Revision Log

<table>
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<th>Revision</th>
<th>Description</th>
<th>Date</th>
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<tr>
<td>C</td>
<td>Critical Design Review</td>
<td>April 9th, 2015</td>
</tr>
<tr>
<td>D</td>
<td>Analysis and Final Report</td>
<td>April 25th, 2015</td>
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1.0 Mission Overview

Mission Statement

Project Ra’s mission is to create an inexpensive and durable one axis Attitude Determination and Control System (ADCS) that continuously photographs the sun in near space while completing the requirements set forth by the University of Colorado Gateway to Space ASEN 1400 class.

Mission Overview

Team Icarus has several objectives for Project Ra. The project will locate the position of the sun with a digital compass and light sensors, adjust a camera-containing unit on top of the BalloonSat to point towards Sun, and continuously track the sun while taking photographs every second. For the flight imaging data, the team expects the degree variation from the focal target to remain under 18 degrees. Post-flight the team will evaluate the accuracy of the ADCS based on this prediction.

Team Icarus was originally inspired to create this mission as a technology demonstration to observe the North American solar eclipse in 2017. Since then, team Icarus has found that there is a need for modification of existing ADCSs for scientific missions on high altitude balloons. Icarus aims to make a system that is lighter and less expensive than existing systems. From astrophysics to earth science, many scientific studies can be carried out at these altitudes. High altitude balloon science has even affected legislation. In a particular case, BalloonSat data collected by NASA on the effect of chlorofluorocarbons on the ozone in the upper atmosphere was referred to as a “smoking gun” in Congressional hearings that lead to stricter environmental regulations. NASA utilizes balloon flight as a means of gathering valuable information on new sensors and instrumentation. The Mars Science Laboratory Curiosity rover contains a tunable laser spectrometer that was first developed as a BalloonSat instrument. The SWIFT

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telescope contains a Cadmium-Zinc-Tellurium detector that was first pioneered by the In-Focus balloon mission\textsuperscript{1}. These are excellent examples of balloon missions that depended on ADCS systems similar to the one Icarus aims to develop. The aforementioned projects had ADCS systems that could turn solar panels to power the instruments or provide a target for telescopes. As instruments have improved and mission complexity has increased, the demand for Balloon missions has upsurged. Balloon mission funding has remained stagnant and in some cases decreased for almost all space agencies such as NASA and JAXA\textsuperscript{1}. These costs can be attributed to many sources, but ADCS in particular can add unexpected costs and delays to a mission. Most balloon missions depend on rotating an entire payload around a flight string or large gondola and this feat requires powerful motors and large amounts of energy\textsuperscript{2}.

![Figure 2: Balloon flight rates over the past 12 years](image)

Team Icarus has discovered few missions that have attempted to improvise a small scale ADCS that moves limited mass. One such instrument is the Jet Propulsion Laboratory’s MkIV Fourier Transform InfraRed Interferometer\textsuperscript{2}. This instrument has made important observations of pollutants in the Earth’s atmosphere using solar absorption spectrometry since 1989 and will continue into the future. Part of the instrument’s success lies in its ADCS. Shown in figure 1 a single sun-tracker sticks out from the larger payload and is used to reflect sunlight into the instrument’s main body. The reduction in size of moving parts lowers the cost of ADCS, making the mission as a whole more feasible. Team Icarus hopes to capitalize on the success of the MkIV Interferometer, and provide further evidence on the reliability and cost-effective nature of single axis small scale ADCS\textsuperscript{1}.

**Mission Purpose**

Icarus aims to develop an original ADCS system. Instead of attempting to move an entire payload, Icarus intends to develop a method to position and isolate the movement of only a single instrument. With an environment such as a BalloonSat, designers must consider the implications of substantial outside torques; it is vital to develop methods to easily stabilize this increasingly popular means of space observation. Icarus will develop a one axis ADCS that rotates a camera to maintain a constant view of the sun.

\textsuperscript{1}NASA, 2010.
\textsuperscript{2}Print.
## 2.0 Requirements Flow Down

The table below indicates all the Level 0 requirements derived from the mission statement. Some requirements are requirements derived from the class requirements and others are requirements that originated from Team Icarus’s unique project design. Each level 1 requirement will present the requirements needed to accomplish the level 0 requirements.

<table>
<thead>
<tr>
<th>#</th>
<th>Requirement</th>
<th>Origin</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.1</td>
<td>Ra’s total weight shall not exceed the agreed upon weight and shall cost below $225 and deliver the science system to a height of 30km.</td>
<td>Mission Statement (class requirements)</td>
</tr>
<tr>
<td>0.2</td>
<td>The internal temperature in Ra shall stay above -10 degrees Celsius.</td>
<td>Mission Statement (class requirements)</td>
</tr>
<tr>
<td>0.3</td>
<td>The environment system shall measure humidity, pressure, and internal and external temperature.</td>
<td>Mission Statement (class requirements)</td>
</tr>
<tr>
<td>0.4</td>
<td>The science system shall sense the position of the sun relative to the BalloonSat.</td>
<td>Mission Statement</td>
</tr>
<tr>
<td>0.5</td>
<td>Ra shall orient the camera towards the sun and take inflight pictures.</td>
<td>Mission Statement</td>
</tr>
</tbody>
</table>

**Requirement 0.1:** Ra’s total weight shall not exceed the agreed upon weight and shall cost below $225 and deliver the science system to a height of 30km.

<table>
<thead>
<tr>
<th>#</th>
<th>Requirement</th>
<th>Origin</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.1.1</td>
<td>The BalloonSat shall be attached via flight string to the Helium Balloon</td>
<td>0.1</td>
</tr>
<tr>
<td>0.1.2</td>
<td>Flight string shall be attached through center of BalloonSat</td>
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**Requirement 0.2:** The internal temperature in Ra shall stay above -10 degrees Celsius.

<table>
<thead>
<tr>
<th>#</th>
<th>Requirement</th>
<th>Origin</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.2.1</td>
<td>A heater system shall be housed in each box and powered by 9v batteries</td>
<td>0.2</td>
</tr>
<tr>
<td>0.2.2</td>
<td>Project Ra shall be insulated with ½ inch foam</td>
<td>0.2</td>
</tr>
<tr>
<td>0.2.3</td>
<td>Internal temperature shall be recorded by a temperature inside the BalloonSat</td>
<td>0.2</td>
</tr>
<tr>
<td>0.2.4</td>
<td>The insulation systems shall be tested prior to launch</td>
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</tbody>
</table>

**Requirement 0.3:** The environment system shall measure humidity, pressure, and internal and external temperature.

<table>
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<tr>
<th>#</th>
<th>Requirement</th>
<th>Origin</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.3.1</td>
<td>Project Ra shall fly an Arduino responsible for the above sensors.</td>
<td>0.3</td>
</tr>
<tr>
<td>0.3.2</td>
<td>Project Ra shall fly a humidity sensor, pressure sensor, and an internal and external temperature sensor.</td>
<td>0.3</td>
</tr>
<tr>
<td>0.3.3</td>
<td>Data from the above sensors shall be recorded to an SD card.</td>
<td>0.3</td>
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</table>

**Requirement 0.4:** The science system shall sense the position of the sun relative to the
<table>
<thead>
<tr>
<th>Requirement</th>
<th>Origin</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.4.1 Project Ra shall fly a compass and four light sensors.</td>
<td>0.4</td>
</tr>
<tr>
<td>0.4.2</td>
<td>0.4</td>
</tr>
<tr>
<td>0.4.3 Project Ra shall an Arduino responsible for interpreting the sensors and directing the motor.</td>
<td>0.4</td>
</tr>
<tr>
<td>0.4.4 Data from the above sensors shall be recorded to an SD card.</td>
<td>0.4</td>
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</tbody>
</table>

**Requirement 0.5:** Ra shall orient the camera towards the sun and take inflight pictures.

<table>
<thead>
<tr>
<th>Requirement</th>
<th>Origin</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.5.1 Project Ra shall fly a motor responsible for orienting the camera towards the sun.</td>
<td>0.5</td>
</tr>
<tr>
<td>0.5.2 Project Ra shall an Arduino responsible for interpreting the sensors and directing the motor.</td>
<td>0.5</td>
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3.0 Design

3.1 Design Plan

**Structure**

The structure of the BalloonSat consists of two units. A main unit that houses the majority of the hardware and software, and a secondary smaller unit that is mounted on top of the main unit and houses the camera and a heater. The main unit has dimensions of 18 cm x 18 cm x 18 cm measured from the exterior. The walls of the unit are constructed by layering one 0.635 cm thick insulation foam with 1 cm thick foam core. The template of the unit was cut from foam core with a laser cutter so that the walls easily folded into a box. The faces of the unit are hot glued and taped together with aluminum tape. The layer of insulation and foam core are secured using hot glue. In one side of the box, there is a 6 cm x 8 cm x 2 cm hole cut out that houses the switches to power the components inside. A separate foam core panel of the same size will protect this indent. 1 cm diameter holes have been carved out in each side of the box to expose
the light sensors. The flight tube passes down the center of the main unit (Refer to figure below). The camera unit has dimensions of 11.5 cm x 8.1 cm x 6.5 cm. This unit is constructed in the same manner as the main unit and with the same materials. On the longer side of the unit a 3.8 cm diameter hole will be cut out. When the camera is placed in the unit the lens will be able to extend through the hole, and clearer pictures will be taken. The camera will be secured inside the unit using Velcro. (Refer to figure)

Inside the main unit along with the hardware and electronics is the stepper motor. Holes of 0.635 cm diameter are cut in the top of the main unit and bottom of the camera unit. This motor along with a light 0.635 cm diameter aluminum rod connect from the main unit into the camera unit through these holes. This is achieved by boring a 0.5 cm diameter hole in the aluminum rod, equivalent to the diameter of the motor’s drive shaft. The motor drive shaft is epoxied and inserted into the hole of the aluminum rod. The other end of the rod has been threaded so that a ¼” nut is screwed to the bottom of the thread. In the camera unit, a nut and washer have been hot glued together and the washer glued to the box. The camera unit is screwed onto the rest of the threaded rod. The motor will be secured in the main unit using hot glue and Velcro. With the motor secured in the main unit, the rod secured to the motor, and the camera unit secured onto the aluminum, the two units will remain connected (Refer to figures 2 and 3).
Figure 2: Main dimensions of box
Science

The motor will be used to operate the rotation of the camera box, based on digital input from the compass and analog input from the light intensity sensors. Because the camera only has a 1-axis rotation, the mission heavily relies on taking place during the morning or evening. This mission will take place during the morning. A small stepper motor will fill the motor role. A stepper motor allows for controlled angle rotation and is programmable with the Arduino Uno. This motor will be connected to a stepper motor driver and the driver will be connected directly to the Arduino. The digital output from the Arduino is registered by the driver and is transferred to electrical power for the motor. The motor takes 1.8-degree partial rotations. Rotation of the actual camera box will occur through an aluminum rod connecting the motor and the camera box itself. The motor
is a Nema 17 bipolar stepper motor. It was ordered from SparkFun and they assure users the holding torque and mass are appropriate for this project. This system will be able to rotate the camera box in a manner ideal for photography of the sun.

The camera that is used for the mission is the Mobius Action Camera. This camera weighs merely 41g and is 2 cm x 1.5 cm x 1 cm. The team is using the Mobius camera instead of the provided Canon camera for several reasons. The Mobius is significantly smaller than the Canon, which allowed the team to reduce the size the camera unit and the main box. This results in the ability to shrink the main unit to its current dimensions as well. The decrease in unit sizes and the decrease in camera weight resulted in an overall decrease in BalloonSat weight that was significant to team Icarus meeting requirement 0.1. The Mobius is programmed to take pictures every four seconds and stores the images locally on an SD card. The pictures taken from the Mobius are of strong quality and are favorable for data analysis.

**Sensing**

The project’s success depends on the sensing system. The exterior portion of the structure will have the external temperature sensor and four light sensors. Within the structure lie many apparatuses. The most prominent of these are the two Arduino Uno microcontroller boards. These boards control the sensors, retrieve data, and operate the sensor system. Both Arduino Unos will be initiated by a switch with an LED for system activation, verification, and power provided by a 9V battery. Therefore, to turn on the full Arduino system, all three switches must be set in the on position. One Arduino Uno will be connected to the sensors for the environment system such as the accelerometer, thermometer, potentiometer, and humidity sensor. The second Arduino Uno will be connected to a compass and the four light sensors located on the faces of the box. These will send commands to the motor and make it turn. Team Icarus will use a compass, fully integrated with 2-Axis Magnetic Sensor. The compass operates at a low voltage of 2.7V to 3.6V and communicates via a two-wire I2C bus system as a slave device. The team will also utilize light sensors to increase the accuracy of the camera’s
orientation towards the sun. These light sensors can operate at minimum temperature of \(-40 \text{C}\) and maximum of 85\text{C}. This functionality in extreme temperatures is slightly better than other average light sensor, but the biggest improvement over plain photocells is a true log-lin relationship with light levels. Most light sensors found have a linear relationship with light levels; this makes them less sensitive in darkened areas and more likely for a sensor to max out when there is a lot of light present. This sensor is logarithmic over a large dynamic range of 3 to 55,000 Lux, so it has a lot of sensitivity at low light levels but is also nearly impossible to max out so it can be used indoors or outdoors without changing code or calibration. This relation is shown in figure 7. This sensor is also compatible with Arduino boards of all variations. These aspects make this sensor an ideal component for this team’s mission.

**Command & Data Handling**

In the standard environment system, one Arduino Uno will be in control of the required environmental sensors and store the data on the micro SD card. This system will be powered by two 9V batteries. The second Arduino Uno will interpret information from the compass and light sensors, determine the position of the sun relative to the BalloonSat, and engage the motor to properly orient the camera. The camera has its own data storage system; there is a memory card in the self-contained unit. While the camera will be under its own power source, the Arduino system will be in charge of orienting the camera and will need a power source of its own.

**Software**

The task of the software is to read the incoming sensor information, decide how far and in what direction to rotate, and move the camera to keep it oriented toward the sun. The software will do this through a series of steps. First, the motor will be calibrated so that initially the camera will point towards the east. During flight the software will first collect information from the sensors and then interpret that data. Once every second the software will note the heading of the electronic compass and record the light intensity at each corner and side of the box. A time interval of a single second was chosen so that the motor will be provided with sufficient time to rotate before the software sends the motor another command. The software will then determine the direction and rotational distance required to point the camera at the desired location. The need to reorient will be determined by either the compass or the light sensors. The software’s first job is to determine which of these sensing systems it will utilize. By observing the compass heading the software will determine if the heading has varied from the direction of the camera by more than 10 degrees in either direction. If so the software will only use the compass data to instruct the motor to turn the camera. At the time of launch, the sun will be to the east. The software will track the position of the camera by recording the heading of the camera and determining if any heading changes have occurred. If the camera’s heading is off by less than 10 degrees, in either direction, the software will then use data from the light sensors to determine the position change. This induces a more precise measurement system. The three light sensors closest to the east will be used to more accurately adjust the camera with motor movement. When using the light sensors, no more than ten degrees of movement from the east will be allowed by the software in order to prevent other light sources from confusing the system. The software will decide on a correctional movement for the motor to make and command the motor to turn. This heavily relies on a clear sky. If there isn’t a clear sky, the
camera will rely on the readings from the compass to keep the camera pointed east until the BalloonSat gets above the clouded layer.

**Power**

To power the electrical components, the BalloonSat will need to carry nine 9V batteries: one will be used for the environmental system, two for the science system, four for heaters, and the motor will use two. For every battery connection there will be a LED to show if the device is receiving power.

**Thermal**

During the flight the BalloonSat will be exposed to temperatures of -80 degrees Celsius. The internal temperature must remain above -10 degrees Celsius. To keep the BalloonSat above -10 degrees Celsius insulation will be placed around the inside of the main box. In addition an electric heating system will keep the inside above -10 degrees Celsius.

**Special Features**

This BalloonSat is unique in that it has a camera box function. The camera box will rotate on the horizontal axis to capture images of the sun. This camera box will house the system’s camera.

**Data Collection**

Icarus's science subsystem will focus on sun tracking and will involve image capture of the sun. On the launch day, the BalloonSat will collect data on Micro SD cards from both environment and science subsystem sensors. Project Ra involves gathering images of the sun, and the data from the camera will be retrieved from its own memory card. The data from the SD cards will be transferred to the team computer after retrieval. Prior to data analysis, Team Icarus will have taken a standard set of images with the camera. In this simulation, a picture will be taken at 0 degrees off target, 2 degrees off target, and 4 degrees off target and so on until the target is out of the shot. With this control data, team Icarus will then interpret the images and calculate the degrees the camera shots were off. Success will be measured by distance of the center of the sun to the center of the image. The camera will also be programmed using the Mobius’s manufacturer’s provided code to add a timestamp to each photograph, which will allow the photos to be synced to the compass and light sensor data.
3.2 Concepts of Operations Diagram

Phase 1: Launch
- Initiate power to heater & motor system.
- Verify motor heater & system power by checking LED.
- Verify Arduino1&2 power, science system functionality, and storage system by checking LED.

Phase 2: Ascent
- Data stored on internal SD card.
- Camera takes a picture every 10 seconds.
- Science and motor system will orient camera towards sun.

Phase 3a: Burst
- Data processed by Arduino and stored on SD card.
- Sensors receive data every ~20 seconds.
- Collection of flight data.

Phase 3b: Decent
- Environmental system continues to collect data.
- Compass reading becomes extremely erratic.
- Arduino 2 science system shuts down.
- Motor system shuts down.

Phase 4: Recovery
- Remove SD cards and transfer data onto computer.
- Turn off power to all systems.
3.3 Functional Block Diagram

4.0 Management

Team Icarus is organized by a three-tier system of project manager, system leads, and system assistants. Reidar Larsen is the project manager for Project Ra, and Kyle Mueller is the project’s treasurer. Each team member is assigned a system lead, as described in the organization chart. Below them, each system lead has one or two assistants who are also responsible for working on that system. To keep the team on track, a schedule including each team meeting and deadline has been created. The team shall adhere to this schedule, especially all deadlines for reports and construction. The team’s main goal is to have all construction and majority of the testing finished before the University’s spring break on March 23, 2015.
**Date** | **Item Deadline or Goal**
---|---
1/31/15 | Team Meeting: Design mission
2/1/15 | Team Meeting: Design mission
2/4/15 | Team Meeting: Group proposal writing
2/7/15 | Team Meeting: Edit proposal
2/8/15 | Team Meeting: Edit proposal
2/9/15 | Proposal Due 8:00 AM
2/11/15 | Team Meeting: Work on part acquisition and coding skills
2/13/15 | Authority to Proceed from Chris and hardware will be ordered
2/14/15 | Team Meeting: Begin laying out parts and sizing box.
2/15/15 | Team Meeting: Begin building foam core box.
2/18/15 | Team Meeting: Continue work on foam core box. Begin writing Design Document Rev. A
2/21/15 | Team Meeting: Continued work on box and dealt with sensor issues.
2/22/15 | Team Meeting: Built foam core box. Worked on DD Rev. A/B
2/25/15 | Team Meeting: Writing DD Rev. A/B
2/28/15 | Team Meeting: Build flight ready foam core box and camera box. Connect all ADCS and sensing components to science Arduino.
3/8/15 | Team Meeting: Structural, Hardware, and Software tests. Finish all flight hardware. BalloonSat will be finished
3/11/15 | Team Meeting: Thermal Tests
3/14/15 | Team Meeting: ADCS Testing- Day
3/15/15 | Team Meeting: Software troubleshooting
3/18/15 | Team Meeting: ADCS Testing-Night
5.0 Budget

ASEN 1400 set mission requirements to follow these requirements; the mission payload will not exceed class funding and mass limits. The cost of every item listed is either provided by the class or by the team funds. Project Ra has stayed within both the mass and monetary budget, while still allocating $50 for spare parts currently not spent.

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<th>Supplier</th>
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<tr>
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<td>$4.21</td>
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<td>50g</td>
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6.0 Test Plan and Results

6.1 Structural Testing

There were four structural tests after preformed on the BalloonSat’s. In the whip, drop and stair tests, the electronics and hardware will not be present within the units. Instead other masses, most likely rocks, will simulate the mass of the electronics and hardware and be placed inside the units. The tests will take place at isolated locations to prevent injuries due to debris.

The Whip Test

The whip test will determine if the box will stay on the string after the balloon bursts during flight. The preparation involves securing the box to the string through the central flight tube and knotting the string at the top and bottom ends of the box. The actual test will consist of two team members holding one end of the string and spin the box around in the air with substantial force for two minutes. Standard methods for spinning the structure will be in vertical circles and horizontal circles. Other methods will be at the team member’s discretion to subject the stringed structure to various centripetal and tension forces. This test will be completed away from windows and other objects that the swinging box could possibly cause damage to.

If the BalloonSat’s units fall off during the whipping or the flight tube loosens from the structure then the BalloonSat string connection is not secure enough and so fails the whip test. If the BalloonSat’s units stay connected and the flight tube is still firmly secured to the main unit, then the BalloonSat has passed the whip test.

In the case of failure the BalloonSat structure will be repaired and connections to the flight tube will be altered and improved by means of adding adhesive, or altering the structure around the flight tube and then be tested once again.

Results of the Whip Test:

The whip test was successful. After the exposing the BalloonSat to various forces, the BalloonSat stayed on the string. The flight tube was not dislodged or moved in any way and the structure around the flight tube sustained.

The Drop Test

The drop test will determine whether the box will survive hitting the ground after falling from flight. To prepare the team will find a location where there are no bystanders and is accessible. A team member will climb to a level of approximately ten meters from the ground. When ready to test, the designated team member will drop the box to the ground.
If by any means the inside of the BalloonSat is visible or the two units of the box separate, then the BalloonSat’s structure is not sturdy enough and so has fails the drop test. If the box is intact, even with minor rips, dents or cracks, then the BalloonSat passes the drop test.

In case of failure, the structure of the box will be redesigned and rebuilt. If revision is necessary, the team will consider improving the connections of the faces, analyzing important points for adhesive application, and reevaluate bracing within the box. Afterward, the new design will be retested.

**Results of the Drop Test:**

Drop test was a success. The BalloonSat was dropped from approximately 10 meters as planned. The box hit ground and no significant damage was assessed. There were minor rips in the paper layer of the foam core and there was a small dent on one side. The inside of the box could not be seen and the two units stayed together.

**The Stair Test**

The stair test, much like the drop test, will determine structure’s capability of surviving impact. Instead of a large single impact, this test will subject the BalloonSat to consecutive small impacts. A team member will traverse up a set of stairs. Ideally the top of the stairs will be approximately 5 meters from the ground. The other team members will stand by and keep bystanders away from the impact zone to prevent injury. The team’s tester will proceed to roll the BalloonSat down the stairs.

The expected results are straightforward. If by any means the inside of the BalloonSat is visible or the two units of the box separate, then the BalloonSat has failed the stair test. If the box is intact, even with minor rips, dents or cracks, then the BalloonSat passes the stair test.

In case of failure, the structure of the box will be redesigned and rebuilt. If revision is necessary, the team will consider improving the connections of the faces, analyzing important points for adhesive application, and reevaluate bracing within the box. Afterward, the new design will be retested.

**Results of the Stair Test**

The stair test was successful. After the BalloonSat rolled down the stairs, there was no damage detected. No cracks, no new rips, no dents resulted from the test. Nothing inside the box could be seen. The two units stayed together.

**Epoxy Test**

The epoxy test was done to test the strength of planned connection mechanism for the rod and motor driver shaft. Using J-B Weld Steel Reinforced Epoxy, the team used the epoxy on two metal plates of composition similar to the metal rod and motor. The epoxy was applied to the metal plates and the plates were stuck together. Once the epoxy had set and cured, the team attempted pulling the plates apart, simulating the pull the connection will experience during flight.

**Results of the Epoxy Test**
The team was unable to produce the amount of force needed to separate the plates. The amount of force exerted on the plates seemed satisfactory and the team believes the epoxy is strong enough for the motor to rod connection.

6.2 Non-Structural Testing

Software Testing
The majority of the software lies within the Arduino. The Arduino’s programming commands the sensors, the motor, and the writing to the SD card. Tests must be done to confirm that the Arduinos are coded correctly. A code was provided by supervisor Chris Koehler as a template for Icarus’s Arduinos. The main pieces of the code were split apart and individually run to assure that they were each performing their desired tasks. This was also helpful for troubleshooting when issues were encountered running the entire code.

Sensor Testing
For all the sensors (humidity, inner and outer temperature, pressure, light, compass and accelerometer sensors) Icarus used the code template provided to test each sensor first. The testing process begins by first configuring the code to the sensor in question. The sensor will then be connected to the Arduino using a breadboard. The code will consist of the Arduino reading the input voltage from the sensor. From that data a formula will be inserted into the code to convert the voltage to appropriate units such as degrees Fahrenheit or humidity percentage. The code will then command the Arduino to write that data into the SD card. This process will be repeated for the remaining sensors.

If the sensor were functional, data would be recorded into the SD card. If there is no data on the SD card, team Icarus will troubleshoot the Arduino code until the error is found and corrected. If the team has absolute confidence in the code but there is no data on the SD card, the team can assume that sensor is not functional and acquire a replacement.

Result from Sensor Tests
The sensor tests have been successful. The humidity, pressure, temperature, light, accelerometer, potentiometer and compass were tested to be functional. The sensors were individually coded and so the Arduinos are able to get readings from the sensors. The readings are converted successfully using formulas from datasheets are written to the SD card.

Hardware Testing
One piece of hardware that is essential to the mission is the motor. For testing, the motor will be set up connected to the motor driver, which will connect to the Arduino. The compass sensor will be connected to the Arduino and that will provide the heading. All of this will be connected to a solid base such as a wooden board that the team can easily rotate. A tape flag will be wrapped around the motor shaft so the team can see the motor turning. Initially the baseboard will be static with the Arduino reading east from the compass and the team will mark the position of the tape flag. Then a team member will rotate the board a slow speed. The motor will observed to see if the tape flag moves in the desired manner. If so, this signifies that the motor is functional. The board will then be rotated in different directions and with different speeds.
If the tape flag is moving, then the team knows that the Arduino code that commands the motor works. An even greater level of success is if the tape flag remains close to marked position at the beginning of the test. This would signify that the motor is capable of keeping an objected pointed at a certain location (e.g. the sun during flight). If the tape flag is not seen moving, the code will be reevaluated and revised. If the code performs correctly, then the problem will lie in the motor driver in which the team will have to order a replacement.

**Results of Motor Testing**

The motor is successful in keeping the tape flag, and in advanced stages, the camera unit pointed in the same direction no matter where the box was turned. During advanced stages of testing, the motor reacted to the readings from the light sensors. The tape flag was able to keep up with the light as the BalloonSat and light source was moved around.

**Camera**

Testing the camera is straightforward. With the ordering of the new Mobius camera, the team had to deal with a different type of code to program the Mobius to take pictures every four seconds. Once the program has been implemented, the camera will be charged, SD card inserted and a team member will walk around taking pictures of the sun and surroundings.

**Results of Camera Test**

The camera testing was successful. The pictures acquired by the Mobius were crystal clear, no distortion, high resolution, and there was a picture every four seconds which signifies the programming was successful.

**Dry Ice Test**

This test will simulate the temperatures that the BalloonSat will be exposed to during flight and will test whether there is enough power present for the systems to work throughout flight. The team will prepare an insulated container, such as cooler, and dry ice. The dry ice along with the BalloonSat, containing all of its components, will be placed within the container and the container will be shut for the approximate flight time of 145 minutes. Afterward, the team will cautiously remove the BalloonSat from the cooler and inspect the components for functionality.

If all components are observed to be functional, as in there is no system that is powered off, and we acquire data from both systems then the test was a success. However, if any system is powered off at the end of flight, then the data written on the SD card by the Arduino will provide insight as to what went wrong. By looking at the data, if at least one part of the data from any of the sensors lasted at least 100 minutes, but data for other sensors stopped early, then the team can conclude it is a power issue. It is possible that no data might be written to the SD card. If that’s the case the Arduino must be analyzed. If data from the internal temperature shows sign of decreasing temperature within the box, and shows that the data for all sensors stopped early, then it is a heating issue. This is what would be expected from the main unit.

For the camera unit, the team expects the camera to only last approximately 90-100 minutes. This is specified as the battery life of the Mobius Actioncam on a single charge. During the test, the camera should have been taking pictures for that duration. If the camera stopped
early, but the camera unit shows sign of warmth, the issue is with the battery of the camera. However, if the camera unit is below 40 degrees Fahrenheit, then the team can conclude that the camera powered off due to the cold temperature. Whatever the result, the team is prepared to modify the BalloonSat to ensure it will be operational for flight. Possible design modification may include adding another heating unit, modifying insulation, or adding extra power sources.

Results of Dry Ice Test

Project Ra passed the dry ice test, proving that it is ready to withstand the conditions of the upper atmosphere. During the test, the BalloonSat stayed above the required temperature limit, and the internal temperature hovered around 13 C. The environmental system took data for the required 3-hour timespan, recording all of the gathered data. The only issue that Icarus noticed during the test was that the stepper motor began to stall after 2 hours and 26 minutes. This indicates that the batteries were running low, and that the motor would be unable to turn the desired number of degrees. However, two and a half hours is longer than the predicted ascent time, leaving the BalloonSat with plenty of power to orient the camera during the main mission phase.

ADCS Testing

This test will determine the effectiveness of the team’s camera motor system. To set up, the team will have the BalloonSat strung to an overhead truss and dangle in the air. The test may be located outside or inside in a dimly lit place and the team’s light sources will be the sun or a flashlight respectively. Initially, the light source will shine onto the box and the camera should be pointed in the light source’s direction. Then the box will spin slowly in both directions first, and then increases in speed to simulate the box’s motion during flight.

The expected results will come from the pictures taken on the camera’s SD card. If the light sources are present at least 70% of the pictures taken, then the test will be a success and the degree of accuracy will be analyzed with the equation mentioned in section 7.5. If the accuracy is off by no more than 18 degrees with each picture, then the test is a significant success.

However, if the percentage of pictures with the light source is low, or the degree of accuracy is greater than 18 degrees, the team must look at the code and revise so the Arduino is commanding the motor with highest speed possible. If the team feels that the code is as effective as it can possibly be, then the team will look into a new stepper motor. However, Icarus feels that this outcome is unlikely.

Results of ADCS Testing

The ADCS testing has given Icarus many chances to tweak and slightly improve the sun tracking software and hardware. Team Icarus went through many software variations as a result of these tests, and was able to significantly improve the reliability of the system. These tests show that the ADCS system works, and can effectively point at the Sun. However, when the BalloonSat was spun too fast, the motor could not turn fast enough to keep the box centered on the sun. However, after slowing down the spinning, the ADCS was able to refocus on the Sun.
6.3 Safety

Team Icarus recognizes the importance of safety measures. When working on the project, team members will wear appropriate wear. During structure creation and soldering, safety glasses and gloves will be worn all time to prevent injuries. Volunteers during the ADCS test will also be provided with these. Long hair will be tied and long sleeve shirts will be worn to deter burns. During tests, team members will keep a safe distance from crowds and conduct the test away from other students and windows. First aid kits will be constantly present in case of minor cuts or burns. The emergency line 911 will be used in cases of severe injury.

7.0 Expected Results

Team Icarus will be collecting data for all the sensors in conjunction with our mission. This is to make sure that the team’s engineering system will work throughout the launch. Icarus has done ground testing with the sensors to make sure the code runs. The data were presented and used as a comparison to what we are expecting in this mission.

7.1 Humidity Data

Team Icarus is expecting to have humidity data that is similar to previous missions. Relative humidity is expected to decrease as the altitude increases. This occurs because as elevation increases, the air gets cooler and is less capable of holding water vapor, thus leading to a decrease in humidity. Team Icarus conducted a ground testing to test the humidity sensors and the results are shown below. The humidity decreases steadily as the temperature increases. The slight increment on the graph is caused by the heater system in the BalloonSat. The spike at the end of the graph is the result of the opening of the BalloonSat.
7.2 Temperature Data

Team Icarus will analyze both external temperatures and internal temperatures of the BalloonSat. The temperature is expected to vary as the payload passes through different layers of the atmosphere. In the troposphere layer, heat from the sun is absorbed by the ground and temperatures decrease by an average of 6.5 degrees Celsius per one thousand meters of elevation. As the BalloonSat passes through the stratosphere the temperature increases with altitude. This is a phenomenon known as thermal inversion. There are two reasons for the inversion. First, the stratosphere has two layers or strata: a cold dense layer on the bottom and a layer of warm, light air on top. Second, the ozone layer in the upper stratosphere readily absorbs ultraviolet light from the sun. As this radiation increases molecular activity, molecular vibrations produce a spike in temperature. The pattern reverses again in the mesosphere. Temperatures again decrease with increasing height as the ozone layer is left behind and the air thins out with increasing altitude. The internal temperature of the BalloonSat is expected to decrease slowly at this point but insulation and a heater system will maintain the temperature within operational limits.

Team Icarus will analyze both external temperatures and internal temperatures of the BalloonSat. The temperature is expected to vary as the payload passes through different layers of the atmosphere. The result from the cold test shows that the temperature eventually dropped to about 55 degree Fahrenheit. The outcome seems to be a bit biased as we only used few pounds of dry ice. Icarus wants to do a second cold test to ensure that the result favors our heater system.
7.3 Pressure Data

As the elevation increases, the atmospheric pressure is expected to decrease. At higher elevations, there are fewer air molecules above a given surface than a similar surface at lower levels. This decrease in air molecule weight as elevation increases causes pressure to decrease. Since most of the atmosphere's molecules are held close to the earth's surface by the force of gravity, air pressure decreases rapidly at first, then more slowly at higher levels. At 18,000 feet (5846.4 meters) the pressure decreases to 7.4 pounds (3.36 kg) per square inch.
7.4 Acceleration Data

During the cold test, the acceleration is to be fairly constant around 1G as minimal movement of the BalloonSat occurred. We predict the small constant acceleration happens when the BalloonSat was slowly slipping as the ice melts.
Icarus predicts that at the beginning of the launch, the BalloonSat will be experiencing rapid movement in the x and z directions due to the ascending balloon. As the altitude increases, the BalloonSat is expected to experience fairly constant acceleration above 1G. When the hydrogen balloon bursts, x acceleration values will change violently as the altitude decreases due to the whipping flight string. As the BalloonSat descends, the acceleration is expected to again hover at the constant value of 1G.
7.5 Science System Data

During the ground test, Icarus is specially concerned about the science system as it validates the main mission. All the sensors are calibrated and tested to ensure its capability of collecting data. The compass was rotated a full circle of 360 degrees to ensure it is correctly orientated. The spike at four milliseconds indicates the turning point from 359 degrees to zero degrees. The actual rotation of the BalloonSat should vary.
7.6 Light Sensor Data

The purpose of project Ra is to take images of the sun. Icarus hopes that clear photographs containing the sun are captured in each stage of the flight. It is important that the position of the sun in each photograph is calculated precisely. Success will be measured by the distance of the center of the sun to the center of the image. The formula that will be used by the team is shown below. This is a standard image processing equation often used in industry.
Project Ra uses light sensors to increase the accuracy of the camera orientation. The test for light sensors was done in a dark room and flashlight was used as the source of light. As predicted, the light sensor showed high value of flux when flashlight was turned on. The placing of the light sensors on the face of the BalloonSat also proved to be helpful as minimal interference occurred when only one of the light sensors is flashed.

7.7 Image of the Sun Data

The purpose of project Ra is to take images of the sun. Icarus hopes that clear photographs containing the sun are captured in each stage of the flight. It is important that the position of the sun in each photograph is calculated precisely. Success will be measured by the distance of the center of the sun to the center of the image. Camera testing is done by running the code and establishing the variation control data. Photos are taken every one second with two degree variation between each consecutive image. We expect the sun to remain within 18 degrees of our vision.
8.0 Launch and Recovery

Team Icarus will launch Project Ra on April 11th, 2015. All team members will gather in the parking lot at east of the DLC at 4.30 a.m. The team will leave Boulder no later than 4.45 a.m. to drive to the launch site in Windsor, Colorado in Reidar’s car. Upon arrival at the launch site Team Icarus will inspect the BalloonSat to make sure that it is ready for launch, and verify that it was not damaged during transport. Syamimah and Madison will take photo documentation of the interior and exterior of BalloonSat before the launch and upon recovery. The team will turn on the power for environmental system and science system. The lens of the camera will be cleaned to avoid fogging. We also make sure that the micro SD cards are placed in both Arduino and in the Mobius camera. George Duong will run through the checklist again to ensure all the subsystem is complete and ready for launch. Reidar Larsen, our team leader will be launching the BalloonSat with the presence of all the team members.

After the launch, all the team members will travel to the recovery site with other teams. After recovery, Brody Rosipajla is in charge to unseal the BalloonSat and check the condition of the satellite. The team will take photos of the satellite’s exterior and interior for documentation and then SD cards will be removed carefully from the Arduino and camera. The data will be saved on Reidar’s and Madison’s laptop and emailed to all the members as backup. Icarus will bring the BalloonSat back to Boulder where it will be further examined.