Ripon-area elementary schools on a number of information sharing projects concerning STEM teaching in the U.S.A. and in Wales..

The goal of the course was to establish the attitude among elementary teachers that active learning about the solar system is not only fun but also appropriate for all learners of all ages. We hoped to help each participant develop or reinforce that attitude as they tried out active-learning strategies, learned about the wealth of teaching and learning resources available from

AESP, NASA, and elsewhere, and worked to design and adapt activities for their own classroom use. Solar-system activities worked their way into every aspect of the course, even refreshments served during the breaks during the evening classes and the Saturday workshop. "Incredible, Edible Comet" and "Cake Tectonics", for example, brought out aspects of comet structure and Earth's crust, respectively, while also providing refreshment.

Conduct of the Course:
The course began meeting on March 10, 2010, just before the beginning of Ripon College's spring break. "Homework" for this class was to complete a short concept inventory with questions related to solar system objects. Although I attempted to design questions that would be addressed later by class activities, I learned by the end of the course that some of the concepts were understood much more fully than others. Although the percentage of correct answers went form about 59% on this "pretest" to 74% correct at the end of the course, there is clearly room for improvement in content learning. Clearly I must try different strategies to help the students in the course learn basic content while engaged in activity-based learning.

Organization of the course and class was the primary activity of the first class. After going over the pretest, the class organized into three teams, each with one of the in-service teachers as leader. Pre-service teachers chose their teams on the basis of the grades taught by these in-service teachers (kindergarten, Grade 1, and Gifted/Talented, respectively) to overlap as closely as possible with their own teaching interests. The teams chose names—Lunar Ladies, Extra-terrestrial Dwarves, and Orbiteers—began working on an in-class presentation activity for the next class. Each student had received a three-ring binder with copies of many AESP toolkit activities at the beginning of class. To encourage them to look in the binder and work as a team, they were assigned to prepare to present ***Those Who Have Come Before Me***. During the next class each team would set up a set of objects with an implied order in the set but placed at random. Another team would locate all of the objects, determine the implied order, and leave a map for the next group. With three teams, each had the opportunity to serve as choosers of objects, map makers, and map followers.

The class next met on March 24. Since daylight saving time was in force by then, we had enough daylight to begin class with a "solar-system hike". With a beach ball about 23 cm in diameter as the Sun, the distances to scale between planetary orbits range from about 11 paces (assuming each pace to be about 60 cm) to 445 paces. Planet sizes to scale ranged downward from Jupiter's 2.3 cm to Mercury's 0.o8 cm. Each planet was modeled in *Play-Doh* and mounted on a card attached to a stake to mark the planet's location along the street as we hiked from orbit to orbit. This activity helps put in perspective the relative sizes and separations among the planets as well as beginning a discussion of the differences between planets and dwarf planets. Our in-class hike went only as far as Neptune, but we repeated the basic activity on a smaller scale out as far as dwarf planet Eris during the Saturday workshop.

Once back from Neptune, teams set up their ***Those Who Have Come Before Me*** collections and completed the activity by mapping and following maps in turn. All teams produced challenging hunts and did well creating and following maps.

The next class topic was the Sun. We made sundials based on calculations for Ripon's latitude and tried them out using flashlights to simulate the Sun. Then we discussed fusion and used an interactive card game to act out the proton-proton chain cycle. Because the moon was at first-quarter phase and skies were clear, we were able to observe the solar spectrum via reflected moonlight using "rainbow peepholes" (crossed diffraction gratings mounted in cardboard frames and sold by *Rainbow Symphony, Inc.* of Reseda, CA).

After a discussion of the historical development of the solar system—including a discussion of constellations and an activity involving original constellation design—we explored planetary orbits and Kepler's laws of planetary motion by drawing ellipses, an activity from the NASA *Stardust* activity guide. Then we tried out a series of short activities related to Earth:

> *Reasons for Seasons*: observing changes of area covered by a "sunbeam" (flashlight beam) from summer-solstice noon to winter-solstice noon and resulting changes in intensity.
>
> *Cake Tectonics*: (edible) observing effects on Earth's (decorated cake) surface as crustal plates (parts of cake attached to separating parts of the cake pan) move apart.
>
> *Land or Water*?: Determining empirically the relative proportions of Earth's surface covered by water and land by tossing a world-globe ball from person to person and recording whether the catcher's index finger landed on water or land.

The PFF presented its unit on crater making, including the reading of <u>The Magic School Bus Out of this World: a Book about space Rocks</u> and an investigation of crater making by dropping objects onto a flour/cocoa surface. After the presentation, teams began conferring with the PFF members to schedule classroom visits when all team members could be present to observe PFF working with the children.

The next class concentrated on Earth's moon. After modeling moon phases by walking around a bright lamp holding foam balls attached to pencils, students decorated crackers with cheddar cheese spread (orange in color, <u>not</u> green) to illustrate the illuminated fractions of the moon from crescent to full. A second "edible" activity from AESP involved modeling the creation of lunar regolith using graham crackers and sugar-coated donut holes.

In-service teachers in the class reported that the idea of the existence of gravity beyond Earth sometimes puzzles children. In the next class we tried out an activity involving measuring individual jump heights on Earth and using these and the law of gravitation to calculate via simple spreadsheet corresponding jump heights on other planets and the moon. Then we talked about the terrestrial planets with an emphasis on Mars and explorations there. The edible AESP activity for the evening was creating edible Mars rovers out of marshmallows, cookies, candies, frosting, etc. Teams began working on designing and scheduling their in-school presentations.

At this class each student also completed her or his individual message to be sent to collaborating teachers in Wales. Responses from Anthony Allen at *Ysgol Yr Esgob* in Caerwys, Flintshire, began coming back to us almost immediately followed by curriculum materials integrating space science and music from Maura Woodward at Venerable Edward Morgan Roman catholic Primary School in Shotton, Flintshire. Menai Baugh, headteacher at *Ysgol Gynradd Henllan* in Henllan, Denbighshire, invited a student in the class who will be studying at Bangor University next semester to visit her school and home while she is in Wales.

Our last class before the Saturday workshop touched upon the Jovian planets, dwarf planets, comets, and other contents of the solar system. To explore some examples of the differences among these objects, we played a "Who am I" game. Each person was assigned an object unknown to her or him—the name of it was on a tag hanging down the person's back—which she or he had to discover by asking questions of other class members. After the object had been identified, the student went to the Internet to find one or more additional facts about it to share with the class as soon as everyone had "identified" themselves. PFF gave a presentation on *oobleck* and teams experimented with the cornstarch and water form as an "unearthly" surface material. The AESP/edible activity for the evening was "Incredible, Edible Comet".

Before the course began I had made arrangements for James Fitzgerald from NASA Glenn Research Center to travel to Ripon and present both the April 24 Saturday workshop—including lunar certification--and the April 26 class. Due to an emergency he was unable to come to Ripon, but he arranged for Richard Varner, another AESP educator, to do the workshop. Unfortunately the notice was too short for him to do the lunar certification, however. Rick proved to be an extraordinary workshop presenter. The class worked through and enjoyed a large number of wonderful activities. In the morning we worked with ultraviolet light detecting beads, 3D websites, several excellent variations on making scale models of the solar system, modeling moon phases, modeling solar and lunar eclipses, and trying out the process of docking in space using cords, balls, and PVC pipe sections.

In the afternoon students built paper rockets and launched them with two different types of compressed-air launchers. Although weather had prevented us from doing solar activities in the morning, rain stopped in time for us to do rocket launches outside in the afternoon. Because Rick has been a teacher and middle-school principal, he was able to share many useful insights about adapting the activities to elementary classroom use. He also provided with class with many activity instructions in print to add to their collections.

Our penultimate class session was a joint meeting with Physics 300: *Introduction to Flight*. We focused on the concept of jet propulsion. Groups in the flight class competed with teams in the solar system class to create the rocket racer that would travel the greatest distance. (The men in the flight class were noticeably disappointed to have been surpassed by one of the solar system class teams!) That week and the week before, teams had visited the schools and assisted with PFF presentations in classrooms. For example, PFF student director—and course student assistant--Bryant Vande Kolk and other PFF members presented the "Wonderful Water" unit including a reading of The Magic School bus at the Waterworks to two classes at Barlow Park Elementary School in Ripon.

Final Projects and Conclusions:

Sixteen students successfully completed the *Exploring, Learning, and Teaching the Solar System* course. The thirteen Ripon college students received two credits each, credits which can be offered as study of physical science to support teacher certification requirements. Each of the three in-service teachers earned three credits in the course because they chose to prepare significant extra-credit work for classroom use. These credits supported the continuing professional development required of them by their school districts.

At the last class, each team presented an excellent detailed PowerPoint presentation of their in-school teaching activities with full details of the associated science lessons, associated teaching standards, and evaluation of children's responses to their learning experiences. The only fault I could find with these carefully prepared and conscientiously executed lessons was the fact that most of them were close adaptations of activities done in class—designer constellations, sundials, crater making, etc.—rather than original activities. Students also answered the "pretest" questions again and completed a standard Physics Department course evaluation form. At the end of the class the three in-service teachers discussed their intended extra-credit projects and details for completing them. The initiative to do extra credit had been started by one of the teachers rather than suggested by me. All were eager to extend their course work extensively and produce units to use in their schools, so I made arrangements with the Ripon College Registrar to allow them to receive an extra credit for the course. The topics they chose for their projects were:

a. Barb Splittgaber (Kindergarten, Barlow Park Elementary School, Ripon): integrating books, mathematics, and imagination into a study of the moon and travel to it.
b. Rachael Ryf (Grade 1, Green Lake Elementary School, Green Lake): introduction to space travel including study of astronauts, rockets, etc.
c. Shaunda Jennings (Gifted and Talented, Ripon Schools): "Journey North", a multi-disciplinary study involving changes of seasons, reasons for them, and effects of them, including an opportunity for correspondence with a class or classes in the Welsh schools to investigate the differences of latitude.

After the course formally concluded, I assembled parcels of instructions for our class favorite activities and a few activity materials (e.g. ultra-violet detecting beads) to send to our collaborating schools in Wales. I also scrutinized course evaluations and used them along with observations made during the class to attempt to improve the course the next time it is offered. These intended improvements include:

a) Improving factual content learning, perhaps by using activities such as the "Who am I?" game more often, assigning individuals to research an assigned topic and share each week.
b) Encouraging design of <u>original</u> activities or activities found in AESP toolkits but not done in class to present in schools by having teams search toolkits and websites for activities that complement what they have done.
c) Improve students understanding of background material by assigning selected outside reading about the topic of each upcoming class and asking for questions about it.
d) Begin correspondence with Welsh schools earlier to facilitate more feedback.

Because the Saturday workshop was so well received, another one would be included in the next course offering during the spring semester in the 2011-2012 academic year. Since we did not have lunar certification during this year's workshop, I plan to arrange for one to be offered in early fall and invite all interested area teachers and all teacher-education students (STEM fields and elementary) to participate.

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Early-Career Leaders In Science Education
(ECLIpSE)

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Purpose

The purpose of the ECLIpSE program is to support the professional development of early-career (<5 years experience) science teachers and provide networking opportunities to increase career satisfaction and retention.

Need

> "The challenge has never been greater for secondary school science teachers to understand, plan, and implement the science-as-inquiry approach – an approach that attempts to assimilate the recommendations of many professional organizations while accommodating the pressures of a changing society (Chiappetta, 2008 p 20)."

In Rising Above The Gathering Storm: Energizing and Employing America for a Brighter Economic Future (2007), the authors argue that the United States' advantages in science and technology have begun to erode while other nations are increasing. Over the past decade, U.S. student performance on international science exams have remained flat and many students are completing high school scientifically and technologically illiterate (Matthews, 2007). As a result, educators, policymakers and business leaders are worried that U.S. students are not prepared to compete in a global economy (Glod, 2008).

Meadows (2009) states, "In today's working world, students need skills for finding, organizing, and managing information. They also need rich skills for working with each other and communicating orally and in print…(Science) Inquiry helps develop all of these skills." In addition, the National Research Council (2000) states "inquiry into authentic questions generated from student experiences is the central strategy for teaching science."

Unfortunately, an inquiry-approach to teaching science is not the norm in secondary schools as "many teachers are still striving to build a shared understanding of what science as inquiry means, and at a more practical level, what it looks like in the classroom (Keeley, 2008)."

The challenge of building an understanding of teaching science as inquiry is confounded by the challenges caused by a growing shortage of qualified science teachers in the United

States. This challenge is felt in Wisconsin. In a recent survey, Wisconsin school district administrators were asked, "Given projections of vacancies over the next five years, which subject/licensure areas do you anticipate will be most problematic for your district to hire qualified personnel?" Over one-third (34.6%) of administrators cited general science as a projected critical shortage area (Fischer & Swanger, 2007). Among the many reasons for this shortage, early career attrition may be the most important (Ingersoll & Smith, 2003). Several studies have found the turnover rate for math and science teachers to be higher than for teachers in other fields. Hackwood, et al. (2006) found that about one in six of math and science teachers either leave the field or move to a new job each year. The attrition rate is even higher for early career teachers with between 40% to 50% of all beginning teachers leaving the profession within the first five years (Guarino et al., 2006; Ingersoll & Smith, 2003).

Approach

The ECLIpSE program was built around an understanding that teachers need professional development that extends far beyond the one-shot workshop (Darling-Hammond & McLaughlin, 1995) and that it must provide opportunities to build content and pedagogical content knowledge, provide opportunities for collaboration, and links with other parts of the education system (Loucks-Horsley et al., 2003). A schedule of events for the ECLIpSE program is located below:

Activity	**Timeframe**
Recruitment and Selection	May 2009
Face-to-face Workshop	August 2009
Virtual Session 1	Fall 2009
Virtual Session 2	Spring 2010
WSST Conference Meeting	March 2010

The face-to-face workshop focused on integrating science inquiry into participants teaching. Science inquiry engages students in using the processes of science to learn content. Specific attention was given to using real-world data, including data from NASA, NOAA, DOE, and other science organizations, in the classroom. Participants also learned about the importance of professional networking and began developing their own professional network. During the face-to-face workshop, participants developed implementation plans to incorporate science inquiry using archived data into their teaching. Two virtual webinars reinforced the content from the face-to-face session and provided additional opportunities for networking. The first webinar focused on using archived data to conduct inquiry and was presented by Dr. Stephanie Slater from the University of Wyoming. The second webinar focused on the Earth-Moon system and was presented by Dr. Neil Comins. This second webinar was hosted by the Lunar Planetary Institute and was chosen because it introduced ECLIpSE participants to opportunities for high quality free professional development. The experience culminated in a face-to-face meeting at the annual conference of the Wisconsin Society of Science Teachers.

Successes

The ECLIpSE program received funding from the Wisconsin Space Grant Consortium (WSGC) and UW Oshkosh EXCEL Center. Response to the initial recruitment was overwhelming and lead to twice as many qualified applicants as funding allowed. A slight increase in funding from WSGC resulted in all 19 applicants being accepted to the program (18 were able to participate). Eight of these participants taught science in middle schools and ten taught at the high school level. Fourteen of the participants were able to attend in the first webinar. Ten of the participants attended the second webinar. Unfortunately, only four of the participants were able to attend the Wisconsin Society of Science Teachers Conference. Evaluation results from participants in the ECLIpSE program (n=18):

	1 (strongly agree) -- 5 (strongly disagree)
I have a deeper understanding of science inquiry.	1.18
I am more likely to implement science inquiry in my teaching.	1.18
I am more likely to use online data sources in my teaching.	1.35
I will engage with other participants in order to develop a professional network of science teachers.	1.47
The ECLIpSE workshop was worth my time investment.	1.41

Looking Ahead

The implementation and results from the ECLIpSE programs informs future professional development activities and projects in a number of ways.

First, participants were specifically asked what they felt they needed from professional development activities (n=18):

	1 (very important) ----- 5 (not important)
Science Inquiry	1.5
How Students Learn Science	1.31
Technology Integration	1.88
Identification of Professional Opportunities	2.06
21st Century Skills	2.06
Curriculum Design / Alignment	2.81
Networking across disciplines and grade-level spans	1.31

It is clear from this survey that participants felt that they needed additional support for implementing science inquiry. In addition, participants felt they needed to deepen their understanding of learning theory and how it specifically impacted student learning of science. Participants also highly valued opportunities to network with other science teachers from a variety of disciplines and grade-levels. Networking is critical for sustained professional growth and career satisfaction.

Second, future professional development in science should promote and model authentic science inquiry approaches that can be translated into the classroom. For example, the Backward Faded Scaffolding model from Slater and Slater at the University of Wyoming (tp://www.uwyo.edu/caper/) provides an accessible approach to science inquiry that is consistent with the NRC National Science Education Standards and the National Academies of Sciences draft Framework for New Science Education Standards.

Third, priority needs to be given to projects that move beyond a “one-shot” workshop approach to professional development. Significant research into professional development has shown that short duration (less than 80 hours) is not sufficient to realize changes in practice. In the current economic climate and with early-career teachers, this is especially challenging. As a result of budget constraints, participating in school year activities and conferences may not be possible. In addition, early-career teachers are often managing multiple personal and professional transitions that limits their ability to engage in sustained professional learning opportunities.

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Investigating Student Views of Relevancy in Introductory Astronomy

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Abstract

This Wisconsin Teaching Fellow project focuses on the views of students as they enter a General Education course in Introductory Astronomy. Education research suggests that students are more likely to engage with material and retain concepts if they feel the material has relevance in their lives. By relevance, I mean "connections / links to life outside class - personal, future careers, media, society". The objective of this project is to explore the links / connections students see between astronomy class and their lives outside that class, as well as how the students' views of relevance correlate to their content knowledge in the course. The results will allow instructors to better 'meet students where they are', and encourage them to engage with the course material.

Introduction

General Problem: Education research suggests that student motivation is an important component of student learning. Students tend to "tune out" course content unless they view the material as personally meaningful, relevant, or useful to them (e.g. Keller 1987, Brophy 2004). Relevance in the context of this project is anything that will help students connect their work in class to their out-of-class experiences.

Specific Context: Introductory Astronomy for non-majors, often called "Astro 101", is taught around the country. This course is usually a General Education science class, and as such is the last formal exposure to science for many students. With the need for a science-literate populace in order to maintain funding for space-related activities, their experience in this class is extremely important.

Professional astronomers and astronomy educators perceive numerous connections and links between course material and life outside class. Although there is existing research on general attitudes towards astronomy as a science, there is currently little research exploring whether students see these specific relationships. For example, the "Survey of Attitudes Towards Astronomy" (SATA; Zeilik & Morris 2003) probes *very general* views on (a) the relevance & worth of astronomy & science (9 items) and (b) positive / negative attitudes about science & astronomy, student competence, and subject difficulty (25 items). However, as far as I know no existing survey explores student perceptions of the relevance of <u>specific</u> aspects of astronomy.

Project Goals: Given the lack of specific information about how students perceive the relevance of astronomy, this project was designed to:

- Investigate student attitudes about the relevance of astronomy at the beginning of the semester.
- Investigate whether they change at the end of the semester.
- Explore whether students' incoming attitudes on relevance are related to their content gains in the course

Method

Procedure: The data were gathered during the Spring 2009 offering of "Stars Galaxies & the Universe" at the University of Wisconsin – La Crosse. This is a General Education science class whose students range from Freshmen to Seniors and have a wide variety of science background.

The project was designed with a Pre-Post methodology. Pre-course data were gathered on the first day of class (65 students), while post-course data were gathered on the last day of class (a subset of 46 students). On both of these days, the instructor (Dr. Sallmen) administered:

1. a survey to investigate student attitudes on the relevance of astronomy
2. the Star Properties Concept Inventory (SPCI; Bailey 2007) to evaluate students' content knowledge

Once the data were collected, we explored coded responses using SPSS for trends & correlations

Survey Details: Lacking an existing suitable instrument, we developed a survey investigating the following Aspects of Relevance:

- how much students enjoy learning / hearing about astronomy, and sharing their understanding with others
- whether / how students anticipate connecting course material to news items and/or popular portrayals of astronomy
- whether students are aware of technological spinoffs (e.g. CCD chips in digital cameras etc.)
- whether students connect material like 'Phases of the Moon' to viewing the sky in their life outside class
- whether students expect to develop any skills in class that might help them elsewhere in their life

The survey was designed with questions in a variety of formats, organized so that students were first prompted for responses with few external cues, then for responses to questions that were more specific[1]. The complete survey included

- Five (5) Open-ended questions about aspects of relevance
- Five (5) "How often do you notice/encounter…" various aspects of astronomy
    - ("Daily or almost daily", … , "I can't think of a time")
- Twelve (12) Likert-scale items about how important astronomy is to them
    - ("I would enjoy…", "I would like…")
- Four (4) questions about their astronomy background (both formal & informal)
- Five (5) Demographic questions (e.g. major, class standing, 1st-generation in college or not)

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[1] The survey can be found at http://www.uwlax.edu/faculty/sallmen/fellow/survey.pdf

Discussion of Open-Ended Responses: Student responses to three of the five open-ended questions were examined and coded into various categories, and then analyzed.

***Is Astronomy Personally Meaningful to You*?**[2] This question was designed to get a "first impression" of students' raw views, before more detailed questions had influenced their responses.

On the first day, 15% of students said "No" without any qualifications, while 63% said "Yes" (with various reasons). However, 22% of responses fell into a category exemplified by the following quote:

> *"I don't know how it personally meaningful, but I do believe it is important to understand the space around us and why things happen. How we are able to survive on this planet. Also I think this is important to understand the different types of stars."*

This "No, but…" category typically began with "No", but students' elaborations typically involved the same types of reasons as those students who had said "Yes, because". This suggests that what students identify as personally meaningful depends greatly on the student: some students have a higher 'threshold' for labeling a topic as personally meaningful.

Explanations associated with "Yes" responses fell into the following categories. Each category is followed by the corresponding percentage of first-day responses, as well as a typical student response or explanation of types of responses.

- Place in the Universe (26%): *"I think it is meaningful to me because it helps me understand my physical place in the universe and what is going on around the Earth and beyond."*
- Personal Connection (19%): (answers involving God, interaction with family, etc.)
- General Interest in Facts (15%): *"Sure, I love stars and would like to know more about them and other things around them (planets, etc.)"*
- Big Questions (8%): *"Astronomy is discovering more answers to life every day. Outer space is the biggest mystery there is."*

Overall, it appears that students' strongest connections to astronomy involve their emotional lives and/or their struggle to relate themselves to the broader world. Pre-course responses to this question were not correlated with content performance in the course, and there was no significant change in responses between the beginning and end of the semester.

***What aspects of astronomy do you notice / encounter in your life outside this class*?**[2] Student responses to this question clearly showed that students are motivated by (a) visible objects in the night sky and (b) emotional connections to the night sky. Since responses frequently spanned more than one category, the categories were considered as "check-boxes". For example, the response *"Outside of class, I encounter the observation of stars and objects as a form of meditation in my life"* counted towards both the "Simple Astronomical Objects" and "Personal Meaning" category. This latter category was used for responses that indicated an emotional aspect.

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[2] For the complete wording of the questions, see the survey instrument at the website indicated in Footnote 1.

On the first day, 80% of students described at least one of Sun, Moon, Stars, while 37% said 2 or more of these. Over ¼ (26%) of students' responses fell into the "Personal Meaning" category On the last day of class, "Personal Meaning" appeared in 29% of responses, indicating this was still a strong student motivator.

Aspects of specific course knowledge appeared in 40% of responses, which was a significant increase from 18% on the first day. What students are learn in class affects their life experience outside of class.

***What skill or skills used by astronomers do you think might be useful to you in your life outside this class*?**[2] First-day responses commonly included aspects that could be assigned to the following "checkbox" categories. Each is followed by an example that includes that category.

- Problem Solving / Scientific Method (26%): *"I think being able to predict and think logically and analyse problems and situations would be useful skills to have."*
- Identifying / Recognizing (19%): *"Being able to name the constellations"*
- Observation / Patience (15%): *"A careful eye and patience. Both seem to be important for life."*
- "Deep Thoughts" (15%): *"If anything it will help you think about things on a broader spectrum, after learning about something as vast and infinite as the universe."*
- Curiosity / Desire to Learn (14%): *"Curiosity, desire to learn, risk-taking/experimentations"* (also counted towards Scientific method).

By the end of the course, significantly more students' responses fell into the *Problem Solving* category (p-value = 0.001), increasing from 26% (pre) to 63% (post). Some other categories of response had a marginal decrease over the course. It should be noted that very few student responses included more than one category

Analysis of Pre-Course Data: A number of trends were apparent in student responses gathered on the first day of the course, reflecting their incoming attitudes and course knowledge.

Importance of Astronomy to Students: Students generally rated "I like / would enjoy…" questions quite positively, with only one item having a mean below neutral (mean = 2.92, Std. Dev. = 0.84). This item asked about astronomy-related podcasts; the "neutral" spike and written student comments suggests that those who don't listen to podcasts had trouble responding to the question. The item yielding the most positive responses related *to identifying planets, stars, constellations, etc. in the sky,* indicating that this is a strong motivator for most students. The pre-course response distributions for three of these items are shown below in Figure 1.

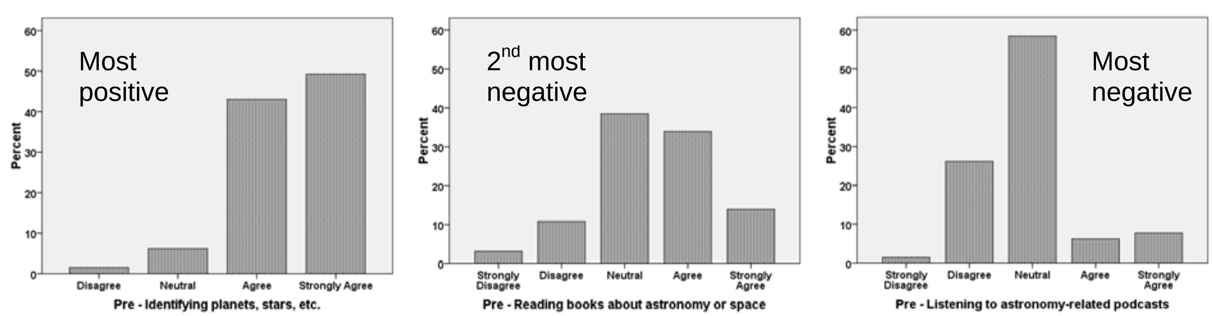

Fig. 1: Pre-course frequency of responses for three Likert-scale items exploring students' views of the relevance of astronomy.

Factor analysis of these 12 items suggests that all are well-described by two dimensions. The results were therefore reduced to two "factor scores", which we named *Sharing / Using Astronomy* and *Personal Enjoyment of Astronomy*. Both factors were significantly related to students' "Reason for Taking course" (see Figure 2 below). Students with higher factor scores were more likely to have taken the course out of interest, implying these are valid measures of students' attitudes towards astronomy. We explored the possibility that student responses might be related to (a) how well they could see the night sky as children and (b) whether they grew up in rural, small-town, suburban, or urban environments, but no such relationship was found.

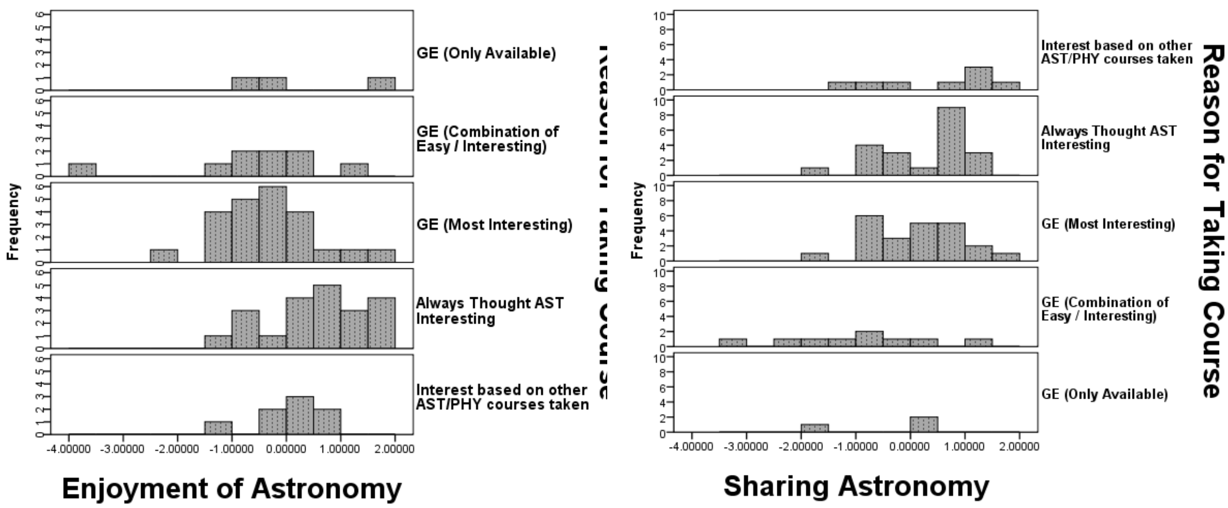

Fig. 2: Pre-course "Enjoyment" (left) and "Sharing" (right) factors as related to students' reasons for taking the course. Note that the (vertical) Reasons axis is in the opposite direction in the two diagrams. Students with higher factor scores (reflecting more positive attitudes) were more likely to take the course out of interest, while those with lower factor scores were more likely to take it because they needed a General Education science and this suited their needs.

Students' SPCI pre-test scores were significantly correlated (p=0.026) with the *Personal Enjoyment* factor score (see Figure 3 below). Students who scored more highly on *Personal Enjoyment* also scored higher on the SPCI Pre-test. It is perhaps not surprising that students who have always had a strong interest should have higher incoming content knowledge, as they would likely be motivated to seek out opportunities (TV shows, articles, books) to learn. Alternatively, their greater knowledge may lead them to greater enjoyment.

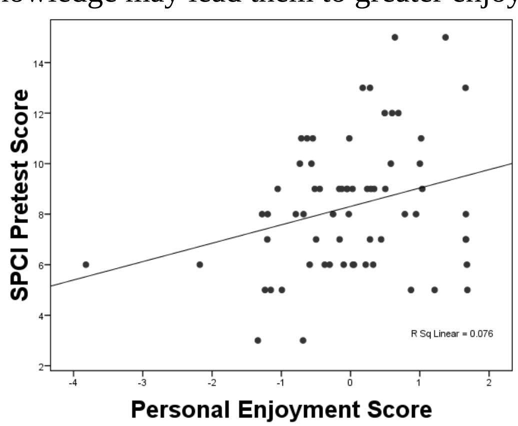

Fig. 3: Pre-course "Enjoyment" factor score (higher score = more positive attitude) correlated with students' content knowledge as reflected by the SPCI pre-test.

How often students notice aspects of Astronomy: In order to summarize the 5 survey items asking students how often they noticed or encountered various aspects of astronomy, we took the median of the responses for those questions. This median was significantly (but weakly) associated with both the SPCI Pretest Score (p-value = 0.006) and *Personal Enjoyment* factor score (p-value = 0.004). These results (shown in Figure 4 below) indicate that:

1. Students who enjoy astronomy are also those who are more aware of its presence in their lives
2. These same students also tend to score more highly on the SPCI pre-test

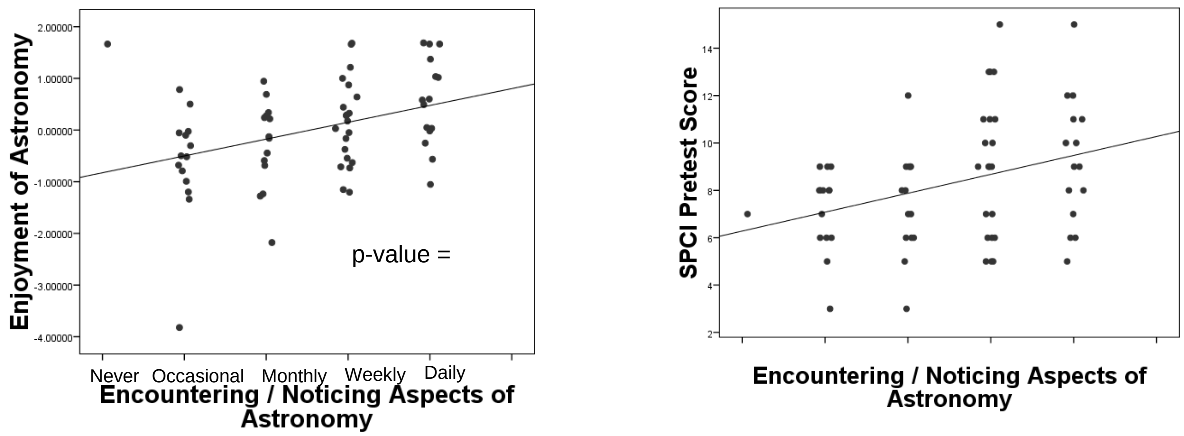

Fig. 4: The x-axis reflects pre-course medians of questions asking students how often they encounter / notice various aspects of astronomy. In both plots, the grouped responses correspond roughly to Never, Occasionally, Monthly, Weekly, and Daily, with increasing frequency towards the right. The left-most plot shows the relationship between students' frequency of encountering aspects of astronomy and the factor score reflecting how much they enjoy astronomy. The right-most plot shows the relationship with their incoming content knowledge as reflected by the SPCI pre-test score.

***SPCI Pretest Score*:** There was a marginally significant (p = 0.072) relationship between students' performance on the pre-test of the concept inventory and their previous Formal Astronomy Background. Students who scored more highly on the SPCI pre-test also tended to have had more formal training in astronomy.

Analysis of Post-Course Data: The post-course data allowed us to examine whether (a) students' incoming attitudes had any impact on their performance in the course and/or gains in content knowledge and (b) whether the students' views on relevance had changed during the course.

***Relationship of Incoming Attitudes to Performance in Course*:** As a measure of content knowledge, we primarily used the normalized gain on the SPCI (SPCI Gain). The normalized gain is a measure of how much the students improved, compared with how much room they had for improvement. It is 0 if a student scores the same on the Pre-test and Post-test, and 1 if he or she scores 100% on the Post-test. It should be noted that there was a high degree of correlation between the SPCI post-test and the SPCI gain, as well as between the SPCI gain and the grade they received in the course, suggesting that this instrument is well-matched to the course content.

When exploring the impact of students' pre-course attitudes about astronomy relevance on their performance in the course we found:

- Overall, there was no strong and significant relationship between attitudes and performance gains as measured by either the SPCI or course grade.
- In a marginally significant trend ($p = 0.068$), students scoring highly on the Pre-enjoyment factor obtained a higher course grade.
- Students who scored highly on the Pre-sharing factor had somewhat greater gains in content as measured by the SPCI ($p = 0.033$; shown in Figure 5 below)

It should be noted that the two factors are correlated with different measures of course performance. Since these measures of course performance are highly correlated with each other, it is possible that these results, although statistically significant, occurred by chance.

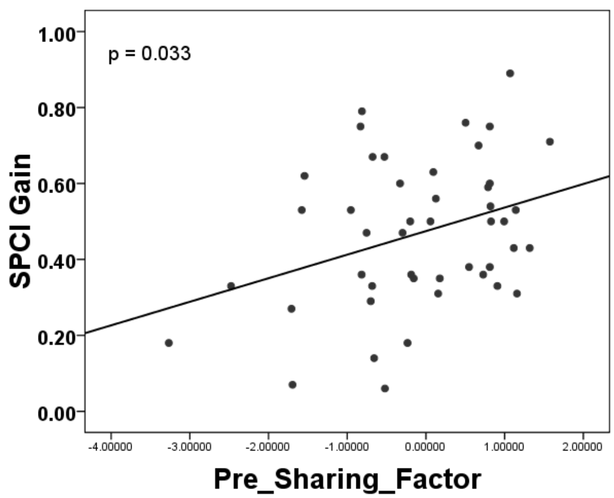

Fig. 5: The x-axis reflects students' pre-course "Sharing" factor score (higher score = more positive attitude). The vertical axis reflects their performance improvement as measured by the normalized gain on the SPCI.

Change in Attitudes during course:

Importance of Astronomy: Factor analysis revealed that the Sharing/Enjoyment factors which described the Pre-course data were not appropriate to the Post-course data. There were, however, no significant changes in most individual items of the "I like/would enjoy…" questions, or in the mean of all such items. There was a slight and marginally significant ($p = 0.07$) decrease in students' anticipated appreciation of an astronomy-related book or equipment as a present (Change = 0.3)

How often students notice / encounter Astronomy: Significant (positive) changes were found in how often students reported encountering "aspects of astronomy" ($p = 0.068$), encountering items/technology originally developed for studying astronomy ($p = 0.01$) and using general skills that astronomers apply in their research to make decisions in their life outside of class ($p = 0.034$), as well as in the median of all similar items ($p = 0.033$; shown in Figure 6 below).

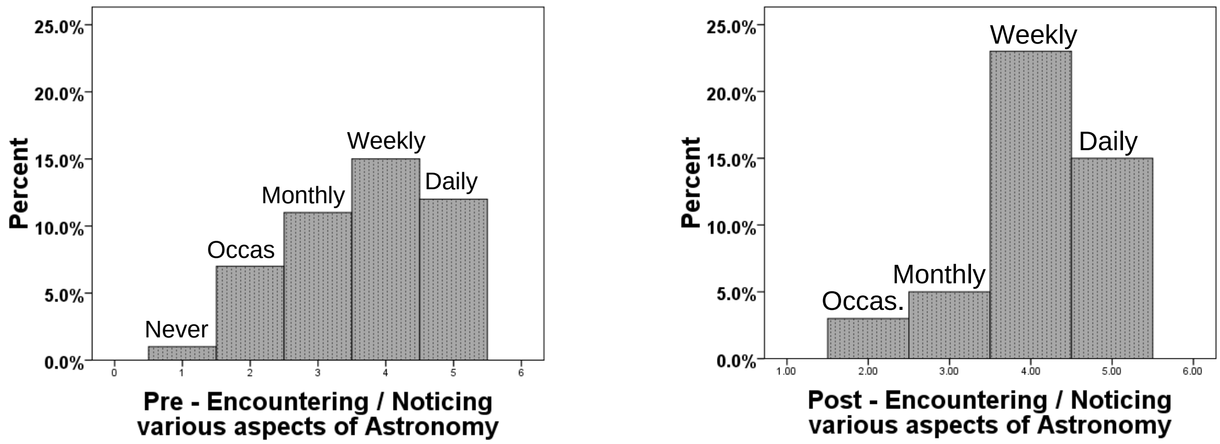

Fig. 6: Distributions of the median of questions asking students how often they encounter and/or notice various aspects of astronomy. The left-most plot shows the pre-course distribution, while the right-hand plot shows the post-course distribution. Between the beginning and end of the semester, there is a significant positive shift in the frequency with which students reported noticing or encountering astronomy outside of class.

Discussion

Conclusions: The following general conclusions can be drawn from the results.

- Identifying stars, planets etc., knowing about astronomical events, and personal (emotional) experiences are the most common ways students perceive astronomy as relevant prior to receiving any other instruction or hints about the course.
- There is a weak relationship between incoming attitudes and incoming content knowledge (SPCI Pre). This is true both for "I would like / enjoy" questions & questions about the frequency of encountering aspects of astronomy. Students who are more interested in astronomy typically already know more at the beginning of the course.
- There is a possible (weak) relationship between incoming attitudes and content gain. However, the result is neither strong nor striking, and is not common to all measures.
- Students are more likely to anticipate applying a scientific approach to problems in their life at the end of the course.
- Students notice astronomy in their lives more at the end of the course than at the beginning of the course.

Fall 2009 Highlights**:** During the Fall 2009 "Solar System Astronomy" course, an extremely similar project was carried out. The "relevance" survey was nearly identical, but instead of the SPCI, we used the Astronomy Diagnostic Test v2.0 (ADT; Deming 2002) because its content was more appropriate to the course. Seventy-six (76) students completed the pre-course instruments, and 66 of those also completed the instruments at the end of the course.

Although the open-ended responses have not been fully analyzed, the results from the other survey items were extremely similar to those for the Spring 2009 "Stars, Galaxies, and the Universe" course. In particular:

- Identifying planets, stars & emotional reactions / interactions are the strongest motivators for students
- There is a weak relationship between incoming attitudes and incoming content knowledge (ADT Pre). This is true both for "I would like / enjoy" questions & frequency of encountering aspects of astronomy
- Students are more likely to notice aspects of astronomy in their lives at the end of the course
- However, no correlations between incoming attitudes and ADT gain / course grade, suggesting that the Spring 2009 weak possible correlation between incoming attitudes and SPCI gain was spurious.

Implications for the Classroom: Based on the results of these projects, instructors of General Education astronomy courses should be encouraged to relate their subject matter to visible objects in the night sky wherever possible. In the Spring 2010 version of "Stars, Galaxies & the Universe", Dr. Sallmen began incorporating "Constellation" mini-lectures that contained (a) hints on how to find the constellation, (b) a multi-cultural discussion of the constellation, and (c) explicit connections between celestial objects found in the constellation and course content (e.g. parallax, stellar evolution…). As the role of these mini-lectures expands in the future, it will be interesting to see how students respond.

Future Work**:** The rich data collected for this project have not been exhausted. The impression of those entering and analyzing the Spring 2009 survey data is that the overall level of open-ended responses across the five questions gained in depth and complexity between the beginning and ending of the course. However, it is difficult to confirm this through analysis of individual questions, in part because student responses are not consistent across questions. One student may address a particular aspect of relevance in question 1, and a different aspect in question 4, while another student may have the ordering reversed. We suspect that a more appropriate analysis would be to: (a) code all open-ended responses together based on a global set of check-boxes and (b) code open-ended responses for overall complexity and depth of response.

In addition, the open-ended responses for the Fall 2009 data have not been analyzed, and data from Spring 2010 remain untouched. It should be noted that the wording of several questions was adjusted after Spring 2009 based on problems encountered while analyzing the earlier data. For example, the opening question has had the underlined section added to elicit more complete responses: "Is astronomy personally meaningful to you? If so, describe how. <u>If not, describe your feelings about astronomy.</u>"

Acknowledgements
The authors would like to thank OPID (Office of Professional and Instructional Development) for providing the Wisconsin Teaching Fellows and Scholars Program, and UW-La Crosse for sponsoring us as Wisconsin Teaching Fellows. We would also like to thank the Wisconsin Space Grant Consortium for giving us the opportunity to present our work at the Wisconsin Space Conference.

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A Space Sciences Capstone Curriculum at Carthage College

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Abstract

The Carthage College Physics & Astronomy Department implemented a capstone program for its upper-level students to provide basic engineering skills, systems engineering principles, and experience in the design and implementation of experimental hardware in support of NASA projects and programs. The capstone curriculum brings together machine shop professionals to train and mentor students in shop operations, instrumentation specialists from partner universities, and scientists and engineers from NASA field centers to provide students with authentic and meaningful research experiences. Primary learning outcomes identified for this curriculum include the role of collaborative working models in the sciences, an understanding of the interdisciplinary approach to problem solving at the heart of large engineering and science challenges, and the enhancement of technical reporting and writing skills.

Introduction

"Undergraduate research is the pedagogy of the twenty first century" [CUR, 2005]. This joint statement of principle from the Council on Undergraduate Research (CUR) and the National Council of Undergraduate Research (NCUR) embodies the commitment to student scholarship and creative activities upheld by the Carthage College Department of Physics & Astronomy. In pursuit of new and effective ways to realize this commitment, the department sought to revitalize its senior capstone curriculum to better reflect the research interests of its faculty and to more effectively achieve key learning outcomes identified by the department's strategic plan. The Wisconsin Space Grant Consortium was instrumental in the support of the initial phase of this curricular revision through its funding of the *Space Sciences Capstone Curriculum* project.

The Carthage Physics and Astronomy department supports physics and astronomy students, as well as students in the dual-degree engineering program. In total, we serve a growing population of 50 majors and approximately 10 minors. The department has experienced unprecedented growth in the last ten years, has a culture of active student engagement, and is involved in several high-profile research programs. Our curriculum has been acknowledged in national studies of successful physics programs for its focus on studio-based learning and for its research exposure at an early stage in academic development[Hake, R. R., 2000]. A growing focus of our program is

*The author gratefully acknowledges the support of the Wisconsin Space Grant Consortium for initial funding of the Space Sciences Capstone Curriculum project at Carthage.

opportunities in the space sciences.

Carthage physics and pre-engineering students typically follow one of two curricular paths. Those with interests in astronomy and astrophysics follow an astrophysics track within the major. Those in the pre-engineering program or with interests in physics pursue a separate track. Each track culminates in a different capstone course, Observational Astrophysics or Experimental Physics. These courses introduce research methodologies, and provide research experiences that result in the definition of a plan for the Senior Thesis, a required component of the Carthage education. Students in these courses are expected to carry out increasingly sophisticated designs in support of collaborative research projects, but have no prior experience with the technical aspects of experiment design. Also missing from our curriculum was a formal consideration of systems engineering principles and concepts. These deficiencies are addressed to varying degrees by the Space Sciences Capstone (SSC) curriculum.

Curricular Elements Developed for the Capstone Program

The core partnership established by the SSC curriculum is a collaboration between local precision machinists, instrumentation experts from University of Chicago's Yerkes Observatory and other regional universities, and a GRC scientist with expertise in *in situ* Resource Utilization (ISRU) research. This loose network of experts supports a two-course capstone experience for our dual-degree engineering and physics students.

At the center of the SSC curriculum is a two-course program consisting of a new Instrumentation and Experimental Design course (IED), followed by a restructured senior capstone course. The first course provides students with a base of CAD/Engineering Graphics, technical machining, and instrumentation skills. This base of technical skills is then applied to solve specific engineering and experimental challenges in the capstone experience of the senior year. These projects derive from our institutional relationship with Yerkes Observatory and our participation with NASA/GRC in the Systems Engineering Exploration Student Discovery (SEED) program.

During the first year of the program, the technical skills course was mentored by a team of faculty and industry partners from Merit Models, Inc. The partnership with Merit, Inc. (a manufacturing facility in Racine, WI) brings the expertise of career machinists and precision fabrication specialists to campus in order to train undergraduate students in the Carthage Physics Department's machine shop. The students were trained to design and build the components and experimental apparatus required to achieve the project goals associated with our existing partnership with researchers at GRC and Yerkes Observatory. Subsequent to proposal funding, our network of partnerships expanded to include two researchers at Lockheed Martin Space Systems working under contract with NASA to support the Constellation program.

Program Implementation

The initial stages of SSC curriculum implementation occurred during the 2009-2010 academic year. The primary elements of the implementation were (1) faculty training in engineering graphics skills, (2) design of the two supporting courses, and (3) delivery of two supporting courses. As the principal faculty member involved in the design and implementation, the author received formal training in *SolidWorks*, an engineering graphics development environment to supplement an existing base of self-taught experience with the software. Two supporting courses funded by the WSGC grant were written by the author and shepherded through the College's curriculum process. The courses "Engineering Graphics" and "Machine Shop Skills" are now catalog offerings of the physics department, and represent an important step forward in the department's efforts to formalize the experimental design components of the capstone curriculum. The courses were delivered during the J-term semester of 2010 to an enrollment of approximately ten students. Syllabi for these courses are available in Appendix A.

During the initial program year, the two skills courses were in support of a large group project proposed and mentored by Jonathan Braun of Lockheed Martin Space Systems. Mr. Braun proposed that the students develop an experimental rig to examine propellant slosh in the down-stream propellant tanks onboard the Orion Service Module. Propellant slosh is a significant challenge to both spacecraft stability and fuel mass gauging. The data requirements established by Lockheed Martin were such that the experiment should reproduce the exact dynamics of the real propellant slosh on a smaller scale during periods of transition from accelerated motion to zero-g environments. The student team designed and proposed an experiment to meet these requirements and were awarded a position in the 2009 NASA SEED program. Ultimately, the experimental rig was flown on two microgravity flights and produced a volume of data that was subsequently analyzed by two Carthage summer research students during the summer of 2010.

Assessment Measures and Outcomes

Program assessment measures for the SSC curriculum are currently in development and will be deployed during the 2010-11 academic year. These assessment measures are being developed in accord with departmental assessment guidelines. The initial assessment measures address four broad program & department learning outcomes concerning values, attitudes, knowledge, and skills. Assessment measures include pre-post testing regarding attitudes and values related to the broad learning goals associated with collaborative work, systems engineering principles, and the nature of professional scientific work.

Additional assessment measures focus on a holistic student self-appraisal of 'value-added' aspects of the program. The latter assessment asks students to reflect on the specific learning outcomes they identify as being important. Initial surveys and anecdotal information suggest that these self-assessments may be particularly useful in understanding the impact the program has on students. Initial student reports suggest that outcomes of most immediate value to the students were those associated with working on a "relevant" project for which there is an interested external partner, learning to work in teams of peers with varied work habits and patterns, and learning to manage time and schedule. Each of the students surveyed during the 2009-10 program year report learning that they were surprised at their ability to handle the demands of large and complex projects within considerable time constraints.

Summary and Future Directions

Introduction of the Space Sciences Capstone Curriculum has enhanced the skill-set of our upper-level students to include crucial machine shop abilities and engineering graphics capabilities. These skills and abilities are necessary to pursue the more sophisticated research program envisioned by the grant. Equally important to the success of the SSC program is the formal introduction of NASA Systems Engineering principles provided by the new program. These new curricular enhancements allow the department to include students directly in faculty research, and to provide authentic, complex research projects through an expanding network of NASA center scientists and partner university investigators. In addition to meeting department learning-outcome goals in new and potentially more effective ways, these curricular elements have added an element of excitement, relevance, and visibility to our upper-level capstone program that should significantly enhance our ability to recruit students into STEM fields at Carthage.

Over the course of the next few years, the SSC program will expand to include a formal course in microgravity experimental platforms to support our participation in the NASA SEED program. This course is currently under development and should be implemented during the 2011 spring semester. To continue to support the SSC program, the department will need to pursue additional funds. These funds are necessary to support the staffing of the machine shop skills class, to support the purchase of annual software licenses, and to maintain shop equipment and supplies. The author is currently involved in an NSF it Course, Curriculum, Laboratory, and Infrastructure (CCLI) proposal that may address these funding needs.

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Flight, Floating, and Mars;
New Courses at Ripon College

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Abstract. New courses have been developed to enhance the Ripon College curriculum in the areas of space exploration and aerospace science. “Exploring Mars” introduces space science and technology to first-year students with major interests outside of the natural sciences. The sequence “Introduction to Flight” and “Flight and Floating” investigates the forces affecting flying and floating object, and is designed for students interested in math, science, and engineering.

Background

The purpose of this project is to introduce aerospace studies and space exploration into the Ripon College curriculum through new courses. The first course, “Exploring Mars,” introduces first- year students to the science of space exploration and is focused on Mars (atmosphere and climate of Mars, evidence of water and life on Mars, future exploration and human colonization of Mars). The course highlights the interdisciplinary nature of challenges of space exploration and is designed for students who are not planning to major in the natural sciences. “Exploring Mars” gives students an opportunity to understand and appreciate the latest discoveries in space exploration, and to become excited about the possibilities of life in space. The course can serve as an alternative or as a compliment to the pre-existing Ripon College astronomy course, which is available to only sixty students each year and is often over-filled.

The course sequence “Introduction to Flight” and “Flight and Floating” has been developed to provide a physics background to students with interests in science, technology, engineering, and math. This course sequence combines mathematical modeling and hands-on projects involving drag, lift, thrust, gravity, and buoyancy, and includes the study of aircraft, rockets, balloons, and other flying objects. This course is unique addition to the small number of elective courses offered to our physics students (quantum mechanics, advanced lab and computational physics, and astrophysics), and it is well-suited for students interested in pursuing further studies in aeronautics and aerospace. The extensive use of mathematical modeling also makes this course an interesting elective for math students fulfilling their natural science requirement.

Additional goals of each course are to improve students’ communication skills (written and oral), quantitative analysis skills, and experimental skills through assignments, projects, and lab activities. Students are also engaged in the courses through invited speakers and field trips. Each of these new courses was offered during the 2009-2010 academic year (“Exploring Mars” in fall 2009, “Introduction to Flight” in spring 2010, and “Flight and Floating” in May 2010). With evaluation and revision, these courses will be offered again during the 2010-2011 academic year.

This project has been supported by the Wisconsin Space Grant Consortium Higher Education Incentives Program and by Ripon College. Also, a special thanks to invited speakers Josh Frey, Dan Hawk, Dan Schick, John Heasley, Larry Huebner, and Memuna Khan.

Exploring Mars

Curriculum "Our Changing Universe: Exploring Mars" is designed for first-year college students who plan to major in subjects outside of the natural sciences. The course is clustered with a new biology course "Our Changing Universe: Plants in Space" (developed by Dr. Skip Wittler, Professor of Biology, Ripon College) as part of Ripon's First-Year Seminar Series. The content and activities of the Mars course are designed for students to:

1) Compare the environment and climate of Mars to that of Earth
2) Understand and evaluate evidence of past life and water on Mars
3) Understand the history and future of space exploration
4) Create and evaluate scenarios for future habitats on Mars
5) Apply the scientific method to formulate and test hypothesis and to draw conclusions
6) Develop skills in experimental design, measuring techniques, and quantitative analysis

The course is structured as a lecture and laboratory class, also including regular group discussions, invited speakers, field trips, and reading, writing, and presentation assignments. The book used throughout the course is "A Case for Mars: The Plan to Settle the Red Planet and Why We Must" (Zubrin, 1996), which provides background on a wide range of topics covered in this course, such as history of astronomy and Mars exploration, physical characteristics, geography, and climate of Mars, rocket technology and modes of space travel, and strategies for reaching Mars, exploring the planet, and utilizing Martian resources to achieve human colonization. Laboratory activities are designed to help students learn the course content and to provide opportunities for building skills in quantitative analysis and experimental techniques. Table 1 is a list of the lab activities initially incorporated into the course.

Lab Activity	Description
Walk the Solar System (Ottewell, 1989)	Illustrates the vastness of our solar system with a scale model
How high can you jump on Mars?	Simple calculations for low-gravity Mars
Mars Observation	Observe Mars in the night sky
Heating the Surfaces of Mars and Earth	Measure heating and cooling profiles of sand (Mars) and water (Earth)
Rocket Design and Launch	Design a water rocket to protect cargo (an egg) during launch and landing
Power of the Sun (Briggs, 1996)	Experimentally determine the power of the sun and calculate the intensity on Mars
Intensity of the Sun: Winter and Summer (Williams-Norton, 2009)	Illustrates the relationship between axial tilt and seasonal patterns
Craters (NASA, 1999)	Design an experiment creating and analyzing craters

Table 1: "Exploring Mars" laboratory activities, fall 2009

The first lab, "Walk the Solar System" is a simple activity where the class walks a scale model of the solar system (stretching ~1000 meters from the sun to Pluto), and each student prepares a few planetary facts to share with the class. This activity demonstrates the vastness of space and gives students basic background information on the planets in our solar system. Subsequent labs involve measurements and the application of relatively simple mathematical theories to calculate interesting quantities ("How High Can You Jump on Mars," "Power of the Sun"). Projects such as the "Rocket Design and Launch," "Heating the Surfaces of Mars and Earth," and "Craters" are more challenging and provide students with experience in experimental design, measurement techniques, and graphical analysis. During the rocket lab, students design a pressurized-water rocket that must carry and protect precious cargo while competing for the highest apogee. During "Craters," students create craters by dropping objects into flour beds, choosing one variable to manipulate (size of falling object, initial drop height of object, mass of object) and one variable to measure (resulting crater depth, crater width, distribution of ejected crater material). The quantitative results are graphed to show relationships between the chosen variables.

Other class activities include field trips to Barlow Planetarium in Menasha and Mitchell Park Conservatory Domes in Milwaukee (to study plant-life in artificial environments), as well as guest-lectures from invited speakers. Throughout the semester, students are assigned one lab report and one design report to help improve student writing skills. Presentations (one PowerPoint and one poster) are also required in order to improve students' communication skills, and a final project assignment requires an in-depth investigation of a course-related topic accompanied by a term paper and a poster presentation.

Results and Revisions. During fall 2009, twenty first-year Ripon College students completed the "Exploring Mars" course. The curriculum and activities described above were largely successful in helping students learn about Mars and space exploration, and in helping to build students' skills in experimental techniques, communication, and quantitative analysis. The Mars course will be offered again in the fall of 2010 and will retain the same basic course structure and content as the original course, with a few modifications. For example, Mars will not be visible in the night sky during the fall of 2010 so an alternative star-gazing activity will be planned. Another adjustment to the course will be an increase in the amount of class time devoted to current events in space science, beyond missions involving Mars. Students will be required, on a regular basis, to read articles and papers reporting current advances in space science, and to share these articles with their classmates. Also, the final project assignment will be revised to be more specific, rather than the "pick anything space-related" type of project assigned last year. This year, the final project assignment is to design some component of a human settlement on Mars (shelter, agriculture, exploration, power, transportation).

This course has sparked students' interest and fascination in the study of Mars and outer space. The students in the course were not likely to major in physics or other areas of science, and for some, this was their only chance to build their background knowledge for a better understanding and appreciation of discoveries in space exploration. On the final course evaluation, students were asked what they liked most about the course. One response was: "I

like that it is something that not many people know about and we would not learn about Mars any other way without taking this course."

"Introduction to Flight" and "Flight and Floating"

Curriculum. "Introduction to Flight" and "Flight and Floating" are designed for students with interests in physics, mathematics, and engineering. In this course, students study various flying systems such as aircraft, rockets, balloons, and kites, through laboratory and modeling activities, invited speakers, and field trips. The introductory course meets on a weekly basis during the spring semester and is followed by the three-week intensive Maymester course "Flight and Floating." The goals of this course sequence are for students to:

1) Become familiar with the concepts of drag, buoyancy, thrust, and lift through basic experiments
2) Study more complex physical systems (involving lift, buoyancy, drag, gravity, and thrust) through modeling and experiments
3) Strengthen general knowledge of aircraft science and history
4) Become familiar with discoveries in space exploration
5) Improve experimental design and mathematical modeling skills
6) Improve scientific writing, graphical analysis, and oral presentation skills

The general format each week of the introductory portion of the course is to provide theory and background on the forces of thrust, lift, drag, and/or buoyancy, followed by a laboratory activity involving the relevant forces and the development of mathematical models (as homework) to predict motion of the system. The small-scale systems analyzed during the introductory course are expanded into larger-scale, more complex systems during the Maymester course, requiring students to design experiments and analyze systems using various measuring and modeling techniques. During the introductory course, for example, students experiment with balloon rockets propelling a straw along a one-dimensional horizontal path. Students measure or estimate "burn" time and "fuel" volume and mass, and, using the rocket equation, develop a model to predict the motion of the balloon rocket (top speed and range). This model is then modified during the Maymester course to describe a solid-fuel rocket, predicting the apogee of a solid-fuel rocket under different conditions (different motor sizes, rocket mass, or fin properties). The apogee of the rockets can measured with an altimeter or geometrically (with large measurement uncertainty), and can be compared to the model predictions. In some cases, experimental measurements (time to apogee, height of apogee, burn time) are used as parameters in the mathematical model to calculate unknown parameters such as exhaust velocity and drag coefficients. A third comparison can be made using RockSim software which also predicts rocket motion.

Table 2 provides a list of laboratory activities for the flight course sequence. Each of the labs involves a combination of experimental measurements and mathematical theory to predict the motion of the system or to determine some unknown quantity. In "Kites," the wind speed v at a specific altitude is determined experimentally by measuring the angle of the kite string, α, the tension T in the string, and the angle of the kite body, θ, when the kite hovers in static equilibrium. A force diagram is shown in Figure 1. Assuming the wind is blowing horizontally, the drag force on the kite is balanced by the horizontal component of the string tension, and the wind speed can be calculated according to equation (1).

Lab Activity	Description
Paper Spinners	Measure terminal velocity and compare to theory
Balloon Rockets	Develop models of horizontal rockets
Helium Balloon I	Calculate theoretical payload for neutral buoyancy, verify experimentally
Bernoulli's Principle	Demonstrations of the pressure/air speed relationship
Parachutes	Determine drag coefficients of several parachutes over a range of payloads
Solid-Fuel Rockets	Series of experiments comparing actual flight to predictions
Kites	Determine the air speed using a kite
Helium vs. Air: Flying Objects	Which flies further: an air- or helium-filled ball?
Solar Bag	Buoyancy achieved from sun-heated air
Helium Balloon II	Design a “high-altitude” experiment

Table 2: “Introduction to Flight” and “Flight and Floating” lab activities, spring 2010

$$v = \sqrt{\frac{2T\cos\alpha}{C_D \rho A \sin\theta}} \qquad (1)$$

During this experiment, a spring gauge can be used to measure the tension in the kite string, and angles θ and α can be estimated or measured with a protractor. In equation (1), ρ is the density of air (calculated from measured or estimated temperature), A is the measured area of the kite (projected area $A_p = A \cos \theta$) and C_D is the estimated drag coefficient of the kite. The altitude at which the experiment is done can be measured with an altimeter or geometrically (knowing the length of the kite string and angle α). The result of this experiment is a profile of wind speed variation with altitude.

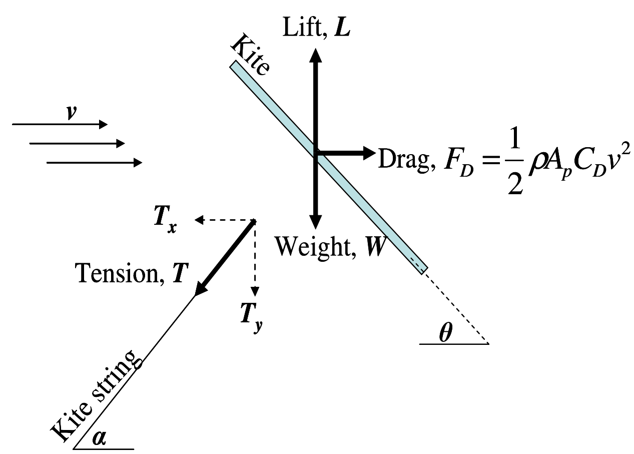

Figure 1: Force diagram of kite

Throughout the Maymester, Logger Pro video analysis software is used to analyze the motion of objects, providing time-dependent velocity, acceleration, and force data. In “Parachutes,” for example, Logger Pro is used to determine the terminal velocity of falling parachutes of various sizes over a range of payloads for each parachute. The terminal velocity is then used to calculate a drag coefficient for the parachute. In addition to labs, other course activities include the construction of simple model airplanes, tours of Enstrom helicopter facility and Sonex aircraft facility, and visits to the EAA (Experimental Aircraft Association) Airventure

museum. On a daily basis during the Maymester portion of the course, students are required to find and share news in space exploration. The course sequence also includes lectures from invited speakers. In 2010, these speakers included Memuna Khan, Assistant Professor of Biology at Ripon College who spoke about the aerodynamics of birds, Larry Huebner of NASA's Dryden Flight Research Center who shared his work on the recent Ares missions and other NASA projects, and Dan Schick who spoke about his experiences as an aircraft pilot. The final Maymester project, accompanied by student presentations, is an open-ended helium balloon project where students design "high-altitude" experiments and model the motion of the buoyant balloons with the experiment attached as a payload.

Results and Revisions. During the spring 2010 semester, eight students enrolled in the introductory course "Introduction to Flight" and six of these students completed the Maymester course "Flight and Floating". All of the students were physics majors or had taken at least one semester of introductory physics. The structure of the course sequence worked well; during the introductory course, the systems were relatively simple so that students could focus on understanding concepts and representing forces mathematically to predict motion of an object, such as a helium-filled balloon (buoyancy, gravity) and horizontal balloon rockets (thrust, drag). As planned, these models became useful tools during the Maymester course when students were asked to study motion in more complex systems involving drag, lift, thrust, gravity, and buoyancy. For example, students were able to adapt their horizontal balloon rocket model to describe the flight of solid-fuel rockets by including gravity and changing parameters such as drag coefficients, mass, and burn time.

During the Maymester portion of the course sequence, daily NASA news discussions were an effective way for students to learn about current discoveries in space exploration, and the trips to the EAA museum and helicopter and aircraft facilities helped students to improve their general knowledge of aircraft science and history. The students each did an excellent job on the final project, working in pairs to design and implement an experiment using a large helium-filled balloon. The projects included 1) Measuring the temperature change with altitude, 2) Studying the effects of "high" altitude on soda carbonation, and 3) Releasing different model airplanes from high altitudes to observe the gliding capabilities of each model.

Through these activities, the students learned how to develop mathematical models to describe systems, to design experiments, and to develop creative techniques for taking measurements and estimating parameters. Students particularly struggled, at first, with making appropriate assumptions for their models, as the systems were more complex than the typical textbook physics problems to which they were accustomed. It is through these challenges that the students gained confidence and improved their experimental and modeling skills. The flight course sequence will be offered for a second time during the spring 2011 semester and subsequent Maymester. No significant changes in the curriculum are planned at this time, although some experiments and activities may be modified. In the future, the course will be advertised to attract students in mathematics (in addition to physics students) to give them an opportunity to apply their mathematical tools to interesting systems.

Summary

"Exploring Mars," "Introduction to Flight," and "Flight and Floating" have been developed to enhance the Ripon College curriculum in space exploration and aerospace studies. The courses have been successful in bringing space science to non-science majors and in providing a unique elective course sequence for students interested in science, technology, math, and engineering. These courses will be offered again during the 2010-2011 with minor revisions in assignments and lab activities. It is likely that both courses will be offered to students on a regular basis beyond 2011.

References

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Flight, Floating, and Mars; New Courses at Ripon College

Sarah J. Desotell
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Abstract. New courses have been developed to enhance the Ripon College curriculum in the areas of space exploration and aerospace science. "Exploring Mars" introduces space science and technology to first-year students with major interests outside of the natural sciences. The sequence "Introduction to Flight" and "Flight and Floating" investigates the forces affecting flying and floating object, and is designed for students interested in math, science, and engineering.

Background

The purpose of this project is to introduce aerospace studies and space exploration into the Ripon College curriculum through new courses. The first course, "Exploring Mars," introduces first- year students to the science of space exploration and is focused on Mars (atmosphere and climate of Mars, evidence of water and life on Mars, future exploration and human colonization of Mars). The course highlights the interdisciplinary nature of challenges of space exploration and is designed for students who are not planning to major in the natural sciences. "Exploring Mars" gives students an opportunity to understand and appreciate the latest discoveries in space exploration, and to become excited about the possibilities of life in space. The course can serve as an alternative or as a compliment to the pre-existing Ripon College astronomy course, which is available to only sixty students each year and is often over-filled.

The course sequence "Introduction to Flight" and "Flight and Floating" has been developed to provide a physics background to students with interests in science, technology, engineering, and math. This course sequence combines mathematical modeling and hands-on projects involving drag, lift, thrust, gravity, and buoyancy, and includes the study of aircraft, rockets, balloons, and other flying objects. This course is unique addition to the small number of elective courses offered to our physics students (quantum mechanics, advanced lab and computational physics, and astrophysics), and it is well-suited for students interested in pursuing further studies in aeronautics and aerospace. The extensive use of mathematical modeling also makes this course an interesting elective for math students fulfilling their natural science requirement.

Additional goals of each course are to improve students' communication skills (written and oral), quantitative analysis skills, and experimental skills through assignments, projects, and lab activities. Students are also engaged in the courses through invited speakers and field trips. Each of these new courses was offered during the 2009-2010 academic year ("Exploring Mars" in fall 2009, "Introduction to Flight" in spring 2010, and "Flight and Floating" in May 2010). With evaluation and revision, these courses will be offered again during the 2010-2011 academic year.

This project has been supported by the Wisconsin Space Grant Consortium Higher Education Incentives Program and by Ripon College. Also, a special thanks to invited speakers Josh Frey, Dan Hawk, Dan Schick, John Heasley, Larry Huebner, and Memuna Khan.

Exploring Mars

Curriculum “Our Changing Universe: Exploring Mars” is designed for first-year college students who plan to major in subjects outside of the natural sciences. The course is clustered with a new biology course “Our Changing Universe: Plants in Space” (developed by Dr. Skip Wittler, Professor of Biology, Ripon College) as part of Ripon’s First-Year Seminar Series. The content and activities of the Mars course are designed for students to:

1) Compare the environment and climate of Mars to that of Earth
2) Understand and evaluate evidence of past life and water on Mars
3) Understand the history and future of space exploration
4) Create and evaluate scenarios for future habitats on Mars
5) Apply the scientific method to formulate and test hypothesis and to draw conclusions
6) Develop skills in experimental design, measuring techniques, and quantitative analysis

The course is structured as a lecture and laboratory class, also including regular group discussions, invited speakers, field trips, and reading, writing, and presentation assignments. The book used throughout the course is “A Case for Mars: The Plan to Settle the Red Planet and Why We Must” (Zubrin, 1996), which provides background on a wide range of topics covered in this course, such as history of astronomy and Mars exploration, physical characteristics, geography, and climate of Mars, rocket technology and modes of space travel, and strategies for reaching Mars, exploring the planet, and utilizing Martian resources to achieve human colonization. Laboratory activities are designed to help students learn the course content and to provide opportunities for building skills in quantitative analysis and experimental techniques. Table 1 is a list of the lab activities initially incorporated into the course.

Lab Activity	Description
Walk the Solar System (Ottewell, 1989)	Illustrates the vastness of our solar system with a scale model
How high can you jump on Mars?	Simple calculations for low-gravity Mars
Mars Observation	Observe Mars in the night sky
Heating the Surfaces of Mars and Earth	Measure heating and cooling profiles of sand (Mars) and water (Earth)
Rocket Design and Launch	Design a water rocket to protect cargo (an egg) during launch and landing
Power of the Sun (Briggs, 1996)	Experimentally determine the power of the sun and calculate the intensity on Mars
Intensity of the Sun: Winter and Summer (Williams-Norton, 2009)	Illustrates the relationship between axial tilt and seasonal patterns
Craters (NASA, 1999)	Design an experiment creating and analyzing craters

Table 1: "Exploring Mars" laboratory activities, fall 2009

The first lab, "Walk the Solar System" is a simple activity where the class walks a scale model of the solar system (stretching ~1000 meters from the sun to Pluto), and each student prepares a few planetary facts to share with the class. This activity demonstrates the vastness of space and gives students basic background information on the planets in our solar system. Subsequent labs involve measurements and the application of relatively simple mathematical theories to calculate interesting quantities ("How High Can You Jump on Mars," "Power of the Sun"). Projects such as the "Rocket Design and Launch," "Heating the Surfaces of Mars and Earth," and "Craters" are more challenging and provide students with experience in experimental design, measurement techniques, and graphical analysis. During the rocket lab, students design a pressurized-water rocket that must carry and protect precious cargo while competing for the highest apogee. During "Craters," students create craters by dropping objects into flour beds, choosing one variable to manipulate (size of falling object, initial drop height of object, mass of object) and one variable to measure (resulting crater depth, crater width, distribution of ejected crater material). The quantitative results are graphed to show relationships between the chosen variables.

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Results and Revisions. During fall 2009, twenty first-year Ripon College students completed the "Exploring Mars" course. The curriculum and activities described above were largely successful in helping students learn about Mars and space exploration, and in helping to build students' skills in experimental techniques, communication, and quantitative analysis. The Mars course will be offered again in the fall of 2010 and will retain the same basic course structure and content as the original course, with a few modifications. For example, Mars will not be visible in the night sky during the fall of 2010 so an alternative star-gazing activity will be planned. Another adjustment to the course will be an increase in the amount of class time devoted to current events in space science, beyond missions involving Mars. Students will be required, on a regular basis, to read articles and papers reporting current advances in space science, and to share these articles with their classmates. Also, the final project assignment will be revised to be more specific, rather than the "pick anything space-related" type of project assigned last year. This year, the final project assignment is to design some component of a human settlement on Mars (shelter, agriculture, exploration, power, transportation).

This course has sparked students' interest and fascination in the study of Mars and outer space. The students in the course were not likely to major in physics or other areas of science, and for some, this was their only chance to build their background knowledge for a better understanding and appreciation of discoveries in space exploration. On the final course evaluation, students were asked what they liked most about the course. One response was: "I

like that it is something that not many people know about and we would not learn about Mars any other way without taking this course."

"Introduction to Flight" and "Flight and Floating"

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1) Become familiar with the concepts of drag, buoyancy, thrust, and lift through basic experiments
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3) Strengthen general knowledge of aircraft science and history
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The general format each week of the introductory portion of the course is to provide theory and background on the forces of thrust, lift, drag, and/or buoyancy, followed by a laboratory activity involving the relevant forces and the development of mathematical models (as homework) to predict motion of the system. The small-scale systems analyzed during the introductory course are expanded into larger-scale, more complex systems during the Maymester course, requiring students to design experiments and analyze systems using various measuring and modeling techniques. During the introductory course, for example, students experiment with balloon rockets propelling a straw along a one-dimensional horizontal path. Students measure or estimate "burn" time and "fuel" volume and mass, and, using the rocket equation, develop a model to predict the motion of the balloon rocket (top speed and range). This model is then modified during the Maymester course to describe a solid-fuel rocket, predicting the apogee of a solid-fuel rocket under different conditions (different motor sizes, rocket mass, or fin properties). The apogee of the rockets can measured with an altimeter or geometrically (with large measurement uncertainty), and can be compared to the model predictions. In some cases, experimental measurements (time to apogee, height of apogee, burn time) are used as parameters in the mathematical model to calculate unknown parameters such as exhaust velocity and drag coefficients. A third comparison can be made using RockSim software which also predicts rocket motion.

Table 2 provides a list of laboratory activities for the flight course sequence. Each of the labs involves a combination of experimental measurements and mathematical theory to predict the motion of the system or to determine some unknown quantity. In "Kites," the wind speed v at a specific altitude is determined experimentally by measuring the angle of the kite string, α, the tension T in the string, and the angle of the kite body, θ, when the kite hovers in static equilibrium. A force diagram is shown in Figure 1. Assuming the wind is blowing horizontally, the drag force on the kite is balanced by the horizontal component of the string tension, and the wind speed can be calculated according to equation (1).

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Balloon Rockets	Develop models of horizontal rockets
Helium Balloon I	Calculate theoretical payload for neutral buoyancy, verify experimentally
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Solar Bag	Buoyancy achieved from sun-heated air
Helium Balloon II	Design a "high-altitude" experiment

Table 2: "Introduction to Flight" and "Flight and Floating" lab activities, spring 2010

$$v = \sqrt{\frac{2T\cos\alpha}{C_D \rho A \sin\theta}} \qquad (1)$$

During this experiment, a spring gauge can be used to measure the tension in the kite string, and angles θ and α can be estimated or measured with a protractor. In equation (1), ρ is the density of air (calculated from measured or estimated temperature), A is the measured area of the kite (projected area $A_p = A \cos\theta$) and C_D is the estimated drag coefficient of the kite. The altitude at which the experiment is done can be measured with an altimeter or geometrically (knowing the length of the kite string and angle α). The result of this experiment is a profile of wind speed variation with altitude.

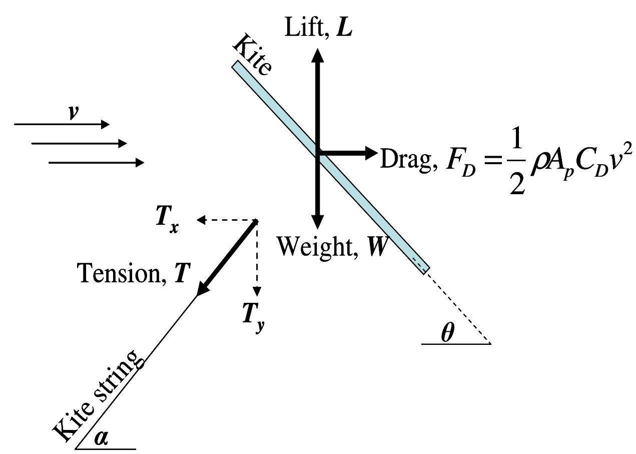

Figure 1: Force diagram of kite

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Lab Activity	Description
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Table 1: "Exploring Mars" laboratory activities, fall 2009

The first lab, “Walk the Solar System” is a simple activity where the class walks a scale model of the solar system (stretching ~1000 meters from the sun to Pluto), and each student prepares a few planetary facts to share with the class. This activity demonstrates the vastness of space and gives students basic background information on the planets in our solar system. Subsequent labs involve measurements and the application of relatively simple mathematical theories to calculate interesting quantities (“How High Can You Jump on Mars,” “Power of the Sun”). Projects such as the “Rocket Design and Launch,” “Heating the Surfaces of Mars and Earth,” and “Craters” are more challenging and provide students with experience in experimental design, measurement techniques, and graphical analysis. During the rocket lab, students design a pressurized-water rocket that must carry and protect precious cargo while competing for the highest apogee. During “Craters,” students create craters by dropping objects into flour beds, choosing one variable to manipulate (size of falling object, initial drop height of object, mass of object) and one variable to measure (resulting crater depth, crater width, distribution of ejected crater material). The quantitative results are graphed to show relationships between the chosen variables.

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Results and Revisions. During fall 2009, twenty first-year Ripon College students completed the “Exploring Mars” course. The curriculum and activities described above were largely successful in helping students learn about Mars and space exploration, and in helping to build students’ skills in experimental techniques, communication, and quantitative analysis. The Mars course will be offered again in the fall of 2010 and will retain the same basic course structure and content as the original course, with a few modifications. For example, Mars will not be visible in the night sky during the fall of 2010 so an alternative star-gazing activity will be planned. Another adjustment to the course will be an increase in the amount of class time devoted to current events in space science, beyond missions involving Mars. Students will be required, on a regular basis, to read articles and papers reporting current advances in space science, and to share these articles with their classmates. Also, the final project assignment will be revised to be more specific, rather than the “pick anything space-related” type of project assigned last year. This year, the final project assignment is to design some component of a human settlement on Mars (shelter, agriculture, exploration, power, transportation).

This course has sparked students’ interest and fascination in the study of Mars and outer space. The students in the course were not likely to major in physics or other areas of science, and for some, this was their only chance to build their background knowledge for a better understanding and appreciation of discoveries in space exploration. On the final course evaluation, students were asked what they liked most about the course. One response was: “I

like that it is something that not many people know about and we would not learn about Mars any other way without taking this course."

"Introduction to Flight" and "Flight and Floating"

Curriculum. "Introduction to Flight" and "Flight and Floating" are designed for students with interests in physics, mathematics, and engineering. In this course, students study various flying systems such as aircraft, rockets, balloons, and kites, through laboratory and modeling activities, invited speakers, and field trips. The introductory course meets on a weekly basis during the spring semester and is followed by the three-week intensive Maymester course "Flight and Floating." The goals of this course sequence are for students to:

1) Become familiar with the concepts of drag, buoyancy, thrust, and lift through basic experiments
2) Study more complex physical systems (involving lift, buoyancy, drag, gravity, and thrust) through modeling and experiments
3) Strengthen general knowledge of aircraft science and history
4) Become familiar with discoveries in space exploration
5) Improve experimental design and mathematical modeling skills
6) Improve scientific writing, graphical analysis, and oral presentation skills

The general format each week of the introductory portion of the course is to provide theory and background on the forces of thrust, lift, drag, and/or buoyancy, followed by a laboratory activity involving the relevant forces and the development of mathematical models (as homework) to predict motion of the system. The small-scale systems analyzed during the introductory course are expanded into larger-scale, more complex systems during the Maymester course, requiring students to design experiments and analyze systems using various measuring and modeling techniques. During the introductory course, for example, students experiment with balloon rockets propelling a straw along a one-dimensional horizontal path. Students measure or estimate "burn" time and "fuel" volume and mass, and, using the rocket equation, develop a model to predict the motion of the balloon rocket (top speed and range). This model is then modified during the Maymester course to describe a solid-fuel rocket, predicting the apogee of a solid-fuel rocket under different conditions (different motor sizes, rocket mass, or fin properties). The apogee of the rockets can measured with an altimeter or geometrically (with large measurement uncertainty), and can be compared to the model predictions. In some cases, experimental measurements (time to apogee, height of apogee, burn time) are used as parameters in the mathematical model to calculate unknown parameters such as exhaust velocity and drag coefficients. A third comparison can be made using RockSim software which also predicts rocket motion.

Table 2 provides a list of laboratory activities for the flight course sequence. Each of the labs involves a combination of experimental measurements and mathematical theory to predict the motion of the system or to determine some unknown quantity. In "Kites," the wind speed v at a specific altitude is determined experimentally by measuring the angle of the kite string, α, the tension T in the string, and the angle of the kite body, θ, when the kite hovers in static equilibrium. A force diagram is shown in Figure 1. Assuming the wind is blowing horizontally, the drag force on the kite is balanced by the horizontal component of the string tension, and the wind speed can be calculated according to equation (1).

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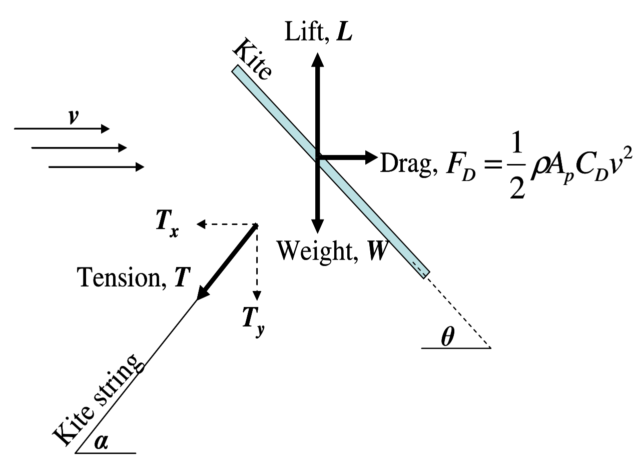
Table 2: "Introduction to Flight" and "Flight and Floating" lab activities, spring 2010

$$v = \sqrt{\frac{2T\cos\alpha}{C_D \rho A \sin\theta}} \qquad (1)$$

During this experiment, a spring gauge can be used to measure the tension in the kite string, and angles θ and α can be estimated or measured with a protractor. In equation (1), ρ is the density of air (calculated from measured or estimated temperature), A is the measured area of the kite (projected area $A_p = A \cos \theta$) and C_D is the estimated drag coefficient of the kite. The altitude at which the experiment is done can be measured with an altimeter or geometrically (knowing the length of the kite string and angle α). The result of this experiment is a profile of wind speed variation with altitude.



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Throughout the Maymester, Logger Pro video analysis software is used to analyze the motion of objects, providing time-dependent velocity, acceleration, and force data. In "Parachutes," for example, Logger Pro is used to determine the terminal velocity of falling parachutes of various sizes over a range of payloads for each parachute. The terminal velocity is then used to calculate a drag coefficient for the parachute. In addition to labs, other course activities include the construction of simple model airplanes, tours of Enstrom helicopter facility and Sonex aircraft facility, and visits to the EAA (Experimental Aircraft Association) Airventure

museum. On a daily basis during the Maymester portion of the course, students are required to find and share news in space exploration. The course sequence also includes lectures from invited speakers. In 2010, these speakers included Memuna Khan, Assistant Professor of Biology at Ripon College who spoke about the aerodynamics of birds, Larry Huebner of NASA's Dryden Flight Research Center who shared his work on the recent Ares missions and other NASA projects, and Dan Schick who spoke about his experiences as an aircraft pilot. The final Maymester project, accompanied by student presentations, is an open-ended helium balloon project where students design "high-altitude" experiments and model the motion of the buoyant balloons with the experiment attached as a payload.

Results and Revisions. During the spring 2010 semester, eight students enrolled in the introductory course "Introduction to Flight" and six of these students completed the Maymester course "Flight and Floating". All of the students were physics majors or had taken at least one semester of introductory physics. The structure of the course sequence worked well; during the introductory course, the systems were relatively simple so that students could focus on understanding concepts and representing forces mathematically to predict motion of an object, such as a helium-filled balloon (buoyancy, gravity) and horizontal balloon rockets (thrust, drag). As planned, these models became useful tools during the Maymester course when students were asked to study motion in more complex systems involving drag, lift, thrust, gravity, and buoyancy. For example, students were able to adapt their horizontal balloon rocket model to describe the flight of solid-fuel rockets by including gravity and changing parameters such as drag coefficients, mass, and burn time.

During the Maymester portion of the course sequence, daily NASA news discussions were an effective way for students to learn about current discoveries in space exploration, and the trips to the EAA museum and helicopter and aircraft facilities helped students to improve their general knowledge of aircraft science and history. The students each did an excellent job on the final project, working in pairs to design and implement an experiment using a large helium-filled balloon. The projects included 1) Measuring the temperature change with altitude, 2) Studying the effects of "high" altitude on soda carbonation, and 3) Releasing different model airplanes from high altitudes to observe the gliding capabilities of each model.

Through these activities, the students learned how to develop mathematical models to describe systems, to design experiments, and to develop creative techniques for taking measurements and estimating parameters. Students particularly struggled, at first, with making appropriate assumptions for their models, as the systems were more complex than the typical textbook physics problems to which they were accustomed. It is through these challenges that the students gained confidence and improved their experimental and modeling skills. The flight course sequence will be offered for a second time during the spring 2011 semester and subsequent Maymester. No significant changes in the curriculum are planned at this time, although some experiments and activities may be modified. In the future, the course will be advertised to attract students in mathematics (in addition to physics students) to give them an opportunity to apply their mathematical tools to interesting systems.

Summary

"Exploring Mars," "Introduction to Flight," and "Flight and Floating" have been developed to enhance the Ripon College curriculum in space exploration and aerospace studies. The courses have been successful in bringing space science to non-science majors and in providing a unique elective course sequence for students interested in science, technology, math, and engineering. These courses will be offered again during the 2010-2011 with minor revisions in assignments and lab activities. It is likely that both courses will be offered to students on a regular basis beyond 2011.

References

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Flight, Floating, and Mars; New Courses at Ripon College

Sarah J. Desotell
Department of Physics, Ripon College, Ripon, Wisconsin

Abstract. New courses have been developed to enhance the Ripon College curriculum in the areas of space exploration and aerospace science. "Exploring Mars" introduces space science and technology to first-year students with major interests outside of the natural sciences. The sequence "Introduction to Flight" and "Flight and Floating" investigates the forces affecting flying and floating object, and is designed for students interested in math, science, and engineering.

Background

The purpose of this project is to introduce aerospace studies and space exploration into the Ripon College curriculum through new courses. The first course, "Exploring Mars," introduces first- year students to the science of space exploration and is focused on Mars (atmosphere and climate of Mars, evidence of water and life on Mars, future exploration and human colonization of Mars). The course highlights the interdisciplinary nature of challenges of space exploration and is designed for students who are not planning to major in the natural sciences. "Exploring Mars" gives students an opportunity to understand and appreciate the latest discoveries in space exploration, and to become excited about the possibilities of life in space. The course can serve as an alternative or as a compliment to the pre-existing Ripon College astronomy course, which is available to only sixty students each year and is often over-filled.

The course sequence "Introduction to Flight" and "Flight and Floating" has been developed to provide a physics background to students with interests in science, technology, engineering, and math. This course sequence combines mathematical modeling and hands-on projects involving drag, lift, thrust, gravity, and buoyancy, and includes the study of aircraft, rockets, balloons, and other flying objects. This course is unique addition to the small number of elective courses offered to our physics students (quantum mechanics, advanced lab and computational physics, and astrophysics), and it is well-suited for students interested in pursuing further studies in aeronautics and aerospace. The extensive use of mathematical modeling also makes this course an interesting elective for math students fulfilling their natural science requirement.

Additional goals of each course are to improve students' communication skills (written and oral), quantitative analysis skills, and experimental skills through assignments, projects, and lab activities. Students are also engaged in the courses through invited speakers and field trips. Each of these new courses was offered during the 2009-2010 academic year ("Exploring Mars" in fall 2009, "Introduction to Flight" in spring 2010, and "Flight and Floating" in May 2010). With evaluation and revision, these courses will be offered again during the 2010-2011 academic year.

This project has been supported by the Wisconsin Space Grant Consortium Higher Education Incentives Program and by Ripon College. Also, a special thanks to invited speakers Josh Frey, Dan Hawk, Dan Schick, John Heasley, Larry Huebner, and Memuna Khan.

Exploring Mars

Curriculum "Our Changing Universe: Exploring Mars" is designed for first-year college students who plan to major in subjects outside of the natural sciences. The course is clustered with a new biology course "Our Changing Universe: Plants in Space" (developed by Dr. Skip Wittler, Professor of Biology, Ripon College) as part of Ripon's First-Year Seminar Series. The content and activities of the Mars course are designed for students to:

1) Compare the environment and climate of Mars to that of Earth
2) Understand and evaluate evidence of past life and water on Mars
3) Understand the history and future of space exploration
4) Create and evaluate scenarios for future habitats on Mars
5) Apply the scientific method to formulate and test hypothesis and to draw conclusions
6) Develop skills in experimental design, measuring techniques, and quantitative analysis

The course is structured as a lecture and laboratory class, also including regular group discussions, invited speakers, field trips, and reading, writing, and presentation assignments. The book used throughout the course is "A Case for Mars: The Plan to Settle the Red Planet and Why We Must" (Zubrin, 1996), which provides background on a wide range of topics covered in this course, such as history of astronomy and Mars exploration, physical characteristics, geography, and climate of Mars, rocket technology and modes of space travel, and strategies for reaching Mars, exploring the planet, and utilizing Martian resources to achieve human colonization. Laboratory activities are designed to help students learn the course content and to provide opportunities for building skills in quantitative analysis and experimental techniques. Table 1 is a list of the lab activities initially incorporated into the course.

Lab Activity	**Description**
Walk the Solar System (Ottewell, 1989)	Illustrates the vastness of our solar system with a scale model
How high can you jump on Mars?	Simple calculations for low-gravity Mars
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Table 1: "Exploring Mars" laboratory activities, fall 2009

The first lab, "Walk the Solar System" is a simple activity where the class walks a scale model of the solar system (stretching ~1000 meters from the sun to Pluto), and each student prepares a few planetary facts to share with the class. This activity demonstrates the vastness of space and gives students basic background information on the planets in our solar system. Subsequent labs involve measurements and the application of relatively simple mathematical theories to calculate interesting quantities ("How High Can You Jump on Mars," "Power of the Sun"). Projects such as the "Rocket Design and Launch," "Heating the Surfaces of Mars and Earth," and "Craters" are more challenging and provide students with experience in experimental design, measurement techniques, and graphical analysis. During the rocket lab, students design a pressurized-water rocket that must carry and protect precious cargo while competing for the highest apogee. During "Craters," students create craters by dropping objects into flour beds, choosing one variable to manipulate (size of falling object, initial drop height of object, mass of object) and one variable to measure (resulting crater depth, crater width, distribution of ejected crater material). The quantitative results are graphed to show relationships between the chosen variables.

Other class activities include field trips to Barlow Planetarium in Menasha and Mitchell Park Conservatory Domes in Milwaukee (to study plant-life in artificial environments), as well as guest-lectures from invited speakers. Throughout the semester, students are assigned one lab report and one design report to help improve student writing skills. Presentations (one PowerPoint and one poster) are also required in order to improve students' communication skills, and a final project assignment requires an in-depth investigation of a course-related topic accompanied by a term paper and a poster presentation.

Results and Revisions. During fall 2009, twenty first-year Ripon College students completed the "Exploring Mars" course. The curriculum and activities described above were largely successful in helping students learn about Mars and space exploration, and in helping to build students' skills in experimental techniques, communication, and quantitative analysis. The Mars course will be offered again in the fall of 2010 and will retain the same basic course structure and content as the original course, with a few modifications. For example, Mars will not be visible in the night sky during the fall of 2010 so an alternative star-gazing activity will be planned. Another adjustment to the course will be an increase in the amount of class time devoted to current events in space science, beyond missions involving Mars. Students will be required, on a regular basis, to read articles and papers reporting current advances in space science, and to share these articles with their classmates. Also, the final project assignment will be revised to be more specific, rather than the "pick anything space-related" type of project assigned last year. This year, the final project assignment is to design some component of a human settlement on Mars (shelter, agriculture, exploration, power, transportation).

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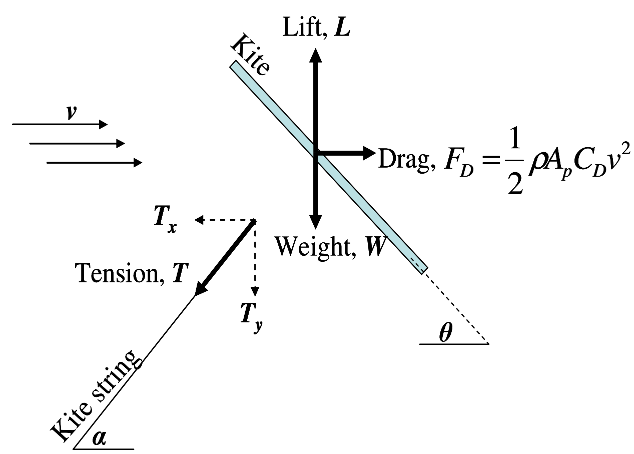

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20th Annual Conference
Appendix A

2010 Program

Wisconsin Space Grant Consortium

&

University of Wisconsin-Sheboygan

Present:

the Twentieth ANNUAL

WISCONSIN SPACE CONFERENCE

“Dawn of a New Age”

University of Wisconsin-Sheboygan
Sheboygan, Wisconsin

Thursday, August 19 – Friday, August 20, 2010

CONFERENCE 2010 PROGRAM

Thursday, August 19, 2010

7:30-8:45 am **Registration** **Entrance, Acuity Technology Center**

Continental Breakfast **Theatre Lobby**

Posters (formal poster session at 2:45 p.m.) **Wombat Room (2114)**

*** Plenary Session ***

8:45-9:05 am **Welcome and Introductions** **Theatre**

R. Aileen Yingst, Director, Wisconsin Space Grant Consortium, University of Wisconsin-Green Bay; NASA Mars Rover Exploration Mission Scientist, NASA DAWN at Vesta, Participating Scientist

Al Hardersen, Dean and CEO, University of Wisconsin-Sheboygan

9:05-10:15 am **Session 1: Keynote Address**

Introduction of Keynote
R. Aileen Yingst, Director, Wisconsin Space Grant Consortium, University of Wisconsin-Green Bay; NASA Mars Rover Exploration Mission Scientist, NASA DAWN at Vesta, Participating Scientist

Dr. Marc D. Rayman, Chief Engineer, Jet Propulsion Laboratory, NASA Dawn Mission, *Flying through the Solar System Near You: NASA's DAWN Mission to the Asteroid Belt*

10:15-10:45 am **Morning Break** **Theatre Lobby**

*** Plenary Session ***

10:45-12:00 pm **Session 2: WSGC Rocket Competition** **Theatre**

Moderator: Bill Farrow, WSGC Associate Director for Special Initiatives, Assistant Professor, Milwaukee School of Engineering

First Place – Non-Engineering Division – Red Hawks
Bryant Vande Kolk, **Charlotte Evans,** Undergraduate Students, Physics Department, Ripon College

Third Place – Engineering Division – Team Rally Axe
Tyler Van Fossen, **Alex Gonring, Ryan Bahr,** Undergraduate Students, Engineering Mechanics & Astronautics Department, University of Wisconsin-Madison

Second Place – Engineering Division – Team Juggernaut
Justin Hare, Graduate Student, **Justin Kenter, Marcus Fritz, Matthew Braunschweig,** Undergraduate Students, Engineering Mechanics and Astronautics Department, University of Wisconsin - Madison

First Place – Engineering Division – Space Badgers
Chelsey Erickson, Graduate Student, Engineering Department, University of Wisconsin - Madison

12:00-1:00 pm **Lunch** **Commons**

*** Concurrent Sessions -- Research Streams ***

1:00-2:30 pm **Session 3R: Geology/Biological Sciences/Atmospheric Science** **Room 2223**

Moderator: David Higgs, Associate Professor, Biosciences, University of Wisconsin-Parkside

Rex A. Hanger, Anoxia *in the Permian Oceans: Evidence from Island Arc Faunas, Pine Forest Range, Nevada*, Associate Professor, Department of Geography and Geology Department, University of Wisconsin-Whitewater

Claus C. Moberg, *The Impact of Stratosphere-Troposphere Exchange on Surface Ozone Concentrations in the Western United States*, PhD Candidate, Center for Sustainability and the Global Environment, University of Wisconsin-Madison

Dan Hawk, *Carbonizing Beetle-Killed Trees for Commercial Ecological Detoxification*, Undergraduate Student, Lawrence University

Paul West, *Trading Carbon for Food: the Carbon Costs of Clearing Natural Ecosystems for New Croplands*, PhD Candidate, Center for Sustainability & the Global Environment, University of Wisconsin-Madison

Lisa Anderson-Antle, *Effects of Photobiomodulation in Osteoclast Formation* in vitro*: a Pilot Study*, Doctoral Candidate, College of Nursing, University of Wisconsin-Milwaukee

Jonathan Van Dyke, *Muscle Atrophy Can and Can't Be Prevented Using Passive Stretch*, Graduate Student, Cell Biology, Neurobiology & Anatomy Department, Medical College of Wisconsin

*** Concurrent Sessions -- Education Stream ***

1:00-2:30 pm **Session 3E: K-12 Education & General Public Outreach** **Wombat Room (2114)**

Moderator: Sarah Desotell, Assistant Professor, Physics Department, Ripon College

Margaret Turnbull, *Journey to Planet Earth: Public Outreach and Teacher Training in Astrobiology*, President, Global Science Institute

Tom Thomas, *Educational Outreach Initiatives of the Centennial Celebration of Powered Flight in Wisconsin*, Wisconsin Aviation Hall of Fame Board of Directors

Sherwood J. Williams, *Teacher Orientation Program (TOP) Flights*, Great Lakes Region Director of Aerospace Education, Northern Flight Alliance

Bradley Staats, *Spaceflight Academy for CESA District #2*, President, Spaceflight Fundamentals, LLC

Mary Williams-Norton, *A Taste of the Solar System*, Professor, Physics Department, Ripon College

Barbara Bielec, *Biotechnology Teacher Training*, K-12 Program Coordinator, BioPharmaceutical Technology Center Institute

2:30-2:45 pm **Afternoon Break** **Outside Wombat Room (2114)**

*** Concurrent Sessions -- Poster Session ***

2:45-3:45 pm **Session 4P: Posters** **Wombat Room (2114)**

Facilitator: R. Aileen Yingst

April Graham, *Passive Stretch Does Not Activate Akt (protein-kinase B) in Rat Fast and Slow Muscle,* Undergraduate Student, Department of Cell Biology, Neurobiology & Anatomy, Medical College of Wisconsin

Sean Harrington, *Temperature Dependence of Quantum Dot, Optically Gated, Field-Effect Transistor Single-Photon Detectors,* Undergraduate Student, Physics, University of Wisconsin-La Crosse

James McGrail, *Research and Development of an Autonomous Lunar Lander*, Graduate Student, Engineering Management, Marquette University

Bryan Sandford, *Effect of Muscle Stimulation on Akt Phosphorylation Compared to Passive Stretch*, Undergraduate Student, Department of Cell Biology, Neurobiology & Anatomy, Medical College of Wisconsin

Senior Design Team Project:
Peer Larson, **Adam Lawrenz,** *ECLIPS: Engineered Compact Lunar Interchangeable Power Systems,* Undergraduate Student, Mechanical Engineering Department, Milwaukee School of Engineering

NASA's Microgravity Team Program:
Kim Schultz/Amber Bakkum, *Investigation of Propellant Sloshing and Zero Gravity Equilibrium for the Orion Service Module Propellant Tanks*, Undergraduate Students, Physics Department, Carthage College

WSGC Elijah Balloon Payload Team:
Stephanie Finnvik, Carthage College; **Tyler Van Fossen**, University of Wisconsin – Madison; **Mike Czech**, University of Wisconsin-Milwaukee; **Billy Lancelle**, Saint Norbert College; **Victoria Falcon**, Milwaukee School of Engineering; **Becca McAuliffe**, Marquette University

WSGC Elijah Balloon Launch Team:
Eric Deering, Milwaukee School of Engineering; **Victoria Salas**, Marquette University; **Peter Schmalz,** Marquette University: and **Kevin Weathers**, University of Wisconsin-La Crosse, Undergraduate Students

*** Concurrent Sessions -- Research Stream ***

2:45-3:45 pm **Session 4R: Engineering** **Room 2223**

Moderator, Invited: John Borg, Professor, Department of Mechanical Engineering, Marquette University

Brandon A. Jackson, *Solid Motor Thrust Oscillation Using Cold Flow Facility*, Undergraduate Student, Mechanical Engineering Department, Milwaukee School of Engineering

Chelsey Y. Erickson, *Life Support Systems / Particulate Matter and Lunar Dust Filtration*, Graduate Student, Mechanical Engineering Department, University of Wisconsin-Madison

Eric Gansen, *Using Semiconductor Quantum Dots to Detect Single Photons of Light*, Assistant Professor, Physics Department, University of Wisconsin-La Crosse

*** Concurrent Sessions -- Education Stream ***

2:45-3:45 pm **Session 4E: Higher Education** **Room 3102**

Moderator: Mary Williams-Norton, Professor, Physics Department, Ripon College

Shauna Sallmen, *Investigating Student Views of Relevancy in Introductory Astronomy*, Associate Professor, Physics Department, University of Wisconsin-La Crosse

Eric Brunsell, *Learning from the ECLISpE Project: Using Real-World Data to Promote Science Inquiry*, Assistant Professor, Science Education, Curriculum and Instruction, University of Wisconsin-Oshkosh

Sarah Desotell, *Flight, Floating, and Mars; New Courses at Ripon College*, Assistant Professor, Ripon College

Kevin Crosby, *A Capstone Curriculum in the Space Sciences*, Associate Professor, Physics Department, Carthage College

3:45-4:00 pm **Afternoon Break** **Outside Wombat Room (2114)**

*** Concurrent Sessions -- Research Stream ***

4:00-5:30 pm **Session 4R: Physics/Astronomy** **Room 2223**

Moderator: Gubbi Sudhakaran, WSGC Associate Director for Higher Education and Chair, Physics Department, University of Wisconsin-La Crosse

Blakesley Burkhart, *Magnetic Turbulence in the Interstellar Medium*, Graduate Student, Astronomy Department, University of Wisconsin-Madison

Amanda Gault, *Millimeter-wave Bolometric Interferometer*, Graduate Student, Physics Department, University of Wisconsin-Madison

Jacob Miller, *Hydrodynamic Simulations of Double-Bent Radio Sources*, Undergraduate Student, Astronomy Department, University of Wisconsin-Madison

Emily Barrentine, Development *of a Transition-Edge Hot-Electron Microbolometer for Observation of the Cosmic Microwave Background*, Graduate Student, University of Wisconsin-Madison

Sara Stanchfield, *Big Bang Blackbody Simulator*, Undergraduate Student, Physics Department, University of Wisconsin-Madison

*** Concurrent Sessions -- Education Stream ***

4:00-5:30 pm **Session 4E: Teacher Training and General Education** **Wombat Room (2114)**

Moderator: Jim Schmidt, WSGC Special Projects Coordinator and Teacher, DePere School District

Kay Kriewald, *Science Outreach for Spanish Speakers*, Sr. Outreach Specialist, UW Space Place, University of Wisconsin-Madison

Barbara Bielec, *A Celebration of Life! A Science Outreach Partnership between the African American Ethnic Academy and the BioPharmaceutical Technology Center Institute,* K-12 Program Coordinator, BioPharmaceutical Technology Center Institute

Claire Miller/Hailey Alfred/Stephanie Sykes, *The Science of Writing and Publishing Science,* Student Reporters/Teen Editor, Simpson Street Free Press

Loretta Krenitsky, *Fly Girls*, Women in Technology Program Coordinator, Applied Research and Grants, Milwaukee School of Engineering

Judy Schieble, *Elementary Rocket Launch K-12,* Elementary Chair, Rockets for Schools, Great Lakes Spaceport Education Foundation

Chrissy Paape, *To the Moon & Beyond: Lunar Expedition*, Vice-President, Space Explorers, Inc.

***** Adjourn for the Day *****

Friday, August 20, 2010

8:00-9:00 am **Registration** **Entrance, Acuity Technology Center**

Continental Breakfast **Theatre Lobby**

8:00-8:45 am **Undergraduate Workshop** **Wombat Room (2114)**

*** Plenary Session ***

9:00-10:00 am **Session 5: Keynote Address** **Theatre**

Introduction of Keynote:
Harald Schenk, UW Colleges Department of Computer Science, Engineering, Physics and Astronomy

Max Mutchler, Research and Instrument Scientist, Telescope Science Institute (STScl), *NASA's DAWN Mission to the Asteroid Belt*

10:00-10:15 am **Morning Break**

*** Plenary Session ***

10:15-11:15 am **Session 6: Student Satellite Program** **Theatre**

Moderator: Bill Farrow, WSGC Associate Director for Special Initiatives, Assistant Professor, Milwaukee School of Engineering

Elijah High Altitude Balloon Program
Balloon Payload Team:
Stephanie Finnvik, Carthage College; **Tyler Van Fossen**, University of Wisconsin – Madison; **Mike Czech**, University of Wisconsin-Milwaukee; **Billy Lancelle**, Saint Norbert College; **Victoria Falcon**, Milwaukee School of Engineering; **Becca McAuliffe**, Marquette University

NASA Microgravity Program
Zach Cheplak, *Regolith Handling Technologies in Lunar Gravity*, Undergraduate Student, Engineering Mechanics and Astronautics Department, University of Wisconsin-Madison

Senior Design Program
Jordan Gruenke, *Condensation In Spacecraft*, Undergraduate Student, Milwaukee School of Engineering

11:15-12:00 pm	**Group Photograph**	**As Directed**
12:00-1:00 pm	**Awards Luncheon**	**Commons**
1:00-2:00 pm	**Awards Ceremony**	
	Sharon D. Brandt, Program Manager, Wisconsin Space Grant Consortium Program Associate Directors	
2:00-2:05 pm	**2011 Conference – Gubbi Sudhakaran**, University of Wisconsin-La Crosse	
2:05 pm	**Conference Adjourned**	

***** Adjournment *****

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