STAR WARS
TEAM VI
REVENGE OF THE SIXTH

PROJECT VADER

PERCY BELL
NATHANAEL BENNETT
HAYDEN FOOTE
ADAM HU
KIERAN O’DAY
PHOEBE RILEY
SRIKANTH VENKATARAMAN

University of Colorado Boulder
COSGC
COLORADO SPACE GRANT CONSORTIUM
1.0 Overview and Mission Statement

1.1 Mission Statement
Team Revenge of the Sixth’s mission is to launch a BalloonSat to an altitude of 30 km to determine the effectiveness of polypropylene and low-density polystyrene as materials for shielding from cosmic radiation. Using Geiger counters to measure the shielding capabilities of each type of plastic, Team Revenge of the Sixth hopes to gain a better understanding for whether these plastics would be viable materials to protect astronauts and equipment from radiation in space.

1.2 Mission Overview
Project Vader is a high altitude BalloonSat for the ASEN 1400 course designed to test polypropylene and low-density polystyrene for their potential radiation-shielding properties. The payload will include three Geiger counters; one will be unshielded as a control sensor, and the other two will each be shielded by polypropylene or low-density polystyrene. After recovery of the payload, Team Revenge of the Sixth will analyze and compare the data collected by each Geiger counter to assess the effectiveness of each plastic in shielding against radiation.

Within the last year, both NASA and Space-X have announced major plans to send manned missions to Mars. [1, 2] Although manned missions have already been flown to Earth’s orbit and the Moon by a variety of agencies and companies, a flight to Mars presents new and greatly magnified challenges because of the duration and distance of such a mission. The foremost concern when planning any manned mission is astronaut safety. Astronauts are exposed to higher radiation levels than people on the ground due to the receding protection from the atmosphere. Much of this radiation comes from Galactic Cosmic Rays (GCR), high-energy atomic nuclei traveling near the speed of light. These nuclei are typically those of hydrogen, but can be from much heavier elements. [3] These heavier elements can cause significant damage to anything they pass through, breaking apart atoms and causing secondary radiation from these reactions. [4] Normally, missions to Low Earth Orbit (LEO) are protected from much of this radiation by the Earth’s magnetosphere. [5] Missions to Mars, however, will be outside of this protection for the majority of the mission’s duration.

---

[5] Figure 1.1 Provided by Caltech
Therefore, the challenge of shielding both astronauts and their equipment from GCR is a major concern. Hydrogen-rich materials have shown to be effective at blocking GCR. NASA has proposed using water as a radiation shield, but its density may introduce more weight than what is practical for a cost-effective launch. Project Vader hopes to prove that alternative hydrogen-rich materials, such as polypropylene and low-density polystyrene may also provide effective shielding. Low-density polystyrene has a density of 1.040 g/cm³, polypropylene has a density of 0.946 g/cm³, and water has a density of 1.000 g/cm³. If the polypropylene shield proves effective, it would enable engineers to provide the same volume of shielding material for less weight. If the low-density polystyrene shield proves effective, it would provide a suitable alternative to water shielding as it is not significantly denser, and also could provide minor structural support. It should be noted that because Project Vader will stay within the Earth’s upper atmosphere and magnetosphere, actual radiation conditions that would be experienced on a flight to Mars cannot be accurately simulated. However, the payload will reach a sufficient altitude for exposure to GCR, as cosmic rays were actually discovered by a similar balloon flight to a much lower altitude (5.3 km). Although the BalloonSat will not achieve a Mars-like mission of higher altitude, these limitations will not stop Team Revenge of the Sixth from obtaining crucial data about the shielding. There will be an extracted model that could be used to predict how the shield performs under more intense radiation.

1.3 Hypothesis
As both low-density polystyrene and polypropylene are hydrogen-rich materials, they will effectively shield from radiation. The Geiger counters being shielded by these materials will report significantly lower levels of radiation than the unshielded control Geiger counter.

2.0 Technical Overview
Team Revenge of the Sixth is committed to comprehensive planning, rigorous testing, and consistent safety standards in order to ensure the creation of a well-designed payload that will gather valuable data regarding radiation shielding materials.

2.1 Structure and Design
The exterior of the satellite will be comprised of foam core in the shape of a cube. The sides will be 260mm in length and width. 220mm in height. The interior walls will be lined with foam insulation while the aggregate walls will be secured with aluminum tape and silicone glue. This is to ensure a lightweight and structurally sound system. Three incisions will

---

be made, one on the top and two on the side of the BalloonSat. One of the lateral cuts will be for the GoPro HERO. The other will be for the external switches. There will be an external temperature sensor which extends 2.54mm perpendicular to the top of the BalloonSat. The interior of the BalloonSat will have three Geiger counters. The first Geiger counter will act as a control group while the other two will be shielded with polypropylene and low-density polystyrene. A 2.4mm flight string will be threaded through a non-metal tube that will pass through the center of the BalloonSat. The tube will be secured with silicon glue and bolts so as to not interfere with the rest of the flight string. The box will contain two Arduino Uno’s, a microSD card, OpenLog data logger, a pressure sensor, internal temperature sensor, humidity sensor, an accelerometer, heater, and lithium 9V batteries. The weight distribution of the components throughout the box will help reduce the horizontal moments of inertia.

2.2 Hardware

Geiger counters and shields
The BalloonSat for Project Vader will be equipped with three Geiger counters. These will consist of Arduino-compatible Geiger kits and Geiger tubes. One Geiger counter will be used as a control. This will be placed in the BalloonSat with no radiation protection. The second Geiger counter will be placed in a case of low-density polystyrene plastic. The third will be placed in a case of polypropylene plastic. The Geiger counters will be connected to one Arduino which will collect the data and store it on a 2GB micro SD card.

Heating systems
Project Vader will house a single central heater. The heater will be part of its own system including three 9V batteries, a switch, and an LED (See section 2.7). This heater will control the environment of the BalloonSat keeping it at operable temperature during the duration of the flight.

Arduino and electrical systems
The BalloonSat will include two Arduino Unos each controlling their own system of parts. Arduino 1 will be hooked up to the three Geiger counters, two 9V batteries, a switch and an LED (See section 2.7). Arduino 2 will get its power from two 9V batteries. This Arduino will be connected to the accelerometer, internal and external thermometers, pressure, and humidity sensor. A switch will connect it to the batteries and an LED. The Arduino will also have access to a 2GB micro SD card. The camera will be connected to its own internal system which includes a lithium ion battery and a 2GB micro SD card.

2.3 Special Features
Each Geiger tube will be attached to its circuit board using wires. The plastics will be bought in sheets and heat molded around the tubes and wires to ensure each tube is completely covered by

Commented [LC7]: You could label which is which in the diagram.
Commented [LC8]: Good work on this section.
Commented [LC9]: This was a typo in RFP, it is really a 32 GB SD card.
its plastic. This will ensure the Geiger tubes are fully shielded and will not be detecting any radiation that did not pass through the shield first.

2.4 Testing

Drop Test
The BalloonSat will experience a rough landing. To make sure the structure is capable of withstanding a violent drop, the team will be dropping the BalloonSat from a height of 10 meters. The BalloonSat will be weighted to simulate the payload and will be dropped onto both grass and concrete. The team will use these tests to improve the construction of the BalloonSat to prove adequate.

Stair Test
The BalloonSat will need to be able to protect the payload in the event that strong winds drag the satellite over long distances. To prepare for this situation, the team will test the integrity of their structure when it is tossed down a flight of stairs with a simulated payload. The structure will need to survive three tumbles down a staircase to be ready for flight. The design will be modified as needed based on the results of this test.

Whip Test
After burst, the BalloonSat will be subject to intense g-forces as it is whipped around. The team will test the structure of the BalloonSat by passing a rope through the center, knotting one end to simulate the flight string. The satellite will be swung in a circular motion with a simulated payload inside. The team will then adjust its design as needed.

Dry Ice Test
The BalloonSat will need to operate in temperatures as low as -80 degrees Celsius. To make sure the insulation and heating systems are effective, the BalloonSat will be placed in a cooler with dry ice for 3 hours. This ensures that the sensors are operating correctly and the power system lasts the duration of the flight.

Sensor Test
The accelerometer, pressure sensor, temperature sensor, and humidity sensor will be calibrated and tested before launch. If there are no available calibrated sensors, current weather data will be used to calibrate the humidity and temperature data. The team has reached out to the Environmental Health and Safety department to gain access to a radiation lab where the Geiger counters can be calibrated.

Mission Test
To make sure the science, software, and power systems are all working correctly with one another, the team will conduct a mission simulation. In addition to the Arduino and Geiger counters, the camera will also be tested to make sure it records correctly throughout the flight. The three-hour test will be used to identify and correct any problems with these subsystems before launch.

2.5 Safety
Team Revenge of the Sixth is committed to ensuring the safety of all throughout the duration of this project. All tests will be conducted away from bystanders to prevent accidental injuries. In addition, no debris will be left behind at any test site. The team will comply with all rules and protocols regarding the safe use of space and equipment. The utmost care will be taken when using dangerous tools like soldering irons and saws. Safety glasses, gloves, and other safety equipment will be used whenever necessary. In addition, the team will maintain a professional working environment and resolve disputes in a mature manner.
2.6 Data Retrieval
Data for Project Vader will be stored on three 2GB micro SD cards. Each Arduino will be hooked up to one SD card. One Arduino/SD card setup will store data from the accelerometer, internal and external thermometers, humidity sensor, and pressure sensor. The second Arduino/SD card setup will store data from the three Geiger counters. The third SD card will be connected to the GoPro Hero4 Session camera and will store pictures taken during the flight. After the mission the data can be easily accessed from the SD cards and evaluated on the computer.

2.7 Functional block Diagram
There are four primary systems; the heater, the Geiger counter Arduino, the sensor Arduino, and the imaging system. The heater will be powered by three 9V batteries, both Arduinos by two 9V batteries, and the imaging system has a self-contained lithium ion battery. The heater and Arduinos will be connected to a switch and LED indicator for functionality. The Arduinos and GoPro will have at least a 2GB capacity storage in order to log the data that is taken from the plethora of sensors and Geiger counters. Each of these systems are isolated to simplify construction and minimize the cost of a single power failure.

2.8 General Mission Requirements
Team Revenge of the Sixth will consistently review the mission requirements, as laid out in Section G of the RPF, in order to ensure that all requirements are being planned for and met during the construction and testing of the BalloonSat. As per the current weight estimate, the BalloonSat will not exceed a weight of 864g. The payload will be constructed primarily from...
Project Vader

3.0 Management and Cost Overview

3.1 Schedule

Team Revenge of the Sixth will meet every Tuesday and Thursday from 3pm-5pm in the ITLL, with an extra meeting on Sunday if necessary to achieve weekly objectives on time. The team is committed to the deadlines listed on this schedule in order to maintain organization and facilitate a less stressful work environment for all team members. The team’s maxim: “Work ahead to never fall behind.”

<table>
<thead>
<tr>
<th>Week</th>
<th>Objective/Event/Deadline</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>February 12 – Feb. 20</strong></td>
<td>• Finalize and submit proposal</td>
</tr>
<tr>
<td></td>
<td>• Learn more coding in Arduino</td>
</tr>
<tr>
<td></td>
<td>• Prepare to order hardware</td>
</tr>
<tr>
<td></td>
<td>• ATP appointment with Chris</td>
</tr>
<tr>
<td></td>
<td>• HW 7 + 8 assigned, HW 6 due</td>
</tr>
<tr>
<td><strong>February 21 – Feb. 27</strong></td>
<td>• Systems Engineering exercise</td>
</tr>
<tr>
<td></td>
<td>• Build heater</td>
</tr>
<tr>
<td></td>
<td>• Start working on Preliminary Design Review (PDR)</td>
</tr>
<tr>
<td></td>
<td>• HW 7 + 8 due</td>
</tr>
<tr>
<td><strong>February 28 - March 6</strong></td>
<td>• PDR submission</td>
</tr>
<tr>
<td></td>
<td>• Complete and submit Design Document (DD) revision A/B</td>
</tr>
<tr>
<td></td>
<td>• Begin coding and prototyping of structure (all hardware and sensors should be acquired by now)</td>
</tr>
<tr>
<td><strong>March 7 – March 13</strong></td>
<td>• DD Rev A/B due</td>
</tr>
<tr>
<td></td>
<td>• DD Rev C and mid-semester team evaluations assigned</td>
</tr>
<tr>
<td></td>
<td>• Prototyping design complete</td>
</tr>
<tr>
<td></td>
<td>• Whip test, drop test, stair test</td>
</tr>
<tr>
<td><strong>March 14 – March 20</strong></td>
<td>• Dry ice test</td>
</tr>
<tr>
<td></td>
<td>• Radiation/sensor testing</td>
</tr>
<tr>
<td></td>
<td>• Team evaluations due</td>
</tr>
<tr>
<td></td>
<td>• Payload inspection by Chris</td>
</tr>
<tr>
<td></td>
<td>• Service approvals due</td>
</tr>
<tr>
<td><strong>March 21 – March 27</strong></td>
<td>• In-Class Mission Simulator Test</td>
</tr>
<tr>
<td></td>
<td>• RFF cards assigned</td>
</tr>
<tr>
<td></td>
<td>• Start of Spring break</td>
</tr>
<tr>
<td><strong>March 28 – April 3</strong></td>
<td>• Spring break</td>
</tr>
<tr>
<td></td>
<td>• Work on Launch Readiness Review (LRR)</td>
</tr>
<tr>
<td><strong>April 4 – April 7</strong></td>
<td>• Present LRR</td>
</tr>
<tr>
<td></td>
<td>• Final touches, ensure everything works ten times over</td>
</tr>
</tbody>
</table>

Commented [LC13]: For specific deliverables like this, put in the exact date due.
3.2 Budget

Team Revenge of the Sixth is on track to create a payload weighing 832.2g, well below the 864g limit. The current budget estimate totals $180.69, not including spare parts, dry ice, and batteries; these and any other expenses beyond the $180 allotment will be paid for by and split evenly between team members. The budget will be monitored by Nate Bennett in order to ensure that every purchase is essential to the success of the mission. Additionally, all purchases will be recorded on a spreadsheet, approved by Chris Koehler beforehand, and (with the exception of out-of-pocket purchases) purchased with Chris’s CU Visa Card. Receipts will be turned in to Chris within 48 hours of the purchase being made.

<table>
<thead>
<tr>
<th>Equipment</th>
<th>Quantity</th>
<th>Source</th>
<th>Weight (g)**</th>
<th>Price ($)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Arduino Uno</td>
<td>2</td>
<td>COSGC</td>
<td>60</td>
<td>$0</td>
</tr>
<tr>
<td>Space Grant Shield Kit</td>
<td>2</td>
<td>COSGC</td>
<td>40</td>
<td>$0</td>
</tr>
<tr>
<td>GoPro Hero4 Session</td>
<td>1</td>
<td>COSGC</td>
<td>73</td>
<td>$0</td>
</tr>
<tr>
<td>(includes battery and SD card)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MicroSD Card</td>
<td>2</td>
<td>COSGC</td>
<td>0.4</td>
<td>$0</td>
</tr>
<tr>
<td>OpenLog Data Logger</td>
<td>2</td>
<td>COSGC</td>
<td>15.8</td>
<td>$0</td>
</tr>
</tbody>
</table>
Project Vader

### Pressure Sensor
1. COSGC
1g
$0

### Temperature Sensor
2. COSGC
2g
$0

### Humidity Sensor
1. COSGC
0.8g
$0

### Accelerometer
1. COSGC
1.2g
$0

### Heater
1. COSGC
100g
$0

### Foam Core
3. COSGC
25g
$0

### Switches
3. COSGC
6g
$0

### LED Indicators
3. COSGC
3g
$0

### Aluminum Tape
1. COSGC
5g
$0

### Glue
1. COSGC
2g
$0

### Wiring, Resistors, etc.
--
30g
$0

### Lithium 9V Batteries*
7. COSGC/Amazon
238g
$0/out of pocket

### Dry Ice
1. King Soopers
--
Out of pocket

### Geiger Tube
3. Tindie.com
30g
$19.99 x 3 = $59.97

### Geiger Kit
3. RH Electronics
150g
$33.25 x 3 = $99.75

### Low-Density Polystyrene sheet
1. USplastic.com
20g
$7.14

### Polypropylene sheet
1. USplastic.com
20g
$13.83

### Spare Parts
--
--
Out of pocket***

### Totals
823.2g
$180.69

*Some batteries for the actual flight will be provided by COSGC. All of the batteries for testing will be purchased by team members.

**Weight estimates include the total weight for duplicate parts

***Since the current budget estimate is almost exactly the allotted $180, Team Revenge of the Sixth has agreed to pay for expenses involving spare or replacement parts out of pocket.

## 3.3 Management

Team Revenge of the Sixth has a varying team composition to accomplish various tasks over the course of the project. Each team member has a responsibility with the leader of the subsystem at the left.
3.4 Team Descriptions

Team Members

Percy Bell  
*Computer Science & Astronomy*

Nate Bennett  
*Technology, Arts & Media*

Hayden Foote  
*Aerospace Engineering Sciences*

Adam Hu  
*Aerospace Engineering Sciences*

Kieran O’Day  
*Aerospace Engineering Sciences*

Phoebe Riley  
*Engineering Physics*

Srikanth Venkataraman  
*Aerospace Engineering Sciences*