Team √Radical
Project Omni

GATEWAY TO SPACE
FALL 2015
DESIGN DOCUMENT

Written by:
Colin Sullivan, Colin Brown, Ryan Marizza, Jack Huun, Nolan Ferguson,
Christopher Peercy

Report Date: December 5th, 2015
Revision D
<table>
<thead>
<tr>
<th>Revision</th>
<th>Description</th>
<th>Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>A/B</td>
<td>Conceptual and Preliminary Design Review</td>
<td>10/08/2015</td>
</tr>
<tr>
<td>C</td>
<td>Critical Design Review</td>
<td>11/05/2015</td>
</tr>
<tr>
<td>D</td>
<td>Analysis and Final Report (First and Final Draft)</td>
<td>12/05/2015, 12/15/2015</td>
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1.0 MISSION OVERVIEW:

1.1 Mission Statement:
Project Omni shall launch a balloon satellite sponsored by the University of Colorado’s Gateway to Space class in order to measure the received signal strength of ground based very high frequency (VHF) transmissions at high altitude. The Project Omni payload shall measure the received signal strength of VHF transmissions from approximately 1.8 km MSL (Mean Sea Level) to approximately 30 km MSL to determine the feasibility of using existing Very High Frequency Omnidirectional Range Radios (VORs) as land based navigation aids (NAVAIDs) for extremely high altitude aircraft. This data will give insight into the capabilities of existing land based NAVAIDs, as well as how signals in the VOR frequency band (108-117.95Mhz) behave in the upper troposphere and lower stratosphere.

1.2 Mission Overview:
VORs transmit on VHF bands from 108.0 to 117.975Mhz (1) and are used as land based radio NAVAIDs for private, commercial, and military air traffic. Depending on VOR type, VORs may be used for navigation up to 18km above ground level (AGL) and out to 100 nautical miles (Nm); or up to 13.7Km out to 130Nm (Figure 1.1). VORs work by transmitting a unidirectional 9960 Hz amplitude modulated subcarrier wave from an antenna rotating at 30 Hz. Meanwhile, an additional 9960 Hz subcarrier is transmitted in all directions. Both subcarriers are transmitted by an amplitude modulated signal on the assigned VHF carrier frequency, along with an audible Morse identifier assigned to the specific VOR. The phase shift between the 30 Hz rotating signal, and omnidirectional signal allows for the receiver to determine the direction to the VOR(2).

Project Omni will be launched as a science payload aboard a hydrogen high altitude balloon which will travel to a maximum altitude of approximately 30 km. The payload will be equipped with a VHF receiver tuned to the operating frequency of the VOR located in Hugo, Colorado. Hugo is located approximately 45 nautical miles southeast of the Deer Trail, Colorado launch site. The VOR at this location transmits on 112.10Mhz. Alternate VORs include the Gill VOR on 114.2Mhz, and the Akron VOR on 114.4Mhz both of which would be able to be received depending on the final
location of the launch site. Project Omni will monitor the correct frequency during all phases of flight and store the received signal strength on an SD card to be analyzed after recovery of the payload. The signal measured will be the audio identification signal which the VOR transmits. This signal is in the form of the letters “HGO” in Morse code (.... -- ---) or the respective VOR identifier. The payload will also include a magnetometer to determine the payload orientation in order to correlate signal strength data with antenna direction.

The purpose of Project Omni is to give insight into the reception consistency of VHF signals in the upper troposphere and lower stratosphere. Analysis of this data should reveal what factors affect VHF transmission, such as: atmospheric factors (weather, air density), interference from other ground based FM transmitters (civilian radio), and changes in the mediums which the signals travel through (signal starting in dense atmosphere and being received in a near vacuum). Current civilian, commercial, and military air traffic rely heavily on VORs for navigation. A better understanding of the limiting factors for this navigation method would give insight into the current capabilities of high altitude aircraft navigation systems. Data from Project Omni will also give insight to the maximum transmission distance of these VORs, allowing for a standard to be created for future very high altitude aircraft.

2.0 REQUIREMENTS FLOW DOWN

The following requirements laid forth by the Project Omni team shall create a gauge to determine the success of the mission. The following is what Project Omni hopes to accomplish in its mission.

2.1 Level 0 Requirements:

<table>
<thead>
<tr>
<th>Number</th>
<th>Details</th>
<th>Derived From:</th>
</tr>
</thead>
<tbody>
<tr>
<td>P0.1</td>
<td>Project Omni shall measure the signal strength of a VOR transmission from high altitude.</td>
<td>Mission Statement, Mission Overview</td>
</tr>
<tr>
<td>P0.2</td>
<td>The mass of Project Omni shall not exceed 864 grams.</td>
<td>Mission Statement, Mission Overview</td>
</tr>
<tr>
<td>P0.3</td>
<td>Project Omni shall fly a Canon A3400-IS digital camera to take and store images and videos from the flight.</td>
<td>Mission Statement, Mission Overview</td>
</tr>
<tr>
<td>P0.4</td>
<td>The total cost of the flight shall not exceed $180.</td>
<td>Mission Statement, Mission Overview, Budget</td>
</tr>
<tr>
<td>P0.5</td>
<td>Project Omni shall measure internal and external temperature, acceleration on three-axes, as well as pressure and relative humidity and record this data to an SD.</td>
<td>Mission Statement, Mission Overview</td>
</tr>
<tr>
<td>P0.6</td>
<td>All parts of Project Omni will be kept intact during flight and post-flight with the intent of being reusable.</td>
<td>Mission Statement, Mission Overview</td>
</tr>
</tbody>
</table>
2.2 Level 1 Requirements

The following are the level 1 requirements for the mission. Each requirement was derived from the previously stated level 0 requirement. Project Omni shall fully meet each of the requirements stated below.

<table>
<thead>
<tr>
<th>Number</th>
<th>Description</th>
<th>Derived From</th>
</tr>
</thead>
<tbody>
<tr>
<td>S1.1</td>
<td>Project Omni shall fly a VHF receiver capable of receiving frequencies from 108.0Mhz to 117.975Mhz and shall be tuned to 112.20Mhz at launch and during flight.</td>
<td>P0.1</td>
</tr>
<tr>
<td>S1.2</td>
<td>Project Omni shall fly a sensor capable of recording current data from the VHF receiver speaker and record data from that sensor to an SD card.</td>
<td>P0.1</td>
</tr>
<tr>
<td>S1.3</td>
<td>Project Omni shall fly a magnetometer in order to record the orientation of the receiver's antenna.</td>
<td>P0.1</td>
</tr>
<tr>
<td>S1.4</td>
<td>Project Omni shall be made out of lightweight materials.</td>
<td>P0.2</td>
</tr>
<tr>
<td>S1.5</td>
<td>Project Omni shall not fly any non-essential parts.</td>
<td>P0.2,P0.4</td>
</tr>
<tr>
<td>S1.6</td>
<td>A pre-loaded code shall instruct the Canon A3400-IS digital camera take a picture every 10 seconds along with a 10-minute video.</td>
<td>P0.3</td>
</tr>
<tr>
<td>S1.7</td>
<td>The Canon A3400-IS digital camera shall function throughout the flight and record images and video to an SD card.</td>
<td>P0.3</td>
</tr>
<tr>
<td>S1.8</td>
<td>Only the most cost effective components shall be purchased.</td>
<td>P0.4</td>
</tr>
<tr>
<td>S1.9</td>
<td>Spare parts shall be included in the budget.</td>
<td>P0.4</td>
</tr>
<tr>
<td>S1.10</td>
<td>Internal temperature, external temperature, acceleration, pressure and relative humidity sensors shall be calibrated before launch.</td>
<td>P0.5</td>
</tr>
<tr>
<td>S1.11</td>
<td>Internal temperature, external temperature, acceleration, pressure and relative humidity sensors shall record data to an SD card throughout flight.</td>
<td>P0.5</td>
</tr>
<tr>
<td>S1.12</td>
<td>A structure capable of protecting Project Omni from all forces experienced during flight shall be created.</td>
<td>P0.6</td>
</tr>
<tr>
<td>S1.13</td>
<td>Team Radical shall perform necessary repairs to ensure that Project Omni has the ability to fly again.</td>
<td>P0.6</td>
</tr>
</tbody>
</table>
S1.14 | A heater shall be flown on Project Omni and be operational throughout the flight. | P0.7
---|---|---
S1.15 | Project Omni shall be well insulated. | P0.7

3.0 DESIGN:

3.1 Design Overview:

In order to complete this mission, Team Radical will record data corresponding to the signal strength of a VOR using a VHF receiver and ammeter writing data to an Arduino Uno with an SD Shield. Team Radical will also utilize a second Arduino to measure environmental data and save it to an SD Shield. The receiver will have the capability of receiving frequencies in the range of the operating band for VORs as described above. The receiver’s antenna will be placed vertically, to allow for the VOR’s vertically polarized signal to be detected. The Arduino will sample the output amperage from the speaker of the receiver at the maximum possible sampling rate of Arduino, which is 24Hz. These recorded signals will be recorded as a current output from the VHF receiver and will then be sent to the Arduino via analog input and stored on an SD card. Well before launch, the team tested the strength of the VHF signal near the VOR site in Gill, Colorado to determine a baseline signal strength. These ground tests shall help the team to compare results of the VOR strength at 18-30 km to those on ground. In addition to testing the functionality of the VHF receiver and VOR signal before launch, the team also tested the durability and stability of Project Omni. Multiple tests were performed to replicate the conditions Project Omni will experience throughout its flight. Project Omni will have dimensions 19cm x 13.5cm x 13.5cm. The antenna will exit the box through a small incision on the bottom of the structure.

3.2 Final Hardware/Parts:

3.2.1 Mission Specific Hardware:

- **Handheld Radio Scanner (Radioshack PRO-649):** The handheld radio scanner was purchased from Radioshack in Boulder, Colorado. It is capable of receiving frequencies in the range of 108.0 to 136.9875 MHz, which is within the operating band for aircraft signals and will allow Project Omni to receive the desired VOR signal. An Arduino compatible ammeter was connected to the scanner to measure current across the speaker. This will allow Project Omni to convert the strength of the signal of the radio into a readable analog signal.

- **Ammeter (SparkFun Low Current Sensor Breakout - ACS712):** The SparkFun Low Current Sensor was purchased from SparkFun in Niwot, Colorado. The ammeter is Arduino compatible and will write the current it measures from the receiver to the SD card as a readable analog signal through Arduino 2. The Low Current Sensor was calibrated by reading a current that had been previously measured with a multimeter and adjusting its code so that it reads the same value as the multimeter.
- **SD Card One**: A thirty-two gigabyte SD card will be used to store the data from the Low Current Sensor and the 3-Axis Magnetometer after the analog data is interpreted by the Arduino. The SD card was obtained from COSGC.

- **Arduino Compatible 3 Axis Magnetometer**: The 3-axis magnetometer will act as Project Omni’s compass. It allows the orientation of Project Omni to be determined in order to analyze the signal strength data from the VHF receiver with reference to the direction the antenna is facing. This magnetometer is Arduino compatible and will write data to the SD card as a readable analog signal through Arduino 2. This component was purchased from Sparkfun.com.

  **3.2.2 General Hardware:**

- **9V Batteries**: Five 9V batteries provide power to the entire system, including both Arduinos, the heater, the sensors, and the radio scanner. Alkaline batteries were used for testing and lithium batteries will be used for the actual mission to reduce weight. The Lithium batteries were obtained from COSGC and the alkaline batteries were purchased from Amazon.com.

- **Canon A4300 Digital Camera W/ SD Card Two**: The pre-programmed digital camera will take pictures every 10 seconds for the duration of the mission. The camera is also programmed to take 10 minutes of video just before burst. All pictures and video taken will be stored on an SD Card inside the Camera. The camera was obtained from COSGC.

- **Simple Resistor Heater**: The heater consists of three four-ohm resistors wired in series. It will be powered by two 9V batteries and provide enough heat to keep all of the components within their operating temperatures. Parts for the heater were obtained from COSGC and directions for assembly were part of the coursework for ASEN 1400.

- **Arduino Uno (x2)**: The Arduino Uno's will act as central processing hubs for Project Omni. They will serve as interfaces for all sensors that will be taking data and will write all received data to the SD cards. Both Arduino Unos were obtained from COSGC.

- **SD Card Three**: All the data received from the sensors on Arduino 1 will be read by Arduino 1 then stored on this 8-gigabyte SD Card. This SD Card was obtained from COSGC.

- **Balloon Shield**: The Balloon Shield is a circuit board that is used to integrate all of the sensors on Arduino 1 (humidity sensor, temperature sensors, pressure sensor, accelerometer) together and allow for them to be switched on and off by a switch attached to the power cord. The Balloon Shield was obtained from COSGC.

- **Humidity Sensor**: The humidity sensor will measure the humidity inside of Project Omni and will be attached to the Balloon Shield on Arduino 1. The humidity sensor was obtained from COSGC.

- **Three-axis accelerometer**: The accelerometer will measure the acceleration of Project Omni during flight, across the X and Z axis. This sensor will be attached to the Balloon Shield on Arduino 1. The accelerometer was obtained from COSGC.

- **Pressure Sensor**: The pressure sensor will measure the pressure inside of Project Omni throughout the duration of the flight. It will be attached to the Balloon Shield on Arduino 1. The pressure sensor was obtained from COSGC.

- **Internal/External Temperature Sensors**: An internal temperature sensor will be placed inside Project Omni to test the temperature throughout the flight. There will also be a sensor protruding from the box that will measure the temperature outside of Project Omni. Both sensors were obtained from COSGC and will be connected to the Balloon Shield on Arduino 1.
- **Switches (x3):** The switches will be used to power on each Arduino and the heater. Each switch will be accessible externally and protected by a cover. Obtained from COSGC.

- **LED Bulbs(x5):** LED Bulbs will be used for each Arduino, the heater, and the balloon shield, to signify when each is on. Additionally, an orange bulb will flash when data is being written to SD Card 3 on Arduino 1. All LEDs will be protruding from the box. LEDs were all obtained from COSGC.

- **Foam Core:** Project Omni utilizes lightweight and durable Elmer’s Foam Core as its main structure. The foam core was obtained from COSGC.

- **Insulation:** Project Omni is insulated with industry grade sheet insulation that was applied to the inside of Project Omni using hot glue in order to sustain an operable temperature for all instruments and sensors. All insulation was obtained from COSGC.

- **Aluminum Tape:** Aluminum tape was used to seal the seams of the box and provide structural support, and was obtained from COSGC.

- **Hot Glue:** Standard hot glue was used to help construct the foam core box of Project Omni. All hot glue is procured from COSGC.

### 3.2.3 Sensor Calibration

- **Temperature Sensors:** Temperature sensors on Project Omni are calibrated using two steps. First, both temperature sensors are introduced to the same environment and adjusted so that the readings are the same for both sensors. From here, these sensors were introduced to an environment with a known temperature so that they could be adjusted to match. This is repeated several times to ensure that the temperature sensors are reading the correct data.

- **Pressure Sensor:** The pressure sensor aboard project Omni is calibrated using a known environment. The sensor is introduced to the ambient pressure in Boulder, Colorado which is known to be about 12 psi. From here, adjustments are made to ensure the sensor is reading correctly.

- **Humidity Sensor:** The humidity sensor aboard project Omni is again calibrated using a known environment. The sensor is introduced to the relative humidity of Boulder, Colorado and adjusted so that it matches this known level.

- **Accelerometer:** Project Omni’s accelerometer is calibrated using a known environment. The sensor is introduced to Earth gravity which is known to be exactly one G. From this, the sensor can be adjusted until it reads this value on the Z-direction when standing still. There should be no acceleration when the sensor is not moving in the X-direction and the sensor is calibrated to account for this.

- **Current Sensor:** The current sensor was calibrated by adjusting the sensor to read zero when there is no current across it. While this is not necessary, as there will still read a change in amperage, it is useful for data manipulation.

### 3.3 Structure:

Project Omni has dimensions of 19cm x 13.5cm x 13.5cm. These dimensions allow room for all components, wiring, and insulation, and allow for the weight requirement outlined in P0.2 to be met. The exterior of Project Omni was constructed using foam core, which was cut using a laser cutter, folded, and attached together with hot glue and aluminum tape. Several systems were attached to or protrude from the sides of Project Omni through holes in the foam core and insulation. The antenna of the radio scanner protrudes approximately 140mm from the top of the
structure. The external temperature sensor protrudes approximately 1 inch through Project Omni through a small hole in the side of the structure. The lens of the camera also protrudes through a larger hole on the same side of the structure. There are five LEDs and three switches protruding from the side of Project Omni. Three LEDs correspond to the switches and two LEDs correspond to Arduino 1. The three switches control Arduino 1, Arduino 2, and the heater. Three of the LEDs light up when their corresponding systems are turned on and functioning correctly. The other two LEDs correspond to the Balloon Shield and signal both power and data being read. Two Arduino Uno systems, two SD shields, an accelerometer, a humidity sensor, an internal temperature sensor, a heater, five 9V batteries, a VHF receiver, and wiring, are all securely attached to the inside of Project Omni using Velcro.

3.3.1 Structure Diagrams:
3.4 Construction and Integration:

The first stage of constructing Project Omni consisted of putting together the outside of its structure. Foam core was cut to specifications using a laser cutter and an X-Acto knife. The foam core sides were securely pieced together with hot glue and aluminum tape. Three structural tests were performed with Project Omni at operational mass. The second stage of construction consisted of assembling the first Arduino system, which is in charge of collecting and storing data from the humidity sensor, pressure sensor, temperature sensors, and accelerometer. The Arduino system was implemented into the structural portion of Project Omni along with the camera and the heater. The team tested to make sure all of these systems were operational and affixed them as needed using Velcro. The third stage of construction consisted of the assembly of the second Arduino system, which consists of the radio scanner, low current sensor, and magnetometer. This system was tested outside of Project Omni at multiple test sites and then was implemented into Project Omni after it was confirmed to operate successfully. The entire system then underwent the temperature test and full mission simulation test after all of the components had been integrated within the structure of Project Omni.

3.5 Data Retrieval:

During testing as well as during flight, all data from Project Omni was and will be collected and stored using two microSD cards. The first microSD card stores data from the first Arduino which measures acceleration on three axes, internal and external temperature in degrees
Fahrenheit, relative humidity, and pressure. After successful testing, Fahrenheit will be converted to Celsius accordingly. The second microSD card stores data from the second Arduino, which will measure the signal strength from the VHF receiver at varying altitudes. Each Arduino will handle converting the raw data output of the components collecting data to readable .csv files using predetermined conversion factors. Data will be stored as .csv files on each respective microSD card. During testing as well as after launch and recovery, the data stored on the microSD cards was and will be downloaded to one of the team-member’s computers, where it can be further examined, interpreted, and analyzed.

3.5 Concept of Operations Diagram:
The following diagram outlines, visually, Project-Omni’s flight. Four stages are outlined and their necessary operations are described below.
3.7 Functional Block Diagram:
The following is a basic diagram of how sensors and other components will be connected
to each Arduino Uno. The components involved in the heater system and camera system and their integration is also shown.

### 3.8 Mission Requirements:

Project Omni will meet all requirements set forth by the Gateway to Space class, ASEN 1400. Project Omni shall carry an additional experiment with the goal of tracking the decrease in magnetic field strength as a function of altitude. This will also allow the data collected by the VHF receiver to be correlated with antenna pointing direction. The design shall be made of foam core and shall be tested to ensure it is robust enough to be in working order after flight. The final design shall be tested to withstand forces greater than those expected during flight. All experiments included in Project Omni are reusable. The components within Project Omni shall be arranged so that that the non-metal tube for the flight string is not affected. Insulation and a heater shall be placed in Project Omni to ensure the internal temperature remains above 0°C throughout the flight. To ensure that this is the case, Project Omni shall be tested in a cooler with dry ice. The total weight of Project Omni shall be less than 864g. This will be achieved by using lightweight components and minimizing the number of components to only those that are necessary to complete the mission and fulfil all requirements. Ascent and descent rates of the flight string shall be acquired using a pressure sensor to estimate altitude...
changes over time. An external temperature sensor will be implemented in the design with a small hole in the foam core, extending outside of the box. The design will allow for a Canon A3400 IS Digital Camera to fly and retrieve images/video of the flight. Spare parts shall be included in the budget for the design. A US flag shall be placed on the exterior of Project Omni along with contact information and a team design. All proposal and design units shall be in metric units. All team members shall be present for the November, 7th launch. No one shall be hurt. All hardware will be returned in working condition after recovery of Project Omni. All parts shall be included in the budget and purchased with Chris Koehler’s CU Visa by appointment. All receipts shall be turned in within 48 hours of purchase with the team name at the top along with a copy of the Gateway order form. All purchases made by individuals on the team shall be approved prior to purchase. Nothing living shall be flown on Project Omni. A post flight final report shall be completed. External LEDs shall confirm that all parts of Project Omni are active prior to launch. Excellent internal wire management standards shall be upheld. External switches shall be protected by foam core.

4.0 MANAGEMENT
4.1 Schedule and Deadline Management:

Group meetings will be every Sunday, Monday, and Wednesday at 7pm in the ITLL. Team Radical is committed to spending six hours a week or more to accomplish the mission of launching by November 7th. The following schedule will keep the team on track.

<table>
<thead>
<tr>
<th>Week</th>
<th>Objectives</th>
<th>Due Dates</th>
</tr>
</thead>
<tbody>
<tr>
<td>September 13-19</td>
<td><strong>Su 9/13</strong> - Continue to work on conceptual design review</td>
<td>9/15 HW 05 due</td>
</tr>
<tr>
<td></td>
<td><strong>M 9/14</strong> - Continue research over VOR components</td>
<td><strong>9/15 Conceptual Design Review</strong></td>
</tr>
<tr>
<td></td>
<td><strong>W 9/16</strong> - Continue work on proposal</td>
<td><strong>9/17 HW 07 assigned</strong></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>September 20-26</td>
<td><strong>Su 9/20</strong> - Finalize preliminary hardware to order as well as finalize proposal</td>
<td>9/21 Proposals due</td>
</tr>
<tr>
<td></td>
<td><strong>M 9/21</strong> - Order hardware per proposal and work on heater</td>
<td>9/22 HW 08 assigned</td>
</tr>
<tr>
<td></td>
<td><strong>W 9/23</strong> - Start working on preliminary code for components</td>
<td>9/24 HW 07 due</td>
</tr>
<tr>
<td></td>
<td></td>
<td>9/25 HW 06 due</td>
</tr>
<tr>
<td></td>
<td></td>
<td><strong>9/25 ATP with Chris</strong></td>
</tr>
<tr>
<td>September 27-October 3</td>
<td><strong>Su 9/27</strong> - Hardware orders, design, and draft coding for VHF and magnetometer.</td>
<td>9/29 DD A/B assigned</td>
</tr>
<tr>
<td></td>
<td><strong>M 9/28</strong> - Begin building</td>
<td>10/1 HW 08 due</td>
</tr>
<tr>
<td>Date Range</td>
<td>Activity Details</td>
<td></td>
</tr>
<tr>
<td>------------</td>
<td>-----------------</td>
<td></td>
</tr>
</tbody>
</table>
| October 4-10 | **Su** 10/4 - PDR Finalizations and presentations  
**M** 10/5 - Finish building preliminary structure  
**W** 10/7 - Begin testing (Drop test)  
**W** 10/7 - Order Magnetometer (GY-271 HMC5883L)  |
| October 11-17 | **Su** 10/11 - Continue testing (Cold test/Whip Test)  
**M** 10/12 - Testing based corrections to design.  
**W** 10/14 - Continue testing (Testing of VHF receiver and magnetometer)  |
| October 18-24 | **Su** 10/18 - Finalize design, prepare LRR presentation.  
**M** 10/19 - Finalize and complete rebuilt structure and components  
**W** 10/21 - Wire management and weight trimming  |
| October 25-31 | **Su** 10/25 - Finalize all testing and programming  
**M** 10/26 - Complete mission simulation tests  
**W** 10/28 - Rebuild to Mk. 3  |
| November 1-7 | **Su** 11/1 - Finalize LRR presentation.  
**M** 11/2 - Conduct mission simulation in Eatonville, CO  
**W** 11/4 - Ensure launch readiness.  |

10/8 - PDR due  
10/9 - DD Rev. A/B due  
10/13 - Mid-semester team assignments assigned  
10/15 - Mid-semester team assignments due  
10/22 - Service Approvals due  
10/27 - RFF Cards due  
10/29 - HW 09 due (optional)  
11/3 - LRR due  
11/3 - Review: Launch Readiness Review (LRR)  
11/5 - DD Rev. C  
11/6 - RFF Cards due  
11/7 - LAUNCH
### Project Omni

| November 8-14          | - Analyze Data  
|                       | - Begin work on video and final presentation | 11/12 - Post-Flight Presentation due |
|-----------------------|------------------------------------------------|
| November 15-21        | - Analyze Data  
|                       | - Begin work on DD. Rev. D  
|                       | - Work on presentations | 11/17 - DD Rev. D assigned |
| November 22-28        | - Analyze Data  
| (Fall Break 11/24 - 11/26) | - Continue work on DD. Rev. D  
|                       | - Work on presentations | |
| November 29- December 5 | - Work on presentations | 12/1 - HW 09 due (actual) |
| December 6-15         | - Work on presentations  
|                       | - Finalize Data | 12/5 - Review ITLL Design Expo  
|                       |                                           | 12/8 - Final Presentations due  
|                       |                                           | 12/10 - HW 10 due  
|                       |                                           | 12/10 - Review Final Presentation  
|                       |                                           | 12/15 - DD Rev. D Due |

#### 4.2 Team Members:
- Ryan Marizza  
- Colin Sullivan  
- Christopher Peercy  
- Jack Huun  
- Colin Brown  
- Nolan Ferguson

#### 4.3 Team Organization:

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**Team Radical**  
15
The team is managed with a lead project manager, and a lead manager for each sub-system. In addition to this, each team member will act as a support in either two or three different sub-systems.

### 5.0 BUDGET

#### 5.1 Budgets Overview:

<table>
<thead>
<tr>
<th>MATERIAL</th>
<th>QUANTITY</th>
<th>SOURCE</th>
<th>COST</th>
<th>WEIGHT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Foam Core Assembly</td>
<td>1</td>
<td>COSGC</td>
<td>$0</td>
<td>155.3g</td>
</tr>
<tr>
<td>Main Arduino Assembly</td>
<td>1</td>
<td>COSGC</td>
<td>$0</td>
<td>75.3g</td>
</tr>
<tr>
<td>Second Arduino Assembly</td>
<td>1</td>
<td>COSGC</td>
<td>$0</td>
<td>245g</td>
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<tr>
<td>Aluminum Tape</td>
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<td>2g</td>
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<td>COSGC</td>
<td>$0</td>
<td>4g (Measured and Included in Foam Core assembly)</td>
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<td>Micro SD Card</td>
<td>2</td>
<td>COSGC</td>
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<td>COSGC(L)</td>
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<td>8(N)</td>
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<td>Radioshack Pro-649 Handheld Radio Scanner (Catalog #: 2000649)</td>
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<td>Radioshack</td>
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<td>80g (Included in Arduino Second Arduino assembly)</td>
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<td>Amazon.com</td>
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<td>Arduino Compatible 3-axis Magnetometer Compass (Part #: GY-271 HMC5883L)</td>
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<td>Sparkfun</td>
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<td>Sparkfun</td>
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<td>--</td>
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<tr>
<td><strong>TOTAL</strong></td>
<td></td>
<td></td>
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Foam Core assembly includes: Hot glue, Aluminum Tape, 2 x Washers, Foam Core assembly.
Main Arduino assembly includes: Balloon shield, 1 x Arduino Uno, 1 x SD Shield, Pressure sensor, Accelerometer, Humidity sensor, External temperature sensor, Internal temperature sensor.

Second Arduino assembly includes: 1 x Arduino Uno, 1 x SD Shield, Radioshack Pro-649 Handheld Radio Scanner, Ammeter, 3-axis Magnetometer Compass.

*The Elenco AM-780K was originally purchased for use as a VHF receiver, however, it was deemed incompatible at the desired frequency, so was replaced by the Radioshack Pro-649 and is not included in the total mass.

Project Omni’s original weight prediction was to be at or under 864 grams. However, it came in 43 grams overweight, at 907 grams. Project Omni was also expected to have more room in the budget, ending at 10.93 dollars under the budget of 180 dollars. This unforeseen weight and budget issuing was due to the purchase of the Radioshack Pro-649.

5.1.1 Parts Contacts:
- COSGC Parts:
  Contact: Chris Koehler
  Email: Prof.Koehler@gmail.com
- Amazon.com:
  Contact: Amazon.com Customer Support
  Phone: 1-(888)-280-4331
- King Soopers:
  Contact: Dry Ice Department
  Phone: (303)-443-9622
  Address: 1650 30th St. Boulder CO, 80301
- SparkFun Electronics:
  Phone: (303)-284-0979
  Address: 6333 Drycreek Pkwy, Niwot, CO 80503
- RadioShack:
  Phone: (303)-449-0635
  Address: 1895 28th St, Boulder, CO 80301

5.2 Budget Management:
The budget which remains $10.93. The amount of funds consumed is $169.07, which is under the budget of $180.00 for the project. Nolan Ferguson is in control of budget for Project Omni. Management will be on a need-to-buy method, meaning no expenses shall be spared unless absolutely necessary. All orders for parts will be sent to Chris Koehler so that the team meet with him for use of the CU Visa card. Mr. Ferguson will also be in charge of submitting the required receipts within 48 hours of the purchase.

6.0 TEST PLAN AND RESULTS
6.1 Project Testing:
- **Structural Testing:** Project Omni was subject to three structural tests: the drop test, the stair test, and the whip test. These tests were performed to determine the structural integrity, stability, and strength of Project Omni and make changes where necessary. All tests were carried out in compliance with the team’s safety standards.

- **Drop Test:** The drop test was performed by dropping the structure from a height of approximately six meters at its full payload weight. This test simulated the force of landing. The structure of Project Omni was analyzed after this test.

  **Changes:** The structure of Project Omni remained fully intact after the drop test with only minor damage, so no changes were necessary.

- **Stair Test:** The stair test was performed by throwing Project Omni at its full payload weight, down a cleared flight of stairs. This test was performed to simulate Project Omni bouncing and being dragged across the ground during landing.

  **Changes:** The structure of Project Omni remained fully intact after the stair test with only minor damage, so no changes were necessary.

- **Whip Test:** The whip test was performed by attaching Project Omni to an artificial flight string that was be held by a team member. This individual swung Project Omni above themselves in a circular motion in order to simulate the velocities and g-forces that will act on Project Omni during flight (particularly after burst). This test was performed for two minutes.

  **Changes:** Problems were discovered with the flight string tube mount. The paper clips holding the tube to the washers were repeatedly pulled loose from the mount. To solve this problem, the paper clips were replaced with rivets.

- **Temperature Test:** The temperature test was performed by placing Project Omni in a cooler containing dry ice for approximately three hours. This test simulated the extreme temperature in near space, which can dip well below 0°C, and evaluated how the components perform in low temperatures. During the test, all hardware and software were operational and recording data. The results of the test were then analyzed.

  **Changes:** To maintain a higher internal temperature, the volume of the interior of Project Omni was decreased. This allowed for all components to be closer to the heat source, solving the problem.

- **Camera:** The camera was tested to make sure it takes pictures every ten seconds and a ten-minute video as it will in flight. The camera was also included in the temperature test and took pictures every ten seconds to ensure it was functioning properly throughout the entire test.

- **VHF Receiver Testing and Calibration:** The receiver has been tested at Boulder Municipal Airport on the frequency 118.825 MHz ensuring that the proper range of frequencies can be received. After this, the receiver was tested in Gill, Colorado on the GLL VOR on the frequency 114.2 MHz. During the temperature test, the receiver was operational, but tuned to 118.825 MHz ensuring that it operates under extreme temperature conditions.

- **Arduino Unos:** Both Arduino Unos were subject to testing individually to ensure that they are recording and storing data correctly. They will also be involved in the temperature test to ensure that they will operate effectively at extreme temperatures.

- **Other Sensors:** The other sensors involved in the experiment including the accelerometer, pressure sensor, internal temperature, external temperature and humidity sensor were subjected to testing both individually and in the temperature test to assure they were working properly in
all conditions. The external LEDs on the side of Project Omni indicated that these sensors remained operational throughout testing.

- **Mission Simulation Test:** To simulate a full mission from launch to touchdown, Project Omni had all switches turned on and all sensors activated. Project Omni was subjected to this simulation of the mission near the predicted launch site, under a realistic time frame of about 90 minutes. During this simulation time, Project Omni collected data, took pictures and video, and performed all actions set to carry out on the actual mission. The results of the simulation were analyzed to confirm that Project Omni is functioning correctly and ready for launch.

6.1 **Safety:**
Team Radical safely and carefully conducted all testing procedures. Protection of University and private property were of the highest priority. In all tests of Project Omni, proper safety equipment was utilized. All tests and assemblies were done with the presence of at least two team members, in order to ensure accuracy and safety in the construction of the BalloonSat. When machinery was being used, all members of the team who were operating the machinery were certified to use it and did so in a safe and responsible manner under the supervision of other team members or staff. Structural testing was carefully conducted so that it is was not performed near any windows or other hazards, in effort to eliminate collateral damage. Proper precautions were taken to ensure that the VHF receiver did not at any time transmit a signal.

**Test Results:**

**Drop test:**
The drop test was a success, with Project Omni only suffering minor damage to its corners.

**Stair Test:**
The stair test was also a success, with Project Omni only suffering minor damage to its corners.
Whip Test:
During the whip test, a problem was discovered with the flight string mount where the paperclips were pulled through the washers. This problem was fixed by replacing the paper clips with small rivets and later iterations of the whip test were a success.
Temperature Test:
The temperature test was a success, with the internal temperature of the box staying approximately 30 degrees Fahrenheit above the external temperature. All systems were functional for the duration of the temperature test, which ended when the heater experienced a power failure at approximately 90 minutes.

Mission Simulation Data:
The data on the next page represents the relative humidity inside of Project Omni, during the 90-minute duration of the simulation. The data supports a steady decrease in humidity until about 60 minutes, where it remains constant from there on out.
The data above represents the pressure change for the duration of the mission simulation test. The data shows a fairly constant pressure for the entire test.
The data above represents the external temperature of Project Omni during the 90-minute mission simulation test. The temperature reads approximately 45 degrees Fahrenheit for the entire flight as it was conducted outside. The data shows the temperature to be fairly steady for the duration of the test.

The data above represents the internal temperature change throughout the 90-minute duration of the simulation test. The data shows a sharp increase in temperature for the first 20 minutes, as the heater was activated. At about the 20-minute mark, the heater experienced a power failure, so the temperature began to flatten out.
The data shown above represents the accelerometer data during the mission simulation test. The simulation was performed with Project Omni in a steady state, so the accelerometer data remained constant.
The data on the previous page shows the current recorded from the scanner using the ammeter during the mission simulation. The data shown is very zoomed out, but is meant to show that the radio scanner successfully operated for 90 minutes on a single 9-volt battery.

7.0 EXPECTED RESULTS

7.1 Sample Data:

The following graph shows the Arduino data during testing once the data is stored to the SD card and later processed through Microsoft Excel. The graph below depicts individual tests of each sensor corresponding to a specific color. The graph below does not depict expected data over the entire time of flight, however, it gives an idea of how flight data might be presented once it is collected during testing.
**Project Omni**

**Project Omni Pressure Test**
- Pressure returns to around 12 psi.
- Pressure is reduced from the sensor by shaking the air out of the tube.

**Project Omni Magnetometer Test**
- Sensor was reset to ensure it was working properly.

**Project Omni Humidity Test**
- Humidity is introduced to the sensor in the form of human breath.
- Humidity then balances to actual relative humidity.
7.2 Expected Data:

7.2.1 VHF Receiver

Team Radical expects that the transmission’s received signal strength will decrease slightly faster than the inverse square of the distance between the transmitter and the receiver from launch altitude to 18 Km. Then, it will decrease almost exactly as the inverse square of distance between 18 Km to 30 Km. The difference in measurements will be affected by the local air density. Therefore, at higher altitudes, VHF transmissions should lose signal strength slower than at lower altitudes with more air density.

When a strong signal is received, the difference in current from when the VOR is transmitting its Morse identifier and when is not transmitting the Morse identifier will be significant and able to be interpreted. When the signal from the VOR is not strong, this difference in current will not be distinguishable from the current created by the noise received by the radio scanner. The maximum operating altitude of the VOR can be determined by comparing the altitude of the payload with the time at which the Morse identifier is no longer distinguishable from the noise.

The first graph below shows what a strong signal from the Morse identifier will look like. The spikes indicate where the Morse identifier of the characters ‘GLL’ are broadcasted. This transmission is approximately 5 seconds, followed by 12 seconds of silence. There is a large
difference between spikes in current where the Morse identifier is being broadcasted and the portions of lower current where the Morse identifier is not being broadcasted.

The second graph below shows what an extremely weak or nonexistent signal would look like. There is no difference between the portions where the Morse identifier is being broadcast and the portions where there is only noise. Essentially, the signal is indistinguishable from the noise.
Therefore, Team Radical expect the tests to show that the existing systems will be reliable at altitudes greater than their stated operating guidelines, if modifications are made to increase the intensity of the VOR’s signal.

7.2.2 Internal and External Temperature
The internal temperature of Project Omni will start at the local temperature of the launch site, then will slowly decrease to no less than 0 degrees Celsius. External temperature will decrease steadily to approximately negative 60 degrees Celsius due to the ideal gas law, then will increase until balloon burst due to the increased concentration of Ozone absorbing.
7.2.3 Relative Humidity
The humidity sensor aboard Project Omni will record data which Team Radical expect to mimic the graph below. The humidity will start at a base value at launch (primarily a factor of weather) and will increase slightly as it ascends through the cloud layer. From here, the humidity will decrease to almost zero at burst.

7.2.4 Pressure
Pressure measured on board project Omni will decrease exponentially as altitude increases, eventually reaching a near vacuum state. The expected pressure versus altitude is shown on the graph below.
7.2.5 Acceleration
Acceleration should remain fairly constant throughout ascent to burst altitude. Project Omni should experience some slight acceleration horizontally during ascent, however this should be very slight. Project Omni should experience its largest acceleration load during the period between burst and parachute deployment which would look like the sudden spikes, as seen below.

7.2.6 Magnetometer/Compass
The magnetometer will determine the orientation of the payload. Output data is given in microtesla, which indicate changes in orientation along a specific plane, thus it is important to understand the orientation of the compass in the payload. Project Omni shall have the magnetometer mounted upside-down on the top side of the payload. As the Magnetometer is measuring the field in three axes, it can be expected one axis not to change very much while the other two change rapidly as the orientation changes. This is due to the fact that one axis will determine the change in orientation along the vertical direction. In Project Omni’s case, the y-axis would not change as much as the others as it would measure vertical tilt. The data output will be in the form of magnetic field strength in relation with the horizontal and vertical axis. The data from the flight should look something like the graph shown below. Were Project Omni to discover a correlation between received signal strength and orientation, we could expect regular and repeated changes in signal strength that correspond to specified orientations.
8.0 LAUNCH AND RECOVERY:

On November 7th, 2015, at 4:35AM, all members of Team Radical left Boulder, Colorado in the ground support and recovery vehicle. Team Radical arrived at the designated launch site before 6:00 AM. Once at the launch site, Team Radical turned on all sensors, switches and the camera and made sure all components of Project Omni were fully operational. The camera was turned on by pressing the button through a pre-drilled hole in the box. Visual indicator lights on the outside of the box ensured this step was done properly. With the weather conditions, Colin Brown launched Project Omni from Deer Trail, Colorado, at approximately 6:50 A.M. Then, during the one hundred and forty-seven-minute flight, team representatives followed Project Omni to the landing point and recovered Project Omni. Immediately after the recovery of Project Omni, photographs of the interior and exterior of Project Omni were taken to document the condition of Project Omni after flight. Six photographs were taken of the exterior of Project Omni, one for each face. Five photographs were taken of the interior of Project Omni, one for each of the four walls and one for the base, as well as a video of the unsealing process. Documentation of the condition of Project Omni post flight helped to aid in failure analysis. Data from Project Omni was read from each of the three SD cards flown. Each of these three SD cards have been tested with an adaptor and were able to adequately read, store and upload data to a team member’s personal computer using this adaptor.

The launch took place on the morning of November 7th, 2015 in Deer Trail, Colorado, where Colin Brown successfully launched Project Omni at 6:50 AM. All aspects of the launch of Project Omni were successful and the Team Radical followed the launch instructions detailed in this document.
The recovery was a success and took place outside of Hugo, Colorado, approximately 147 minutes after the launch of Project Omni. Photographs were taken of the interior and exterior of Project Omni at the recovery site and the data from the SD cards was downloaded the next day in Boulder, Colorado. The payload suffered minimal damage to the edges of the main structure, but the rest of the exterior and all of the internal components were undamaged, except for the switch for Arduino 1 being in the off position due to impact with the ground.

Before:

![Before Image]

After:

![After Image]
9.0 RESULTS, DATA ANALYSIS, FAILURE ANALYSIS, CONCLUSIONS

9.1 Results and Data Analysis
Team Radical does to some extent believe that the mission was successful. The following analysis looks at each individual sensor and its relation to predicted and mission simulation data.

9.1.0 Pressure Sensor
During flight, the pressure steadily decreased from an initial pressure of approximately 12.2psi to a minimum pressure of 0.16psi at about 110 minutes when burst occurred. The pressure then went back up to approximately 12.2psi when it returned to the ground.

This data confirms that Project Omni’s pressure sensor was operational and fully functional throughout flight with no errors. This data was approximately in alignment with the expected results which predicted a steady decrease in pressure as altitude increases. This helps address the environmental data at these high altitudes, which, if behaving as predicted, should not have affected the engineering mission data.

9.1.1 Humidity Sensor
At launch, the relative humidity was about 41 percent. As Project Omni ascended, the relative humidity dropped very harshly. At about 40 minutes, the relative humidity was recorded at 5 percent. The humidity slowly rose to about 10 percent at 50 minutes and stayed at this level.
until 110 minutes, where the balloon burst. As Project Omni started to descend, the humidity dropped off sharply to a low of about 0 percent and stayed at this level until the 140-minute mark, where it began to rapidly rise again until landing.

Based on this data, it can be concluded that Project Omni’s humidity sensor was a success in terms of Project Omni’s environmental test mission. In the beginning, both the projected and actual data show a spike in humidity, the actual being much less dramatic. The projected data supported the major drop in humidity during the ascent. The projected data shows the lowest recorded humidity reaching almost 0 percent, which was supported by the humidity during the actual flight reaching similar numbers. The projected data shows a steadier increase in humidity than what actually occurred during the flight, however the overall shape of the projected graph is very similar to the actual flight. Since humidity varies on a daily basis, it is to be expected that the projected humidity will be slightly different from the recorded humidity, especially being in the unpredictable conditions of eastern Colorado.

9.1.2 Temperature

The internal temperature remained fairly constant for the duration of the flight. It started at 40 degrees Fahrenheit, and fluctuated between 40 and 60 degrees Fahrenheit until about 100 minutes into the flight, where it rose up to about 70 degrees Fahrenheit. At burst the internal temperature continued to rise for about 5 minutes, then began to drop back down to 40 degrees Fahrenheit until landing. The external temperature started at about 25 degrees Fahrenheit and began to dramatically drop about 20 minutes into the flight. The external temperature reached a low of -61.2 degrees Fahrenheit at about 40 minutes into the flight and then began to rise steadily until burst. As Project Omni first started descending after burst, the temperature dropped
aggressively until it reached the low from before of -61.2 degrees Fahrenheit. From there, the external temperature slowly rose to about 40 degrees Fahrenheit before landing.

Based on this data, it can be concluded that Project Omni’s temperature sensors, in their contribution to the mission overall, were successful. The values of the temperature mirrored the predicted data. The temperature steadily dropped until around 40 minutes where the payload reaches around 15,000m. The temperature rises to near the ground temperature just before burst occurs. This almost exactly mirrors the predicted results. The internal temperature consistently had higher values than the external temperature indicating the successful operation of the heater as a key requirement of the mission. This data does address Project Omni’s environmental data mission component.

9.1.3 Accelerometer
Before launch, accelerometer data was skewed because of the orientation of Project Omni. At launch, a large spike in acceleration occurs reaching ~2g in the X direction due to the horizontal tug on Project Omni right before release and -1g in the Z direction due to the change in orientation of Project Omni from horizontal to vertical. While the balloon was rising (between 5 minutes and 110 minutes) the acceleration is very close to 0 and can be explained by the fact that there is no movement along the flight string. At 110 minutes, when the balloon burst, acceleration in the X and Z directions spiked with the X direction acceleration fluctuating rapidly between 1g and -1g and the Z direction acceleration reaching a maximum of ~3g in the Z direction before fluctuating between 1g and -1g. As the payload descended, this fluctuation eventually tapered down to fluctuations between 0.5g and -0.5g before finally touching down at 150 minutes. This data correlates well with expected accelerometer data. No mission failures were caused by acceleration, and since the maximum acceleration in any direction was ~3g, this was expected. There is no acceleration data after impact with the ground because this impact with the ground turned off the switch for the Arduino that recorded environmental data.

9.1.4 Radio Receiver Data

The VHF receiver was tuned to 112.1 MHz prior to payload sealing and was activated at the launch site approximately 15 minutes prior to launch. The radio was confirmed to be working by a team member and was receiving static as expected before launch occurred. After launch, the signal clearly experienced an increase in strength. This shows that per FAA standards the VOR was performing as expected. The signal strength remains the same throughout the duration of the flight, up to payload burst. At burst, there are significant fluctuations in signal strength. This is mostly due to the jostling the payload experienced during flight. Since the VOR transmits a vertically polarized signal, instances where the payload’s antenna is not vertical reflect the loss of signal strength. As the parachute became more effective, the payload stabilized and the signal strength increased until the payload passed out line of sight with the VOR seconds before landing. At touchdown, the wire connecting to the VHF receiver to the ammeter was jarred in a manner which it no longer functioned properly.

The radio data was analyzed by first adjusting the data points to fall in a range centered on zero, then the data was divided by five so all values fell between zero and one. This allowed the data to be written to a .wav file. The .wav file was then compared to a 9960 hertz wave as well as a 1020 Hz wave. By comparing the raw flight data to both the subcarrier reference signal as well as the 1020 Hz Morse code tone, Team Radical was able to verify that the signal was congruent to the 1020 Hz tone, as well as the 9960 Hz tone. The figure shown below shows a small sample of the analyzed signal. The signals can be seen as congruent, due to the largest recorded values from the radio falling at points where the largest values of the 9960 Hz and 1020 Hz signal exist, and smaller values fall where smaller values of the 9960 Hz and 1020 Hz signal exist. The reason why there are not as many sample points on the data sample compared to the subcarrier waves is because the Arduino system was only able to sample at 24 Hz, compared to the faster sample rate of the .wav files used for the subcarrier comparison.

In addition to the side by side comparison of the data and expected signal, the key points of the payload’s flight provided additional insight to the data. In the graphic below, the signal is clearly not present until after launch, after which, the average amplitude of the signal decreases very slightly as the payload climbs. At burst, the lower graph shows that the orientation of the
payload rapidly oscillated between horizontal and vertical. The average amplitude of the signal decreases during this period as a result of the vertical polarization of the transmission. As the payload begins to stabilize, the signal returns to it the previous average amplitude. Shortly before landing, the signal rapidly decreases in strength as the payload no longer has a direct line of sight to the transmitting VOR. The graphs shown below from top to bottom include: the VHF signal, the Morse signal, and the vertical orientation data.

The actual signal received was similar but not quite the same as the signal received during testing, and did not show noticeable decay as altitude increased. This matches other unexpected data from the flight, where the Morse identifier can be clearly heard in the flight video, which was recorded at approximately 27km.

This information is significant, as it shows that despite the ratings published by the FAA, VORs are still usable at altitudes exceeding 18 kilometers.

It is also of significance to note the change in the strength of the received signal with the distance from the payload to the VOR. As shown in the image below, the payload traveled southeast toward the VOR (indicated by the yellow pin on the map), so the signal strength should increase slightly as the payload moves closer to the VOR.
The distance from the payload to the VOR was calculated using the coordinates of the payload provided by Edge of Space Sciences (EOSS) which was then translated into nautical miles. This data was then combined with the altitude of the payload given by EOSS to find the exact distance from the Hugo VOR to the payload during the entire flight.
Radio Receiver Data (Entire Flight):

![Graph showing project Omni flight current vs time with power failure at approximately 147 minutes.]

Radio Receiver Data (Closer look at 2 minutes of the flight):

![Graph showing project Omni flight current vs time at a closer time resolution.]
9.1.5 Magnetometer

As seen in the figure below, the orientation of the magnetometer changed continuously and rapidly throughout the flight. The magnetometer registered an initial orientation as it was handled prior to flight and quickly changed approximately 8 minutes into the flight where it rotated rapidly. The x and z axes (horizontal), had the highest changes in orientation as the payload rotated throughout the flight on the flight string. The y-axis had little change in its orientation other than slight gyrations in the vertical direction. When burst occurred at approximately 110 minutes, the orientation rapidly changed as the payload tumbled in all directions and whipped about randomly. At approximately 147 minutes, the orientation of Project Omni stabilized as it lay motionless on the ground until it was recovered.

This collected data approximately mirrors the predicted data. Orientation does change rapidly on two axes, while the third remains approximately the same. In both testing and throughout the duration of Project Omni’s flight, there was no distinguishable correlation between the orientation of the payload and the strength of the VOR signal, so long as the payload remained vertical. Team Radical believes this is due to a couple of reasons. The first of these is the orientation of the receiving antenna on the payload on the bottom of the satellite; while in any orientation on the flight string, there is no physical intrusion to the antenna. This is combined with the fact that as the payload rotates in flight and changes orientation, the distance between the receiver and VOR transmitter only varies by about six centimeters. This miniscule difference in distance from the receiver is indistinguishable based on the data. The second reason Team Radical believes there is no distinguishable correlation between orientation and signal strength lies in the way the data was collected, apart from the signal being weaker when the antenna was horizontal. As stated in the predicted data, if there were a correlation between signal strength and orientation, Team Radical could expect to see regular and repeated changes in strength throughout the duration of the flight. Instead, Team Radical saw a relatively constant signal strength with variations only in the chaotic descent.
9.2 Failure Analysis

Project Omni experienced a few errors during its flight however none of them majorly detracted from the mission objectives, mission requirements, or collected data. The first of these was that an error was made in the calibration of the current sensor. Although this calibration was initially made and leveled at zero amps, Team Radical suspects that the sensor was bumped during final assembly of the box or during transportation and caused the calibrated value to be removed. Instead of reading 0 amps as a value of 0, the sensor read it as a value of approximately -8, leaving each current measurement 8 amps lower than it should be. This was easily solved by adding 8 amps to each data value before analyzing the data. The second major failure was the ammeter failure at landing. This could be corrected by ensuring a sturdier connection between the Arduino and ammeter is made. The third and final failure of the flight is the power failure of the camera prior to burst. The camera recorded pictures and videos up until 136 minutes. This failure is primarily due to the fact that the battery would not charge up to 100% and Team Radical was unable to procure a replacement due to COSGC limitations. Still given these failures, Project Omni was able to successfully complete the mission.

10.0 FLIGHT READINESS

Project Omni’s payload is ready to fly again, after a few small adjustments to avoid failures from the first flight. To correct the lack of power from the previous flight batteries, each 9V battery was replaced with a new, fully-charged counterpart. Second, to address the error in the calibration of the current sensor, the current sensor was re-zeroed so that the current sensor reads a value of zero when no current is passed through it. The SD cards were cleared and the software on each Arduino was reloaded to confirm that they were up to date. In order to address the premature power loss of the camera, a new battery was procured so that it will be able to hold a full charge and thus last for the entire flight. With these given, Project Omni is ready for another flight.
11.0 LESSONS LEARNED

Were this project to be repeated, there are some changes that would have optimized progress and made for a better end result. The original plan was to modify a basic inductor/capacitor circuit in order to make a radio receiver. However, building this kind of circuit and successfully tuning it to a very specific frequency proved to be very challenging. If the project were to be repeated, the radio scanner which Team Radical used for the flight would have been the original plan, which would have given Team Radical more time to focus on perfecting other systems of Project Omni. Another thing which Team Radical would do differently would be to worry about weight earlier. The team ended up building and rebuilding the box three different times which proved to be a major draw on resources and time.

Team Radical also learned a lot about working as a team on an engineering project: how to divide and conquer, how to communicate clearly between members who are working on different aspects of the project, and how to work well with people that each member of the team has never worked with before. As it pertains to the technical side of things, the members of Team Radical learned about VORs and navigational aids, how to use and write programs for Arduino, how to calibrate sensors and read the technical documents for these sensors, how to use a laser cutter properly, how to solder, and how to troubleshoot problems.

12.0 MESSAGE TO NEXT SEMESTER

As you’ve probably heard, this class is a ton of work and requires a very generous amount of time, however it is also the most rewarding class you will have taken in your life. You should keep in mind that the course requires a lot of dedication and a consistent time commitment. You should be ready to work hard and dedicate at least 15 hours per week working on the project outside of class. Be sure to keep true to the schedule you create at the beginning. Don’t skip meetings on any day just because you don’t have any immediate deadlines, there is always work to be done. Plan to get your most of your balloon satellite done a week in advance to avoid a brutal last week.

The most important aspect of your project will be getting to know the total strangers you are grouped up with. Even if you don’t immediately mesh well with your group, you have to work through it and learn to connect. You will be spending a ton of time together, so it is really important to find common ground and work together with ease. It is important to hold yourself accountable to do your work, because you will not have constant reminders of what you actually have to get done. You must actively check the website and make sure you stay caught up on all the homework and assignments. Other than that, it’s a lot of fun, You're going to meet a lot of great people, and make some good friends. So stick with it, and you won't be sorry.

13.0 REFERENCES