Colorado Space Grant Consortium

Gateway to Space
Fall 2013
Design Document

Team Heavyweight
Project Lightweight
GAS-E
(Gas Analyzing Stratospheric Explorer)

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Due: November 14
Revision C

November 14, 2013
Rev C
Revision Log

<table>
<thead>
<tr>
<th>Revision</th>
<th>Description</th>
<th>Due Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>A/B</td>
<td>Conceptual and Preliminary Design Review</td>
<td>October 17</td>
</tr>
<tr>
<td>C</td>
<td>Critical Design Review</td>
<td>November 16</td>
</tr>
<tr>
<td>D</td>
<td>Analysis and Final Report</td>
<td>First Draft: December 7</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Final Draft: December 16</td>
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</tbody>
</table>

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1.0 Mission Overview

1.1 Mission Statement:

The mission of Team Heavyweight is to develop a BalloonSAT, GAS-E, by the launch date of November 16, 2013. GAS-E will climb to the lower level of the stratosphere, up to an approximate altitude of 30 km where the balloon will burst. GAS-E will have a payload that will collect data on the four gases of carbon dioxide (CO₂), carbon monoxide (CO), methane (CH₄), and ozone (O₃). Team Heavyweight shall compare those results to data recorded from previous years according to the EPA (Environmental Protection Agency) as well as data that will be recorded during testing on the ground before launch. The purpose of this mission is to determine whether there have been changes in the concentrations of the four gases listed since 2010 and if an increase in levels of CO, CO₂, and CH₄ molecules in the atmosphere inversely correlates with the level of ozone molecules in the atmosphere.

1.2 Mission Objectives:

1. To design, build, and prepare our BalloonSAT, GAS-E, to be ready to launch by November 16, 2013 and contain an environment Arduino working humidity, pressure, and internal and external temperature sensors, as well as a camera to photograph the flight.
2. To properly test the structural integrity, and all sensors, codes, and subsystems to ensure that GAS-E is ready to launch and survive in the near space environment.
3. To use a carbon monoxide sensor, methane sensor, carbon dioxide sensor, and ozone sensor to measure their respective gas levels as GAS-E climbs to an altitude of 30 km.
4. To retrieve and use the data that GAS-E collects to analyze and compare it to previously collected data from past years research and ground data that will be previously collected during testing.
5. To follow all the requirements given to Team Heavyweight in ASEN 1400 plus the requirements outlined in the Design Document and the RFP, as well as turning in higher quality work than our initial request for proposal.

1.3 Mission Overview:

Team Heavyweight’s BalloonSat will fly to an altitude of 30 km, through the tropopause and into the lower level of the stratosphere. The stratosphere extends to an altitude of about 50 km and is the layer of the atmosphere where ozone is created and destroyed. Carbon Dioxide levels in the upper Troposphere (Tropopause) and lower stratosphere are not consistent, with rates changing by 7 parts per million over 20 km.³ Oxygen makes up about 21% of Earth’s atmosphere, and is fairly consistent throughout each layer. On the other hand, ozone predominantly exists in the stratosphere, about 90% of the total ozone in our atmosphere, and only has about 3 molecules for every 10 million air molecules (.00003% of the stratosphere).² Ozone is very important because it absorbs UV radiation (specifically UVB) which has been proven to be harmful to both people and vegetation. Team Heavyweight hypothesizes that ozone
has decreased from past years' values while carbon monoxide, methane, and carbon dioxide have increased from past values due to human causes. The United States carbon dioxide emissions have risen by about 8.4% from 1990 to 2011 while consequently ozone depletion has been made a public concern. If the hypothesis is correct, then it will indicate the further degradation of the ozone and that "greenhouse gases" have become more prominent in the troposphere, therefore expanding more into the stratosphere, furthering global climate change. There is great concern that this is the case, as humans have impacted the atmosphere through many industrial actions. Chlorofluorocarbons (CFCs) were used in industry for many purposes (until they were eventually banned by the Montreal Protocol in 1987), such as spray cans and refrigeration, and is a leading proponent of ozone-depleting substances (ODS). The CFCs are stable enough to reach the stratosphere and through complex chemistry (the Sun’s radiation breaks down the CFC, releasing chlorine, which has the power to destroy ozone, because the chlorine binds with a monoatomic oxygen, preventing O₂ from bonding with monoatomic oxygen, which forms natural ozone), has been proven to destroy ozone. Even though CFCs are not in use, their past impact on ozone is still a problem today. The increase in carbon emissions in such gases as carbon dioxide, methane, and carbon monoxide have also been shown to damage the ozone. This is important, as many ecosystems will be destroyed through global climate change and there may be severe consequences for coastal cities as polar ice caps melt and the sea levels rise. Cancer rates and other medical problems will also rise as the ozone decreases and cannot filter as much of the Sun’s radiation. Even though ozone is helpful in blocking radiation, this experiment will also measure ozone levels in the troposphere, which is also important medically as long term exposure to ozone has induced fatal respiratory illness in humans. The gases measured in this experiment are very important for the human race and the environment as an imbalance in any of the gases can cause many negative consequence.


2.0 Requirements Flow Down

For a successful mission and successful operation of GAS-E, Team Heavyweight has created a preliminary Requirements Flow Down chart. These requirements fulfill the mission objective and mission statement. Level 0 requirements are the most basic requirements, but are integral for the mission’s success. Level 1 Requirements state the requirements for which Level 0 Requirements need to operate successfully (this trend continues as level 2 state the requirements for which level 1 needs to operate successfully, and this continues as higher level requirements state what must occur for the lower level requirements to be fulfilled).
### Level 0 requirements

<table>
<thead>
<tr>
<th>Number</th>
<th>Requirement</th>
<th>Origin</th>
</tr>
</thead>
<tbody>
<tr>
<td>M 0.1</td>
<td>GAS-E shall have gas sensors measuring the gas concentrations of CO&lt;sub&gt;2&lt;/sub&gt;, CH&lt;sub&gt;4&lt;/sub&gt;, CO, and O&lt;sub&gt;3&lt;/sub&gt; through its ascension up the atmosphere.</td>
<td>Objective 3</td>
</tr>
<tr>
<td>M 0.2</td>
<td>Team Heavyweight shall ensure that no one is hurt during construction and testing (Safety &amp; Reliability)</td>
<td>RFP</td>
</tr>
<tr>
<td>M 0.3</td>
<td>GAS-E shall measure humidity levels, pressure levels, acceleration and internal and external temperature while taking pictures of the flight</td>
<td>Objective 1</td>
</tr>
<tr>
<td>M 0.4</td>
<td>Team Heavyweight shall reach an altitude of 30 km</td>
<td>Objective 3</td>
</tr>
<tr>
<td>M 0.5</td>
<td>GAS-E shall measure internal and external temperatures with varying altitudes</td>
<td>Objective 1</td>
</tr>
<tr>
<td>M 0.6</td>
<td>The BalloonSat shall be able to endure near space conditions.</td>
<td>Objective 2</td>
</tr>
<tr>
<td>M 0.7</td>
<td>To retrieve GAS-E and analyze data</td>
<td>Objective 4</td>
</tr>
</tbody>
</table>

### Level 1 Requirements

#### Objective 1
GAS-E shall have gas sensors measuring the gas concentrations of CO<sub>2</sub>, CH<sub>4</sub>, CO, and O<sub>3</sub> through its ascension up the atmosphere.

<table>
<thead>
<tr>
<th>Number</th>
<th>Requirement</th>
<th>Origin</th>
</tr>
</thead>
<tbody>
<tr>
<td>M 1.1.1</td>
<td>Sensors will be correctly wired and coded to the Arduino to measure gas levels for each sensor</td>
<td>M 0.1</td>
</tr>
<tr>
<td>M 1.1.2</td>
<td>Measurements will take place every 1.1 seconds for 20 foot increments of measurements</td>
<td>M 0.1</td>
</tr>
<tr>
<td>M 1.1.3</td>
<td>Perform tests to ensure that each sensor records in correct increments</td>
<td>M 0.1</td>
</tr>
<tr>
<td>M 1.1.4</td>
<td>Perform tests to ensure that each sensor will last for the duration of the flight</td>
<td>M 0.1</td>
</tr>
</tbody>
</table>

#### Objective 2
Team Heavyweight will ensure that no one is hurt during construction and testing (Safety and Reliability)

<table>
<thead>
<tr>
<th>Number</th>
<th>Requirement</th>
<th>Origin</th>
</tr>
</thead>
<tbody>
<tr>
<td>M 1.2.1</td>
<td>Maintain safe habits when working with GAS-E</td>
<td>M 0.2</td>
</tr>
<tr>
<td>M 1.2.2</td>
<td>Perform safe tests where no one will be injured or anything damaged</td>
<td>M 0.2</td>
</tr>
</tbody>
</table>

#### Objective 3
GAS-E shall measure humidity levels, pressure levels, acceleration and internal and external temperature while taking pictures of the flight.

<table>
<thead>
<tr>
<th>Number</th>
<th>Requirement</th>
<th>Origin</th>
</tr>
</thead>
<tbody>
<tr>
<td>M 1.3.1</td>
<td>Sensors will be connected and coded to the Arduino to record correct data values</td>
<td>M 0.3</td>
</tr>
<tr>
<td>M1.3.2</td>
<td>Test will be performed to ensure that each sensor works correctly</td>
<td>M 0.3</td>
</tr>
<tr>
<td>--------</td>
<td>---------------------------------------------------------------</td>
<td>------</td>
</tr>
</tbody>
</table>

### Objective 4
Team Heavyweight shall reach an altitude of 30 km

<table>
<thead>
<tr>
<th>Number</th>
<th>Requirement</th>
<th>Origin</th>
</tr>
</thead>
<tbody>
<tr>
<td>M 1.4.1</td>
<td>GAS-E will be tied to the weather balloon rope</td>
<td>M 0.4</td>
</tr>
<tr>
<td>M 1.4.2</td>
<td>GAS-E will be attached using the provided tube and clips</td>
<td>M 0.4</td>
</tr>
</tbody>
</table>

### Objective 5
GAS-E shall measure internal and external temperatures with varying altitudes

<table>
<thead>
<tr>
<th>Number</th>
<th>Requirement</th>
<th>Origin</th>
</tr>
</thead>
<tbody>
<tr>
<td>M 1.5.1</td>
<td>GAS-E will be equipped with the given temperature sensors</td>
<td>M 0.5</td>
</tr>
<tr>
<td>M 1.5.2</td>
<td>One temperature will be one inch outside of the surface of the box while one will be internally</td>
<td>M 0.5</td>
</tr>
<tr>
<td>M 1.5.3</td>
<td>Each temperature sensor will be tested thoroughly to ensure that they function properly</td>
<td>M 0.5</td>
</tr>
</tbody>
</table>

### Objective 6
The BalloonSat shall be able to endure near space conditions.

<table>
<thead>
<tr>
<th>Number</th>
<th>Requirement</th>
<th>Origin</th>
</tr>
</thead>
<tbody>
<tr>
<td>M 1.6.1</td>
<td>GAS-E will be constructed out of foam core and lined with insulation to keep heat in</td>
<td>M 0.6</td>
</tr>
<tr>
<td>M 1.6.2</td>
<td>The heater provided will be implemented to ensure that the internal temperature stays in a range where the hardware functions properly</td>
<td>M 0.6</td>
</tr>
<tr>
<td>M 1.6.3</td>
<td>Tests will be performed with dry ice and a cooler to ensure that the box and hardware will survive sub-zero temperatures when we reach the tropopause</td>
<td>M 0.6</td>
</tr>
</tbody>
</table>

### Objective 7
To retrieve GAS-E and analyze data

<table>
<thead>
<tr>
<th>Number</th>
<th>Requirement</th>
<th>Origin</th>
</tr>
</thead>
<tbody>
<tr>
<td>M 1.7.1</td>
<td>GAS-E will be tested so that our sensors will provide accurate and data that can be easily analyzed</td>
<td>M 0.7</td>
</tr>
<tr>
<td>M 1.7.2</td>
<td>GAS-E will be discovered with minor damages to the structure given that the landing is in a dry area and the data will be retrieved with the box and analyzed and implemented in the DD Rev D</td>
<td>M 0.7</td>
</tr>
</tbody>
</table>
3.0 Design

3.1 Sensors

With the purpose of the mission being to measure the gas concentrations of the troposphere, tropopause, and stratosphere, it is imperative that the gas sensors function properly. The code will be re-checked multiple times before launch and will also be calibrated multiple times until the sensors are as close to maximum accuracy as possible, as they will be reading gas particles in the parts-per-million and parts-per-billion range. Unfortunately, the gas sensors do have ranges in which they are able to read concentrations, so if the concentration is out of the sensor’s range than data may be skewed. The ranges for the sensors are (10 ppb-2 ppm) for ozone, (0 ppm-10,000 ppm) for carbon dioxide, (20 ppm-20,000 ppm) for carbon monoxide, and (200-10,000 ppm) for the methane sensor. The sensors will run from take off until retrieval and will measure gas concentrations every 1.1 seconds allowing a reading every 20 feet. This data will then be sent to the Arduino and will be stored on one of the 2 GB SD cards.

3.2 Structures

The shape of the structure is not relevant to the mission’s success so the structure that will contain the payload will be a cube, measuring 16 cm x 16 cm x 16 cm (roughly 6 inches), for simplicity. This will let a gas sensor stick out of the four sides of the cube. Four holes will be carefully cut in the sides to allow the gas sensors to stick out into the air of the troposphere and stratosphere. With carefully cut holes, the outside air should not be able to leak into the inside of the satellite and cause a decrease in internal temperature. If needed, insulation material will be set around the holes to keep internal temperature constant and as long as the insulating material does not interfere with the performance of the gas sensors our box will stay warm enough to function properly.

3.3 Arduino Uno

The Arduino Uno units will be programmed so that the data being measured by all of the sensors will be recorded to the SD cards every 1.1 seconds. Team Heavyweight chose 1.1 seconds because of the information given about the time it takes to get to burst and the height at burst. The satellite travels 30 km in 90 min which can be converted into 20 ft. every 1.1 seconds. This will ensure that there will be enough data points recorded from all of the sensors that any, and all, comparisons made with the data collected and previously collected data will yield accurate conclusions on how the gas levels of the atmosphere have changed and how the different carbon type molecules are related to ozone levels.

3.4 Data Retrieval

Data will be retrieved throughout the flight by the sensors that have been purchased from various places. The data will be retrieved for each gas every 20 feet. The sensors will also be recording during descent to give extra data points. When the BalloonSat is retrieved, all data that the sensors collected and recorded to the SD cards will be taken and uploaded onto a computer.
where this data will then be transformed into multiple graphs for each gas using Microsoft Excel to more easily understand the data and compare to data previously collected. We will compare the data taken from the troposphere and stratosphere. The camera, also having recorded all pictures taken during flight to an internal SD card, will have the SD card removed and have pictures uploaded to a computer for viewing.

3.5 Functional Block Diagram

![Functional Block Diagram Image]
3.6 Design Diagrams

Internal Design Diagram

[Diagram of a spacecraft interior with labels and components]

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3.7 Hardware

Accelerometer (COM-09605/SEN-09652) - Provided
The accelerometer that is provided for the team is from SparkFun and is a triple axis analog accelerometer which measures the g-load on the certain axis the g-load is being performed on. It includes both the accelerometer and a breakout board for the sensor.

Pressure Sensor - Provided
The pressure sensor provided is from SparkFun and measures both Altitude and Pressure in 20-bit measurements in Pascals and meters respectively. This is compatible with the Arduino allowing the storage of the data to an SD card through the Arduino.

Temperature Sensor (SEN-10988) - Provided
The temperature sensor that is provided can measure in a range of -40° C up to 125° C as explained by SparkFun allowing all the temperature ranges that GAS-E will be experiencing.

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throughout the flight to be recorded. The temperature sensor sends the recorded data to the Arduino and is then stored on an SD card.

Humidity Sensor (SEN-09569) - Provided
The humidity sensor provided to us is from SparkFun allowing it to be compatible with the Arduino unit providing information through the unit to a SD card. The sensor has fast response time and enhanced accuracy allowing for reliable data.

Sensor Breakout Board (BOB-08891) - SparkFun
The sensor breakout boards that were purchased through SparkFun are necessary to wire our gas sensors to the Arduino. They give a visual cue to allow easier access to understand which wires go where.

Carbon Monoxide Sensor MQ-7 (SEN-09403) - SparkFun
The carbon monoxide sensor purchased from SparkFun can measure CO levels anywhere from 20 to 20,000 ppm, as well as having a fast response time with high sensitivity allows for reliable data to be stored through our Arduino to an SD card.

Methane Sensor MQ-4 (SEN-09404) - SparkFun
The methane sensor purchased from SparkFun has the ability to record levels of methane from 200 to 10,000 ppm. This sensor also has high sensitivity with a fast response time as well as being compatible with an Arduino to allow us to store reliable data on the SD card through our Arduino.

Ozone Sensor MQ-131 (MQ131) - Futurlec
The ozone sensor that was purchased from Futurlec can measure ozone levels from 10 ppb up to 2 ppm giving us very precise measurements of ozone in the atmosphere. This ozone sensor is also compatible with Arduino allowing us to store data through the Arduino to a SD card.

Carbon Dioxide Sensor MG-811 (CO2SENSOR) - Futurlec
The carbon dioxide sensor that has been purchased from Futurlec is able to measure CO₂ levels from 0 to 10,000 ppm and it is described as being easy to use and incorporated into a small portable unit allowing us to hook it up with our Arduino to store the data to the SD card.
3.8 Concept of Operations

Make sure camera is secure and on

Flip all switches on

Arduino Uno starts recording sensor data every five seconds

Double Check to make sure heater is

Seal the lid of the box for launch with aluminum tape and hot glue

Take pictures every few seconds throughout the journey

Make sure all sensor indicator LED lights are on

Balloon is released and GAS-E rises through the atmosphere

Sensors will record data every 1.1 seconds (every 20 feet)

At 30 km balloon bursts

GAS-E falls back to Earth

Sensors are still recording data on the fall back to Earth

Retrieve GAS-E from wherever it crashes into the Earth

Switch all power off

Collect SD cards from GAS-E

Upload all data from flight onto computers and turn into graphs

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4.0 Management

To ensure each and every subsystem gets completed in a successful and timely manner, each team member is assigned to one specific duty that involves the management of a single subsystem to make sure that the progress of that subsystem is always on-time. As well as managing the one assigned subsystem, each team member is expected to work on any other subsystem that requires the time to keep the entire project on schedule. A weekly group meeting at 11 AM on Thursday is held to also facilitate this goal and spontaneous meeting throughout the week may also be held. The following chart demonstrates the allocation of duties to the subsystems:

The following is a representation of the team’s schedule. It includes all previous dates and accomplishments, as well as important deadlines, events, and meetings that the team is expecting in the future read left to right:
<table>
<thead>
<tr>
<th>Date</th>
<th>Day</th>
<th>Schedule</th>
<th>Date</th>
<th>Day</th>
<th>Schedule</th>
</tr>
</thead>
<tbody>
<tr>
<td>9-19-13</td>
<td>Thu</td>
<td>Team lunch @ Half Fast Subs</td>
<td>9-22-13</td>
<td>Sun</td>
<td>Team Meeting - Soldering and Group HW in Kitt Central</td>
</tr>
<tr>
<td>9-24-13</td>
<td>Tue</td>
<td>Team Meeting - Work on and Complete CoDR</td>
<td>9-26-13</td>
<td>Thu</td>
<td>Team Meeting - Work on Proposal</td>
</tr>
<tr>
<td>9-29-13</td>
<td>Sun</td>
<td>Complete Proposal</td>
<td>9-30-13</td>
<td>Mon</td>
<td>PROPOSAL DUE</td>
</tr>
<tr>
<td>10-1-13</td>
<td>Tue</td>
<td>HW 6 DUE</td>
<td>10-3-13</td>
<td>Thu</td>
<td>Team Meeting</td>
</tr>
<tr>
<td>10-4-13</td>
<td>Fri</td>
<td>Submit Order for Parts HW 7</td>
<td>10-8-13</td>
<td>Tue</td>
<td>Parts Arrival/Begin Piecing Together Systems</td>
</tr>
<tr>
<td>10-10-13</td>
<td>Thu</td>
<td>Team Meeting/Build DD and PDR</td>
<td>10-12-13</td>
<td>Sat</td>
<td>Begin Structural Design</td>
</tr>
<tr>
<td>10-15-13</td>
<td>Tue</td>
<td>HW 8 DUE</td>
<td>10-17-13</td>
<td>Thu</td>
<td>PRELIMINARY DESIGN REVIEW DUE</td>
</tr>
<tr>
<td>10-17-13</td>
<td>Thu</td>
<td>Team Meeting/Begin Building Sensors to Arduino/Construc</td>
<td>10-20-13</td>
<td>Sun</td>
<td>Team Meeting/ALL PHYSICAL TESTS TO BE DONE.</td>
</tr>
<tr>
<td>11-5-13</td>
<td>Tue</td>
<td>Finalize Assembly</td>
<td>11-7-13</td>
<td>Thu</td>
<td>Team Meeting - Testing/Systems check.</td>
</tr>
<tr>
<td>11-12-13</td>
<td>Tue</td>
<td>LLR PRESENTATION DUE</td>
<td>11-14-13</td>
<td>Thu</td>
<td>Team Meeting - Last Minute Systems Check</td>
</tr>
<tr>
<td>11-14-13</td>
<td>Thu</td>
<td>DD Rev C DUE</td>
<td>11-15-13</td>
<td>Fri</td>
<td>BalloonSat Weigh-in and TURN-IN</td>
</tr>
<tr>
<td>11-16-13</td>
<td>Sat</td>
<td>[LAUNCH DAY]</td>
<td>11-19-13</td>
<td>Tue</td>
<td>Bring Raw Flight Data</td>
</tr>
<tr>
<td>11-21-13</td>
<td>Thu</td>
<td>POST LAUNCH PRESENTATION DUE</td>
<td>12-5-13</td>
<td>Thu</td>
<td>Team Meeting</td>
</tr>
<tr>
<td>12-7-13</td>
<td>Sat</td>
<td>1st DD Rev D Draft &amp; Team Video Due</td>
<td>12-10-13</td>
<td>Tue</td>
<td>All Data Due &amp; Bring All Hardware</td>
</tr>
<tr>
<td>12-10-13</td>
<td>Tue</td>
<td>FINAL PRESENTATIONS DUE</td>
<td>12-16-13</td>
<td>Mon</td>
<td>Final DD Rev D Due</td>
</tr>
</tbody>
</table>
## 5.0 Budget

Below is a table of the expenses of the satellite as well as the weight of each item that will be and will not be in our satellite.

<table>
<thead>
<tr>
<th>Amount</th>
<th>Item</th>
<th>Cost</th>
<th>Weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>Sensor Breakout Board</td>
<td>$4.00</td>
<td>5.6 g</td>
</tr>
<tr>
<td>2</td>
<td>Methane Sensor MQ</td>
<td>$10.00</td>
<td>5 g</td>
</tr>
<tr>
<td>2</td>
<td>Carbon Monoxide Sensor MQ-7</td>
<td>$14.00</td>
<td>4 g</td>
</tr>
<tr>
<td>2</td>
<td>Ozone Sensor MQ-131</td>
<td>$26.00</td>
<td>5 g</td>
</tr>
<tr>
<td>2</td>
<td>Carbon Dioxide Sensor MG-811</td>
<td>$70.00</td>
<td>13.59g</td>
</tr>
<tr>
<td>10 lbs.</td>
<td>Dry Ice</td>
<td>$18.30</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>Batteries</td>
<td>$17.50</td>
<td>228 g</td>
</tr>
<tr>
<td>1</td>
<td>Camera</td>
<td>Given</td>
<td>138.9 g</td>
</tr>
<tr>
<td>2</td>
<td>SD cards</td>
<td>Given</td>
<td>0.2 g</td>
</tr>
<tr>
<td>2</td>
<td>Arduino Units</td>
<td>Given</td>
<td>28.5 g</td>
</tr>
<tr>
<td>1</td>
<td>Flight Tube</td>
<td>Given</td>
<td>10.9 g</td>
</tr>
<tr>
<td>2</td>
<td>Washers</td>
<td>Given</td>
<td>18.1 g</td>
</tr>
<tr>
<td>2</td>
<td>Paper Clips</td>
<td>Given</td>
<td>5 g</td>
</tr>
<tr>
<td>2 each</td>
<td>Shields/SD boards</td>
<td>Given</td>
<td>15.2 g</td>
</tr>
<tr>
<td>1 board</td>
<td>Foam Core</td>
<td>Given</td>
<td>240.0 g</td>
</tr>
<tr>
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<td>Accelerometer</td>
<td>Given</td>
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<td>Pressure Sensor</td>
<td>Given</td>
<td>1.1 g</td>
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</table>
### Temperature Sensor
- Given
- 0.4 g

### Humidity Sensor
- Given
- 0.9 g

### Flag Sticker
- Given
- 0.01 g

### Wires
- Given
- 20 g

### Switches
- Given
- 15 g

### Velcro
- Given
- 1.1 g

### Hot Glue
- Given
- 5.0 g

### LEDs
- Given
- 1.5 g

### Tape
- Given
- 70.0 g

### Heater
- Given
- 41.0 g

### Ozone Generator
- Borrowed
- ~ $20 per use

### Switch covers (Foam Core)
- Given
- 4.5 g

<table>
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<td>0.4 g</td>
</tr>
<tr>
<td>1</td>
<td>Humidity Sensor</td>
<td>Given</td>
<td>0.9 g</td>
</tr>
<tr>
<td>1</td>
<td>Flag Sticker</td>
<td>Given</td>
<td>0.01 g</td>
</tr>
<tr>
<td>20</td>
<td>Wires</td>
<td>Given</td>
<td>20 g</td>
</tr>
<tr>
<td>3</td>
<td>Switches</td>
<td>Given</td>
<td>15 g</td>
</tr>
<tr>
<td></td>
<td>Velcro</td>
<td>Given</td>
<td>1.1 g</td>
</tr>
<tr>
<td></td>
<td>Hot Glue</td>
<td>Given</td>
<td>5.0 g</td>
</tr>
<tr>
<td>3</td>
<td>LEDs</td>
<td>Given</td>
<td>1.5 g</td>
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<tr>
<td>6</td>
<td>Feet</td>
<td>Given</td>
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<tr>
<td>1</td>
<td>Heater</td>
<td>Given</td>
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<tr>
<td>1</td>
<td>Ozone Generator</td>
<td>Borrowed</td>
<td>~$20</td>
</tr>
</tbody>
</table>

### Switch covers (Foam Core)
- Given
- 4.5 g

### Total
- $179.80
- 841.71 g

#### 6.0 Test Plan and Results

**Safety Rules:**

All tests were done in an area that is not heavily trafficked by students or faculty. Certain group members ensured that no one was able to enter the test area while the rest of the group performs the test and records the result. Ozone testing must be done in a room free of people and with a window open or a vent taking out the air for safety purposes due to the dangerous effects of ozone on human beings. Some of the tests must be performed using the tailpipe of a car, therefore, the members of team Heavyweight must take extra caution around the active car and the fumes emitted by the car. While testing and using other implements during the building and soldering phase, team Heavyweight will have multiple members present and aware to prevent disastrous occurrences and major injuries. During certain tests that involve open spaces, like the structural tests, the group will make sure that no innocent bystander or passerby is within a distance where he or she could be in harm’s way as well as no windows will be near to prevent the glass from breaking and causing harm if control is lost. During the usage of dry-ice, no team member shall handle the dry-ice without using the proper precautions to avoid serious injury. This team will also make sure that no one from the team that is helping or observing the tests is present.
in any position where they could get hurt. Lastly, during team meetings no illegal or illicit activity will be performed.

Testing Schedule:
Drop Test - 10/24
Tumble Test - 10/24
Whip Test - 10/24
Camera Test - 10/31
Sensor Calibration Tests - 11/11; 11/12; 11/3
Given Sensor Tests - 10/29
Dry Ice Test/Cold Test - 11/11
Complete Systems Test - 11/13
Mission Demo Test - 11/13

Drop Test:
Once the structure was completed, to simulate an impact on the ground to ensure our structure will survive, a drop test was performed. This test was done by dropping it from multiple height levels (away from windows and not on top of anyone) until the structure proved that it will survive the impact on launch day. Rocks were included inside the structure in order to accurately imitate the weight of our actual sciences and components inside.

Drop Test Results:
The Drop test was a successful test with minor damages to the box. The box was filled with rocks to simulate the weight that will occupy the box during flight, and there was damage due to these rocks not being secured down during the testing. The box first experienced a one story drop to make sure that our box can survive a small drop then increased the drop to two stories and then to three stories to simulate larger falls. The three story drop was performed twice to make sure that the box was durable enough to survive more difficult landings on hard surfaces.

Tumble Test:
After the drop test was completed, Team Heavyweight took their structure and its simulated contents to several flights of stairs where it was rolled down to ensure it can keep the components intact.

Tumble Test Results:
The tumble test was completed by throwing the box down the stairs in the DLC allowing the box to tumble down one flight of stairs to simulate when the box will be violently rolled around on the ground after landing. It was completed alongside the drop test as these components of the landing will coincide when the box hits the ground and rolls about on the ground.

Whip Test:
To guarantee that GAS-E will remain attached to the balloon rope under the most extreme conditions, the tube used to hold the rope was tested through a Whip Test to see that the rope would not come undone during flight. GAS-E was taken to the business fields, an open space away from windows and people, and violently swung around to ensure the strength of the
tube/rope connection is stable and stays connected to GAS-E all the way through the recovery stage.

Whip Test Results:
The whip test was completed successfully. The structure survived several tests, but it did sustain a good amount of damage throughout the process. This can partly be attributed to the use of rocks in GAS-E to simulate its weight at launch. Since the rocks were not firmly secured to the structure, they were free to do more damage than would be expected during the real launch. There was also a problem of the tube holding the rope slipping into the structure. The paperclip device holding the string and tube to the bottom of the box failed, stronger or multiple paper clips will be adequate during launch.

Camera Test:
To simulate our single camera system, the camera will be powered on for a full two hours, simulating the duration of actual flight. For this test, the team left the system in its structure undisturbed. (The camera is programmed to take photos every 13 seconds and once test is completed, the data will then be uploaded to computers to ensure the system functioned correctly.)

Camera Test Results:
The team turned the camera on. Then verified that the camera went through preprogrammed setting and started taking pictures every 13 seconds just as programmed.

Carbon Monoxide Test:
To test whether the Carbon Monoxide sensor was responding correctly, Team Heavyweight placed GAS-E under a 1998 Chevy Blazer with a funnel on the muffler to direct the exhaust directly to the carbon monoxide sensor. Although vehicles produced after 1975 (in the US) were all made with catalytic converters, which converts carbon monoxide into less harmful substances, our sensor was still able to recognize a substantial elevation in CO levels. The carbon monoxide sensor was held under the exhaust pipe for 30 seconds and then removed and held in normal air for 15 seconds.

![Carbon Monoxide Graph]

Comment [8]: Include test picture too.
Methane Calibration:
To calibrate the methane sensor, Team Heavyweight took GAS-E to one of Professor Mike Hannigan’s labs here at Colorado University-Boulder and worked with graduate student Joanna Gordon and John Ortega, the lab manager. Team Heavyweight was able to use one of the lab’s methane canisters, with 356ppm of methane (approximately 70% of the canister was pure methane, meaning our sensor recognizes the presence of all hydrocarbons), to test the sensor reads under different mixing ratios. The mixing ratio is determined by the amount of ambient air compared to the amount natural gas (methane) that is being flowed. Team Heavyweight tested the sensor readings under two different airflow rates, including .1 L/min and .2 L/min. Graph 1 below showed Team Heavyweight that the same mixing ratios can produce different results under different airflow rates. This is most likely due the high sensitivity of the sensors to temperature, and higher airflow rates tend to cool the surface temperature of the sensor and affect the data. Graph 2 shows the different values that all correspond to zero-values at different airflow rates. From this data, Team Heavyweight can determine that the higher the flow rate, the lower the sensor’s zero value becomes. When the 356ppm methane canister was flowed over the sensor without mixing it with ambient air, it rose quickly and began to level out at approximately 108 millivolts, as seen in Graph 3.
Ozone Testing:
To test the ozone sensor, Team Heavyweight rented an FM-1 ozone generator from Alpine Auto Detailing, with an output of 2000 milligrams per hour, and again took it to Professor Hannigan’s lab to test in a controlled environment, because of the harmful effects of ozone. Once in the lab, both the generator and GAS-E were placed under a ventilated hood and then a large plastic container was placed over both to capture/contain the ozone (this prevented the ventilation system from sucking up all the ozone). The ozone generator was then arranged at various angles, with respect to the sensor, to give off various levels of ozone. Team Heavyweight found that when the ozone generator was turned on, our sensor read decreasing levels in millivolts, and when the generator was turned off, the ozone levels began to rise back to normal. After several tests, the downward trend continued and from that it was determined that the sensor is characterized to read inversely.

Carbon Dioxide Test:
To test the carbon dioxide sensor, Team Heavyweight used the dry ice (solid CO$_2$) test to register a change in the sensor value. Six pounds of dry ice was used during the test and GAS-E was placed inside a foam cooler for over two hours. Similar to the ozone sensor, the carbon dioxide sensor recorded a gradual decrease in millivolts as the carbon dioxide levels increased over the two hour period. From this data, Team Heavyweight can determine that the carbon dioxide
sensor is also characterized inversely (relevant or not, the ozone sensor and the carbon dioxide sensor were the two that did not come from SparkFun).

Given Sensor Test Results:
Team Heavyweight was given a humidity sensor, pressure sensor, temperature sensor, and an accelerometer. To test each sensor, the team performed the following actions:
- For the humidity sensor, the team began by testing the humidity indoors to get a base level. From there, the team breathed on the sensor so that it registered a large spike and then let it return to the normal indoor level. Once at about the same indoor level it started at the team took the Arduino (with sensor on it) outside on a misty, foggy day and allowed the sensor to recognize a much slower increase in humidity levels; which it did, and then the team brought the sensor back indoors.

- For the pressure sensor, the team used a syringe to remove air from the area surrounding the pressure sensor. The sensor registered a steady drop in air pressure as the team pulled up on the syringe (as expected), and then a large jump when the syringe was removed, returning to normal air pressure.

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For the internal temperature sensor, the team began by letting it read the room temperature to have a starting level to compare it to. A few seconds later, the team covered the sensor with fingers to get an increase in temperature, which registered as a large spike. Then the team removed the fingers, let the sensor return to room temperature and then the team put the whole Arduino in a freezer. The temperature sensor on the Arduino dropped below -5°C and then the team took it out of the freezer. It quickly jumped back to positive values and then it slowly began to return to room temperature.

For the accelerometer, Team Heavyweight rotated the Arduino 180° on three different axes for 5 second increments, returning to the original position in between each test for 5 second increments. The first axis was on a horizontal plane, and the graph registered movement but not much change. Then the Arduino was returned to its original position for 5 seconds, and then...
rotated it 180° in a vertical plane parallel to the holder and held it for 5 seconds. The Accelerometer climbed in the x-direction and dropped in the z-direction with almost the same change of values for each, while the y-direction remained fairly constant. The Arduino was again returned to its original position for 5 seconds and then rotated on the other vertical plane (perpendicular to the holder) and held it there for 5 seconds. This time, the y-direction and z-direction both dropped with near equivalent change of values, while the x-direction stayed almost consistent (dropped miniscule). Team Heavyweight then returned the sensor to its original position.

Dry Ice/Cold Test:
Once all systems were calibrated and tested separately in their own specific manner, then the entire system was subjected as a whole to a dramatic cold temperature range to ensure it still functions. This was done by placing the structure in a cooler with dry ice and leaving it for 1.5 hours with the systems powered on. This simulates the cold temperature fluctuation that will occur on the ascent of the actual flight.

(Once completed, the data will be analyzed from the SD cards on a computer to ensure all sensors took data throughout the test. All the gas sensors are expected to take constant data, while the temperature sensor inside is expected to have a constant reading above -10 degrees Celsius. This will also test the functionality of our heater system, if the systems fail, the heater did not do its job. If all sensors functioned and the temperature sensor reads the data expected, the heater system will be known to have worked successfully.)

Dry Ice/Cold Test Results:
Members of Team Heavyweight had placed 6 pounds of dry ice into a cooler and proceeded to place GAS-E in the cooler with the external temperature sensor pointed toward the dry ice. The satellite was left in the cooler for 90 minutes and then removed from the cooler for 30 minutes to re-acclimate to room temperature. Both of the temperature sensors responded as they were expected to have responded and all systems functioned according to plan, with the exception of the heater turning off due to insufficient battery power. We will add additional batteries so the heater will stay powered during flight.
Complete Systems Test:
Team Heavyweight will be testing all systems in the Dry Ice test and, unless systems fail, it will be unnecessary for our team to complete the same test over again. However, if any systems fail during the dry ice test, the errors that occur will be fixed and another complete systems test will be performed and then the data will be compared to ensure that it’s improved and will successfully record during the actual launch. During the class period the systems will be on for the duration of the class period allowing us to get a final systems check for the BalloonSAT.

Demo Mission Test Results:
The demo test was performed outside in the business field on November 14th to simulate the ground data needed. The sensors ran for the full two hour simulation and recorded the ground data that can be analyzed and compared to flight data.

7.0 Expected Results

Team Heavyweight expects to record accurate data on Carbon Monoxide, Methane, Carbon Dioxide, and Ozone gases while the BalloonSAT is moving upward through the troposphere, tropopause, and the lower part of the stratosphere. The expected results will follow the trend of decreasing ozone amounts in the stratosphere when compared to the ozone values of the past couple decades. The plan is to gather data that shows that Carbon Monoxide, Carbon Dioxide and Methane molecules are abundant in the troposphere, and less abundant in the stratosphere than the troposphere, because research that has been discovered has found that the CO\textsubscript{2} levels have been increasing by 1 to 1.5 ppm at ground level as well as at lower stratospheric heights (15-30 km) over the course of the last 30 years. Our research shows that from the tropopause (about 15 km) to an altitude of 35 km, the carbon dioxide levels decrease by about 7 ppm, so the anticipation is to record a total decrease of about 5.25 ppm from the tropopause to burst. Team Heavyweight expects the carbon levels in the stratosphere to be heavier than previous year’s data, because the levels of carbon in the troposphere are increasing and leaking upward into the stratosphere. From compiling these expectations carbon dioxide, carbon monoxide and methane are anticipated to have similar results as they are also carbon based molecules released by human and natural pollution. Furthermore, the estimation is that ozone will have the greatest concentration in the stratosphere and continue to grow as our altitude increases because ozone is predominantly located between an altitude of 20 km and 30 km in the stratosphere. The expectation for the environmental readings are that the temperature will drop through the troposphere until the satellite enters the tropopause and then the stratosphere where the temperature will begin to climb steadily until burst. The pressure as the satellite rises will drop at an exponential rate until burst where it will increase exponentially during the descent. The humidity will drop during the ascent until reaching burst where the humidity is expected to reach zero then increasingly grow as the box descends to landing. The expectation is that the sensors will work properly during the flight and the results that will be obtained will be as follows: in the troposphere the carbon monoxide, carbon dioxide and methane sensors will have the highest readings and the ozone sensors readings will be minimal. We anticipate to see opposite data in the stratosphere than in the troposphere, with high levels of ozone and low levels of carbon dioxide, carbon monoxide, and methane (but still higher than previous years data).
Expected Data in Graph Form

Ozone profile from 23 / 6 / 2006

Mean June profile for 1991 - 2001 period

Source: MeteoSwiss / Payerne

http://oceanworld.tamu.edu/resources/oceanography-book/atmosphere.html


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8.0 Launch and Recovery

On November 16, Team Heavyweight will meet with all materials at 4:45 am and drive in three vehicles to the launch site in Windsor, CO. Upon arrival, the team will immediately set up their satellite and ensure everything is in proper working order. Next, Team Heavyweight will install fresh batteries and turn the power on, checking to make sure all systems are performing as expected. Internal and external pictures will also be taken at this time by Justin Wherry for post flight failure analysis. The team will check the LED indicator lights and the heater, and the sensors will start taking measurements of gases in the atmosphere, and storing the data, as it will perform throughout its journey. Once it has been confirmed that everything is ready for launch, Cameron Heppe of Team Heavyweight will attach GAS-E to the weather balloon in the order determined by weight and will launch the payload. Following all of the satellites being attached to the balloon, the balloon will be released for takeoff. Team Heavyweight will follow as close as possible (dictated by road layout) in order to recover the satellite. Justin Wherry will be responsible for payload recovery along with Calvin Buechler and Ryan Patton. Team Heavyweight will retrieve the SD cards and upload the data to a computer, where it will be converted to graph format in Microsoft Excel, and saved for further analysis. This retrieval strategy will work because Team Heavyweight has retrieved all of the test data in the same manner of taking the SD cards and plugging them into the computer and then converting the data into graph format.