# Piedmont Student Launch Team

## Flight Readiness Review

## 2017 NASA Student Launch

Piedmont Virginia Community College
501 College Drive, Charlottesville, Virginia 22902

March 6, 2017

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# Glossary of Acronyms

| | | |
|---|---|---|
| ABS | - | Acrylonitrile Butadiene Styrene |
| AGL | - | Above Ground Level |
| Cd | - | Coefficient of Drag |
| CG | - | Center of Gravity |
| CP | - | Center of Pressure |
| GPS | - | Global Positioning System |
| NAR | - | National Association of Rocketry |
| NASA | - | National Aeronautics and Space Administration |
| PSLT | - | Piedmont Student Launch Team |
| PVCC | - | Piedmont Virginia Community College |
| TADI | - | Test, Analysis, Demonstration, or Inspection |
| TRA | - | Tripoli Rocketry Association |
| RPM | - | Rotations Per Minute |
| UBEC | - | Universal Battery Elimination Circuit |

# 1 Summary

## 1.1 Team Summary

The Piedmont Student Launch Team (PSLT) represents Piedmont Virginia Community College (PVCC).

Mailing address: 501 College Drive, Charlottesville, Virginia 22902.

The team's mentor is David Oxford, NAR number: 101883, certified NAR and TRA level 2.

## 1.2 Launch Vehicle Summary

| Statistic | Value |
|---|---|
| Length (in) | 107.5 |
| Body tube diameter (in) | 5.525 |
| Mass (lbs) | 29.17 |
| Motor choice | Aerotech L1150 |
| Main parachute diameter (in) | 84 |
| Drogue parachute diameter (in) | 18 |
| Recovery harness length (ft) | 27 |
| Ejection charge size (g) | 3 |
| Rail length (ft) | 12 |
| Rail size | 1515 |

Table 1.1 - Launch Vehicle Summary

## 1.3 Experiment Summary

The experiment is to induce a moment in the rocket to cause it to roll 3 times about its long axis, then induce a counter moment to return it to its roll as measured at motor burnout. This experiment will be performed by the onboard payload, which uses a reaction wheel to induce the necessary moments and the magnetometer on an Inertial Measurement Unit (IMU) to detect the roll of the rocket.

In addition to this experiment, a team derived experiment will be performed to identify the targets to be used for the target identification and vertical landing challenge during ascent. This will be accomplished with an onboard, externally mounted camera.

# 2 Changes Since CDR

## 2.1 Changes to Launch Vehicle Criteria

There were no changes to the launch vehicle criteria between the CDR and this document. There were changes made to some parts of the launch vehicle, which are discussed in section 3.1.1 Design Changes Since CDR.

## 2.2 Changes to Experiment Criteria

The only change to the experiment criteria since the CDR is the decision to use 9 V batteries to power the reaction wheel instead of A23 batteries. The decision was made because A23 batteries do not hold sufficient charge to run the experiment if it must stay on the launch pad for an extended period.

## 2.3 Changes to Project Plan

The major changes to the project plan are the canceling of a few launches and 1 Girls' Geek Day. The launches were all canceled either due to weather or because they were backup launch days that were not needed. The Girls' Geek Day on January 7th was canceled because of snow, but the team was able to attend the next one on February 11th. Additionally, the Math of Space event with the Math Club was canceled because of the other time constraints on team members, as was the Mini Maker Faire.

# 3 Launch Vehicle Criteria

## 3.1 Design and Construction of Launch Vehicle

### 3.1.1 Design Changes Since CDR

Several changes were incorporated into the final launch vehicle design. Those changes are illustrated in the schematics below along with the reasoning. Pictures are not included in this section, however there are pictures of the construction of these parts in section 3.1.2 Launch Vehicle Construction

On the avionics bay end caps, two pairs of holes of diameter 3/16 in were relocated to 0.75 in from the center and the perimeter of the larger bulkhead respectively. The changes were made to ensure that the ejection charge terminals and ejection cups would fit properly on the end caps, with the outer pair of holes attaching to the ejection cups while the inner pair attach the terminals.

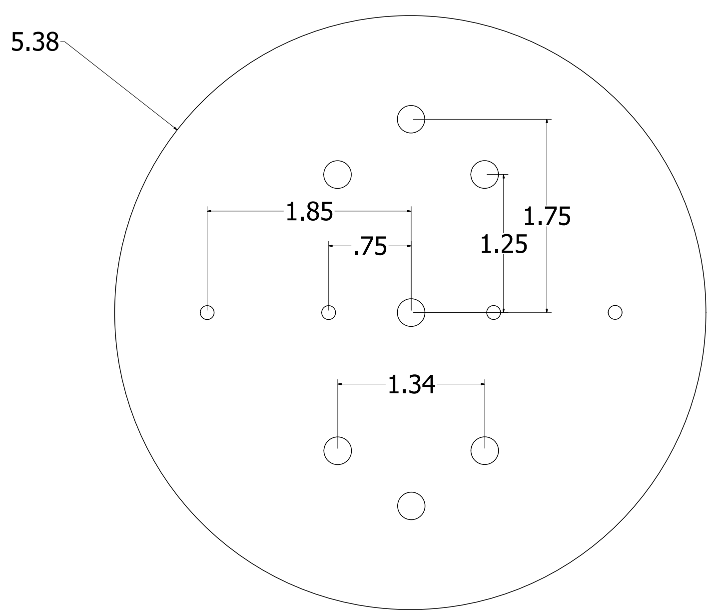


Figure 3.1 - Avionics Bay End Cap Bulkhead Drawing

The battery sled was changed to 3D printed ABS plastic instead of fiberglass, both strengthening the final product and simplifying construction. Channels for the threaded rods, which secure the assembly in the avionics bay, were made larger so that, in the event of the sled shifting during flight, and if the threaded rods are not perfectly parallel, there will be less stress on the sled. The shelves that the batteries rest on had fillets added to improve their ability to withstand the force from the relatively heavy batteries during the powered phase of the flight. Additionally, holes for battery leads to pass through have been removed, and access slots for the battery restraint system have been enlarged. The final design schematic appears below.

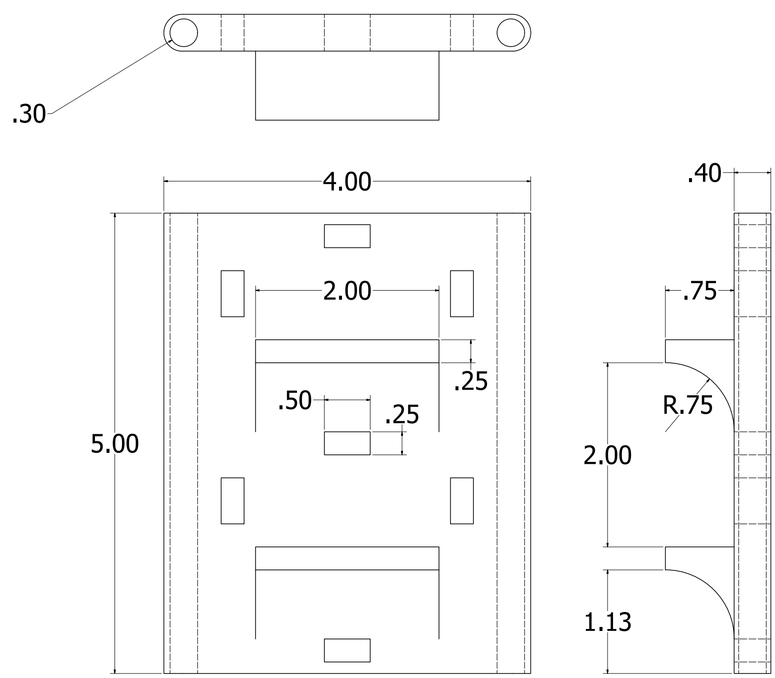


Figure 3.2 - Avionics Sled Drawing

The upper bulkhead was modified to accommodate larger U-bolts, a precaution to prevent in-flight damage during launch vehicle separation. Additionally, a second section of coupler was added below the upper bulkhead to act as a rest for it to push against during launch vehicle separation.

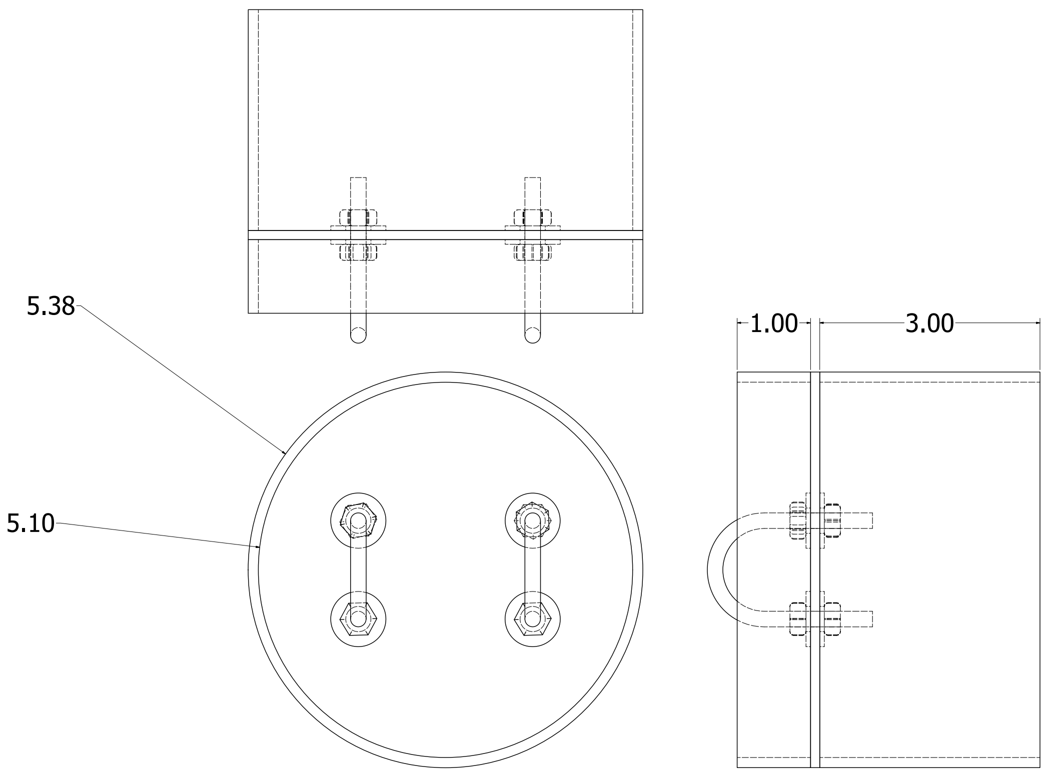


Figure 3.3 - Upper Bulkhead Drawing

The fore centering ring was modified for the same reason as the upper bulkhead; enlarging and repositioning the holes in this component to allow for the use of larger U-bolts to prevent damage during ejection charge separation.

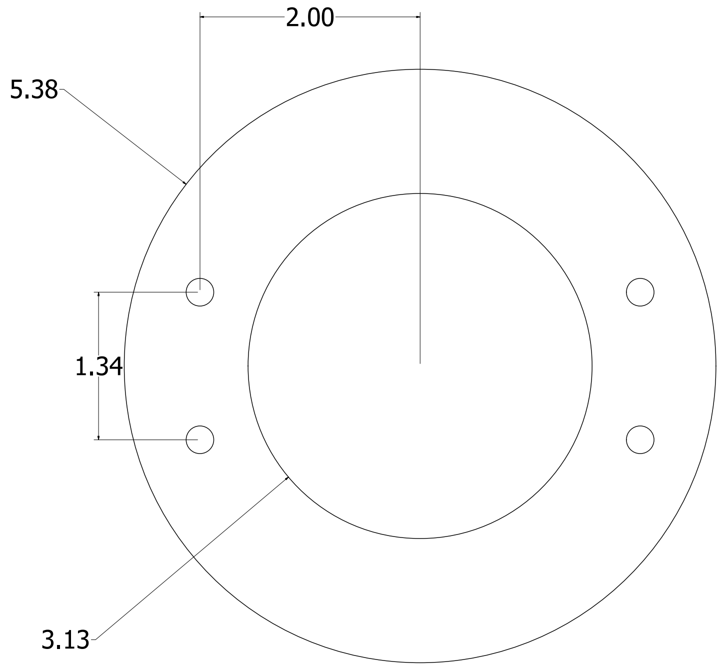


Figure 3.4 - Fore Centering Ring Drawing

## 3.1.2 Launch Vehicle Construction

Except for changes noted in section 3.1.1 Design Changes Since CDR, the Launch Vehicle Design remained unchanged.

### 3.1.2.1 Avionics Bay

The construction of the avionics bay started with cutting the ring seen in Figure 3.5 from a fiberglass body tube.

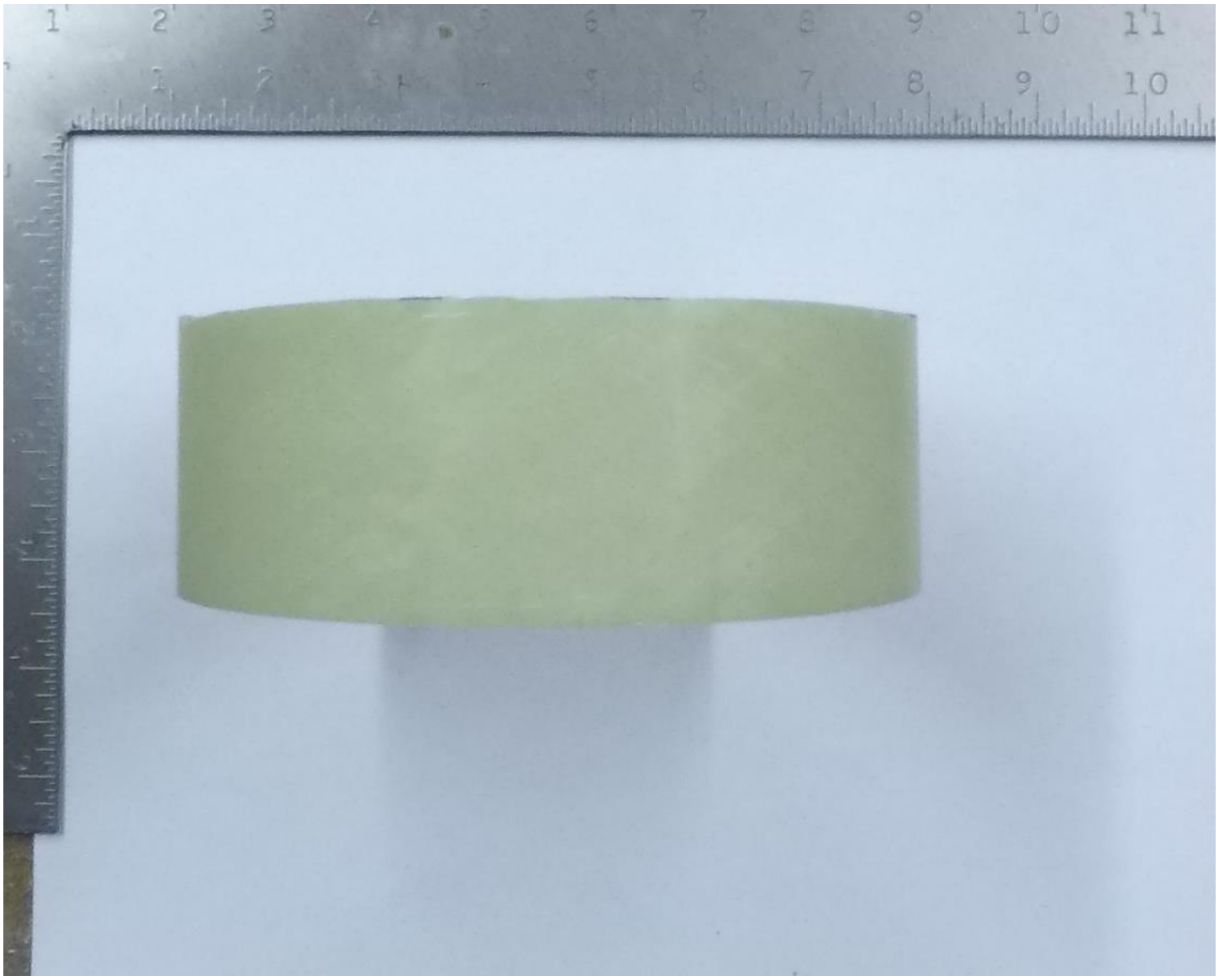

Figure 3.5 - Avionics Bay Ring Back

Next, two holes were drilled into the ring for the altimeter switches to fit into as seen in Figure 3.6.

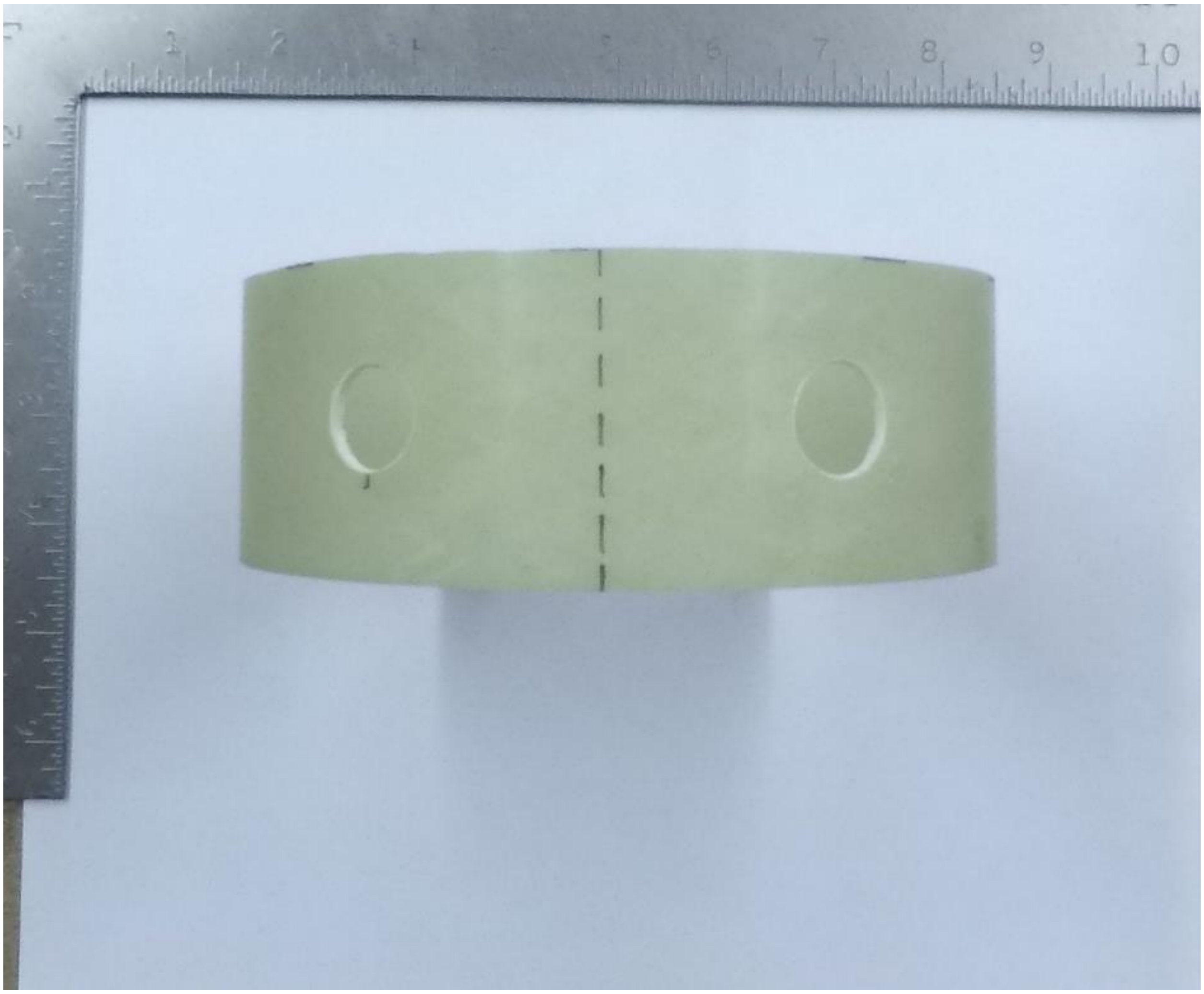

Figure 3.6 - Avionics Bay Ring Front

After the holes were drilled, matching holes were drilled into the coupler piece that is used for the avionics bay, also for the switches. See Figure 3.7.

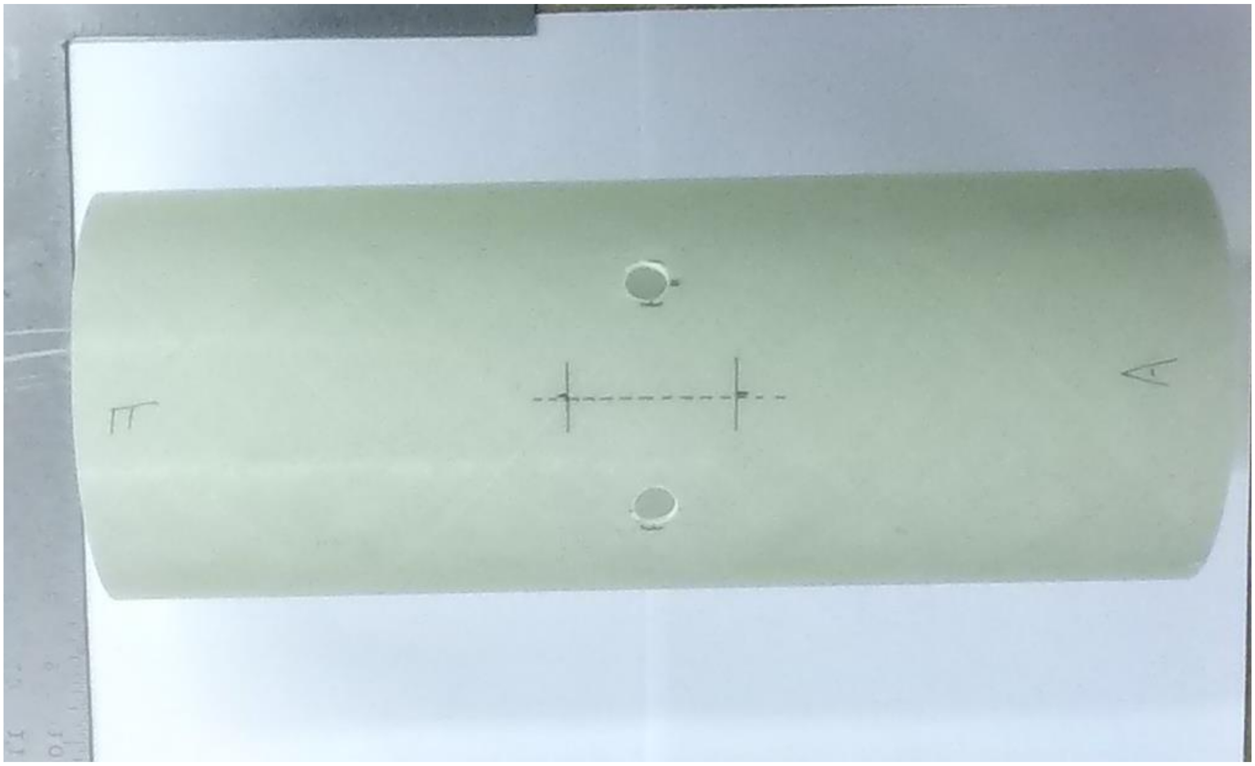

Figure 3.7 - Avionics Bay Couper Front

With both sets of holes drilled, the avionics bay coupler and ring were epoxied together as in Figure 3.8.

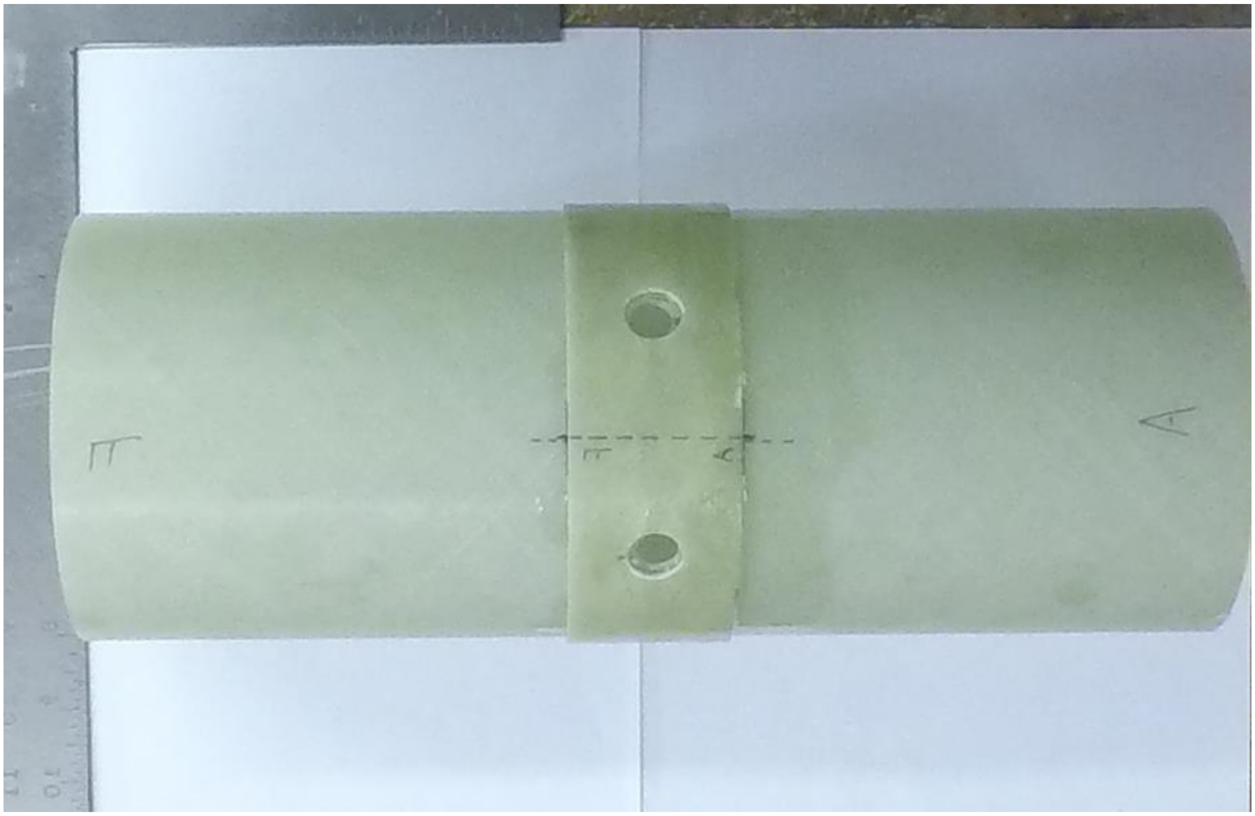

Figure 3.8 - Avionics Bay with Ring

Once the coupler and ring were epoxied together, the bulkheads for the avionics bay end caps had holes drilled in them for the U-bolts, the threaded rods, the terminals, the ejections cups, and the wires from the altimeters as shown in Figure 3.9.

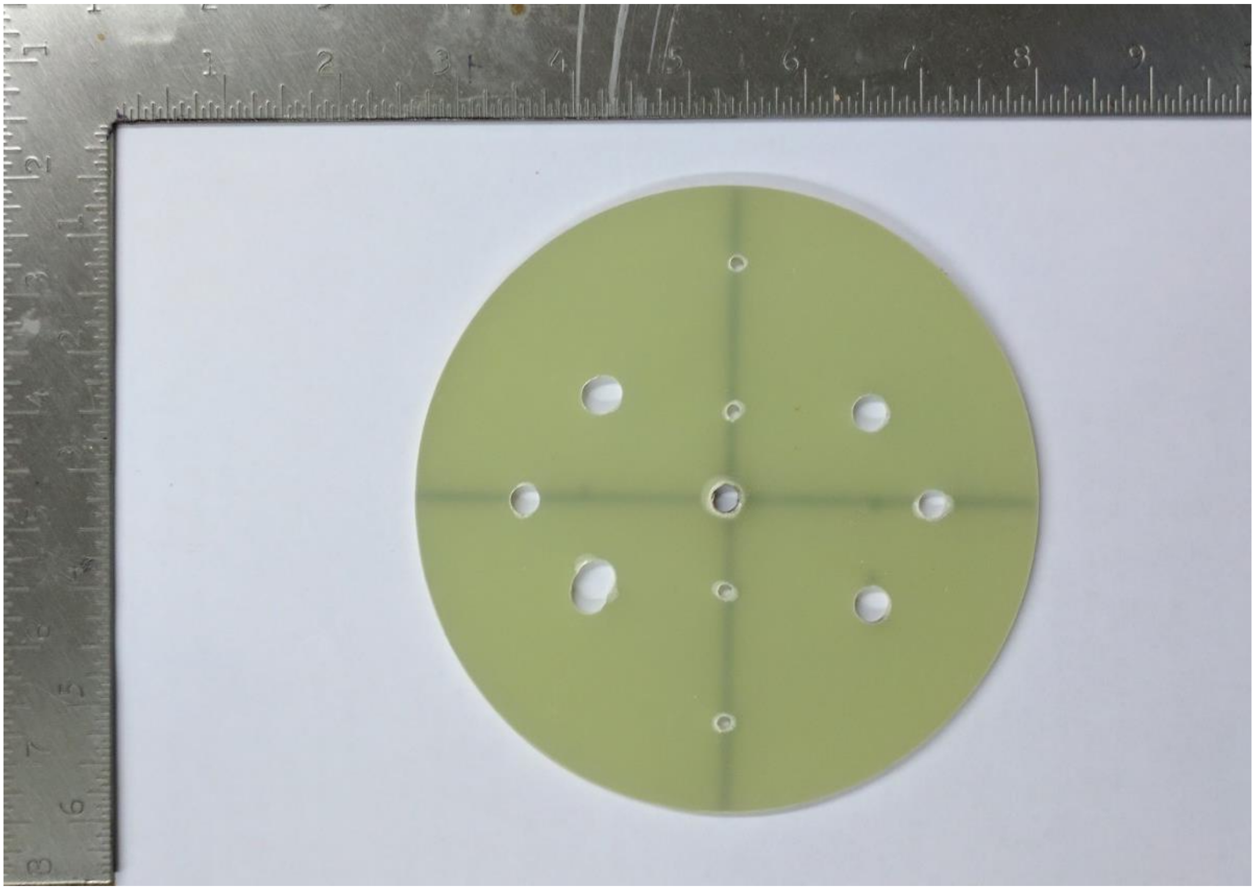

Figure 3.9 - Avionics Bay End Cap Bulkhead

Then, the 2 bulkheads for each end cap were epoxied together with the U-bolts and terminals in place to ensure that they lined up correctly as in Figures 3.10, 3.11, and 3.12 below.

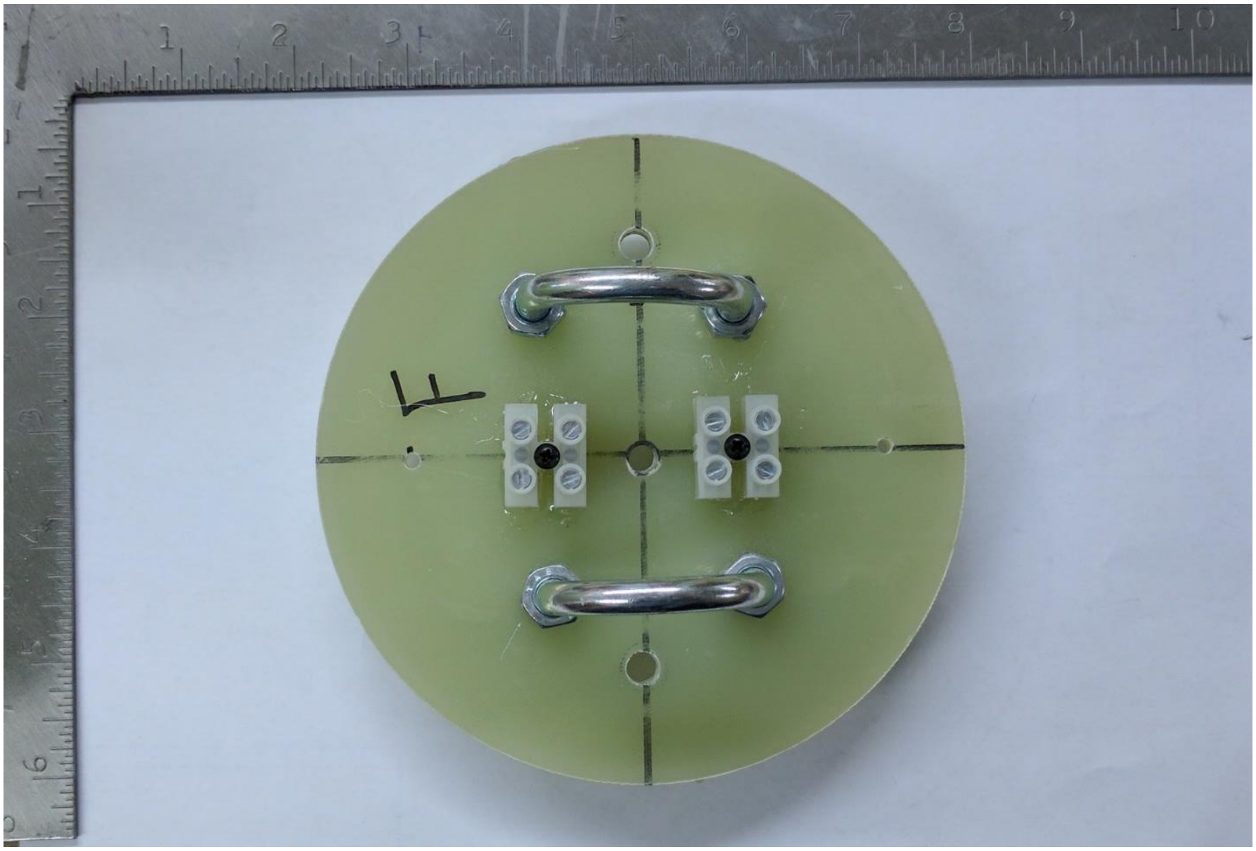

Figure 3.10 - Fore Avionics Bay End Cap with U-bolts and Terminals

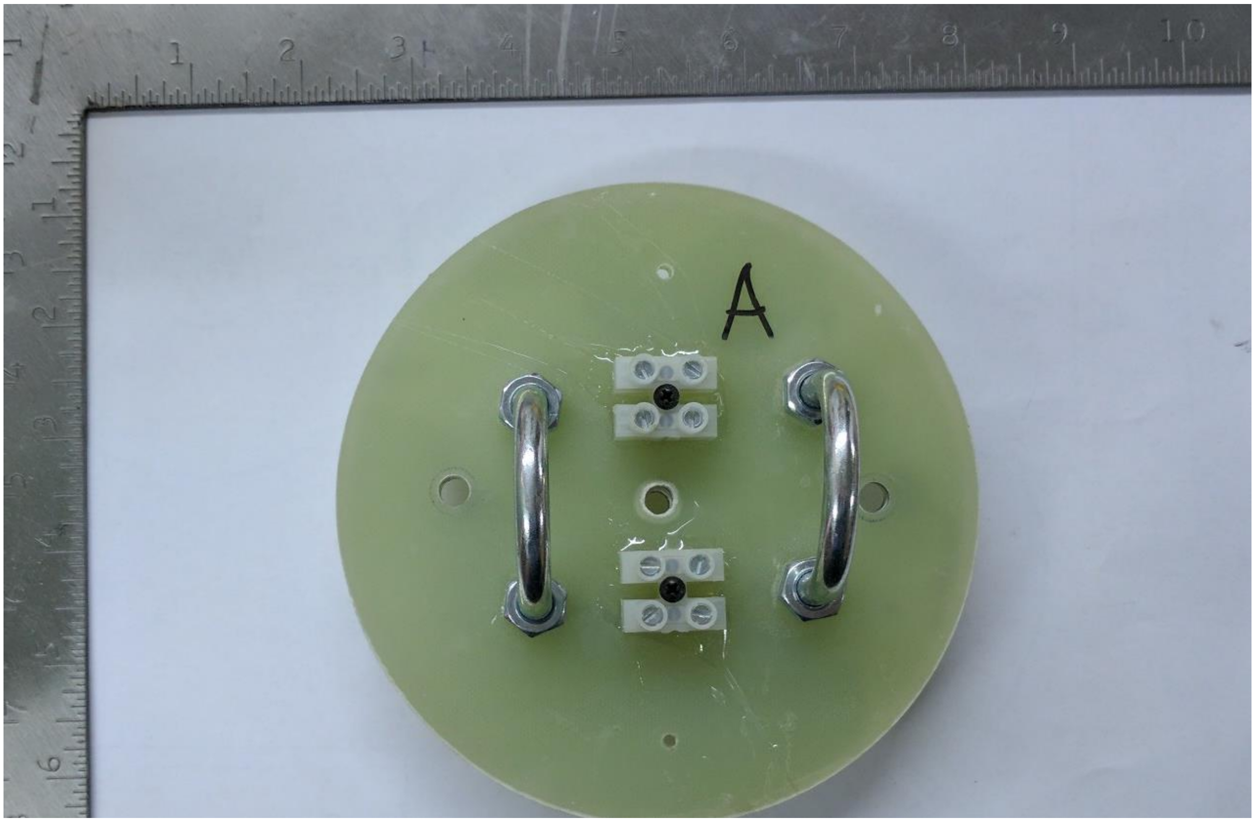


Figure 3.11 - Aft Avionics Bay End Cap with U-bolts and Terminals Top

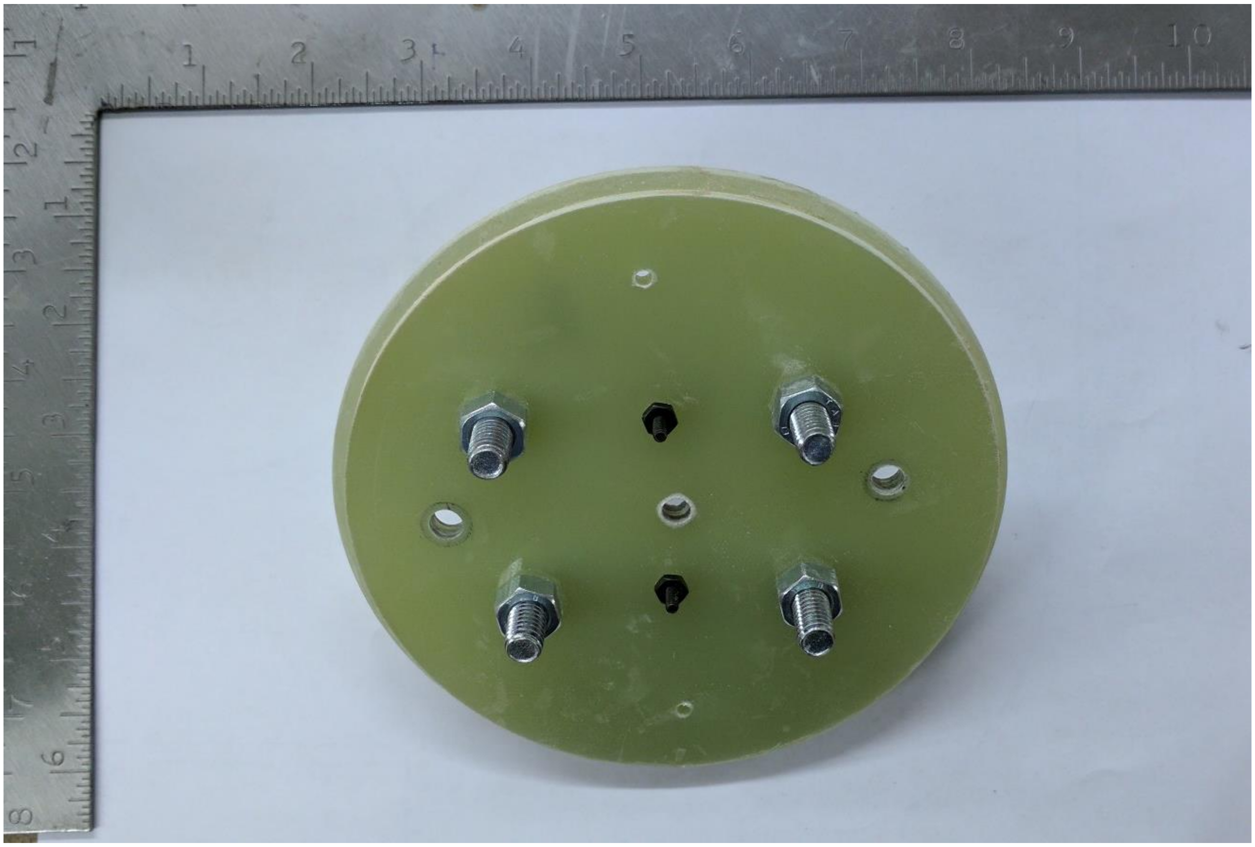

Figure 3.12 - Aft Avionics Bay End Cap with U-bolts and Terminals Bottom

Next, the wires from the altimeters were threaded through the central hole of each end cap and epoxy clay was placed in the hole to seal it against the blast from the ejection charges. See Figures 3.13, 3.14, 3.15, and 3.16.

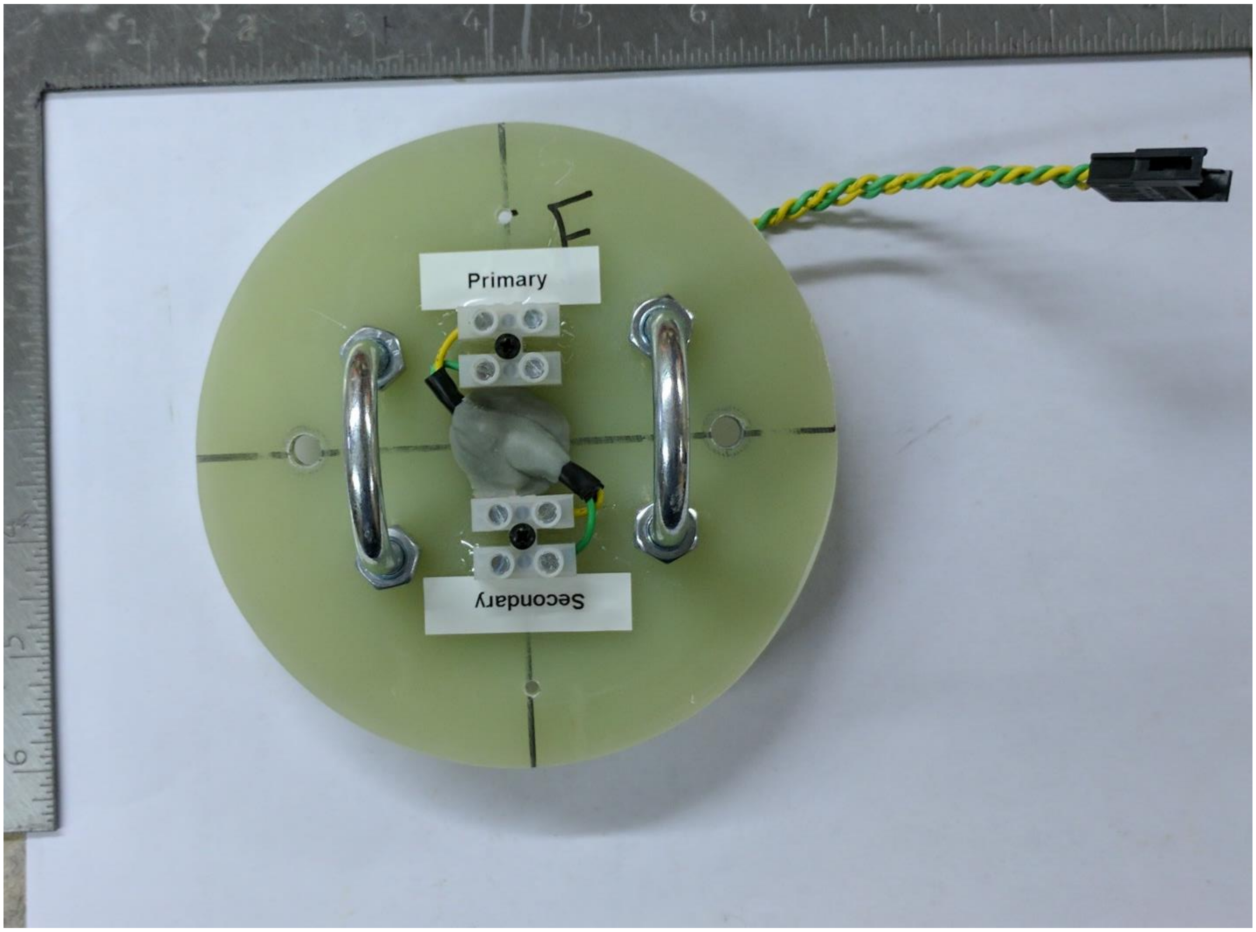


Figure 3.13 - Fore End Cap with Wires Top

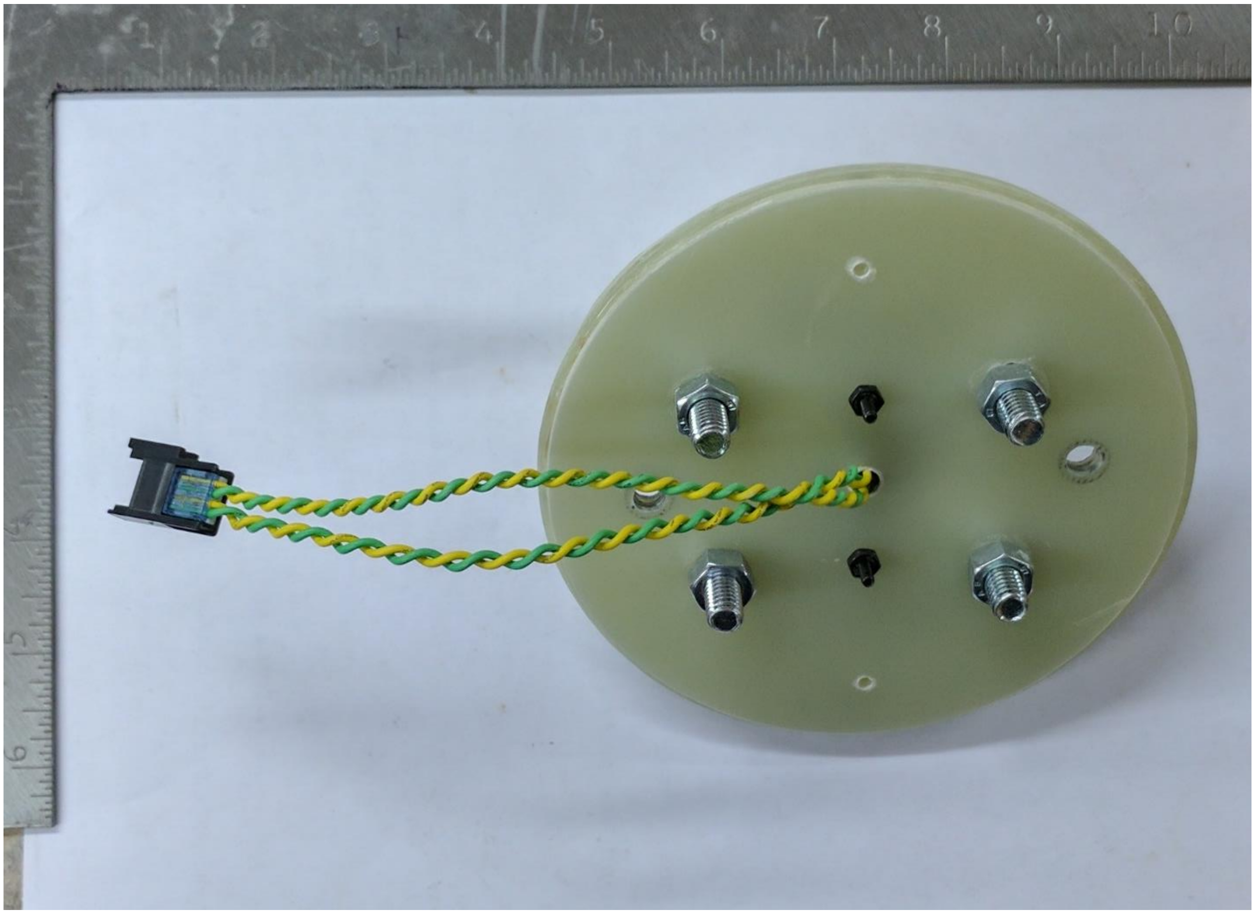

Figure 3.14 - Fore End Cap with Wires Bottom

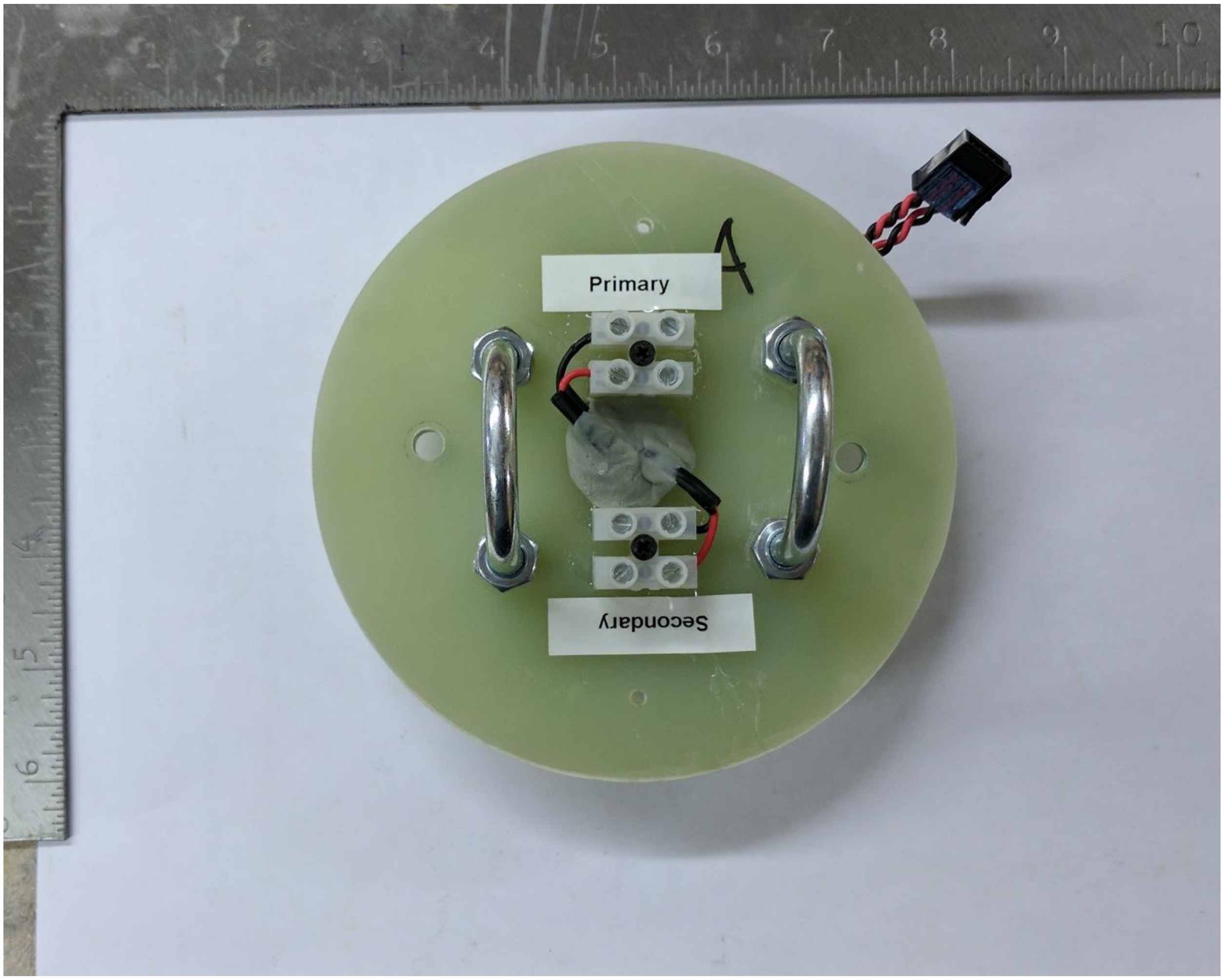


Figure 3.15 - Aft End Cap with Wires Top

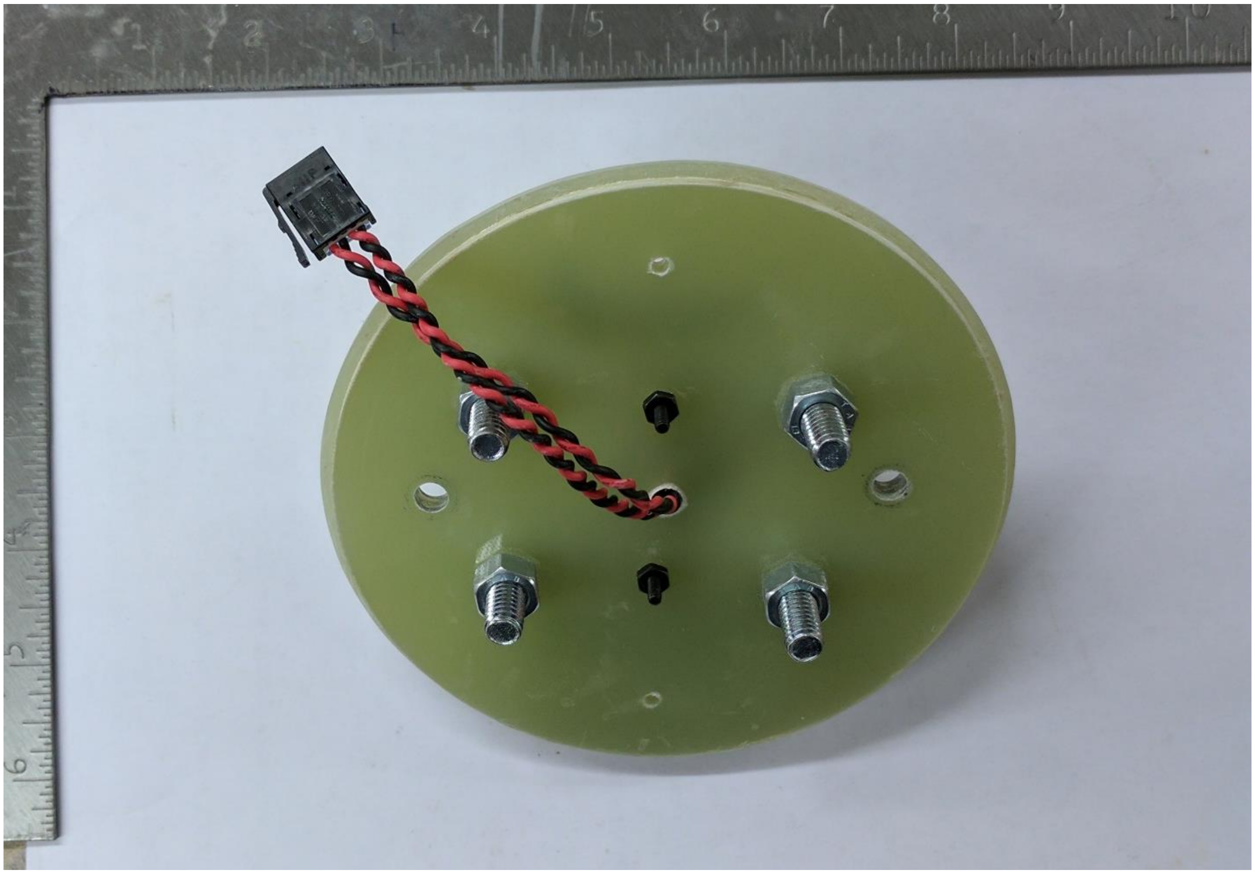

Figure 3.16 - Aft End Cap with Wires Bottom

Finally, ejection cups were bolted and epoxied onto each end cap.

After the avionics bay itself was completed, the avionics sled was 3D printed. Then, 8 holes were drilled into it and tapped for the standoffs that the altimeters rest on. See Figure 3.17.

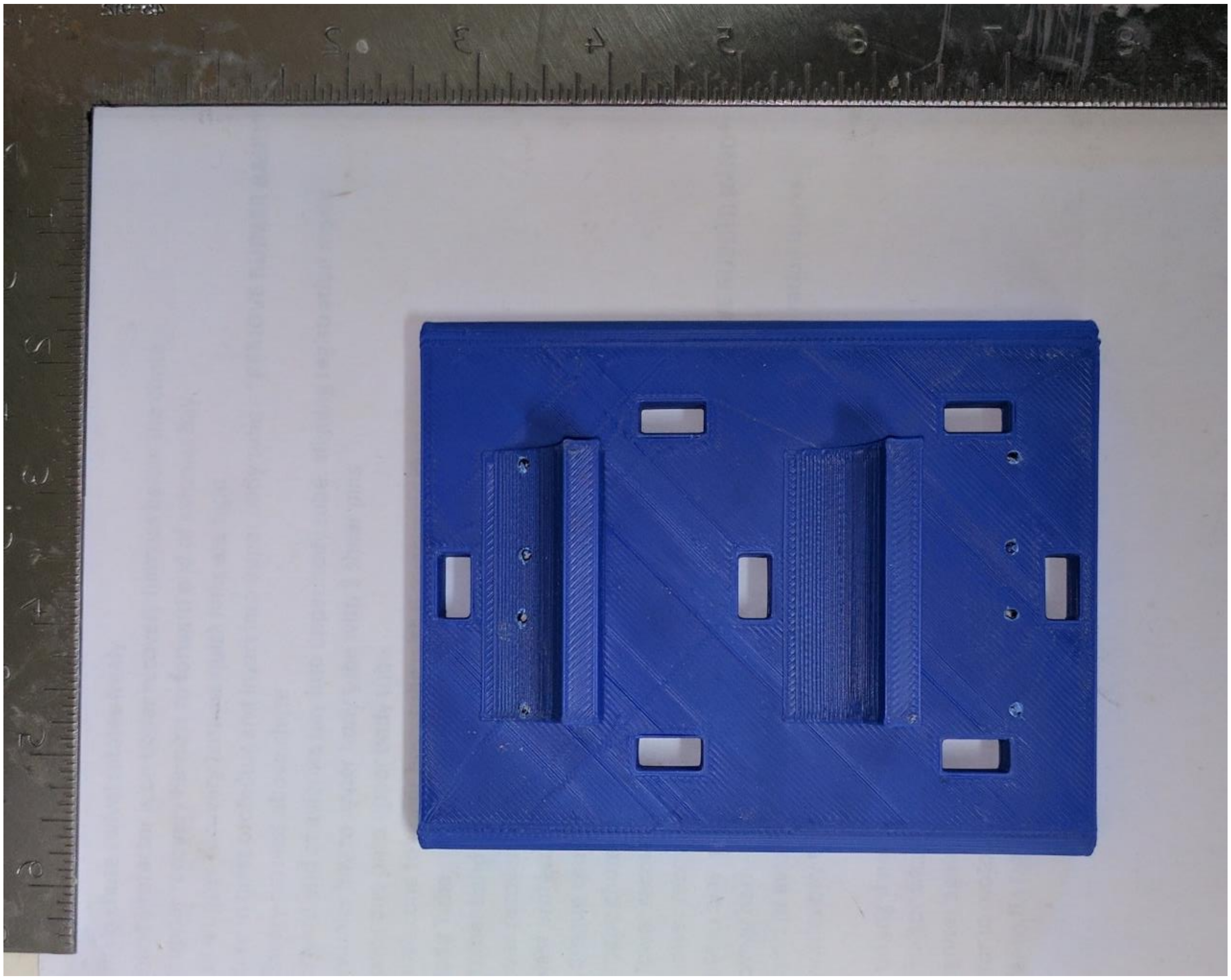

Figure 3.17 - Avionics Sled

### 3.1.2.2 Nose Cone

The nose cone was not modified from the purchased part with the exception of 3 holes that were drilled into its shoulder for its attachment to the upper body tube.

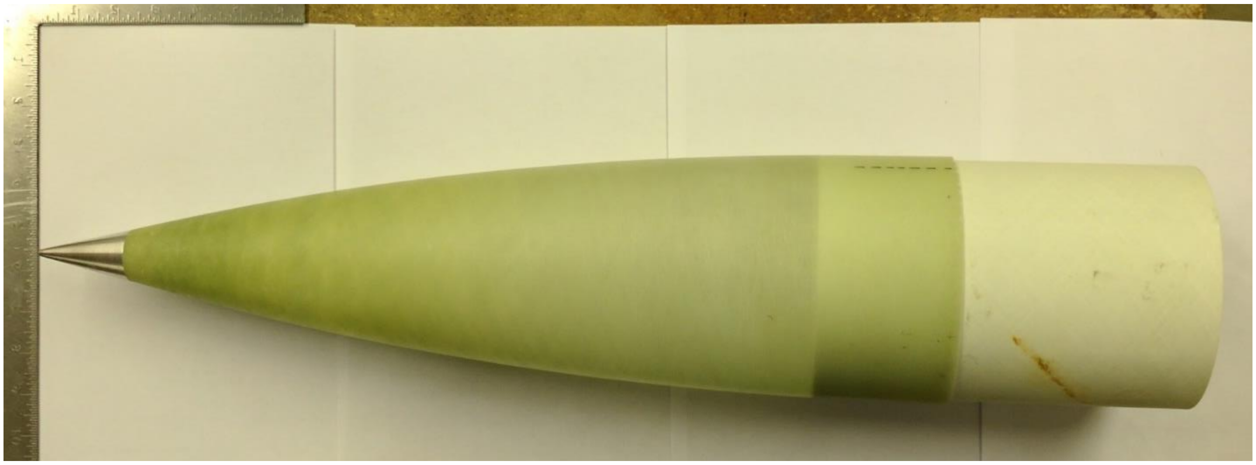

Figure 3.18 - Nose Cone Side

Figure 3.19 - Nose Cone Top

### 3.1.2.3 Upper Section

The upper body tube was cut down to 44 in.  Next, 4 holes were drilled and tapped at the bottom for its attachment, with shear pins, to the avionics bay.  After that, 3 holes were drilled in the top, with 6 in 2 rings of 3 below them for the attachment of the nose cone and payload respectively.  A large, square hole with 2 smaller holes, 1 above and 1 below, were then made for the camera back plate to mount to.

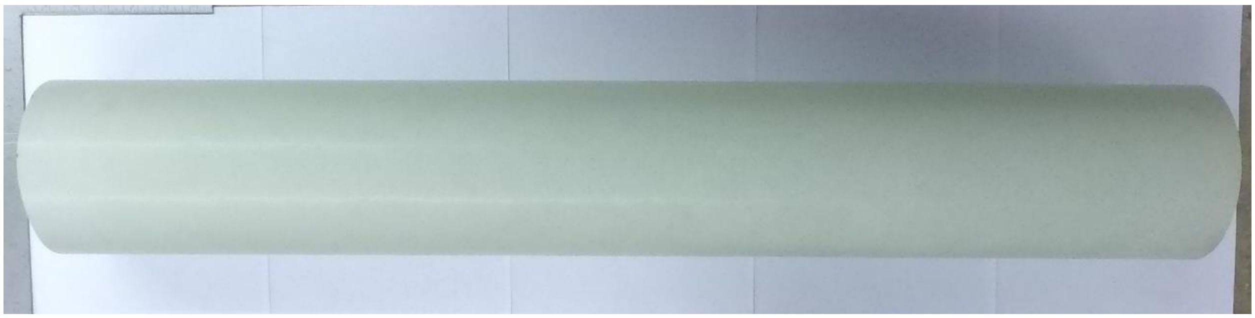

Figure 3.20 - Upper Body Tube

After completing the upper body tube, holes were drilled in the upper bulkhead for U-bolts to mount in. See Figure 3.21.

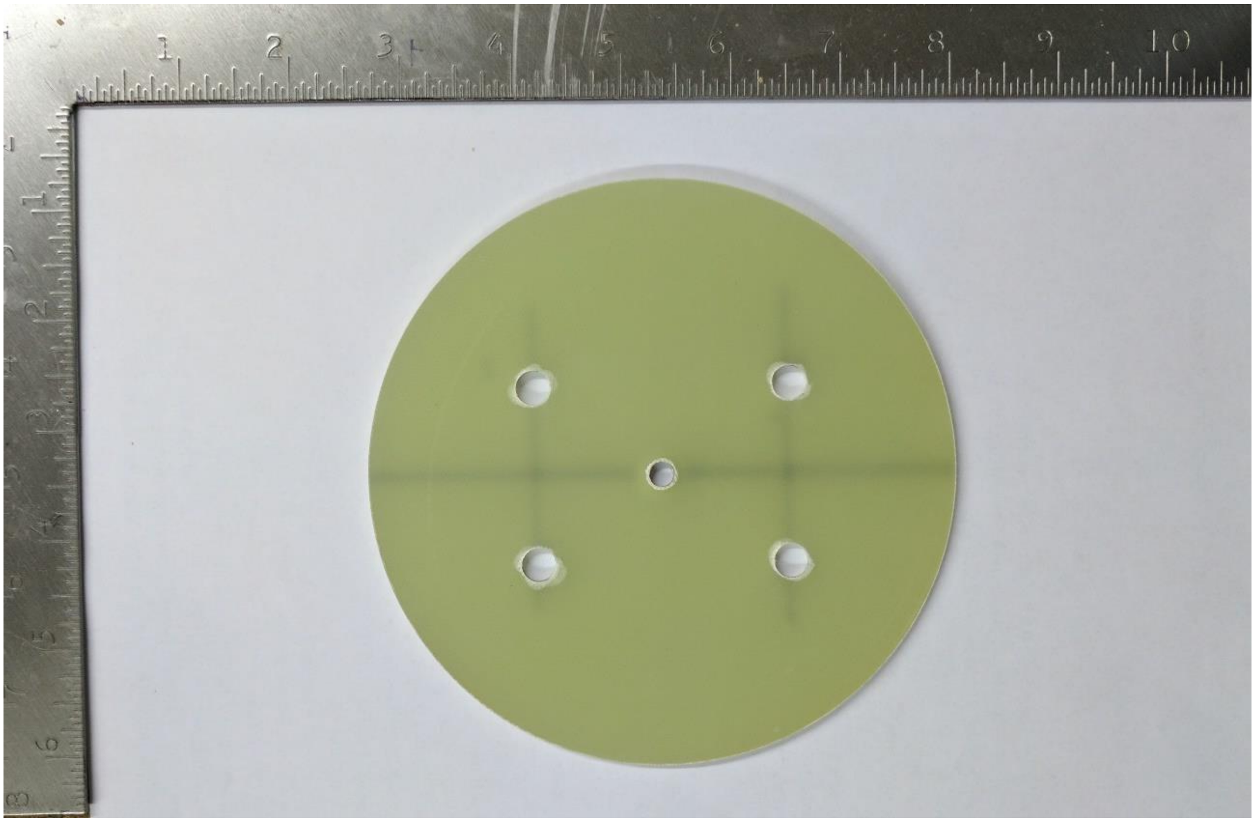

Figure 3.21 - Upper Bulkhead

Then, the top and bottom coupler sections for the upper bulkhead were cut from larger pieces of coupler. See Figures 3.22 and 3.23.

Figure 3.22 - Upper Bulkhead Top Coupler Section

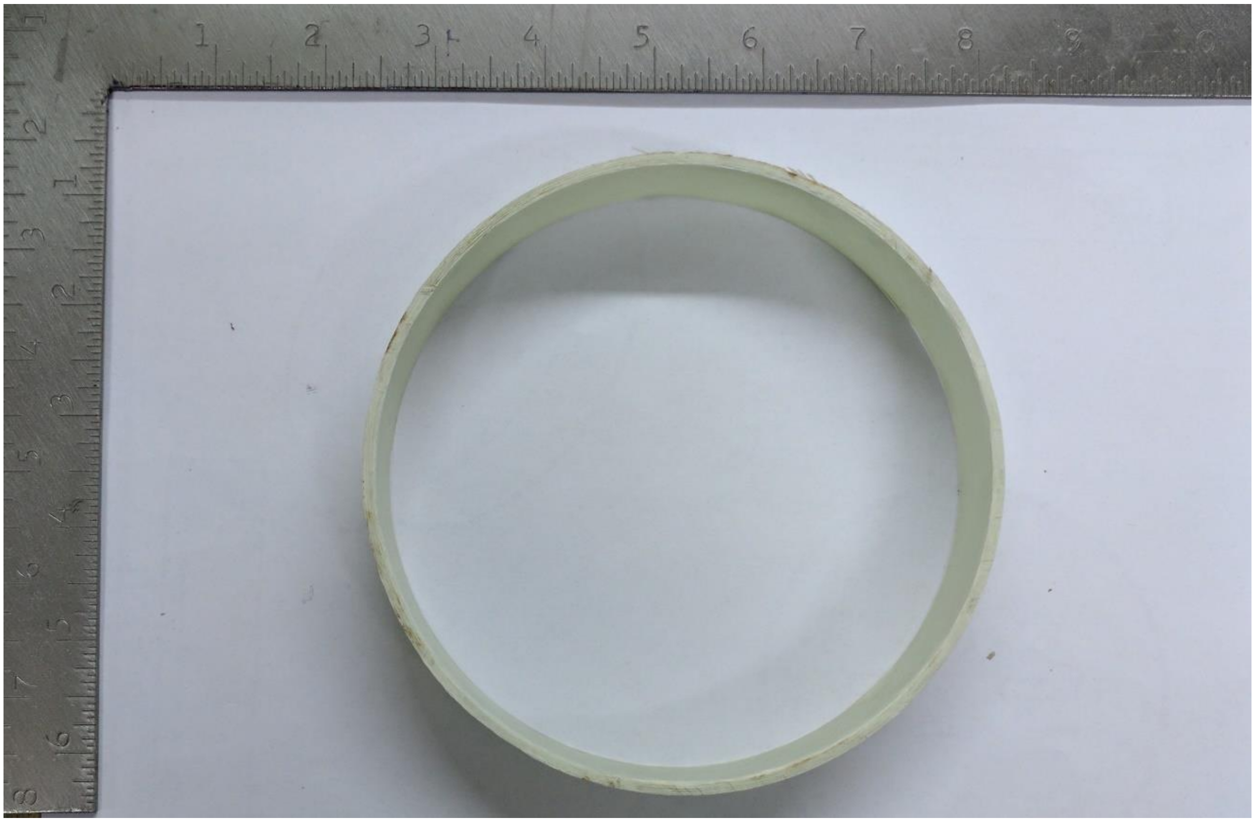

Figure 3.23 - Upper Bulkhead Bottom Coupler Section

The U-bolts were attached to the upper bulkhead with steel back plates to better distribute the force from the launch vehicle separation.  See Figures 3.24 and 3.25.

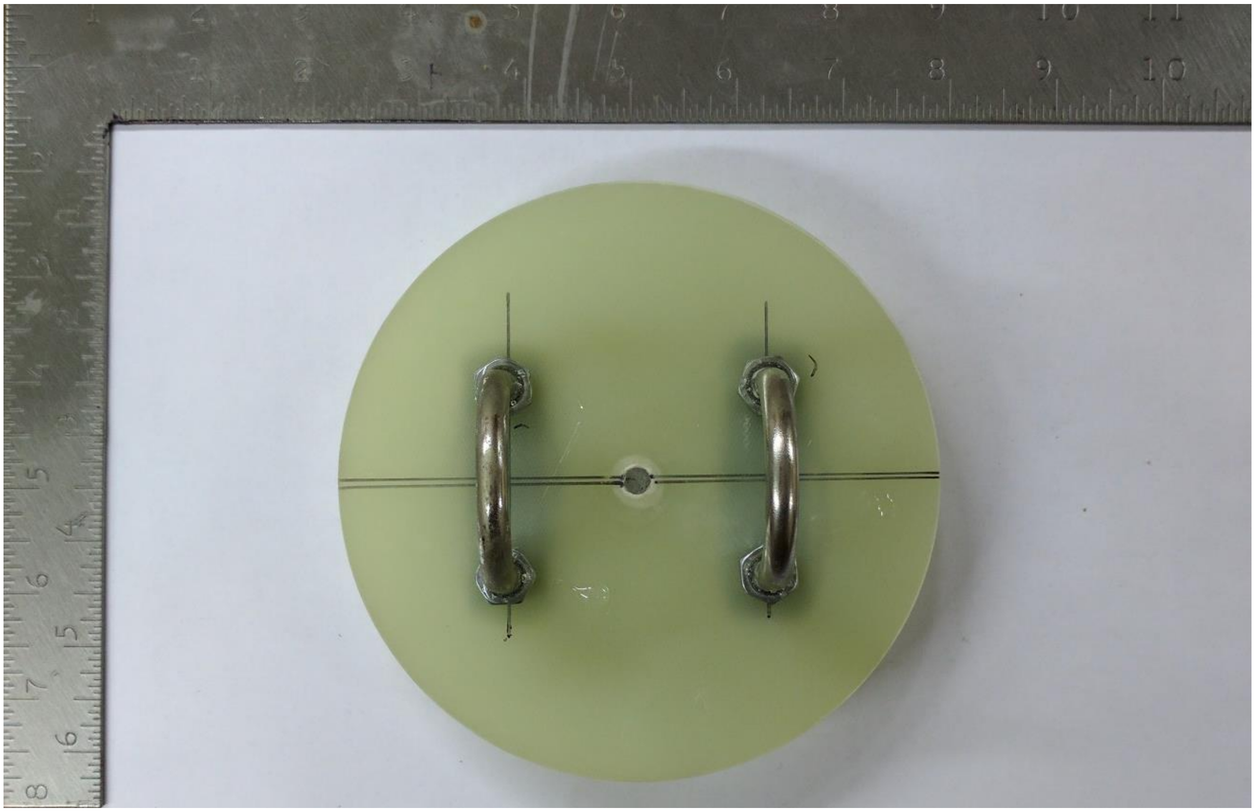

Figure 3.24 - Upper Bulkhead with U-bolts Top

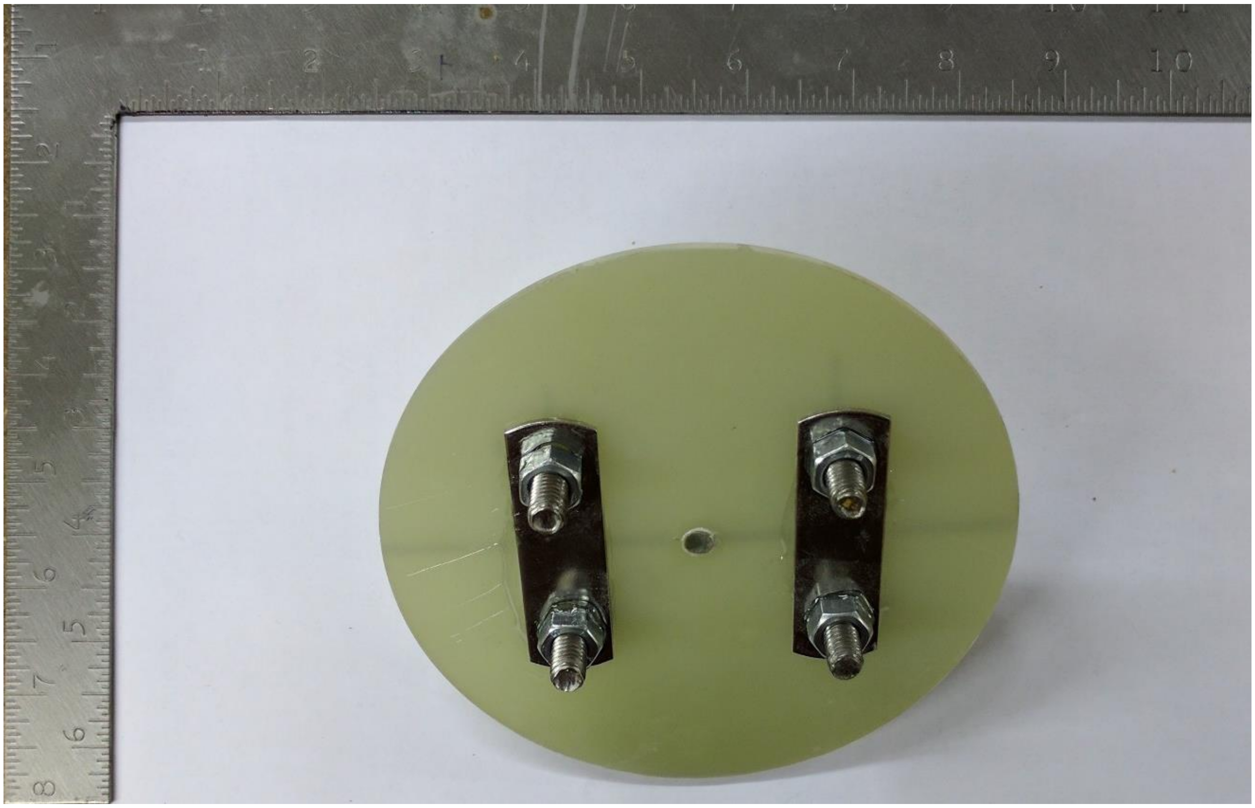

Figure 3.25 - Upper Bulkhead with U-bolts Bottom

Once the U-bolts were attached, the coupler sections were epoxied onto the upper bulkhead and reinforced with epoxy clay fillets. See Figures 3.26 and 3.27.

Figure 3.26 - Upper Bulkhead with Coupler Sections Bottom

Figure 3.27 - Upper Bulkhead with Coupler Sections Side

Then the upper bulkhead was epoxied into the upper body tube and 4 holes were drilled through the upper body tube and the bottom coupler section on the upper bulkhead.  4 screws were then screwed into those holes to provide additional strength for the bulkhead during launch vehicle separation.

#### 3.1.2.3 Lower Section

First, the lower body tube was shortened to 36 in, and 4 holes were drilled in the top of it to attach it to the avionics bay with shear pins.  Then, 3 slots were cut in it at the base for the fins to fit into.  Finally, 2 holes were drilled in line for the rail buttons.

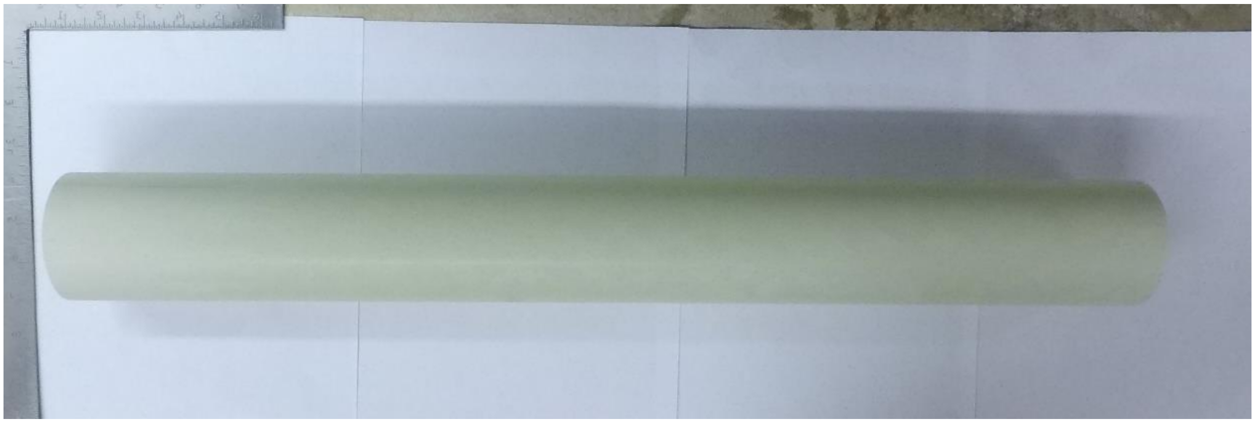

Figure 3.28 - Lower Body Section

Next, 4 holes were drilled into 2 centering rings, which were then laminated together to form the fore centering ring as shown in Figure 3.29.

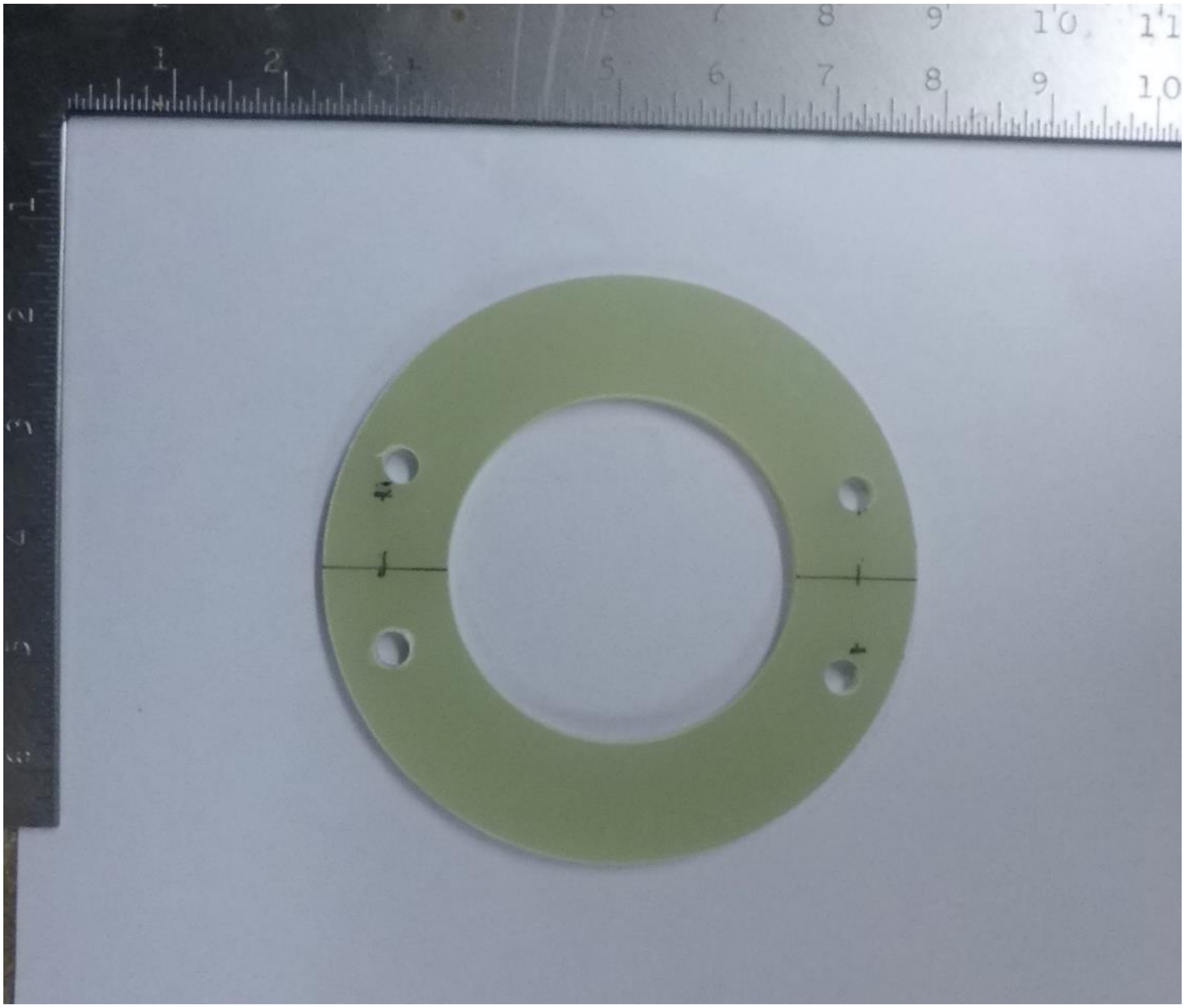

Figure 3.29 - Fore Centering Ring

Once the fore centering ring was made, 2 U-bolts were bolted and epoxied into it as seen in Figures 3.30 and 3.31.

Figure 3.30 - Fore Centering Ring with U-bolts Top

Figure 3.31 - Fore Centering Ring with U-bolts Bottom

Next, the motor mount tube was cut down to 26 in. The fore centering ring was epoxied onto it, and then into the lower body tube. Then the second centering ring was epoxied to the motor mount tube and the lower body tube.

After that, the fins were cut as seen in Figure 3.32.

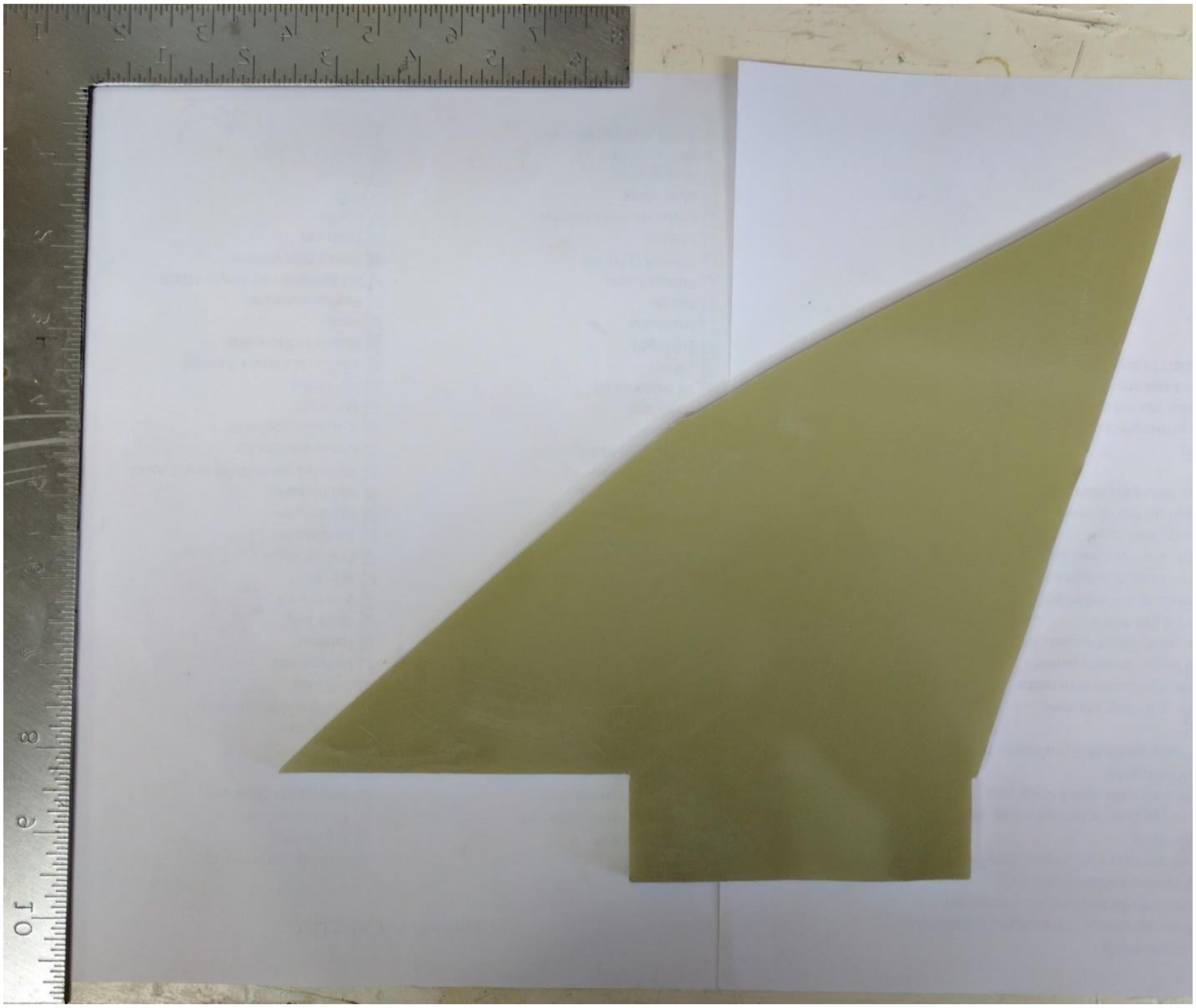

Figure 3.32 - Fin

Once the fins were cut, they were inserted through the slots in the lower body tube and epoxied onto the motor mount tube and the lower body tube.  Then the lower rail button was attached.  Next, the last centering ring was epoxied into place.

After attaching the motor mount, the tail cone was epoxied onto it and the aft most centering ring.  Then the motor retainer was epoxied onto the motor mount tube using a high heat epoxy.

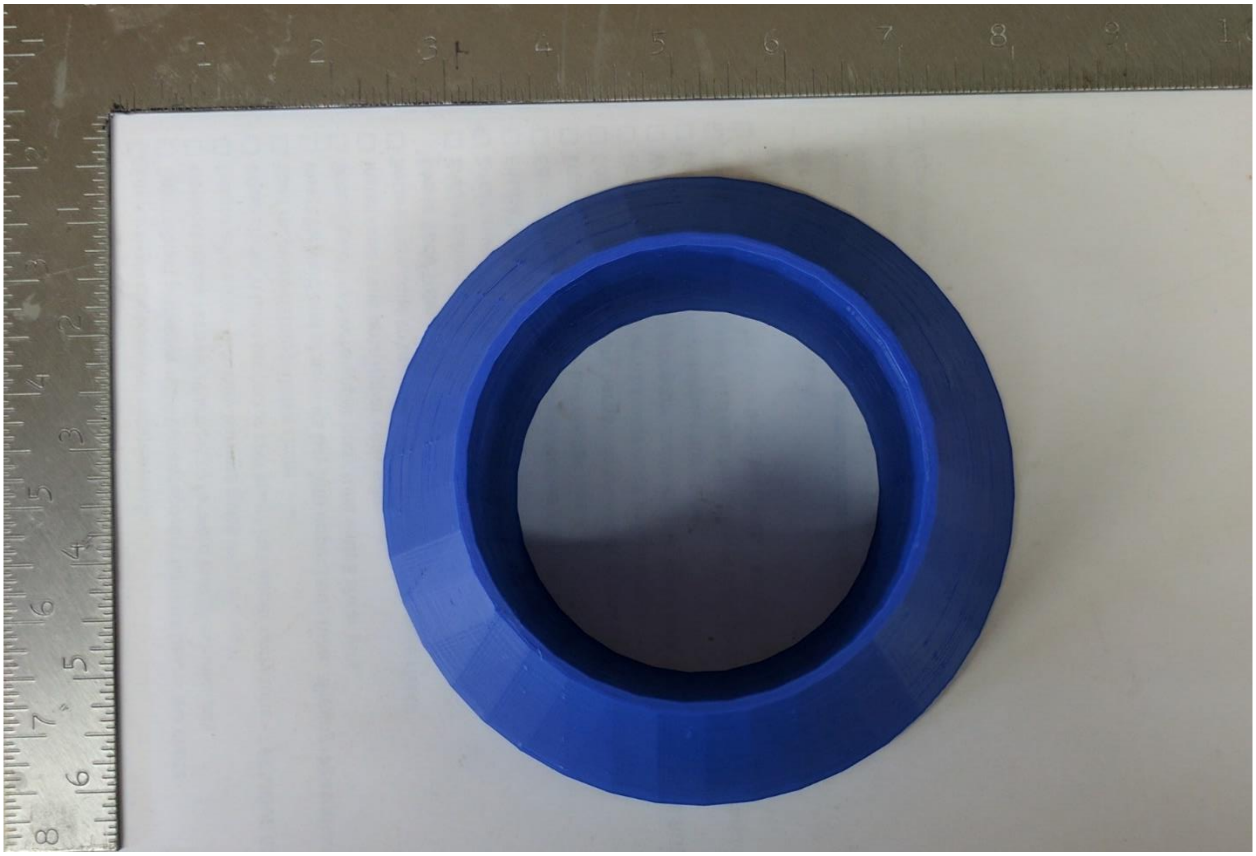

Figure 3.33 - Tail Cone Bottom

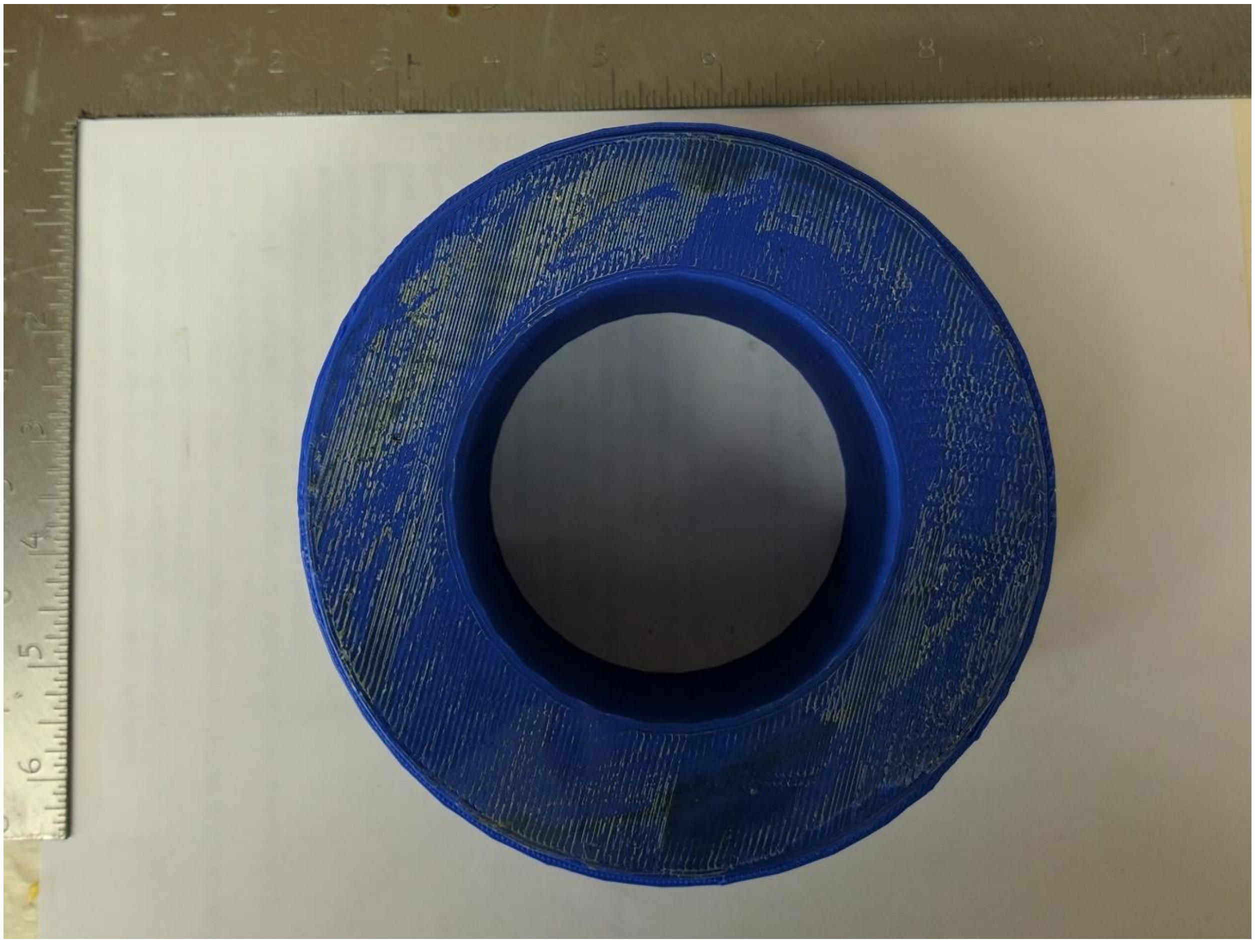

Figure 3.34 - Tail Cone Top

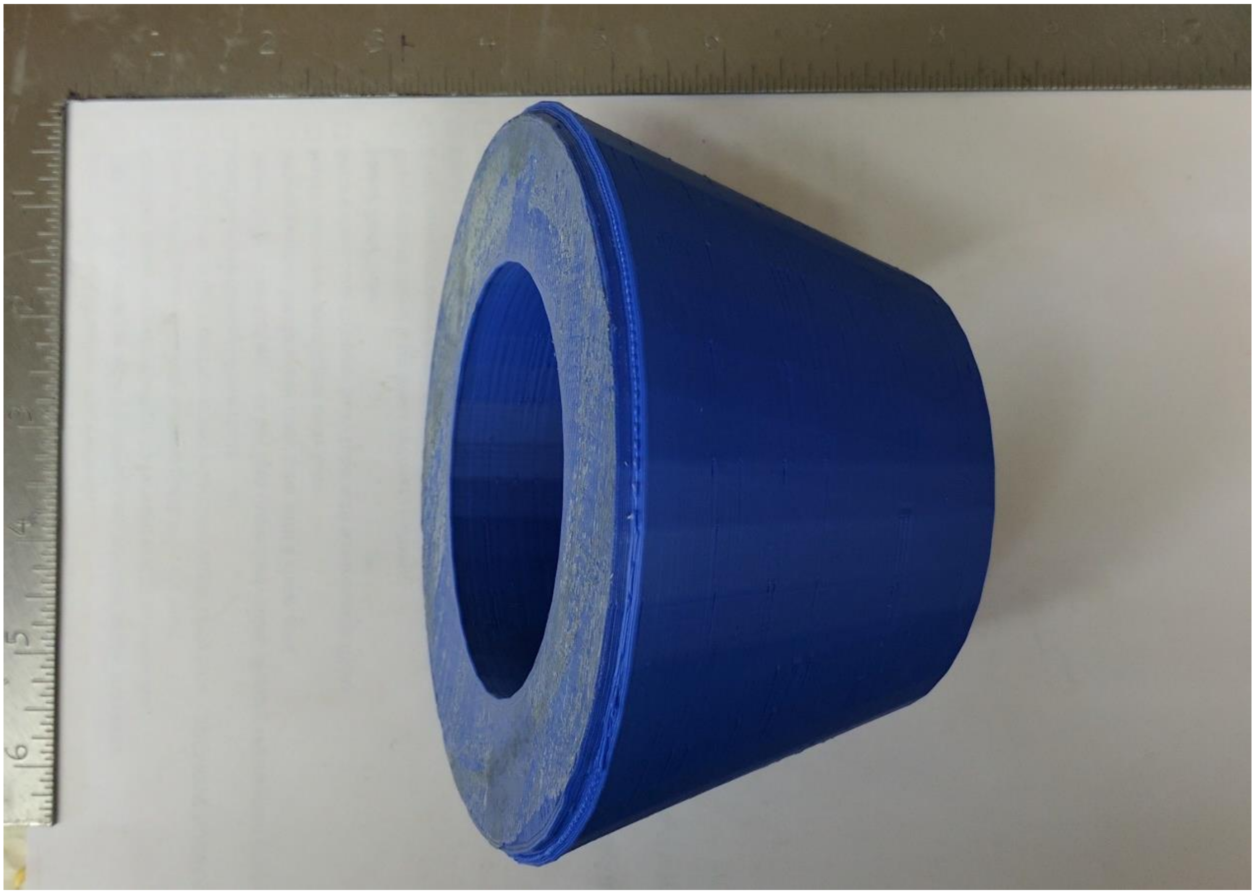

Figure 3.35 - Tail Cone Side

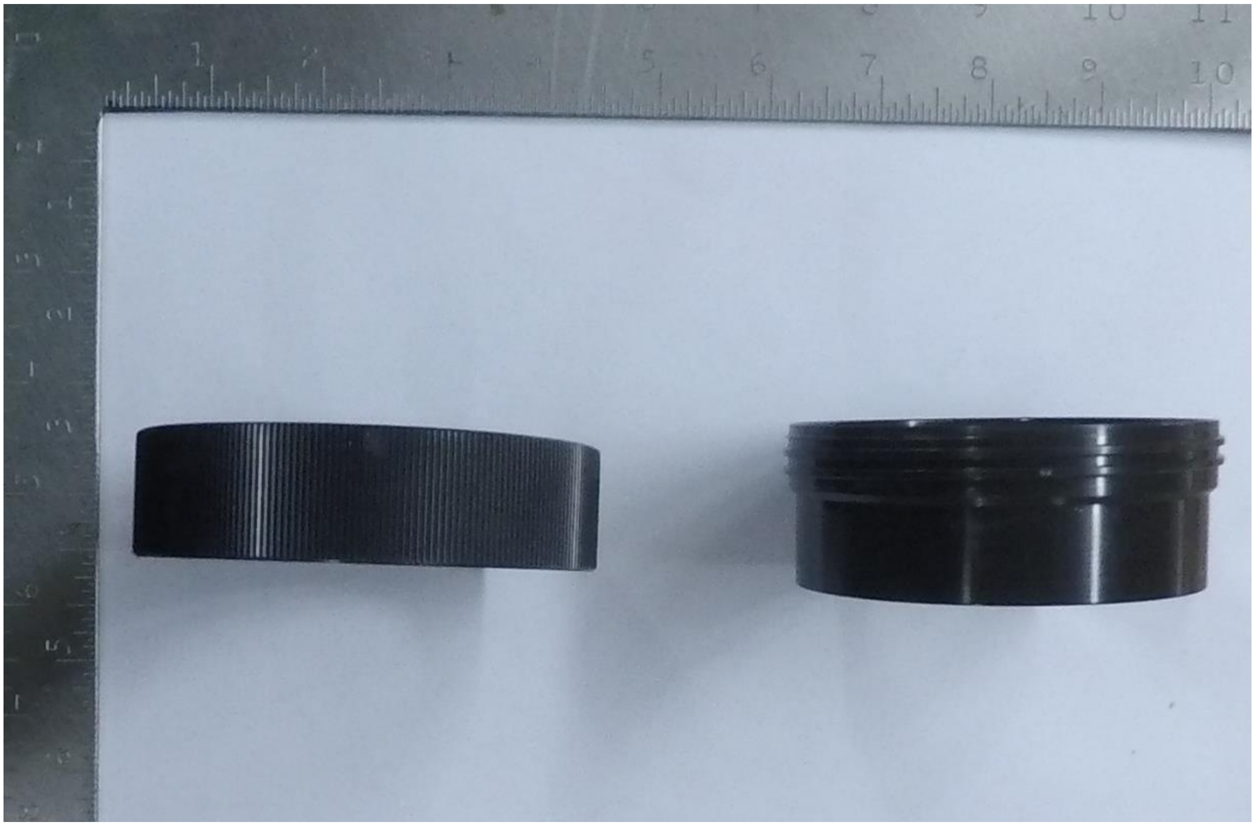

Figure 3.36 - Motor Retainer

### 3.1.2.4 Ballasting

The drag coefficient was calculated to be lower than anticipated; therefore no additional ballasting was necessary.

## 3.1.3 Flight Reliability Confidence

### 3.1.3.1 Altitude

The rocket is light enough with sufficiently low drag to reach the target altitude using the L-class motor that was chosen. Although the use of this motor increases the associated hazards, all precautions for handling and firing the motor are being taken.

### 3.1.3.2 Reusability

All major structural components are made from fiberglass to ensure that the rocket can be reused after flight. The increased weight of fiberglass increases the risk of causing injury or damage if the rocket goes off course, however using fiberglass decreases the risk of the rocket being damaged before or between flights, which in turn decreases the risk of something going wrong during flight. Finally, the addition of fillets around all fins increases the structural integrity of the fins, which are the most at risk of suffering damage.

### 3.1.3.3 Avionics Batteries

The avionics sled has two shelves for the two commercially available 9 V batteries used to power the recovery system electronics. The batteries are on the opposite side of the sled from the altimeters so that if either battery comes loose, there is only a low risk of damaging the altimeters. Both batteries are secured horizontally and vertically to reduce the chance of coming loose during the mission.

### 3.1.3.4 Pad Stay Time

The only components that are affected by remaining in the launch ready configuration are the payload and avionics as those require power, however the batteries for both systems provide ample power to remain in the launch ready configuration for at least 1 hour. Additionally, the batteries will be replaced before each flight.

### 3.1.3.5 Rail Exit

The launch vehicle is light enough to reach 52 ft/s, and the CG and CP of the launch vehicle allow it to have a static stability margin greater than 2 at rail exit using the chosen motor. Rail exit velocity for a 12-foot rail is 71.4 ft/s, and the static stability margin at rail exit is 3.4.

### 3.1.3.6 Recovery System Deployment

The launch vehicle is designed to stage the deployment of both the drogue and main parachutes electronically. Both parachutes have redundant altimeters and ejection charges. The parachute compartments are both held closed using removable shear pins to prevent the rocket from separating during flight before the ejection charges are fired.

#### 3.1.3.7 Tracking System

The payload in the upper section of the rocket includes a GPS module that will be used to detect the location of the rocket during and after the flight and a radio transceiver to transmit that data.

#### 3.1.3.8 Recovery System Inadvertent Excitation

The recovery system electronics are located in a separate section of the rocket from all of the other onboard electronics. Additionally, shielding is in place in the upper section of the rocket to prevent any electromagnetic interference with the recovery system from the payload.

#### 3.1.3.9 Accessing the Altimeters

The avionics bay can be opened by detaching the end caps so that the scoring altimeter can be accessed for marking, as well as replacing the batteries used for the altimeters. The end caps are held onto the avionics bay by 2 1/4 in threaded steel rods with nuts at each end. This provides enough strength to hold the avionics bay together under the force of the ejection charges and the recovery harnesses reaching their full length.

#### 3.1.3.10 Preparation

The designs of the launch vehicle and payload are simple enough that they can be prepared for flight within four hours. The highly modular design of the rocket allows for some preparations to be made ahead of time.

#### 3.1.3.11 Launch Initiation

The motor chosen can be ignited using a standard 12 V firing system, and the rocket requires no additional ground support equipment to initiate launch.

#### 3.1.3.12 Recovery System Activation

Each altimeter is activated by its own rotary switch, mounted externally to the rocket, which is capable of being locked in the on position for flight.

#### 3.1.3.13 Recovery System Power

Each altimeter is connected to a separate battery. Neither battery is used to power any components other that the altimeters.

## 3.2 Recovery Subsystem

The recovery system still uses the standard dual deployment method, using a main and a drogue parachute in separate compartments, both deployed electronically by fully redundant control systems.

### 3.2.1 Structural Robustness

#### 3.2.1.1 Recovery Harness Attachment to Bulkheads and Centering Ring

There are 4 areas where the recovery harnesses attach to the launch vehicle: the fore centering ring on the motor mount in the lower section, the aft end of the avionics bay, the fore end of the avionics bay, and the upper bulkhead in the upper section. Each of those connections is made with 1 swivel and 2 quick links. One end of the swivel is tied onto the end of the recovery harness with a slip knot wrapped with masking tape. Both quick links are attached both to the other end of the swivel and to the 2 U-bolts on that section of the launch vehicle. The only exception to that is the connection to the fore centering ring. That connection uses a third quick link because the U-bolts are too far apart for only 2 quick links to reach. In that case, one of the connections is the same as for the other areas, but on the other one, 2 quick links are formed into a chain which connects to the swivel on one end and a U-bolt on the other end.

This approach means that there are 2 points of connection to the launch vehicle at each end of the recovery harnesses. This halves the force applied to each U-bolt, and thus to the part of the bulkhead or centering ring that each U-bolt is attached to, reducing the risk of it breaking due to the force caused by the separation of the sections of the launch vehicle.

Because of the force applied to each of the bulkheads and the centering ring being used as attachment points for the recovery harnesses, all of them, except for the upper bulkhead, have 2 layers of fiberglass. Because the upper bulkhead is only 1 layer, both the U-bolts in it have steel backplates to help distribute force.

#### 3.2.1.2 Bulkhead and Centering Ring Attachment to the Launch Vehicle

The fore centering ring is attached to the lower section's body tube and to the motor mount tube by epoxy. Having both of those attachment points provides a sufficiently strong attachment to keep the centering ring securely mounted.

Both the bulkheads on the avionics bay are mechanically connected to each other by 2, 1/4 in threaded steel rods. They are fitted onto the ends of the avionics bay so that they rest against the edge of the coupler that forms it, preventing them from moving in one direction. When force is applied to one of the bulkheads, it is transferred through the threaded rods to the other, which is pressed into the avionics bay coupler, keeping both bulkheads securely in place.

The upper bulkhead is epoxied into the upper section's body tube. Additionally, there are sections of coupler epoxied into the body tube directly above and below the bulkhead, providing rests for it to press against to keep it in place.

#### 3.2.1.3 Recovery Harnesses

Both sections of the recovery harness are 27 ft long, 1/2 in tubular Kevlar. This provides sufficient strength to withstand the force from the separation of the sections of the launch vehicle, as well as providing enough length to allow the sections to lose a moderate amount of their energy before any force is applied to the harnesses.

#### 3.2.1.4 Parachute Attachment to the Recovery Harnesses

Both the main parachute and the drogue have their shroud lines attached to a swivel. The main parachute has a loop sown into its shroud lines with the swivel in the loop; the drogue parachute is tied onto its swivel.  The swivels are attached to their respective recovery harnesses by a quick link that goes through the swivel on one end and a knot in the harness on the other.

#### 3.2.1.5 Parachutes

The diameter of the drogue parachute is 18 in, and the main parachute has a diameter of 84 in.  These provide descent rates of 116.5 ft/s and 19.33 ft/s respectively.  Because the descent rate under the drogue parachute is relatively high, the deployment altitude for the main parachute was set at 800 ft to allow sufficient time for it to deploy fully.

Both parachutes are protected for the gasses produced by the ejection charges by reusable blast protectors.  The drogue parachute is wrapped entirely in its blast protector, while only the end of the main parachute that faces the ejection charges is covered by its due to its size.

### 3.2.2 Electrical Robustness

#### 3.2.2.1 Altimeters

There are 2, commercially available RRC3 sport altimeters controlling the ejection system on the rocket. They are wired independently of each other so that if there is an issue with either altimeter or the wiring for one, there is still a fully functional backup.  This includes batteries, switches, terminals for the ignitors, and ejection charges.  See Figure 3.37.

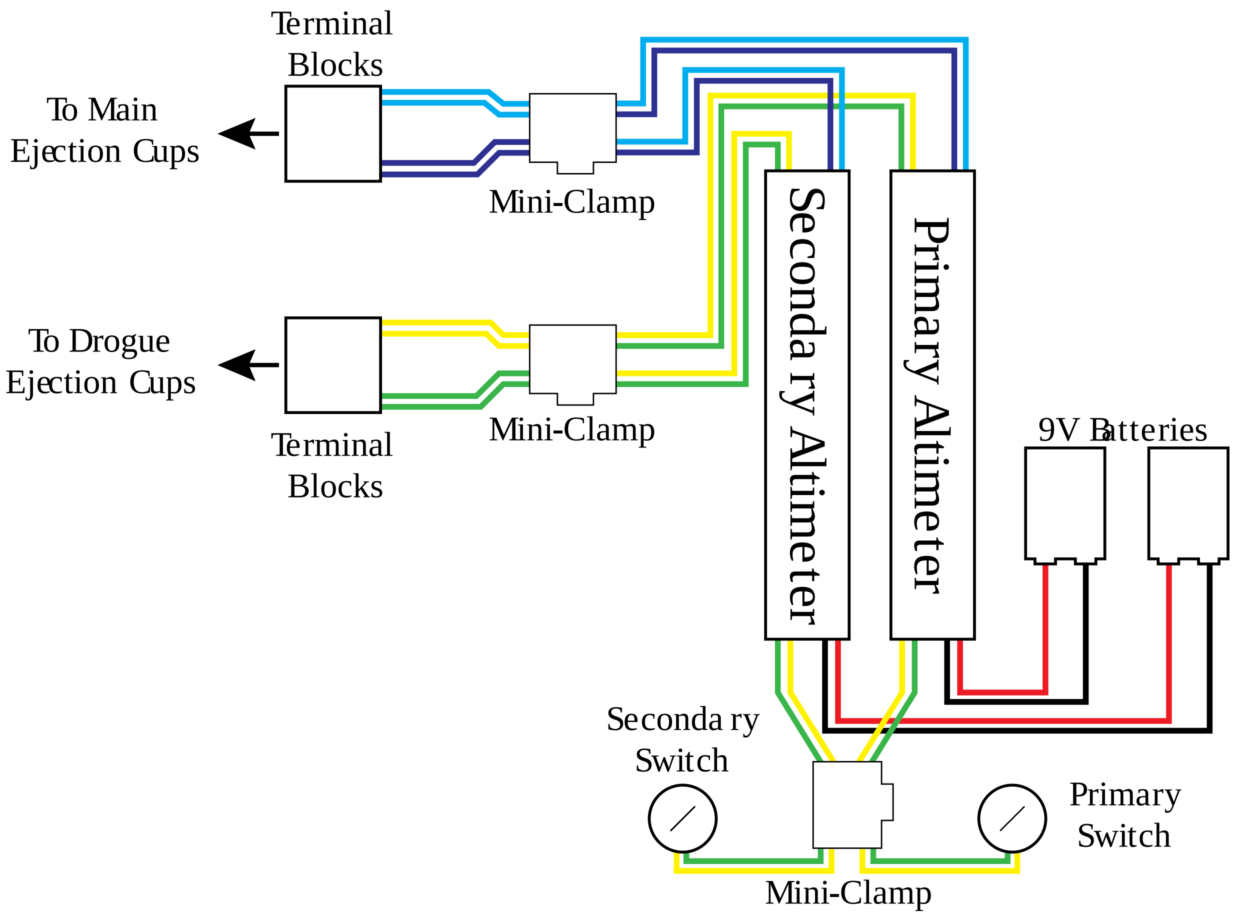


Figure 3.37 - Altimeter Wiring Diagram

The batteries and altimeters are mounted on opposite sides of the avionics sled so that, should a battery break lose, it will be less likely to damage either altimeter and cause a failure of the recovery system. To further that goal, each battery is held in place by 2 Velcro straps, 1 horizontal and 1 vertical.

To prevent any interference with the altimeters from other onboard electronics, they are in a section of the rocket separate from any other electronics. The only other electronics onboard that could cause issues for the altimeters are the transmitter and the electric motor in the payload. The transmitter is located at the fore end of the payload to keep it as far away from the avionics electronics as possible. Additionally, the avionics bay is shielded from payload with a layer of aluminum tape placed over the upper bulkhead.

Each altimeter is capable of conveying the altitude that it recorded via beeps and can be turned off with the externally mounted switches to make finding the altitude easier.

#### 3.2.2.2 Ejection Charge Firing

To ensure that at least 1 ejection charge is fired for both the drogue parachute and for the main parachute, each one can be fired by 2, completely independent charges. Each charge is fired by its own ignitor, which are connected to 2 separate terminals, each of which is connected to a different altimeter. This way, even if 1 altimeter, ignitor, connection, switch, or battery should fail, there is still 1 fully functional deployment system.

To ensure that the sections of the rocket separate cleanly, ground fire tests were performed for the ejection system. Through these tests, it was determined that ejections charges of 3 g of black powder in each ejection charge is sufficient. To further aid in a clean separation, both shoulders of the avionics bay coupler are greased before each flight. With 3 g ejection charges and the greased avionics bay, separation speeds of 17.4 ft/s and 34.69 ft/s were achieved for lower section and upper section separation respectively.

#### 3.2.2.3 Locator

The location system for the rocket is incorporated into the experimental payload. It consists of a GPS module that feeds the rocket position, along with some additional information, into the experiment's Raspberry Pi control unit. From there, the position is transmitted to the same ground station as the other data from the experiment. Some of the key features of the transmitter used are shown in Table 3.1, below.

| Statistic | Value |
|---|---|
| Frequency (MHz) | 902.4 - 927.6, 64 channels at intervals of 0.4 |
| Wattage (mW) | 250 |
| Range (ft) | 21120 |

Table 3.1 - Transmitter Statistics

The range of the transmitter is sufficient to allow a signal to make it to the ground station even at the maximum range and altitude expected.

### 3.2.3 System Robustness

The recovery system as a whole has been tested both on the ground and in flight to ensure its robustness. These tests have shown that all electrical and mechanical systems in the recovery system work consistently and as expected.

## 3.3 Mission Performance Predictions

### 3.3.1 Mission Performance Criteria

The criteria for a successful mission are as follows:

- The rocket can be prepared for flight in less than 4 hours
- The rocket can remain in the launch ready configuration for at least 1 hour
- The payload can roll the rocket 3 times around its long axis
- The payload can return the rocket to within 5 °/s of its burnout angular velocity
- The rocket deploys the drogue parachute at apogee
- The rocket achieves an apogee between 5000 ft and 5400 ft
- The rocket deploys the main parachute at 800 ft
- The rocket drifts less than 2500 ft
- All sections of the rocket land with less than 75 ft-lbs of energy
- The rocket is sufficiently undamaged by the flight that it is re-flyable without any repair

### 3.3.2 Flight Profile

Table 3.2 shows the major expected flight events for the mission in order alongside the expected times for them to occur. Times are the averages taken from the flight simulations in section 3.3.3 Flight Simulations or are based on, for example, for roll induced.

| Event | Time (s) |
|---|---|
| Launch | T + 0 |
| Motor burnout | T + 3.165 |
| Roll induced | T + 3.5 |
| Rotations completed | T + 15.5 |
| Counter roll induced | T + 15.5 |

| Event | Time (s) |
|---|---|
| Apogee reached | T + 18.445 |
| Drogue parachute deployed | T + 18.445 |
| Main parachute deployed | T + 57.400 |
| Landing | T + 98.171 |

Table 3.2 - Flight Events Average

Table 3.3 shows the major expected values for the flight, taken as the average of the same values from the simulations in section 3.3.3 Flight Simulations.

| Statistic | Value |
|---|---|
| Apogee (ft) | 5118.03 |
| Maximum acceleration under power ($ft/s^2$) | 263.632 |
| Maximum velocity (ft/s) | 597.56 |
| Velocity at main parachute deployment (ft/s) | 116.53 |
| Rail exit velocity (ft/s) | 71.3688 |
| Velocity at landing (ft/s) | 19.338 |
| Drift from RockSim (ft) | 367.362 |
| Drift calculated (ft) | 1190.44 |
| Static stability margin at rail exit | 3.402 |

Table 3.3 - Key Flight Statistics Average

Table 3.4 shows the error and percentage error between the averages shown in Table 3.3 and the values from section 3.3.3 Flight Simulations.

| Statistic | Error | Percentage Error (%) |
|---|---|---|
| Apogee (ft) | 151.79 | 2.966 |
| Maximum acceleration under power ($ft/s^2$) | 0.032 | 0.01214 |
| Maximum velocity (ft/s) | 1.27 | 0.2125 |
| Velocity at main parachute deployment (ft/s) | 2.29 | 1.965 |
| Rail exit velocity (ft/s) | 0.0018 | 0.002522 |
| Velocity at landing (ft/s) | 3.672 | 18.99 |
| Drift from RockSim (ft) | 393.648 | 107.2 |
| Drift calculated (ft) | 1190.44 | 100.0 |
| Static stability margin at rail exit | 0.008 | 0.2352 |

Table 3.4 - Key Flight Statistics Error

For most of the values, the percentage error is relatively small; the notable exceptions are the drift distances and velocity at landing. While the percentage error for drift distances is very high, that is to be expected, given that the only variable between the simulations is wind speed, which directly affects the drift distance, and it varies significantly.  Of more concern is the velocity at landing, however, that is the result of 1 outlier value, without which it is much more consistent and safe.

Figure 3.38 is a graph of the altitude versus time from averaged from the simulations in section 3.3.3 Flight Simulations.

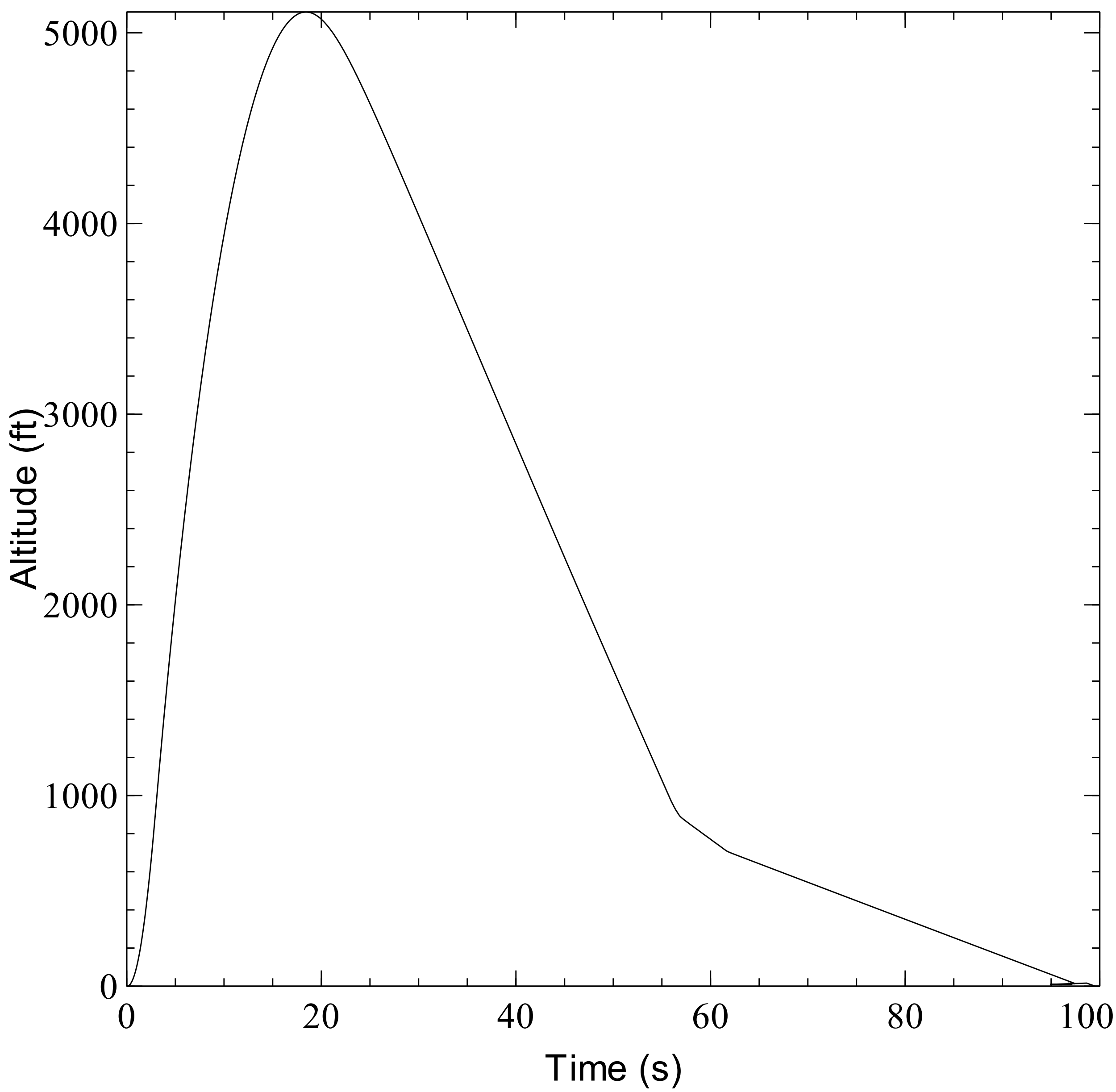


Figure 3.38 - Average Altitude vs Time

### 3.3.3 Flight Simulations

All flight simulations were performed using RockSim with altitude and longitude for Huntsville, AL, and average temperatures. They also use the coefficient of drag (Cd) found from the full-scale test flight of 0.35 and the measured mass of the rocket of 29.17 lbs.

#### 3.3.3.1 0 MPH Wind

| Event | Time (s) |
|---|---|
| Launch | T + 0 |
| Motor burnout | T + 3.165 |
| Roll induced | T + 3.5 |
| Rotations completed | T + 15.5 |
| Counter roll induced | T + 15.5 |
| Apogee reached | T + 18.613 |
| Drogue parachute deployed | T + 18.613 |
| Main parachute deployed | T + 57.266 |
| Landing | T + 91.282 |

Table 3.5 - Flight Events 0 MPH Wind

Table 3.6 shows some key values from the simulation.

| Statistic | Value |
|---|---|
| Apogee (ft) | 5209.38 |
| Maximum acceleration under power (ft/$s^2$) | 263.65 |
| Maximum velocity (ft/s) | 598.33 |
| Velocity at main parachute deployment (ft/s) | 118.82 |
| Rail exit velocity (ft/s) | 71.367 |
| Velocity at landing (ft/s) | 23.01 |
| Drift from RockSim (ft) | 0 |
| Drift calculated (ft) | 0 |
| Static stability margin at rail exit | 3.41 |

Table 3.6 - Key Flight Statistics 0 MPH Wind

#### 3.3.3.2 5 MPH Wind

| Event | Time (s) |
|---|---|
| Launch | T + 0 |
| Motor burnout | T + 3.165 |
| Roll induced | T + 3.5 |

| Event | Time (s) |
|---|---|
| Rotations completed | T + 15.5 |
| Counter roll induced | T + 15.5 |
| Apogee reached | T + 18.584 |
| Drogue parachute deployed | T + 18.584 |
| Main parachute deployed | T + 58.477 |
| Landing | T + 100.936 |

Table 3.7 - Flight Events 5 MPH Wind

Table 3.8 shows some key values from the simulation.

| Statistic | Value |
|---|---|
| Apogee (ft) | 5194.32 |
| Maximum acceleration under power (ft/$s^2$) | 263.65 |
| Maximum velocity (ft/s) | 598.20 |
| Velocity at main parachute deployment (ft/s) | 114.44 |
| Rail exit velocity (ft/s) | 71.367 |
| Velocity at landing (ft/s) | 18.42 |
| Drift from RockSim (ft) | 167.37 |
| Drift calculated (ft) | 603.89 |
| Static stability margin at rail exit | 3.40 |

Table 3.8 - Key Flight Statistics 5 MPH Wind

#### 3.3.3.3 10 MPH Wind

| Event | Time (s) |
|---|---|
| Launch | T + 0 |
| Motor burnout | T + 3.165 |
| Roll induced | T + 3.5 |
| Rotations completed | T + 15.5 |
| Counter roll induced | T + 15.5 |
| Apogee reached | T + 18.500 |
| Drogue parachute deployed | T + 18.500 |
| Main parachute deployed | T + 58.014 |
| Landing | T + 100.477 |

Table 3.9 - Flight Events 10 MPH Wind

Table 3.10 shows some key values from the simulation.

| Statistic | Value |
|---|---|
| Apogee (ft) | 5148.43 |
| Maximum acceleration under power (ft/$s^2$) | 263.64 |

| Statistic | Value |
| --- | --- |
| Maximum velocity (ft/s) | 597.81 |
| Velocity at main parachute deployment (ft/s) | 115.15 |
| Rail exit velocity (ft/s) | 71.37 |
| Velocity at landing (ft/s) | 18.42 |
| Drift from RockSim (ft) | 356.80 |
| Drift calculated (ft) | 1202.33 |
| Static stability margin at rail exit | 3.40 |

Table 3.10 - Key Flight Statistics 10 MPH Wind

#### 3.3.3.4 15 MPH Wind

| Event | Time (s) |
| --- | --- |
| Launch | T + 0 |
| Motor burnout | T + 3.165 |
| Roll induced | T + 3.5 |
| Rotations completed | T + 15.5 |
| Counter roll induced | T + 15.5 |
| Apogee reached | T + 18.360 |
| Drogue parachute deployed | T + 18.360 |
| Main parachute deployed | T + 57.069 |
| Landing | T + 99.526 |

Table 3.11 - Flight Events 15 MPH Wind

Table 3.12 shows some key values from the simulation.

| Statistic | Value |
| --- | --- |
| Apogee (ft) | 5071.78 |
| Maximum acceleration under power (ft/$s^2$) | 263.62 |
| Maximum velocity (ft/s) | 597.17 |
| Velocity at main parachute deployment (ft/s) | 116.32 |
| Rail exit velocity (ft/s) | 71.37 |
| Velocity at landing (ft/s) | 18.42 |
| Drift from RockSim (ft) | 551.63 |
| Drift calculated (ft) | 1785.65 |
| Static stability margin at rail exit | 3.40 |

Table 3.12 - Key Flight Statistics 15 MPH Wind

#### 3.3.3.5 20 MPH Wind

| Event | Time (s) |
|---|---|
| Launch | T + 0 |
| Motor burnout | T + 3.165 |
| Roll induced | T + 3.5 |
| Rotations completed | T + 15.5 |
| Counter roll induced | T + 15.5 |
| Apogee reached | T + 18.168 |
| Drogue parachute deployed | T + 18.168 |
| Main parachute deployed | T + 56.176 |
| Landing | T + 98.634 |

Table 3.13 - Flight Events 20 MPH Wind

Table 3.14 shows some key values from the simulation.

| Statistic | Value |
|---|---|
| Apogee (ft) | 4966.24 |
| Maximum acceleration under power (ft/$s^2$) | 263.60 |
| Maximum velocity (ft/s) | 596.29 |
| Velocity at main parachute deployment (ft/s) | 117.92 |
| Rail exit velocity (ft/s) | 71.37 |
| Velocity at landing (ft/s) | 18.42 |
| Drift from RockSim (ft) | 761.01 |
| Drift calculated (ft) | 2360.33 |
| Static stability margin at rail exit | 3.40 |

Table 3.14 - Key Flight Statistics 20 MPH Wind

### 3.3.4 Stability

This section uses the averaged data from section 3.3.2 Flight Profile. The 2 most important considerations for stability are static stability margin and rail exit velocity. The static stability margin of the rocket on the launch pad is 3.33 and by rail exit it increases to 3.40. While this is close to being over stable, it is still reasonable, and importantly, it is above the required minimum of 2. Rail exit velocity is 71.37 ft/s, putting it safely above the minimum requirement of 52 ft/s. The combination of these values indicates that the rocket is stable, which is corroborated by the test flights.

Figure 3.39 shows a graph of the Center of Pressure (CP) and the Center of Gravity (CG) versus time, and Figure 3.40 is a graph of the static stability margin versus time. Both graphs show from launch until apogee.

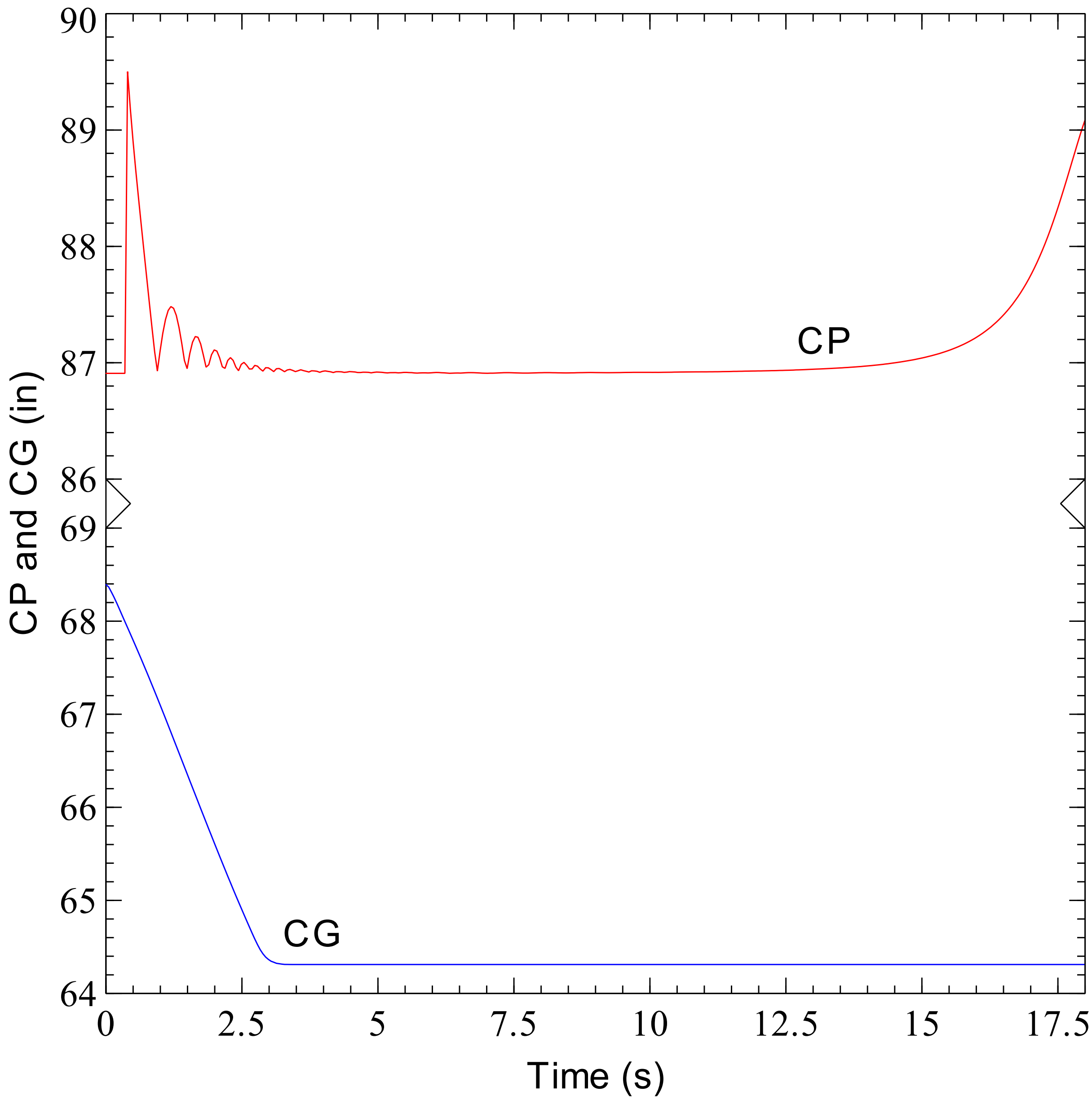


Figure 3.39 - CP and CG vs Time

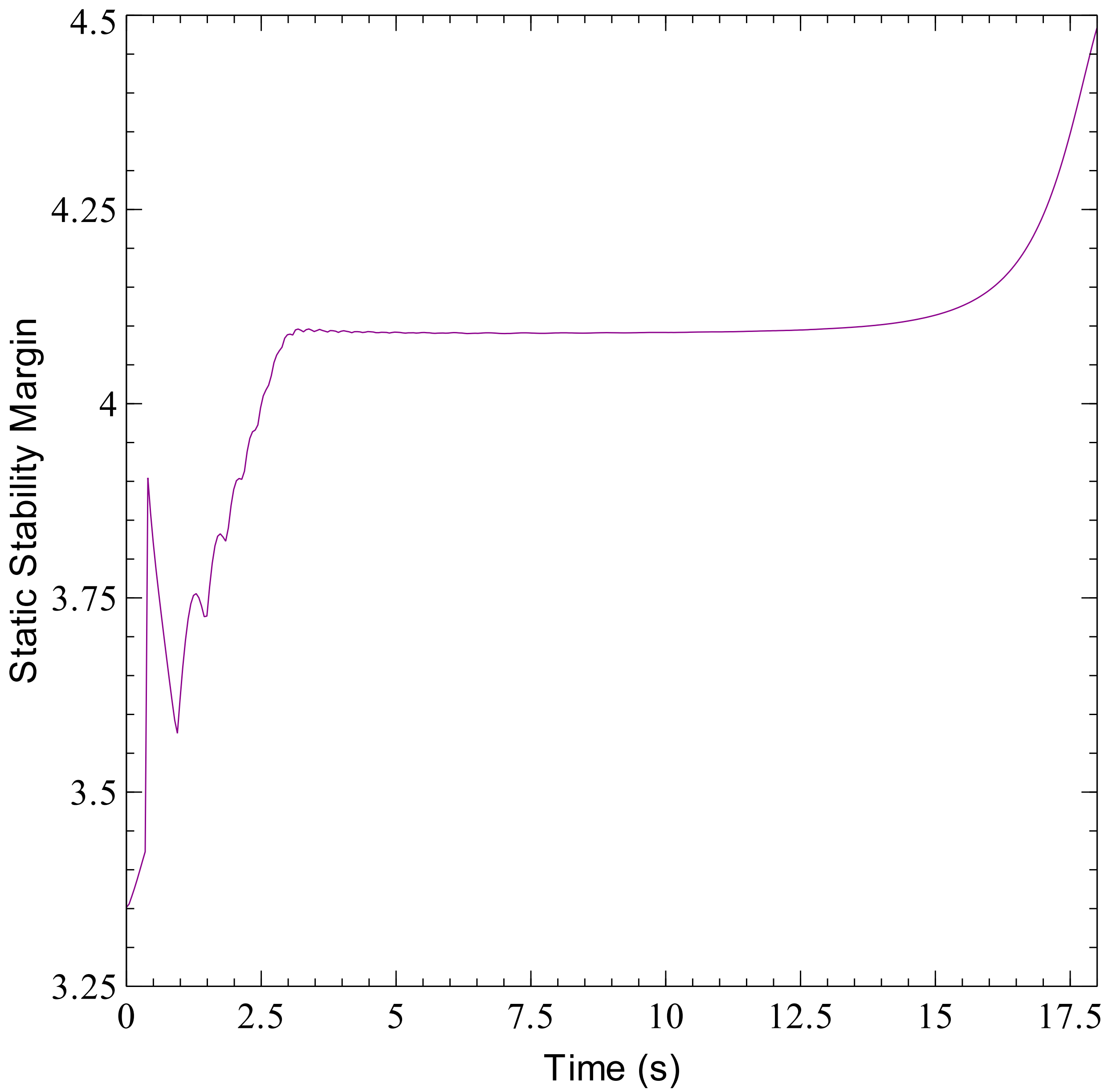


Figure 3.40 - Static Stability Margin vs Time

### 3.3.5 Kinetic Energy

Table 3.15 shows the kinetic energy of each independent section of the rocket at main parachute deployment and landing. The calculations were made using the averaged data from section 3.3.2 Flight Profile.

| Flight Event | Upper Section (ft-lbs) | Avionics Bay (ft-lbs) | Lower Section (ft-lbs) |
|---|---|---|---|
| Main parachute deployment | 2622 | 847.7 | 1763 |
| Landing | 72.2 | 23.3 | 48.5 |

Table 3.15 - Kinetic Energy

Although the value for the upper section is close to the maximum allowable energy of 75 ft-lbs, it is likely that that section will land after the lower section, meaning that it will be traveling more slowly than the simulated value for landing velocity. Even without that however, all the sections are below the limit.

## 3.4 Full Scale Flight

### 3.4.1 Launch Day

The full-scale rocket was launched on February 11th, 2017 at the Tripoli Central Virginia launch site in Rapidan, Virginia. The weather conditions on launch day are listed below:

| Condition | Value |
|---|---|
| Wind (MPH) | 6 |
| Temperature (°F) | 56 |
| Altitude Above Sea Level (ft) | 410 |

Table 3.16 - Full-Scale Test Flight Conditions

### 3.4.2 Results

#### 3.4.2.1 Launch Vehicle

The flight, landing, and recovery were all successful. The rocket flew straight, with no significant oscillations as it came off the launch rail. All recovery system events occurred at the correct times, and the rocket was safely recovered.

#### 3.4.2.2 Payload

The fully-assembled payload was flown on the test flight to provide the correct weight. However, it was turned off.

### 3.4.3 Test Flight Simulations

A simulation was done in RockSim using the launch day conditions listed above. A graph of the altitude versus time is shown in Figure 3.41, and some key flight statistics are shown in Table 3.17.

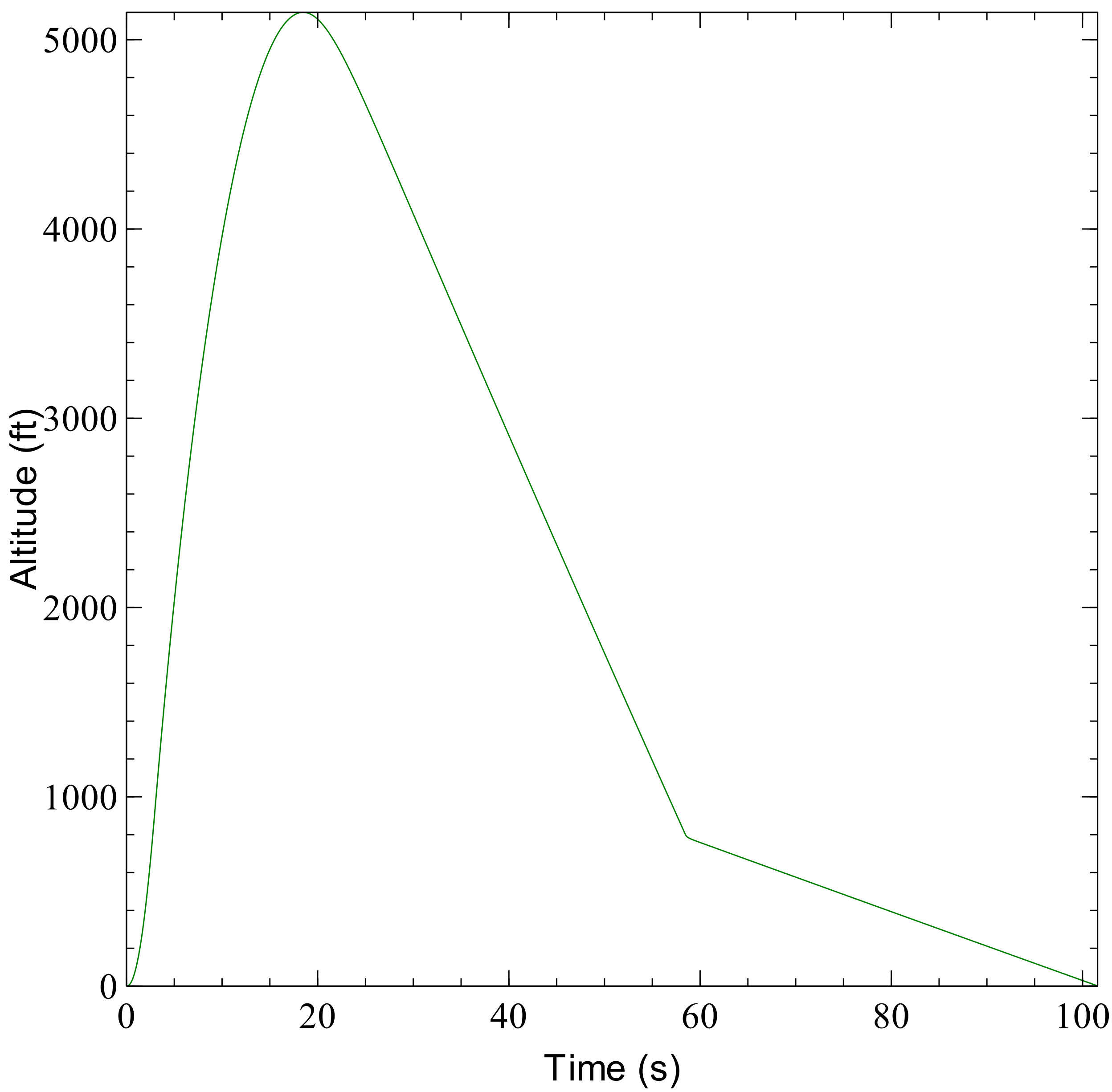


Figure 3.41 - Full-Scale Test Simulation Altitude vs Time

| Statistic | Value |
|---|---|
| Apogee (ft) | 5144.62 |
| Maximum velocity (ft/s) | 597.27 |

| Statistic | Value |
|---|---|
| Drogue descent rate (ft/s) | 112.72 |
| Main descent rate (ft/s) | 18.12 |
| Drift (ft) | 152.7 |
| Time to burnout (s) | 3.165 |
| Time to apogee (s) | 18.476 |
| Time to main deployment (s) | 58.474 |
| Time to landing (s) | 101.637 |

Table 3.17 - Full-Scale Test Simulation Key Flight Statistics

### 3.4.4 Analysis

All data from the flight was gathered using the Missile Works RRC3 altimeters in the recovery system or from video analysis.

| Statistic | Value |
|---|---|
| Apogee (ft) | 5150 |
| Maximum velocity (ft/s) | 571 |
| Drogue descent rate (ft/s) | 88 |
| Main descent rate (ft/s) | 30 |
| Drift (ft) | 1584 |
| Time to burnout (s) | 4.7 |
| Time to apogee (s) | 19.2 |
| Time to main deployment (s) | 68.7 |
| Time to landing (s) | 95.0 |

Table 3.18 - Full-Scale Test Flight Data

| Statistic | Simulation Value | Actual Value | Difference |
|---|---|---|---|
| Apogee (ft) | 5144.62 | 5150 | 5.38 |
| Maximum velocity (ft/s) | 597.27 | 571 | 26.27 |
| Drogue descent rate (ft/s) | 112.72 | 88 | 24.72 |
| Main descent rate (ft/s) | 18.12 | 30 | 11.88 |
| Drift (ft) | 152.7 | 1584 | 1431.3 |
| Time to burnout (s) | 3.165 | 4.7 | 1.535 |
| Time to apogee (s) | 18.476 | 18 | 0.476 |
| Time to main deployment (s) | 58.474 | 68.7 | 10.226 |
| Time to landing (s) | 101.637 | 95.0 | 6.637 |

Table 3.19 - Comparison of Full-Scale Test Flight and Simulation Data

The difference in the drift distance has in part to do with the fact that the RockSim simulations have a tendency to overestimate wind cocking, and likely also because of higher wind speeds at altitude.

The likely cause of the difference in time to burnout is the fact that the actual measurement was not very precise because it was based off of videos of the flight.

The estimated coefficient of drag (Cd) from this flight is 0.35. This is substantially lower than the Cd estimated at CDR, 0.52. This difference likely explains the fact that the apogee was higher than expected on the full-scale flight. The Cd estimated at CDR was based off the subscale rocket's apogee, which was lower than expected. This lower apogee was attributed to drag, resulting in a higher estimate for the full-scale Cd. It may be the case, however, that the altitude was lost due to oscillations as the subscale rocket came off the launch rail. The full-scale rocket does not have that issue however, due to its higher rail exit velocity of 71 ft/s as opposed to 43 ft/s.

# 4 Experiment Criteria

## 4.1 Design and Construction of Payload

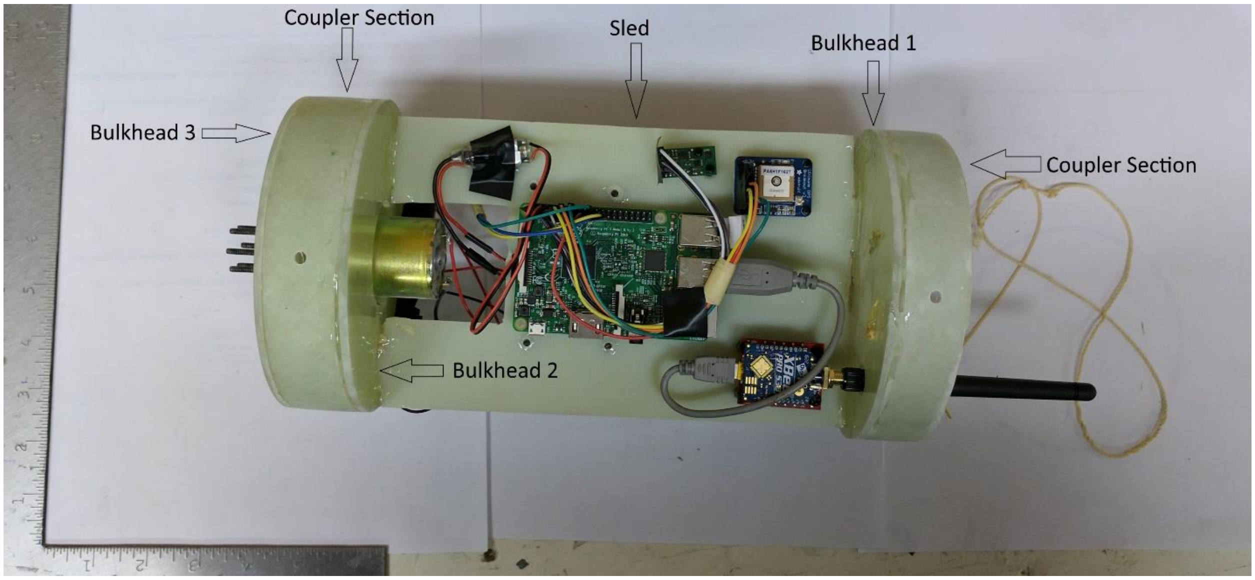


Figure 4.1 - Payload Front Side without Reaction Wheel

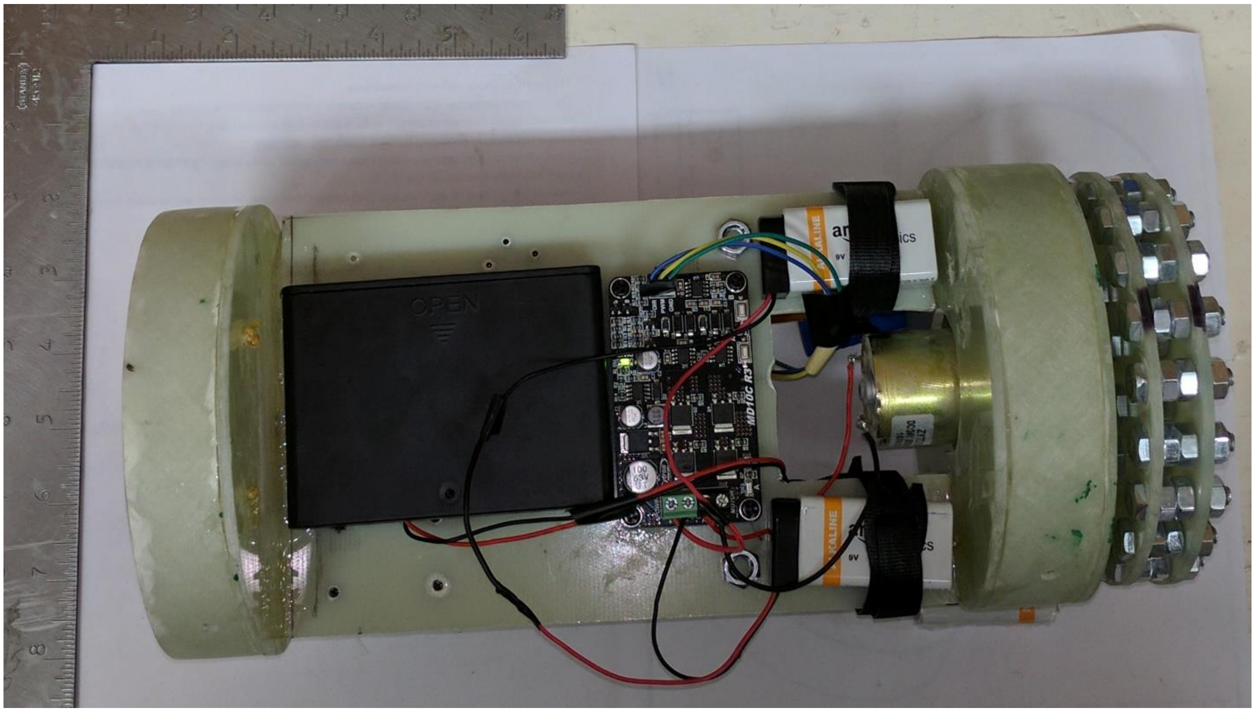

Figure 4.2 - Payload Back Side with Reaction Wheel

## 4.1.1 Sled

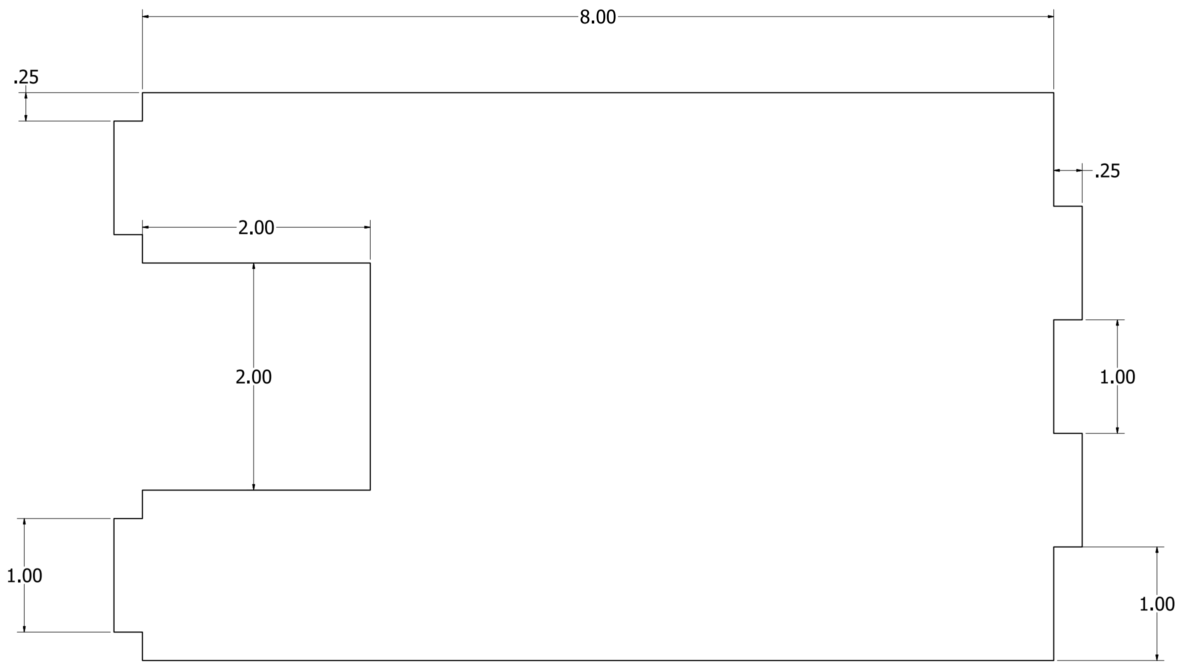


Figure 4.3 - Payload Electronics Sled Drawing

The payload electronics sled was cut out of 0.25 in fiberglass. A cutout was made in the bottom for the DC motor to sit in. Tabs were cut on the ends of the sled to slot with the bulkheads. Holes were drilled where the standoffs are placed.

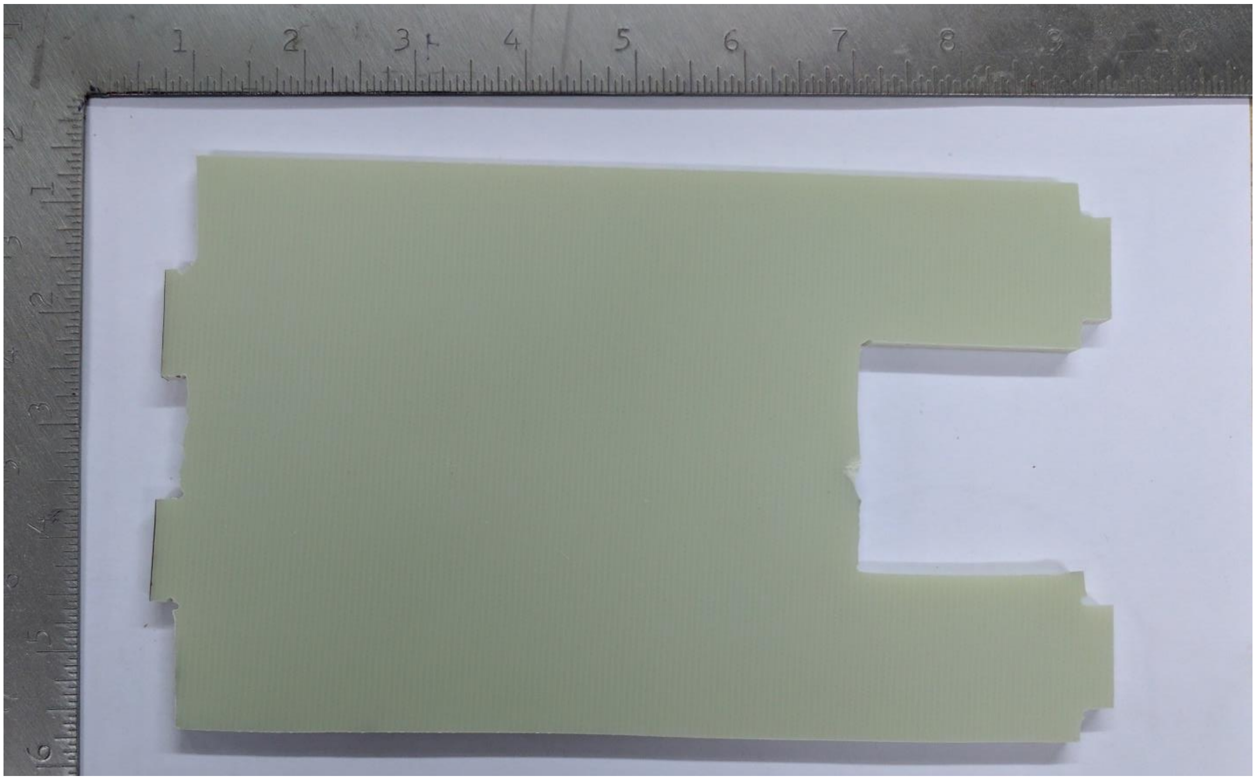

Figure 4.4 - Payload Electronics Sled without Holes

## 4.1.2 Bulkhead 1

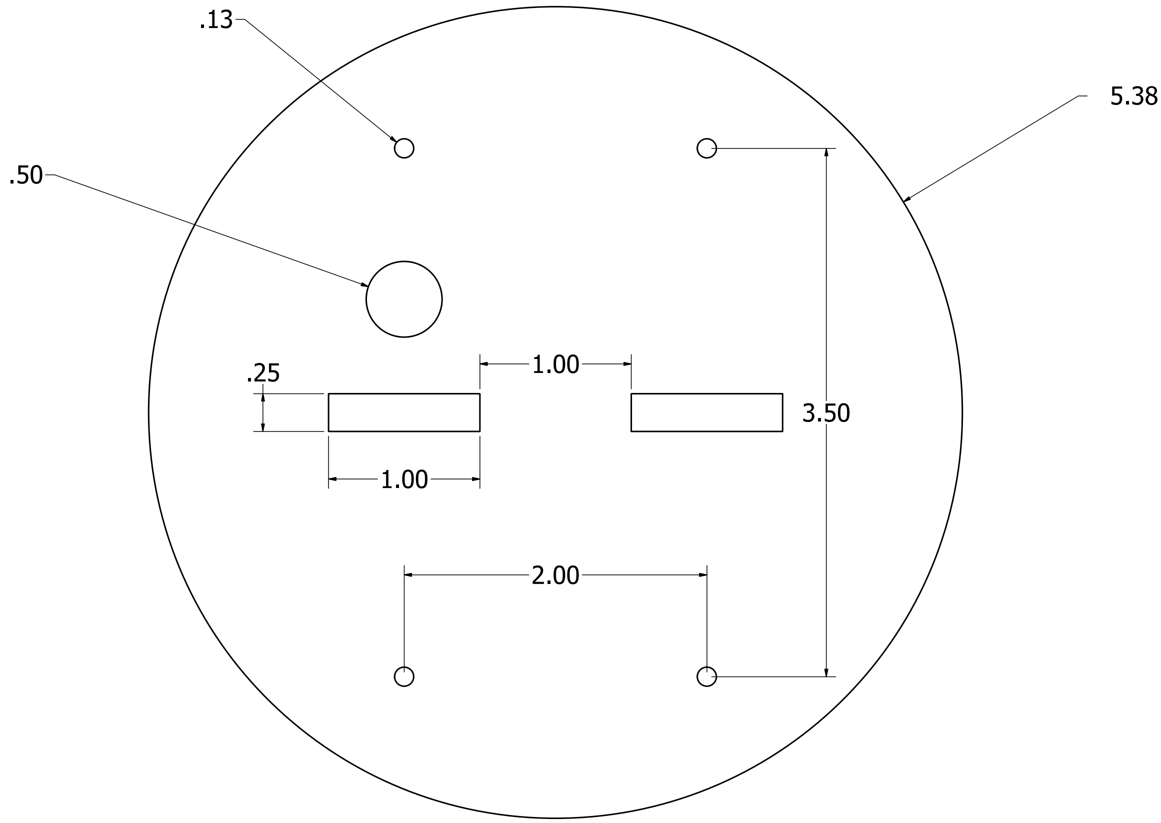


Figure 4.5 - Bulkhead 1 Drawing

This bulkhead is a commercial 0.13 in thick fiberglass bulkhead with slots cut for the sled. It is attached to the sled with epoxy. There is 1 large hole for the transceiver antenna and a hole in the center to assist in centering the bulkhead. The 4 small holes are for attaching a piece of string to use as a handle allowing for easy placement of the payload within the upper section as well as easy retrieval of the payload. The bulkhead and the other 2 bulkheads have had their edges sanded down so that the payload can be inserted smoothly into the upper section.

Figure 4.6 - Bulkhead 1

### 4.1.3 Bulkhead 2

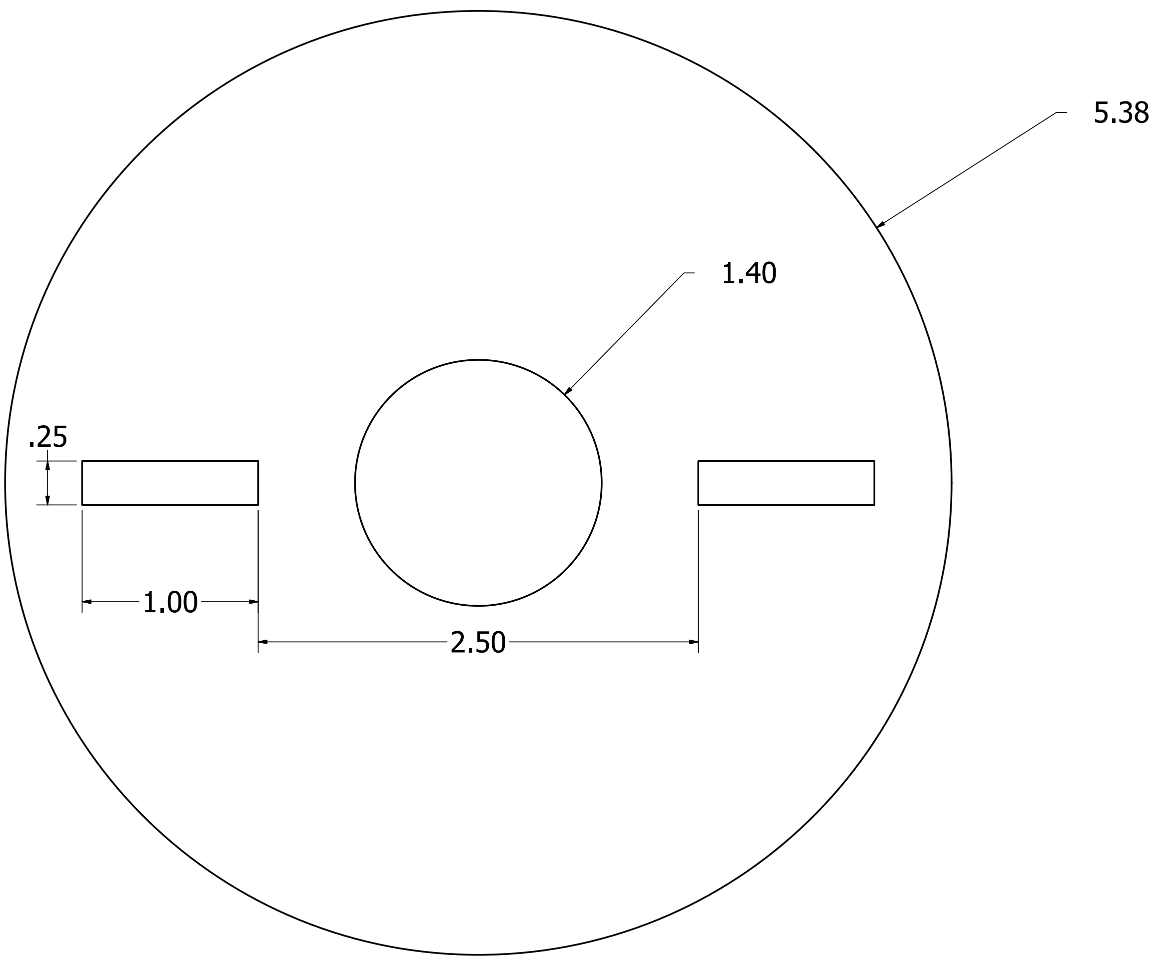


Figure 4.7 - Bulkhead 2 Drawing

This bulkhead is a commercial 0.13 in thick fiberglass bulkhead with slots cut for the sled. It is attached to the sled with epoxy. A large hole is in the center for the DC motor to pass through. This bulkhead is also epoxied to a coupler section and then bulkhead 3.

Figure 4.8 - Bulkhead 2

## 4.1.4 Bulkhead 3

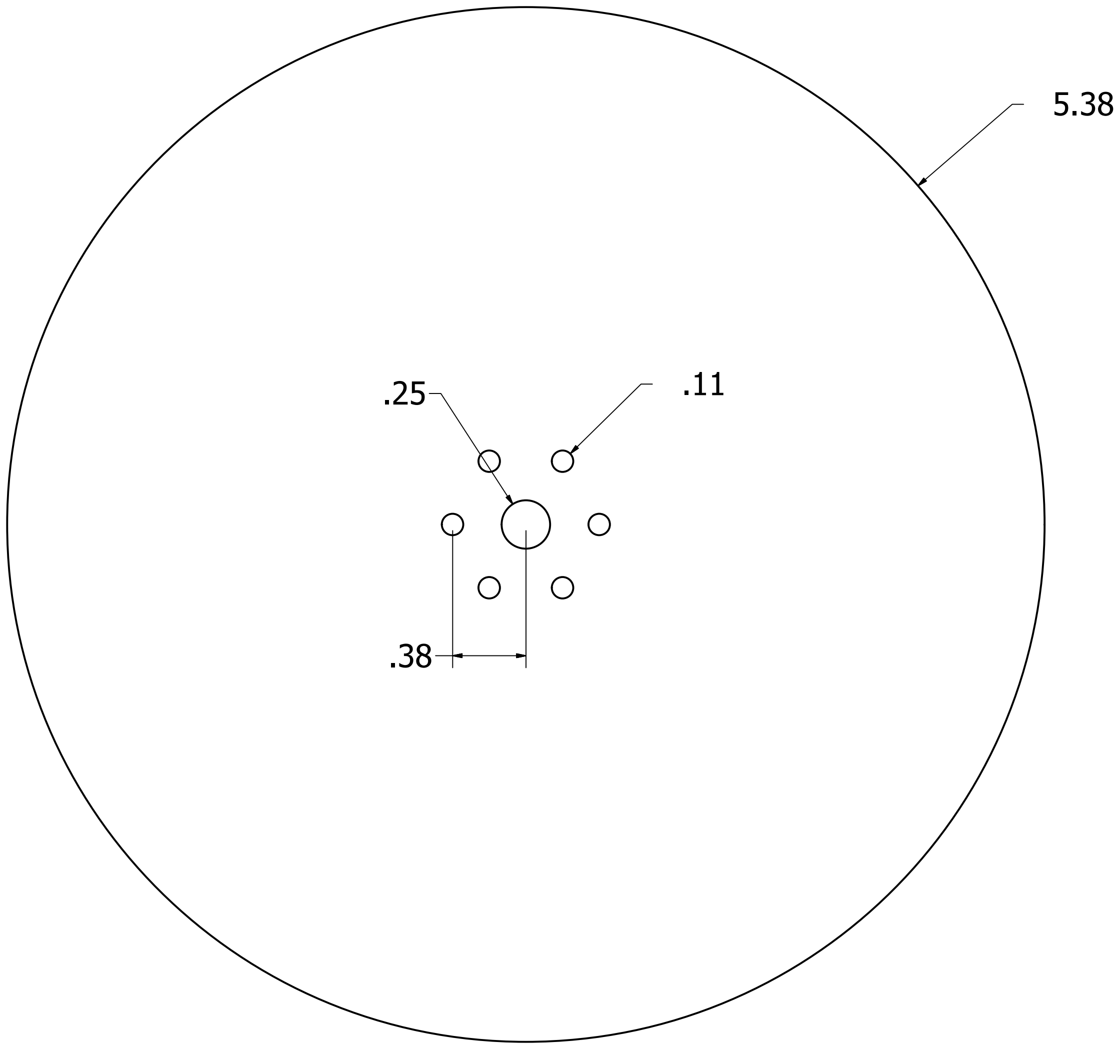


Figure 4.9 - Bulkhead 3 Drawing

This bulkhead is a commercial 0.13 in thick fiberglass bulkhead. There is a hole in the center for the DC motor shaft to protrude through, and 6 holes around the center for M3 bolts to secure the DC motor. 3 holes are used to secure the DC motor; the other 3 are unused.

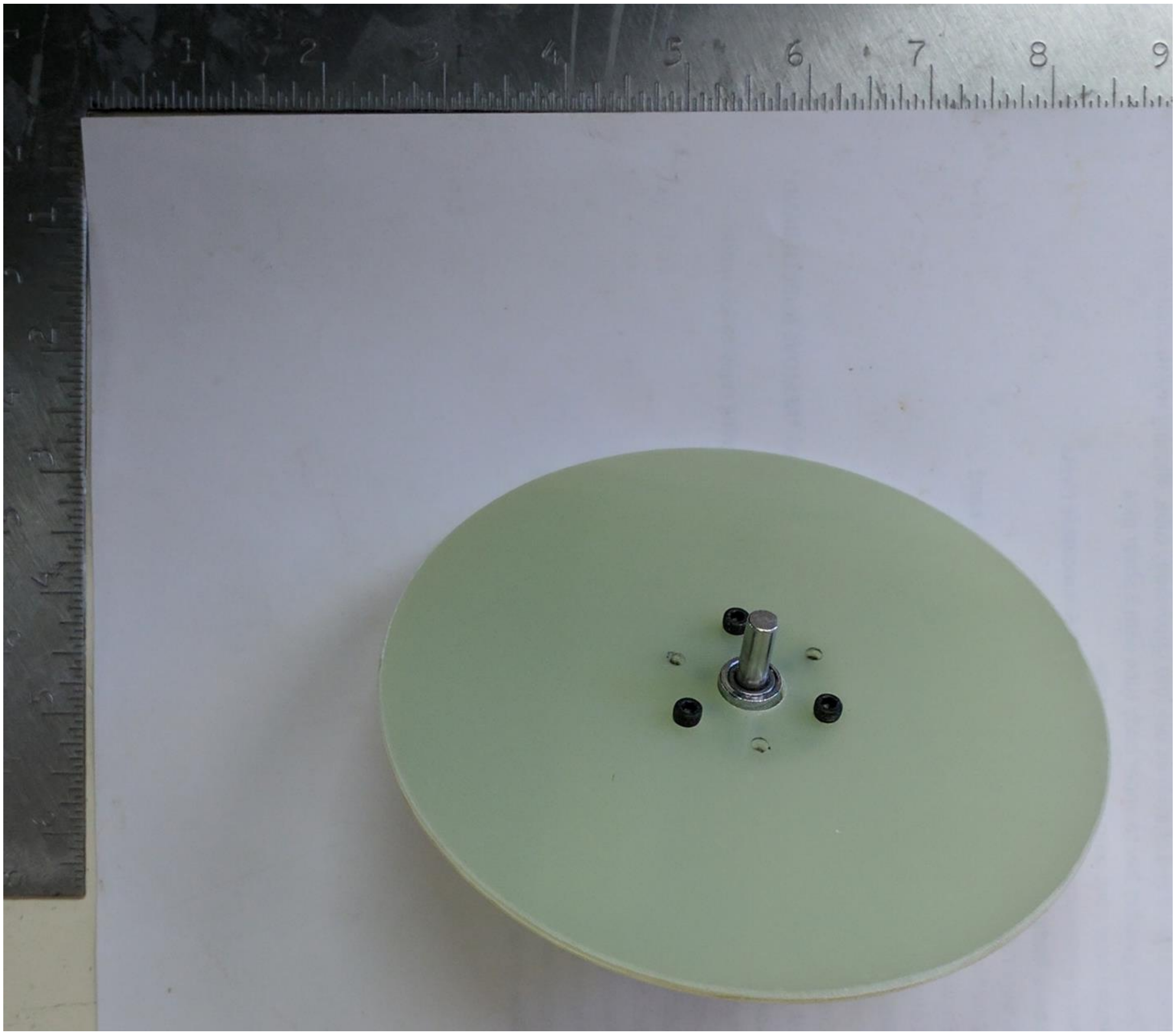

Figure 4.10 - Bulkhead 3 with DC Motor Attached

## 4.1.5 Coupler Sections

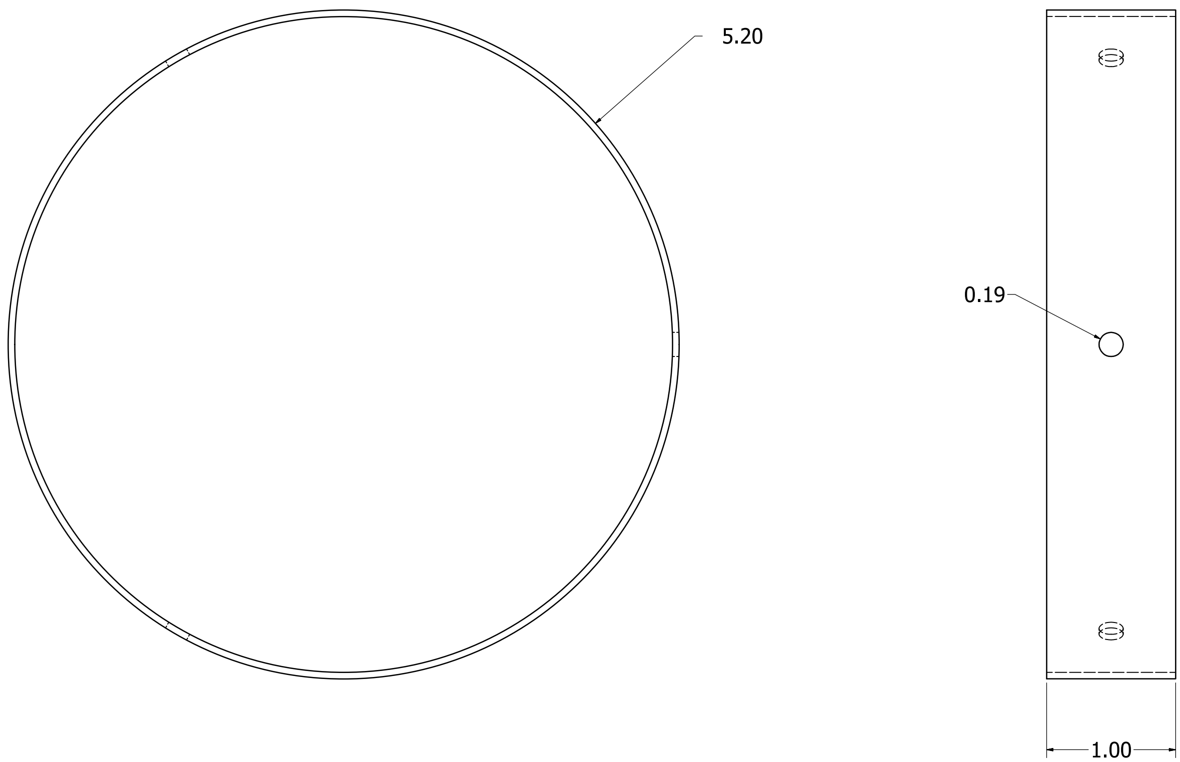


Figure 4.11 - Coupler Section Drawing

There are two identical 1 in sections of coupler in the payload. One is epoxied to Bulkhead 1 at the top and the other coupler is epoxied between bulkhead 2 and 3. 3 holes are drilled into each coupler at 120° apart for rivets to be placed, this is how the payload is attached to the upper section of the rocket.

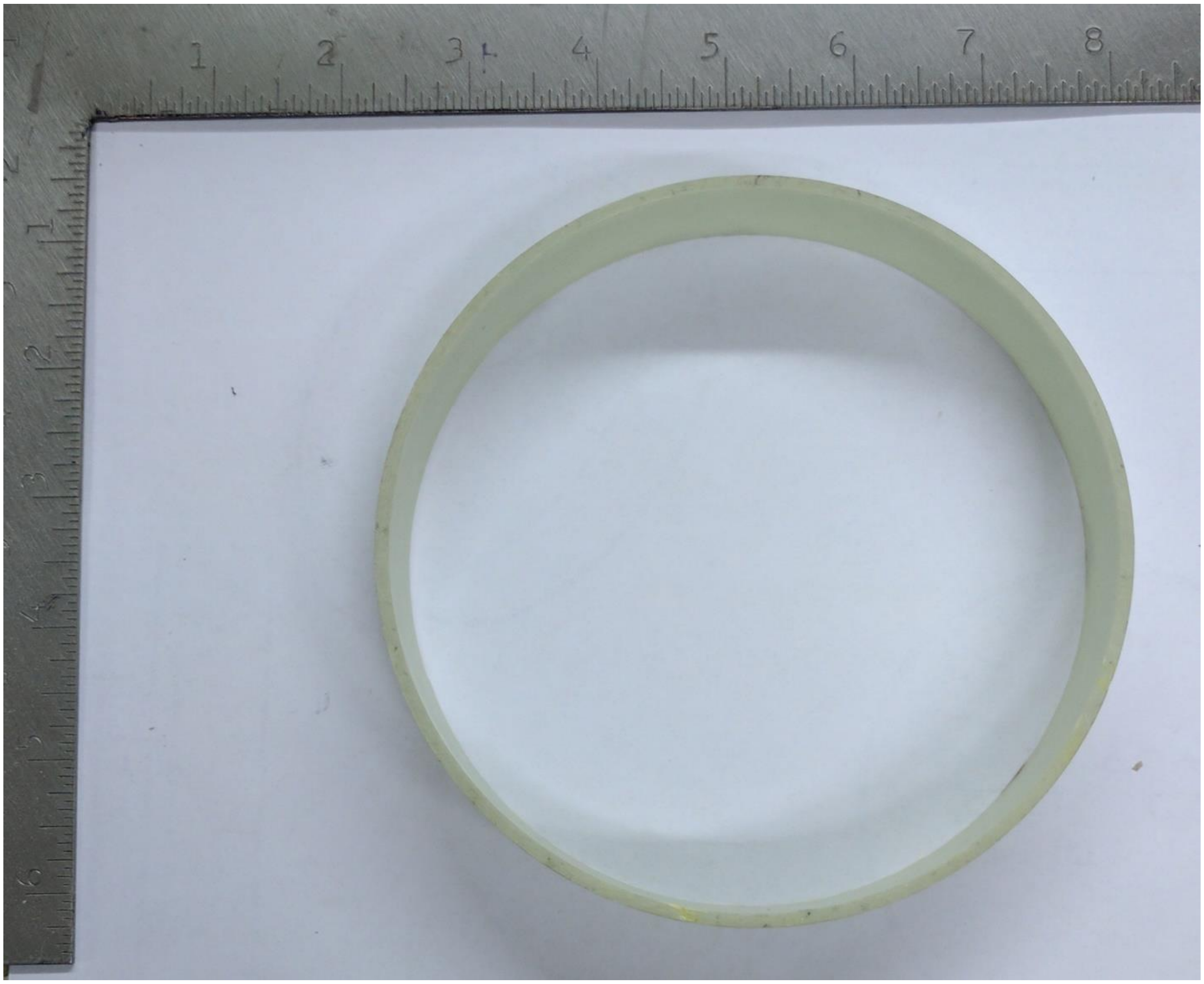


Figure 4.12 - Coupler Section Top View

### 4.1.6 Reaction Wheel

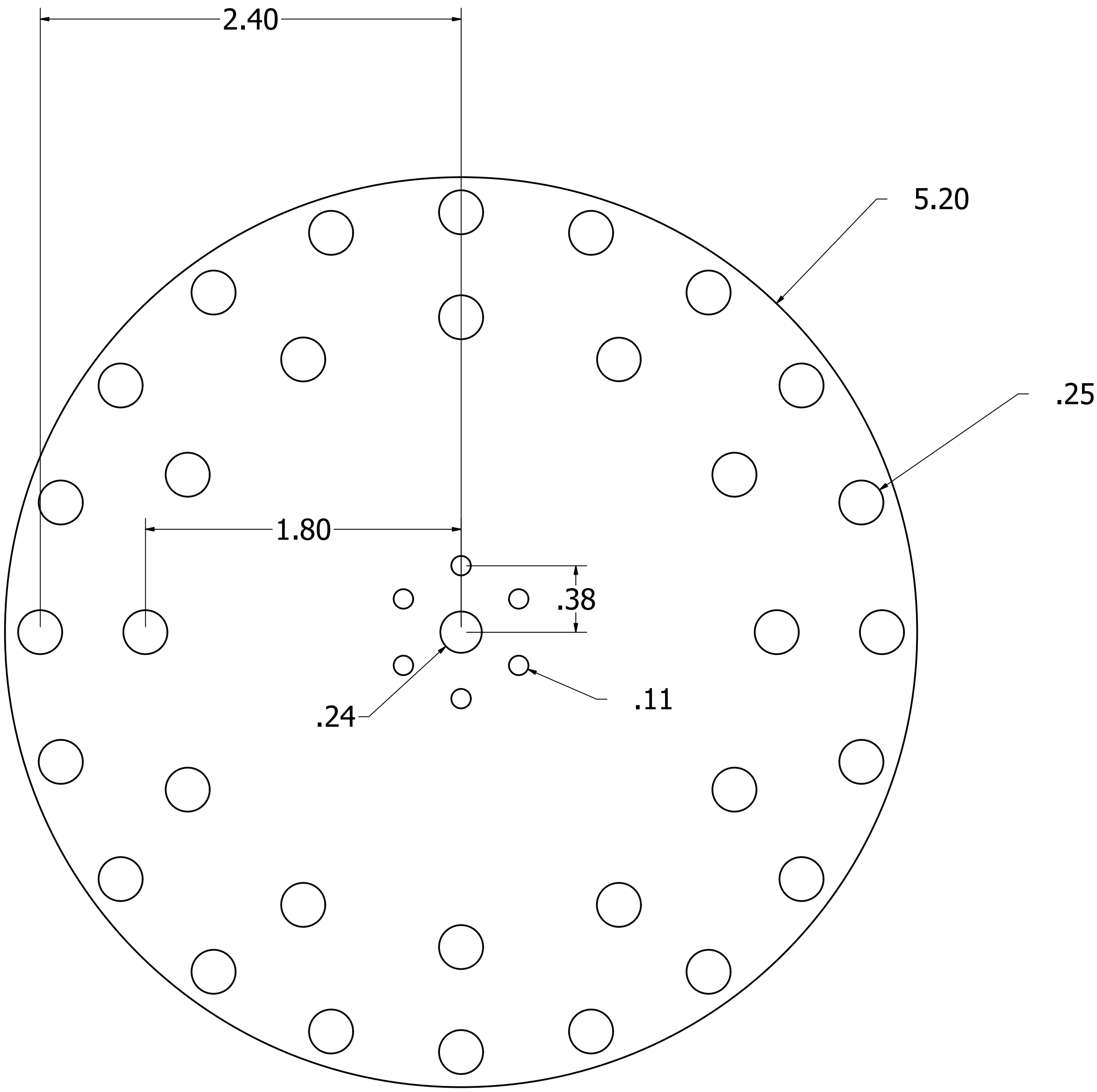


Figure 4.13 - Reaction Wheel Disk Drawing

The reaction wheel is made up 2 5.194 in diameter fiberglass coupler bulkheads that are 0.13 in thick with 2 rings of 1/4-20 x 1 in bolts going through both bulkheads; 20 bolts go around the outer ring and 12 bolts are in the inner ring. There are 2 nuts in between the bulkheads followed by a nut on the end of the bolt outside of the second bulkhead. These outer nuts are thread-locked to prevent the reaction wheel from coming apart. The nuts and bolts provide an equal distribution of mass across the reaction wheel. 6 4-

40 x 1 in bolts span through both bulkheads to attach to a motor shaft coupler. This shaft coupler joins the reaction wheel to the motor drive shaft.

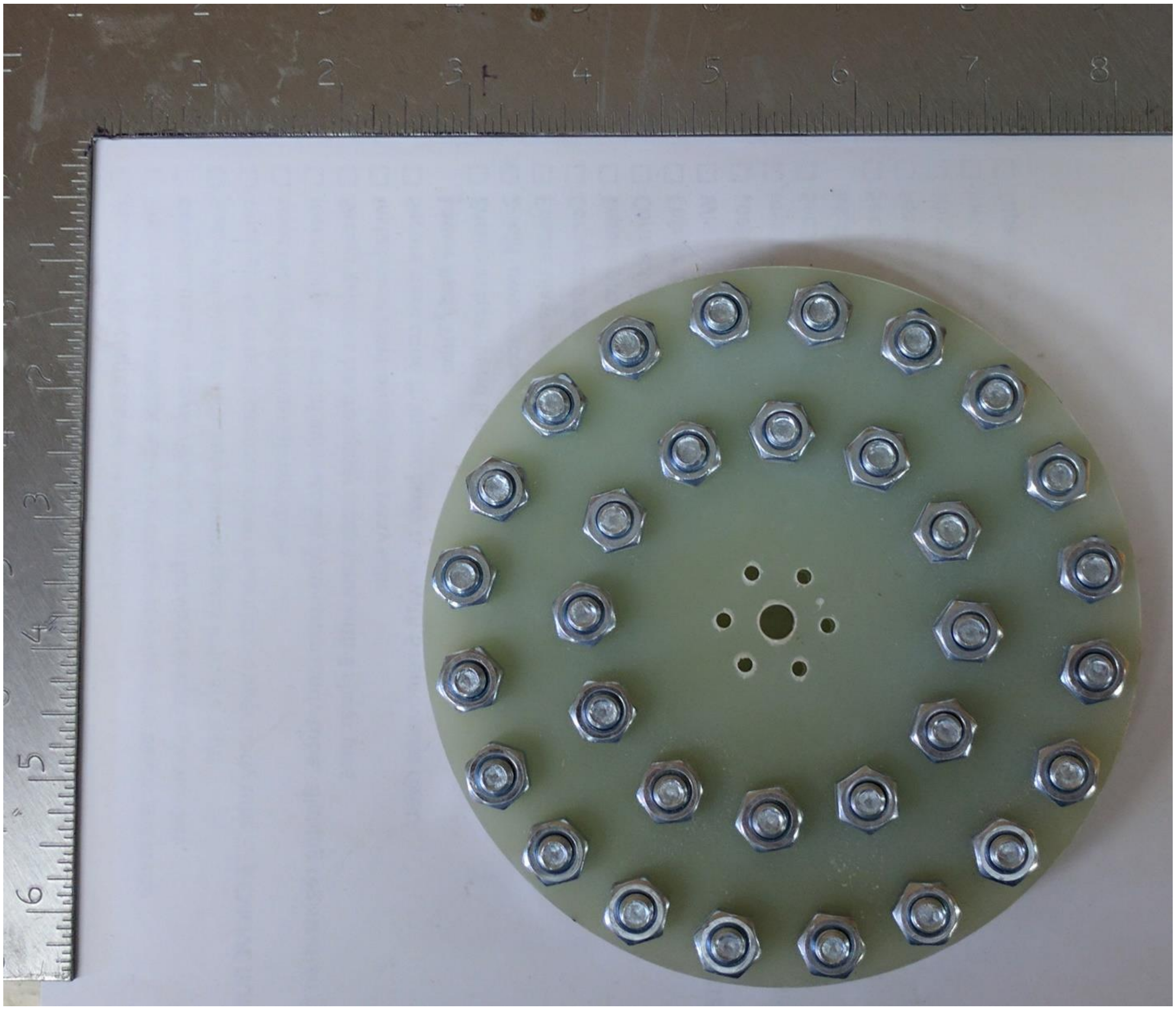

Figure 4.14 - Reaction Wheel Bottom View

Figure 4.15 - Reaction Wheel Side View

## 4.2 Ability to Meet Mission Success Criteria

### 4.2.1 Roll Induction

The moment of inertia of the launch vehicle has been estimated to be 338 lb-in$^2$, using OpenRocket. The moment of inertia of the reaction wheel has been calculated to be 7.7 lb-in$^2$. The ratio between these numbers is 43.9, meaning the reaction wheel must spin 43.9 times faster than the desired angular velocity of the rocket. The desired angular velocity is 0.25 rotations per second (to complete 3 rotations in 12 seconds). The reaction wheel rotation rate required to achieve this is 11 rotations per second, or 660 rotations per minute (rpm). This is well under the motor's 1000 rpm rating.

### 4.2.2 Counter Roll

The reaction wheel can be slowed to as low as 70 rpm. This is slow enough to allow precise control of launch vehicle rotation.

### 4.2.3 Data Collection

The payload is capable of collecting and storing data from the instruments. The data is stored on an SD card and a USB flash drive, both of which are resistant to crashes and power loss.

### 4.2.4 Data Transmission

The payload is capable of transmitting data, including position. This data is used to track the rocket and to determine if the flight is proceeding in a safe manner (e.g. is the rocket travelling at the expected velocity?).

### 4.2.5 Target Identification

The camera can take high enough resolution video to identify targets on the ground. The Raspberry Pi's processor is fast enough to process the video while coordinating the activities of the instruments, transceiver, and DC motor.

## 4.3 Instrumentation

Onboard is an Inertial Measurement Unit (IMU), a GPS tracker, and a camera. The magnetometer and accelerometer on the IMU are used to calculate angular velocity. The camera provides visual evidence of rotation, and is used to identify the ground targets.

### 4.3.1 IMU

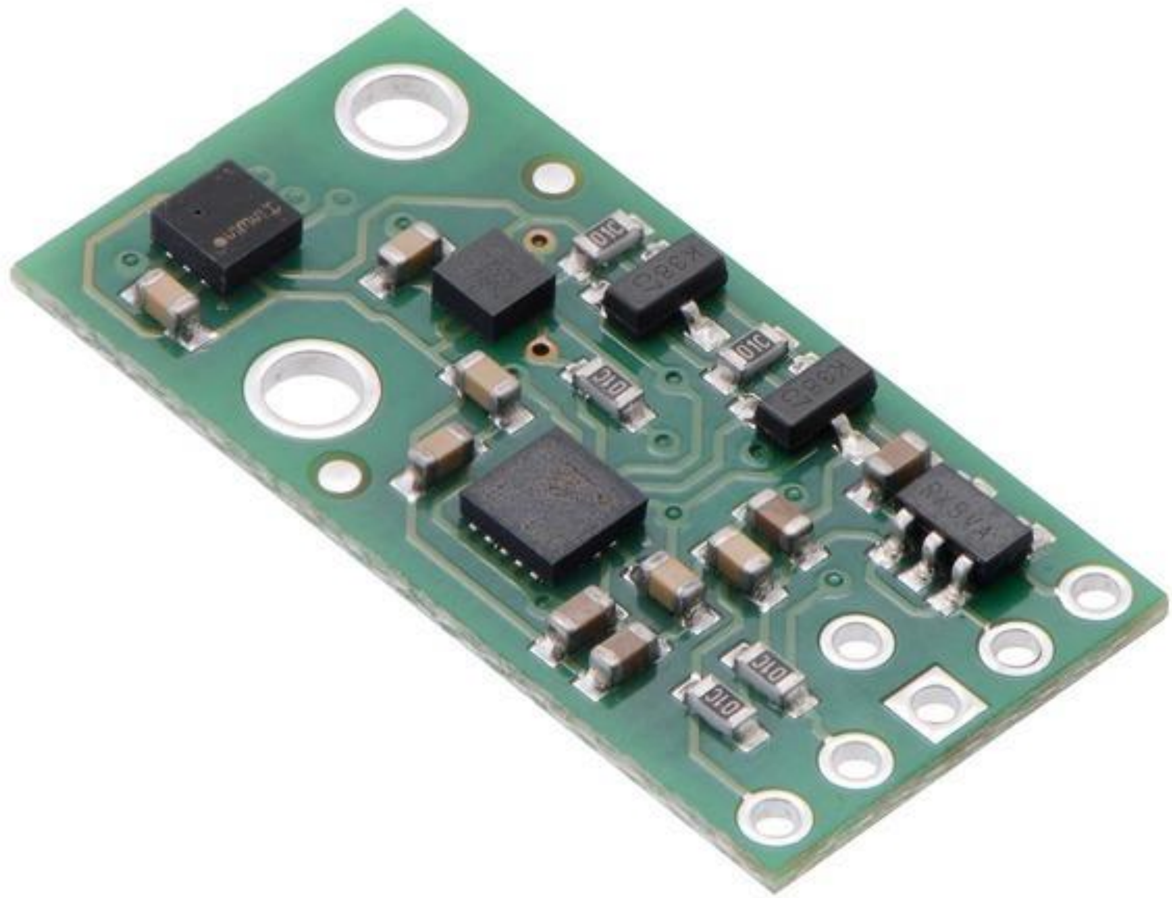

Figure 4.16 - IMU

The IMU is an AltIMU-10 v5 from Pololu. It includes an accelerometer, a gyroscope, a magnetometer, and a barometer. It is connected to the Raspberry Pi via an $I^2C$ connection. The IMU is mounted on M2 nylon standoffs, which are epoxied into holes on the payload electronics sled.

| Instrument | Precision | Uncertainty |
|---|---|---|
| Accelerometer | 0.0024 m/s$^2$ | ±0.0012 m/s$^2$ |
| Gyroscope | 0.0175 °/s | ±0.00875 °/s |
| Magnetometer | 0.15 mgauss | ±0.075 mgauss |
| Barometer | 0.024 Pa | ±0.012 Pa |

Table 4.1 - IMU Statistics

## 4.3.2 GPS

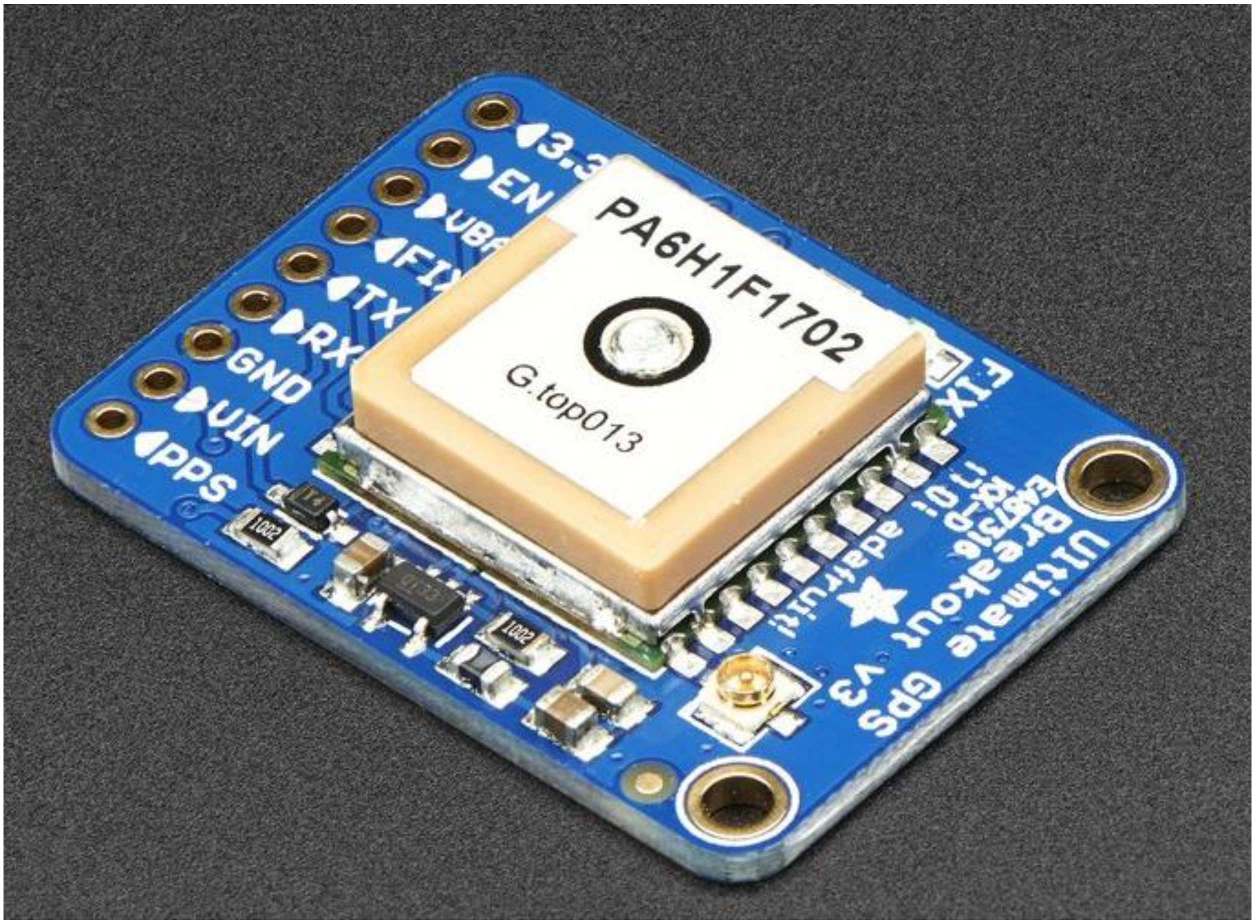


Figure 4.17 - GPS Tracker

The GPS tracker is an Ultimate GPS Breakout Version 3 from Adafruit. It is connected to the Raspberry Pi via the software serial port (the UART pins). The GPS tracker is mounted on M2 nylon standoffs, which are epoxied into holes on the payload electronics sled.

| Measurement | Precision | Uncertainty |
|---|---|---|
| Position | 3 m | ±1.5 m |

Table 4.2 - GPS Module Statistics

### 4.3.3 Camera

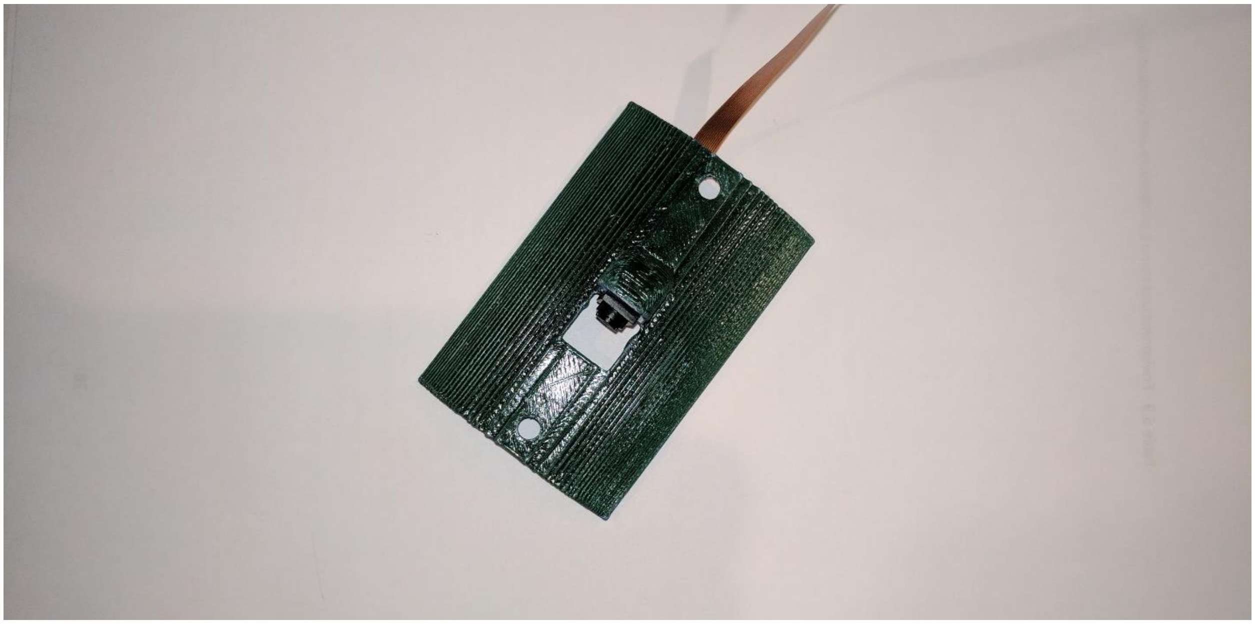

Figure 4.18 - Camera

The camera is a 5-megapixel Spy Camera for Raspberry Pi from Adafruit. It is connected to the Raspberry Pi via the Camera Serial Interface (CSI) port. The camera is epoxied onto a back plate that is 3D-printed from ABS. The back plate sits inside the upper body tube, and is held in place by 2 rivets.

## 4.4 Payload Electronics

### 4.4.1 Raspberry Pi

The control unit for the payload is a Raspberry Pi 3 Model B from Adafruit. The Raspberry Pi coordinates the instruments, transceiver, camera, and motor controller. The video from the camera is stored on a 128GB USB flash drive from Samsung. All other data is stored on an 8 GB SD card.

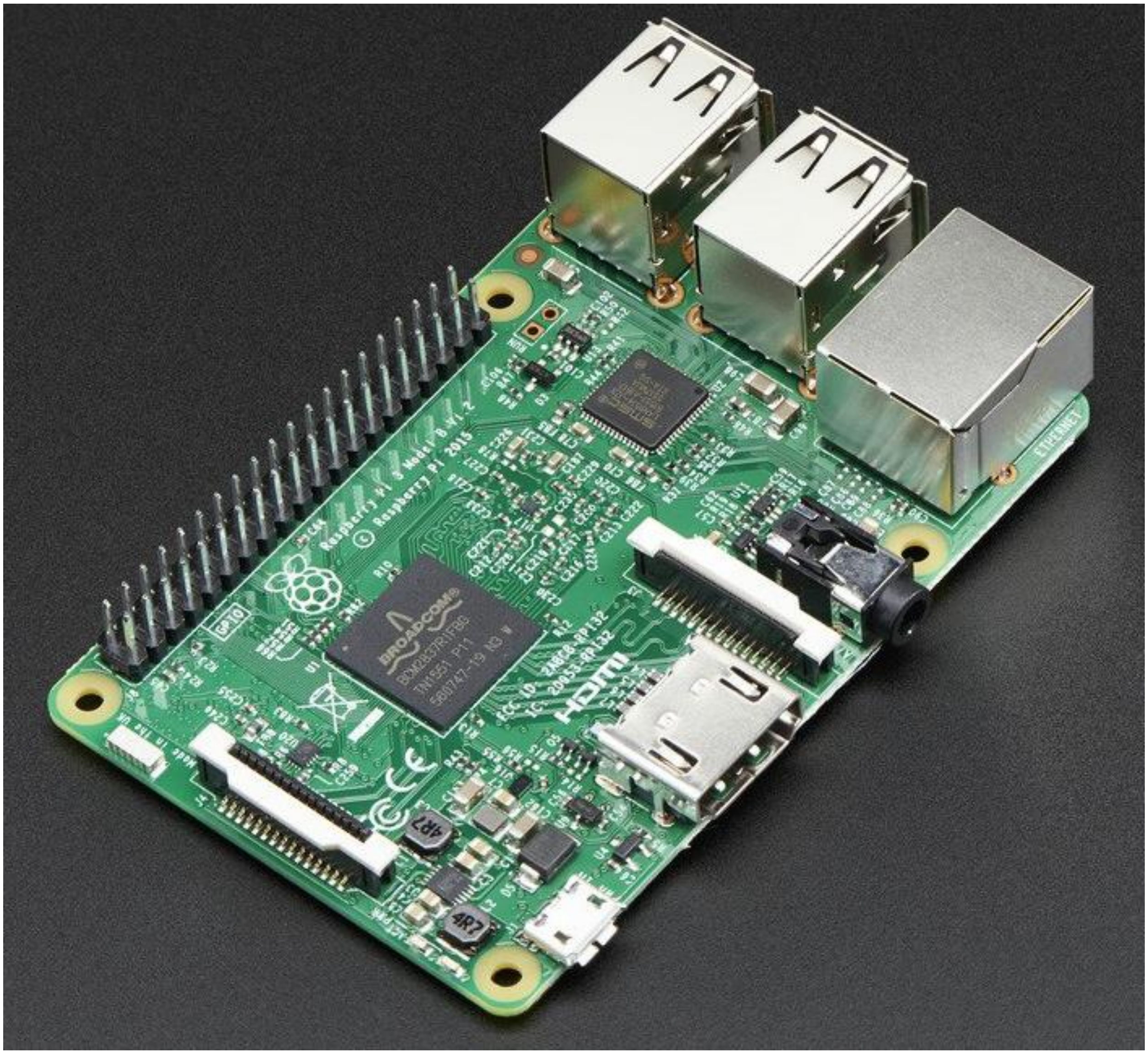

Figure 4.19 - Raspberry Pi

## 4.4.2 Transceiver

The transceiver consists of three parts: an XBee-Pro 900HP radio module from Digi-Key, an XBee Explorer USB from SparkFun, and a 900 MHz RP-SMA Duck Antenna from SparkFun. The XBee module operates in the 902.4 MHz to 927.6 MHz range. The antenna has a sensitivity of 2dBi. The XBee Explorer is connected to the Raspberry Pi with a Mini-USB to USB cable. The XBee Explorer is mounted on M3 nylon standoffs, which are epoxied into holes on the payload electronics sled.

Figure 4.20 - Antenna


Figure 4.21 - XBee Radio Module

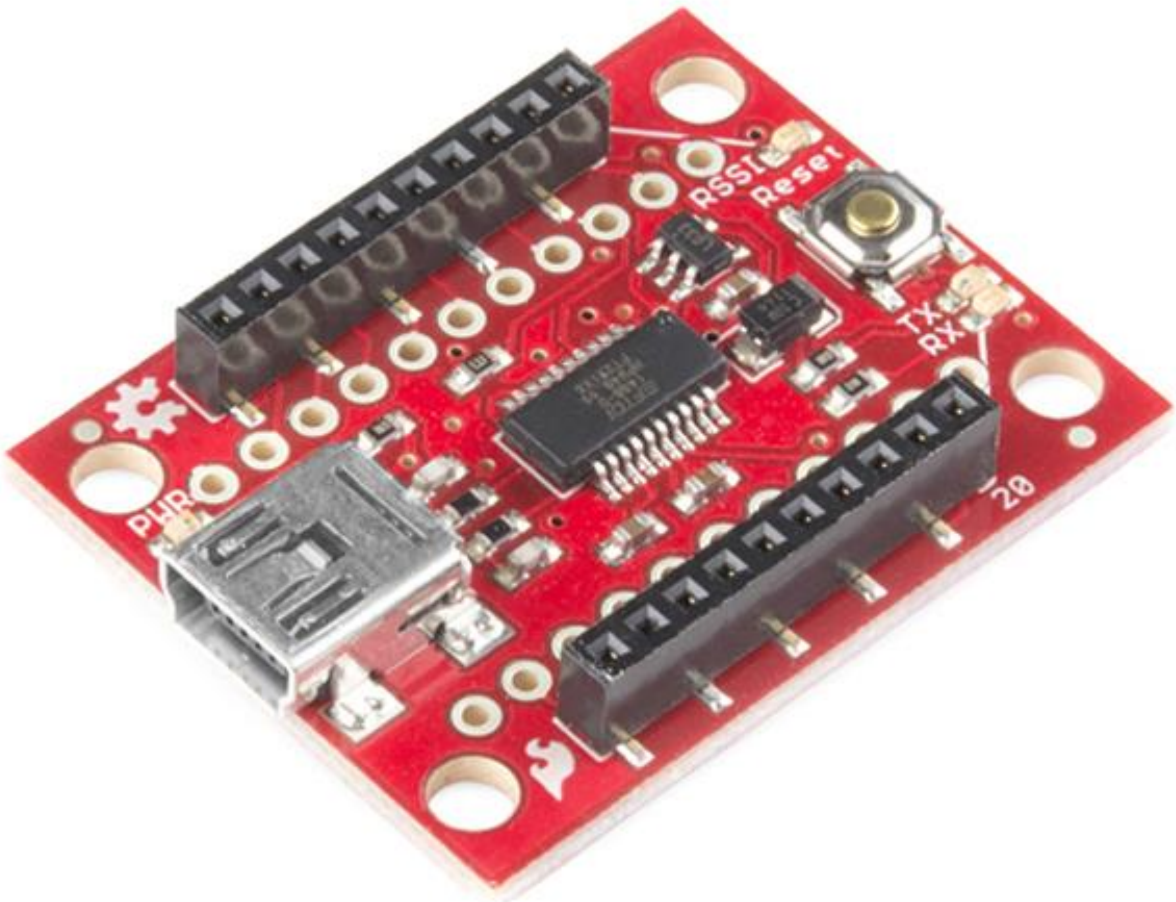


Figure 4.22 - XBee Explorer USB


Figure 4.23 - Assembled Transceiver

### 4.4.3 Motor Controller

The motor controller is an MD10C R3 from Cytron. It takes power from the two 9-volt batteries (see section 4.4.6) and feeds it to the DC motor. It is connected to the GPIO pins on Raspberry PI. The motor controller is mounted on M3 nylon standoffs, which are epoxied into holes on the payload electronics sled.


Figure 4.24 - Motor Controller

### 4.4.4 DC Motor

The DC motor is a 24 V 1000 rpm geared motor, made by uxcell. Its rated torque is 0.4 kg*cm. It is connected to bulkhead 3 with three M3 bolts.

Figure 4.25 - DC Motor

## 4.4.5 Main Power

The main power for the payload comes from a battery pack containing 6 AA batteries in series. This pack connects to a Universal Battery Elimination Circuit (UBEC), which connects to the Raspberry Pi and regulates voltage and amperage. The battery pack is epoxied onto the payload electronics sled. The UBEC is taped to the payload sled. The battery pack is made by uxcell. The UBEC is a DC/DC Step-Down Converter from Adafruit, with an output of 5 V at 3 A.

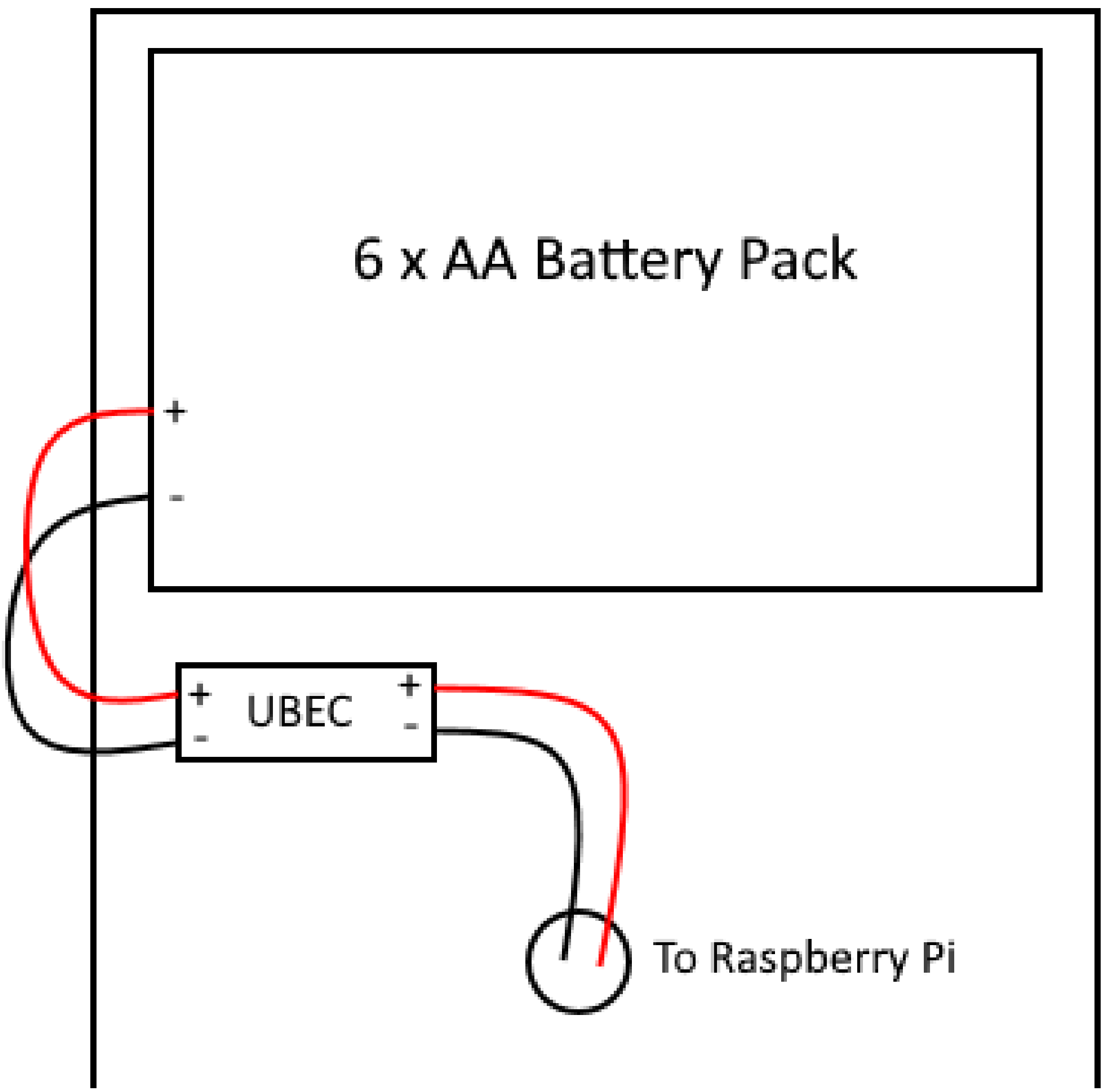


Figure 4.27 - Main Power Diagram

## 4.4.6 Motor Power

The motor is powered by 2 9-volt alkaline batteries connected in series. The batteries connect to the motor controller, which feeds power to the DC motor. The batteries are secured horizontally by Velcro straps, and vertically by bulkhead 2 below and nuts epoxied to the sled above.

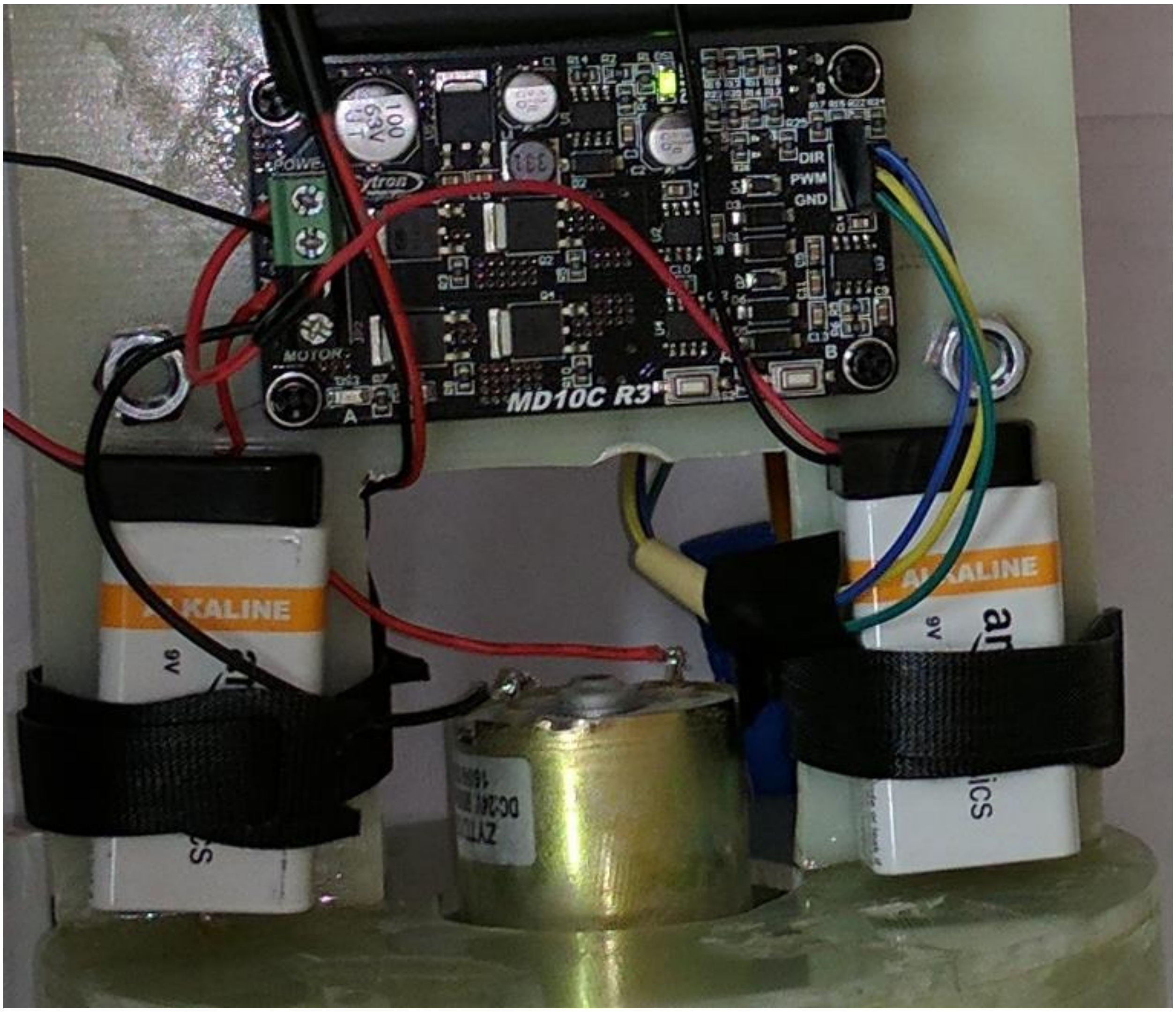


Figure 4.28 - Batteries for DC Motor

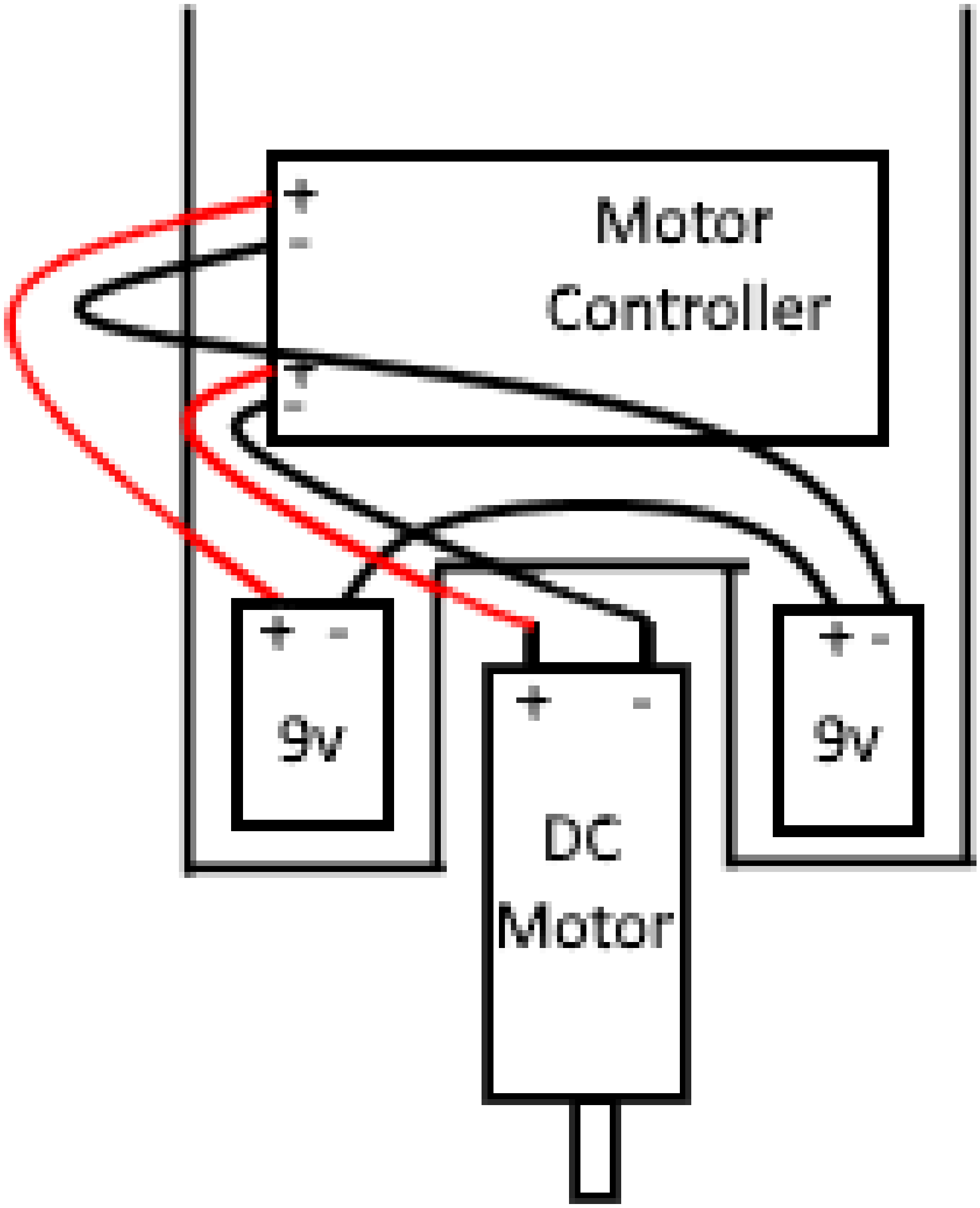


Figure 4.29 - Motor Power Diagram

# 5 Safety

## 5.1 Personnel Hazard Analysis

### 5.1.1 Personnel Hazards

| Hazard | Causes | Effects | Mitigation ID |
|---|---|---|---|
| Accidental black powder ignition | Mishandling. Improper storage. | Moderate injury (burns, concussion) | P-1 |
| Power tools | Improper use. Distractions | Minor to severe injury | P-2 |
| Fiberglass | Fiberglass dust on skin, in eyes, and/or in lungs | Irritation | P-3 |
| Rocket flies into personnel | Rocket goes off course | Severe injury or death | P-4. See Failure Modes and Effects Analysis for additional |
| Motor flies into personnel | Motor comes out of rocket | Severe injury or death | P-4. See Failure Modes and Effects Analysis for additional |
| Falling debris | Rocket breaks. Recovery system fails. Top of engine not capped. Too much black powder. Motor failure. | Moderate to severe injury | P-4. See Failure Modes and Effects Analysis for additional |
| Ballistic return | Recovery system does not work as intended. | Potential severe injury or death | P-4. See Failure Modes and Effects Analysis for additional |

Table 5.1 - Personnel Hazards

### 5.1.2 Personnel Hazard Mitigation and Verification

| Mitigation ID | Mitigation | Verification |
|---|---|---|
| P-1 | Black powder will be properly stored and handled only by those that have been briefed on proper handling | It will be clearly explained only the mentor shall handle black powder |
| P-2 | All team members involved in the fabrication of the rocket will be briefed on how to safely use all power tools. The safety officer or deputy safety officer will supervise the use of power tools. | Regular briefings on safety with tools. All new members will be trained to use necessary tools. No work shall be completed without the safety officer or deputy safety officer present |

| Mitigation ID | Mitigation | Verification |
|---|---|---|
| P-3 | Gloves, masks, and safety glasses will be worn when working with fiberglass. Any fiberglass dust will be cleaned up promptly. | The safety officer or deputy safety officer shall ensure everyone wears gloves, masks, and safety glasses. |
| P-4 | Members shall keep eyes on the rocket during flight and move to avoid any danger if necessary. | The safety officer will ensure members are aware of surroundings and inform them of danger if necessary. |

Table 5.2 - Personnel Hazard Mitigations and Verifications

# 5.2 Failure Modes and Effects Analysis

## 5.2.1 Failure Modes and Effects

| Hazard | Causes | Effects | Mitigation ID |
|---|---|---|---|
| Engine fails to ignite | Bad igniter | Recycle/delay of launch | None |
| Rocket goes off course | Launch rail is not vertical. Incorrectly aligned fins. Offset CG. Misaligned engine/engine mount. Reaction wheel breaks off motor. Rotation while flying at high velocity breaks fins. | Failure to reach desired altitude. Vehicle flies into crowd. Rocket lands in undesirable location. Failure to reach sufficient altitude for recovery system. | FG-1, FG-2, FG-3, FE-2, FG-7 |
| Internal damage | High acceleration. Reaction wheel breaks. Nuts break off reaction wheel. | Damage to rocket. Experiment failure. Recovery system failure. | FG-5 |
| Engine ejects from rocket | Top of engine not capped. Engine mount fails. | Falling debris. Damage to rocket. Engine flies into crowd. | FG-6, FG-7 |
| Reaction wheel does not start | Payload electronics failure. Reaction wheel is jammed. | Experiment failure. | FE-1 |
| Reaction wheel breaks off motor hub | Too much angular acceleration | Rocket goes off course. Experiment failure. | FG-5, FE-2 |
| Nuts break off reaction wheel | Not attached properly | Internal damage. Airframe damage. | FG-13 |
| Vibration | Reaction wheel off center | Damage to electronics | FE-3 |
| Rotation breaks fins | Rotational forces | Rocket goes off course. Falling debris. | FG-7 |

| Hazard | Causes | Effects | Mitigation ID |
|---|---|---|---|
| Reaction wheel spins at wrong speed | Electronic subsystem failure | Experiment failure | FE-4 |
| Ejection charge does not ignite | Bad igniter. Altimeters not turned on. Altimeters not programmed correctly. Batteries not charged. Wires come loose. | Ballistic return. Damage to rocket. Potential injury. | FR-4 |
| Ejection charge fires but drogue parachute does not deploy | Not enough black powder | Drogue parachute does not deploy. Potential ballistic return. Rocket may hit ground too hard. | FR-1 |
| Ejection charge fires but main parachute does not deploy | Not enough black powder | Main parachute does not deploy. Potential ballistic return. Rocket hits ground too hard. | FR-1 |
| Rocket hits ground too hard. | Parachute is too small. Recovery system fails. Motor failure. | Damage to rocket. | FR-6 |
| Rocket lands in undesirable place. | Wind. Rocket goes off course. | Rocket falls on people. Rocket damaged during retrieval. | See "Rocket goes off course" |
| Data collection failure | Software failure. Electronics break. Sensor wires loose or unplugged. | Data transmission failure. Experiment failure. No proof of veracity of experiment. | FE-4, FE-6, FG-11, FG-14 |
| Data transmission failure. | Software failure. Antenna or other electronics break. Wires loose or unplugged. | No ground based data backup. Tracking failure. | FE-4, FE-5, FE-6, FG-11, FG-14 |
| Main parachute recovery harness breaks | Too much black powder. Damaged recovery harness. Rocket is moving too fast. | Falling debris. Damage to rocket. | FR-1, FR-2, FR-3 |
| Drogue parachute recovery harness breaks | Too much black powder. Damage to recovery harness. Rocket is moving too fast. | Falling debris. Damage to rocket. | FR-1, FR-2, FR-3 |
| Motor failure | Manufacturer error | Rocket breaks apart. Falling debris | FG-12 |
| Rivets holding experiment break | Torque | Internal damage. Experiment failure | FE-2 |

| Hazard | Causes | Effects | Mitigation ID |
|---|---|---|---|
| Recovery system prematurely fires | Interference | Failure to reach desired altitude. Damage to rocket. | FR-9 |
| Motor mount breaks | Forces acting on motor mount are too great. | Internal damage. Experiment failure. Rocket goes off course. | FE-7 |
| Altimeters not turned on | Human error | Recovery system does not fire | FR-10 |
| Ejection charge improperly packed | Human error | Recovery system does not fire or work properly. Damage to rocket. Damage to recovery harness. Damage to parachute. | FR-1, FR-11 |
| Avionics bay wires come loose | Not secured properly | Recovery system does not fire | FR-12 |
| Avionics batteries come loose | Not secured properly | Recovery system does not fire | FR-12 |
| Failure to separate | Altimeters not turned on. Ejection charges improperly packed. Wires come loose. | Damage to rocket. Ballistic return. | FR-10, FR-11, FR-12 |
| Recovery harnesses improperly attached | Human error | Recovery system does not work as intended | FR-13 |
| Fins misaligned | Human error | Induce rotation. Difficulty measuring roll | FG-2 |
| Bulk heads break or come loose | Not secured properly. Not strong enough | Rocket sections not attached to harnesses during ejection charge firing | FG-5, FG-15 |
| Rocket too slow | Improper motor choice | Rocket too slow at rail exit to be stable | FG-16 |
| Rail buttons break | Not secured properly. Not strong enough | Rocket comes off rail improperly | FG-5, FG-17 |
| Parachute melted to side of rocket | Parachute not properly packed | Failure to deploy | FR-13 |
| Parachute caught | Parachute caught on something | Failure to deploy. Damage to parachute | FR-13, FR-14 |
| Parachute deploys too slowly | Parachute melted to side of rocket due to high temperatures or direct sunlight | Rocket hits ground too hard | FR-13, FR-15 |
| Shroud line snaps | Damage to shroud line | Parachute does not deploy properly | FR-16 |

| Hazard | Causes | Effects | Mitigation ID |
|---|---|---|---|
| Mounting for recovery harness breaks | Not secured properly. Not strong enough | Recovery system does not work as intended. Falling debris as rocket sections not attached together | FG-5 |
| Experiment batteries low | Not new/charged enough | Experiment failure | FG-11 |
| Avionics batteries low | Now new/charged enough | Recovery system does not deploy | FG-11 |

Table 5.3 - Failure Modes and Effect Analysis

## 5.2.2 Failure Modes Mitigation and Verification

All verifications mentioning the checklist

### 5.2.2.1 Failure Modes Mitigation – General

| Mitigation ID | Mitigation | Verification |
|---|---|---|
| FG-1 | Check launch rail direction before launch. | Pre-flight checklist, specifically the launch setup section. |
| FG-2 | Use necessary tools to ensure fins are aligned correctly. | The launch vehicle team lead shall be responsible for inspecting fins and ensuring they are aligned properly |
| FG-3 | Use ballast to ensure the CG is centered. | The CG will be calculated after rocket is constructed. |
| FG-4 | Use laser cutter to cut pieces for the engine mount. | N/A |
| FG-5 | Ensure all points of failure are strong enough to withstand the maximum expected acceleration with a margin of safety. | Materials will be chosen to meet this requirement after extensive research. |
| FG-6` | Ensure the engine is capped with something that can withstand the exhaust. | Engines shall be thoroughly researched by the mentor and team leader to ensure quality products are chosen. |
| FG-7 | Ensure the engine mount is strong enough to withstand the force from the engine. | The material chosen for the engine mount shall be researched in order to ensure it meets the necessary needs and constraints. |

| Mitigation ID | Mitigation | Verification |
|---|---|---|
| FG-8 | Don't launch when there is too much wind. | Check wind speed before launch. |
| FG-9 | Angle the launch rail to account for wind. | Pre-flight checklist, specifically the launch setup section |
| FG-10 | Choose suitable launch sites for rocket size. | Inspect launch site beforehand for hazards |
| FG-11 | Do ground tests to find out how long the batteries will last; keep track of how long each battery has been used | Testing of batteries. |
| FG-12 | Inspect motor before launch | Pre-flight checklist, specifically motor preparation section. |
| FG-13 | Tighten nuts thoroughly during assembly. Epoxy the nuts for extra security. | The experiment team shall tighten the nuts. The nuts will be inspected by the safety officer or deputy safety officer to ensure they will not come off easily. |
| FG-14 | Check for loose wires | Pre-flight checklist, in both the experiment and avionics bay sections. |
| FG-15 | A strong material shall be chosen for the bulkheads. Bulkheads will be secured with epoxy, epoxy clay, and other fasteners as necessary. | Testing of bulkhead strength. Team members shall apply adequate amounts of adhesives in order to ensure the bulkheads are thoroughly secured. |
| FG-16 | Run simulations to choose a proper motor size. Examine flight data and video to ensure motor choice is proper. | Simulations in RockSim shall be used for the preliminary motor choice. Post-flight analysis of all data shall be used to determine viability of choice. |
| FG-17 | Rail buttons should be secured with epoxy and screwed in tightly. Ensure that they can support the weight of the rocket. | Rail buttons will be thoroughly secured during rocket assembly. The rail buttons should be able to handle the weight of the rocket as well as forces before rail exit. |

Table 5.4 - General Failure Modes Mitigations and Verifications

### 5.2.2.2 Failure Modes Mitigation – Experiment

| Mitigation ID | Mitigation | Verification |
|---|---|---|
| FE-1 | Make sure there are no loose wires or other obstructions near the reaction wheel. | Pre-flight checklist, specifically the experiment assembly section. |
| FE-2 | Test starting and stopping the experiment on the ground; if the acceleration causes damage, the reaction wheel can spin up and spin down slower. | Testing by hanging experiment on string and examining effects of reaction wheel spinning on the experiment electronics. |
| FE-3 | Make sure the reaction wheel is centered; run the experiment on the ground many times to ensure vibrations are at safe levels. | Testing by hanging experiment on string and examining effects of reaction wheel spinning on the experiment electronics. |
| FE-4 | The payload control program will be tested on the ground and in test flights; every part of the program will be reviewed by multiple people. | Testing by hanging experiment on string and examining effects of reaction wheel spinning on the experiment electronics. The programming and experiment teams shall examine data from tests an flights. Code shall be reviewed before tests in order to ensure there are no crucial errors. |
| FE-5 | The transceivers will use the 900 MHz frequency to avoid interference from most common radio devices (e.g. Wi-Fi, Bluetooth, etc.). | Ground and in flight tests will ensure the transmitter and receiver have sufficient range. |
| FE-6 | Ensure electronics are secured and will not break during flight | The electronics will be placed on spacers and be screwed on tightly. If possible other fasteners will be used. |
| FE-7 | Ensure the motor mount can handle the forces from the reaction wheel spinning. | The reaction wheel will be run hanging from a string in order to determine how the experimental payload reacts while the reaction wheel spins. |

Table 5.5 - Experiment Failure Modes Mitigations and Verifications

### 5.2.2.3 Failure Modes Mitigation – Recovery System

| Mitigation ID | Mitigation | Verification |
|---|---|---|
| FR-1 | Repeated tests of the ejection system on the ground. | Testing by connecting ignition wires to remote and firing. Calculations should be done to determine ejection charge amounts beforehand. |
| FR-2 | Inspect the recovery harness before launch. | Pre-flight checklist, in both the lower body and upper body sections for the drogue parachute and main parachute, respectively. |
| FR-3 | Choose the engine and ballast such that the rocket is moving at a safe velocity when the parachute deploys. | Simulations in RockSim will be used to determine any necessary ballast as well as the motor choice. Simulations and calculations will be used to determine the velocity at time of ejection charge firing to ensure damage is not sustained. |
| FR-4 | Redundant igniters and ejection cups. | Follow pre-launch checklist. Have the mentor and safety officer inspect the ejection system before launch. |
| FR-5 | Choose the size of the drogue chute such that the rocket is moving at a safe velocity when the parachute deploys. | Simulations in RockSim will be used to determine an appropriate drogue chute size. |
| FR-6 | Run simulations to ensure the parachute is the correct size for the rocket. | Simulations in RockSim will be used to determine an appropriate drogue chute size. |
| FR-7 | Use the smallest possible drogue that will allow safe deployment of the main chute. | Simulations in RockSim will be used to determine an appropriate drogue chute size. |
| FR-8 | There will be redundant accelerometers/gyroscopes. | Install multiple modules within experiment bay |
| FR-9 | Shield the altimeters and avionics bay as necessary to avoid interference | Testing shall be done to see if any radio signals might interfere with the altimeters and affect their viability for the recovery system. |
| FR-10 | The mentor shall turn on the altimeter. Members shall listen for the beeps of the altimeters. | Both the team leader and safety officer will have the pre-flight checklist at the launch pad. They shall both run through launch pad procedures |

| Mitigation ID | Mitigation | Verification |
|---|---|---|
| | | independently to ensure nothing is missed |
| FR-11 | The mentor shall practice packing ejection charges for ground fire tests. The mentor shall ensure they have followed all proper procedures. | Pre-flight checklist, specifically the ejection charge section under the avionics bay section. |
| FR-12 | The wires and batteries of the avionics bay shall be thoroughly secured using zipties, glue, and other fasteners as necessary. | Team members shall use epoxy and other adhesives in order to ensure that battery cases are secured. Wires will be ziptied to ensure they do not come loose. |
| FR-13 | Members shall practice folding the parachutes as well as packing the parachute and recovery harness into the airframe. The safety officer shall oversee the packing of the items in preparation for launch. | Pre-flight checklist, under both the lower body and upper body section for the drogue parachute and main parachute, respectively. |
| FR-14 | Ensure nothing is inside the airframe for the parachute to be caught on. | The inside of the body tubes shall be inspected to ensure there is nothing for the parachute to be snagged on. |
| FR-15 | Keep rocket out of direct sunlight. Inspect parachute if temperatures are high. | Assembly shall take place in shaded area. The temperature shall be checked. |
| FR-16 | Inspect the parachute and shroud lines for any damage. Have backups ready to be used. | Pre-flight checklist, in both the lower body and upper body sections for the drogue parachute and main parachute, respectively. |

Table 5.6 - Recovery System Failure Modes Mitigations and Verifications

# 5.3 Environmental Hazard Analysis

## 5.3.1 Environmental Hazards on Rocket

| Hazard | Effects | Mitigation ID |
|---|---|---|
| Direct sunlight or high temperatures | Overheating of electronic components, might not work properly. Possible distortion of airframe | E-1 |

| Hazard | Effects | Mitigation ID |
|---|---|---|
| Humidity | Swelling of airframe. Wet rocket and electronics. | E-2 |
| Wind | Rocket goes off course. Drifts further after parachute deployment | E-3 |

Table 5.7 - Environmental Hazards to Rocket

### 5.3.2 Environmental Hazards from Rocket

| Hazard | Causes | Effects | Mitigation ID |
|---|---|---|---|
| Grass fire | Rocket crashes while motor is still burning | Burnt vegetation. Potential injury | E-4 |
| Scattered rocket components | Rocket breaks during flight. Recovery system fails. Motor failure. | Harmful chemicals and materials released into environment | E-5 |
| Wildlife harmed | Animals wander onto launch field | Wildlife harmed or killed | E-6 |

Table 5.8 - Environmental Hazards from Rocket

### 5.3.3 Environmental Hazard Mitigation and Verification

| Mitigation ID | Mitigation | Verification |
|---|---|---|
| E-1 | Assemble and store rocket in shaded area. | Safety officer or deputy safety officer will ensure assembly takes place within proper conditions |
| E-2 | Inspect rocket before launch for airframe swelling. Electronics should be sealed to protect from water. | Pre-flight checklist, should be done at the beginning of the lower body and upper body sections. |
| E-3 | Minimize time on main parachute to ensure minimal drift while maintaining safe landing speed. | Simulations shall be used to determine an appropriate parachute size |
| E-4 | Fire extinguishers shall be ready during launch. | Packing checklist. Members shall be ready with fire extinguishers |
| E-5 | Inspect launch field for potential wildlife. | Pre-flight checklist, specifically launch setup section. |
| E-6 | Inspect field for debris | The team will thoroughly inspect the launch site for any components after landing. |

| Mitigation ID | Mitigation | Verification |
|---|---|---|
| | | Search should continue until all parts are accounted for. |

Table 5.9 - Environmental Hazard Mitigations and Verifications

# 6 Launch Operations Procedures

## 6.1 Recovery Preparation

### 6.1.1 Lower body section

Can be done by any team member. Must be observed and checked off by either the Safety Officer or the Deputy Safety Officer.

- ☐ Separate the lower body section completely
- ☐ Ensure that both of the quick links at the bottom end of the recovery harness are attached to the U-bolts on the lower section
- ☐ Ensure that the marked end of the recovery harness is not the end attached to the lower section
- ☐ Ensure that the quick links are tight. WARNING! Failure to secure the quick links can result in the recovery harness detaching during flight!
- ☐ Pull test the lower recovery harness
- ☐ Fold the drogue parachute
- ☐ Put a rubber band on the lower recovery harness
- ☐ Z-fold the lower recovery harness
- ☐ Attach the drogue parachute to lower recovery harness
- ☐ Ensure the blast protector is on the lower recovery harness
- ☐ Wrap the drogue parachute in the blast protector. WARNING! Failure to wrap the drogue parachute can result in melting the drogue parachute!
- ☐ Insert the lower recovery harness and the drogue parachute into the lower body tube

### 6.1.2 Upper body section

Can be done by any team member. Must be observed and checked off by either the Safety Officer or the Deputy Safety Officer.

- ☐ Separate the upper body section completely
- ☐ Ensure that both of the quick links at the end of the upper recovery harness are attached to the U-bolts on the upper section
- ☐ Ensure that the marked end of the recovery harness is not the end connected to the upper section

- ☐ Ensure that the quick links are tight. WARNING! Failure to secure the quick links can result in the recovery harness detaching during flight!
- ☐ Pull test the upper recovery harness
- ☐ Fold the main parachute
- ☐ Put a rubber band on the main parachute
- ☐ Put a rubber band on the upper recovery harness
- ☐ Z-fold the upper recovery harness
- ☐ Attach the main parachute to the upper recovery harness
- ☐ Ensure the blast protector is on the upper recovery harness
- ☐ Remove the rubber band from the main parachute. WARNING! Failure to remove the rubber band from the main parachute can result in the main parachute not opening!
- ☐ Wrap the main parachute with the blast protector. WARNING! Failure to warp the main parachute can result in melting the main parachute!
- ☐ Insert the upper recovery harness and the main parachute into the upper body tube

### 6.1.3 Avionics bay

Can be done by any team member. Must be observed and checked off by either the Safety Officer or the Deputy Safety Officer.

- ☐ Remove the aft nuts, use 7/16 in wrench
- ☐ Remove the aft bulkhead, unclipping the red/black connector
- ☐ Remove the avionics sled and the forward bulkhead, unclipping the blue/white connector
- ☐ Pull test all wires on the altimeters (2 main + 2 drogue + 2 switch + 2 battery per altimeter)
- ☐ Put 2 fresh 9 volt batteries on the battery shelves. WARNING! Failure to use fresh batteries can result in insufficient current to the ignitors and failure of the recovery system!
- ☐ Attach the battery connectors to both batteries. WARNING! Failure to attach connectors means no power for the recovery system!
- ☐ Strap in each battery with one vertical and one horizontal Velcro strap each
- ☐ Ensure that batteries are secure. WARNING! Failure to properly secure the batteries can lead to them coming loose in flight and coming off of their connectors or damaging the altimeters!

- ☐ Use the LCD screen to ensure that the programming for the altimeters is correct, primary drogue at apogee, secondary drogue at apogee + 2 s, primary main at 800 ft, and secondary main at 700 ft
- ☐ Place the avionics sled onto the threaded rods
- ☐ Secure the avionics sled on the threaded rods with nuts, WARNING! Failure to secure the sled can result in damage to the avionics during flight!
- ☐ Insert the sled into the avionics bay
- ☐ Connect the switch connector (blue/white)
- ☐ Turn on primary the altimeter and wait for 1 long beep followed by 3 short beeps, repeated. If this fails, go to section 6.7.1 to troubleshoot
- ☐ Turn off the primary altimeter
- ☐ Turn on the secondary altimeter and wait for 1 long beep followed by 3 short beeps, repeated. If this fails, go to section 6.7.1 to troubleshoot
- ☐ Turn off the secondary altimeter
- ☐ Connect the drogue connector (red/black)
- ☐ Attach the aft bulkhead with 2 nuts, use 7/16 in wrench
- ☐ Grease both ends of the avionics bay

#### 6.1.3.1 Ejection Charges

Can be done only by the mentor. Must be observed and checked off by either the Safety Officer or the Deputy Safety Officer.

- ☐ Connect ignitor leads to aft primary terminal block
- ☐ Insert ignitor tip into bottom of primary ejection cup
- ☐ Pour in pre-measured black powder (3 g)
- ☐ Insert wadding
- ☐ Secure with masking tape
- ☐ Connect ignitor leads to aft secondary terminal block
- ☐ Insert ignitor tip into bottom of secondary ejection cup
- ☐ Pour in pre-measured black powder (3 g)
- ☐ Insert wadding
- ☐ Secure with masking tape
- ☐ Connect ignitor leads to forward primary terminal block

- ☐ Insert ignitor tip into bottom of primary ejection cup
- ☐ Pour in pre-measured black powder (3 g)
- ☐ Insert wadding
- ☐ Secure with masking tape
- ☐ Connect ignitor leads to forward secondary terminal block
- ☐ Insert ignitor tip into bottom of secondary ejection cup
- ☐ Pour in pre-measured black powder (3 g)
- ☐ Insert wadding.
- ☐ Secure with masking tap
- ☐ Take altimeter outside
- ☐ Making sure ejection cups are pointed away from people, turn on primary altimeter and wait for 1 long beep then 3 short beeps repeated
- ☐ Turn off primary altimeter
- ☐ Making sure ejection cups are pointed away from people, turn on secondary altimeter and wait for 1 long beep then 3 short beeps repeated
- ☐ Turn off secondary altimeter
- ☐ WARNING! double check all ejection charge loading steps, failure to properly load the ejection charges can result in failure of the recovery system to be deployed

### 6.1.4 Body Assembly

Can be done by any team member. Must be observed and checked off by either the Safety Officer or the Deputy Safety Officer.

- ☐ Connect lower recovery harness to aft end of avionics bay with two quick links
- ☐ Ensure quick links are tight. WARNING! Failure to secure quick links can result in recovery harness detaching during flight!
- ☐ Insert aft end of avionics bay into lower body tube
- ☐ Secure with 4 shear pins. WARNING! Failure to insert shear pins can result in drag separation!
- ☐ Connect upper recovery harness to forward end of avionics bay with two quick links
- ☐ Ensure quick links are tight. WARNING! Failure to secure quick links can result in recovery harness detaching during flight!

☐ Insert forward end of avionics bay into upper body tube

☐ Secure with 4 shear pins. WARNING! Failure to insert shear pins can result in drag separation!

## 6.2 Experiment

Can be done by any member of the experiment team. Must be observed and checked off by either the Safety Officer, the Deputy Safety Officer, or a member of the experiment team.

☐ Pull test connections on motor controller

☐ Check GPIO connections (power, GPS, IMU, and motor controller) against schematic

☐ Check USB connections (flash drive and Xbee)

☐ Attach antenna

☐ Attach camera

☐ Turn on power

☐ Wait for GPS acquisition (LED flashes every 15 seconds)

☐ Holding camera close to sled, insert reaction wheel end of experiment into upper body tube

☐ Secure camera with 2 rivets

☐ Secure experiment with 3 rivets at the bottom and 3 rivets at the top

☐ Insert nosecone into upper body tube

☐ Secure nosecone with 3 rivets

## 6.3 Motor Preparation

Can be done only by the mentor. Must be observed and checked off by either the Safety Officer or the Deputy Safety Officer.

☐ Assemble motor according to manufacturer's instructions

☐ Measure ignitor against motor. WARNING! Do not insert ignitor into motor!

☐ Install motor in motor mount and secure with retaining ring

☐ Tape ignitor to fin for transport to pad

## 6.4 Set Up on Launcher

Can be done by any team member. Must be observed and checked off by either the Safety Officer or the Deputy Safety Officer.

- ☐ Take rocket, laptop, and Wi-Fi hotspot to launcher
- ☐ Disconnect ignition system power. WARNING! Leaving the ignition system powered could result in the rocket launching while there are still people at the launcher!
- ☐ Lower launch rail
- ☐ Slide rocket onto launch rail. WARNING! If the rocket is not kept straight the rail buttons might break!
- ☐ Raise launch rail
- ☐ Secure launch rail in vertical position
- ☐ If possible, spray down launch area. WARNING! Launching on dry grass could start a fire!
- ☐ Clear launch area of unnecessary personnel. WARNING! Having unnecessary personnel near the launch area could result in more injuries if the rocket launches unexpectedly or CATOs!

## 6.5 Ignitor Installation

Can be done only by the mentor. Must be observed and checked off by either the Safety Officer or the Deputy Safety Officer.

- ☐ Insert ignitor into motor and secure with plug
- ☐ Wrap ignition system wire around launch pad
- ☐ Ensure ignition system leads are not powered (touch them together and look for sparks). WARNING! Attaching live leads to the ignitor could lead to unexpected motor ignition!
- ☐ Connect ignition system leads to ignitor leads

## 6.6 Launch Procedure

Can be done by any member of the programming team. Must be observed and checked off by either the Safety Officer or the Deputy Safety Officer.

- ☐ Open an ssh connection to the Pi from the laptop

- ☐ Enter “cd Desktop/PSLT-Fullscale”
- ☐ Enter “sudo nohup python Driver.py”
- ☐ Wait for confirmation that the program is running
- ☐ On the laptop, open a command prompt
- ☐ Enter “cd Documents/Github/PSLT-Fullscale”
- ☐ Enter “python ReceiveData.py”
- ☐ Ensure data is being received
- ☐ Clear launch area
- ☐ Reconnect ignition system power
- ☐ Inform RSO that the rocket is ready for launch

## 6.7 Troubleshooting

### 6.7.1 Altimeters

- ☐ If altimeter does not beep:
    - ☐ Turn altimeter off
    - ☐ Open avionics bay
    - ☐ Check battery connectors
    - ☐ Check altimeter for damage
- ☐ If altimeter produces wrong sound:
    - ☐ Turn altimeter off
    - ☐ Check connection of ignitors to terminals
    - ☐ If problem persists:
    - ☐ Open avionics bay
    - ☐ Check quick connector
    - ☐ Check terminals on altimeter

### 6.7.2 Ignition

- ☐ If motor fails to ignite:
    - ☐ Wait 60 seconds to approach.
    - ☐ Check firing system power.
    - ☐ Check firing system lead connection.
    - ☐ If neither of those are the issue:
    - ☐ Replace the ignitor.
    - ☐ If replacing ignitor, follow procedures for installing ignitor.

## 6.8 Post-flight Inspection

### 6.8.1 Successful Flight

- ☐ Take pictures of all components before moving them.
- ☐ Make sure all 4 ejection charges have fired.
- ☐ Record apogee altitude.
- ☐ Turn off both altimeters.
- ☐ Check fins for damage.
- ☐ Check body for damage.
- ☐ Make sure motor is still secured.
- ☐ Check main parachute for damage.
- ☐ Check upper blast protector for damage.
- ☐ Check drogue parachute for damage.
- ☐ Check drogue blast protector for damage.
- ☐ Check drogue quick link for damage.
- ☐ Check drogue swivel for damage.
- ☐ Check lower recovery harness swivel for damage.
- ☐ Check 5 lower recovery harness quick links for damage.
- ☐ Check 4 lower recovery harness U-bolts for damage.
- ☐ Check main parachute quick link for damage.
- ☐ Check main parachute swivel for damage.

☐ Check upper recovery harness swivel for damage.

☐ Check 5 upper recovery harness quick links for damage.

☐ Check 4 upper recovery harness U-bolts for damage.

☐ Disconnect lower recovery harness from avionics bay (2 quick links).

☐ Make sure quick links are closed.

☐ Disconnect upper recovery harness from avionics bay (2 quick links).

☐ Make sure quick links are closed.

☐ Return rocket (in 3 pieces) to tent / assembly area.

☐ Remove motor retainer.

☐ Remove and safe motor.

☐ Check motor mount for damage.

☐ Reattach motor retainer.

☐ Remove 3 rivets on the nosecone.

☐ Remove nosecone.

☐ Remove 2 rivets on the camera back plate.

☐ Remove 6 rivets on the experiment.

☐ Remove experiment.

☐ Take pictures of experiment from all angles.

☐ Remove 2 nuts and 2 washers from aft end of avionics bay.

☐ Remove aft bulkhead, unclipping red / black connectors.

☐ Remove sled (do not unclip blue / white connector).

☐ Take pictures of sled from all angles.

☐ Turn on primary altimeter.

☐ Record data from primary altimeter.

☐ Turn off primary altimeter.

☐ Turn on secondary altimeter.

☐ Record data from secondary altimeter.

☐ Turn off secondary altimeter.

☐ Insert sled into forward end of avionics bay.

☐ Connect red / black connector.

☐ Attach aft bulkhead.

☐ Secure aft bulkhead with 2 nuts and 2 washers (7/16 in wrench).

- ☐ Pull test lower recovery harness.
- ☐ Pull test upper recovery harness.
- ☐ Insert drogue, lower blast protector, and lower recovery harness into lower body tube.
- ☐ Insert main parachute, upper blast protector, and upper recovery harness into upper body tube.
- ☐ Insert nosecone into upper body tube.
- ☐ Connect the laptop to the Pi via ssh.
- ☐ Connect the laptop to the Pi with an FTP client (e.g. FileZilla).
- ☐ Copy “/home/pi/Desktop/PSLT-Fullscale/” to a data recovery folder on the laptop.
- ☐ Copy “/media/pi/Samsung USB/video.h264” to the same folder.
- ☐ Copy “C:\Users\admin\Documents\Github\PSLT-Fullscale\exData.csv” to the same folder.
- ☐ Copy the data recovery folder onto a flash drive.
- ☐ Disconnect the FTP client.
- ☐ On the laptop, in the ssh terminal, run “sudo shutdown -h now”.
- ☐ Turn off experiment power.

### 6.8.2 Failed Flight

- ☐ Check for fires or embers and put them out if necessary.
- ☐ Take pictures of all debris.
- ☐ Record the radius of the debris field.
- ☐ Collect all debris.
- ☐ Make sure no pieces are missing.

Proceed with as much of the successful flight checklist as possible

# 7 Project Plan

## 7.1 Test Results and Impact on Design

### 7.1.1 Testing Procedures

#### 7.1.1.1 Motor Mount Stress Test

Goal:

- Ensure that the motor mount is able to withstand at least as much force as will be exerted on it during motor burn

Success criteria:

- There is no damage to the motor mount

Testing variable:

- Weight

Procedure:

1. Place lower section so that the fore end is on the ground
2. Remove the motor retainer
3. Place a weigh on the motor mount that is equivalent to or greater than the maximum force produced by the motor during flight
4. Leave the weight for at least ten seconds
5. Inspect the motor mount for any damage

Results / Analysis:

- There was no damage to the motor mount, any part of the lower section of the rocket, or to any connections between parts

#### 7.1.1.2 Lower Section Recovery Harness Pull Test

Goal:

- Ensure that the lower recovery harness mounting point is able to withstand the forces exerted on it during ejection charge firing

Success criteria:

- There is no damage to the recovery harness
- There is no damage to the recovery harness mounting point
- There is no damage to the recovery harness mounting hardware

Testing variable:

- Weight

Procedure:

1. Connect the lower section to the lower recovery harness
2. Ensure the other end of the lower recovery harness is not attached to the avionics bay
3. Place the lower section somewhere where there is enough space below it for the recovery harness to hang freely
4. Attach a weight to the recovery harness that is equivalent to the force exerted on the recovery harness during ejection charge firing
5. Leave the weight for at least five seconds
6. Inspect the recovery harness, for centering ring, and recovery harness mounting hardware for any damage

Results / Analysis:

- There was no damage to the recovery harness, the mounting points, or the mounting hardware

#### 7.1.1.3 Upper Section Recovery Harness Pull Test

Goal:

- Ensure that the upper recovery harness mounting point is able to withstand the forces exerted on it during ejection charge firing

Success criteria:

- There is no damage to the recovery harness
- There is no damage to the recovery harness mounting point
- There is no damage to the recovery harness mounting hardware

Testing variable:

- Weight

Procedure:

1. Connect the upper section to the upper recovery harness
2. Ensure the other end of the upper recovery harness is not attached to the avionics bay
3. Place the upper section somewhere where there is enough space below it for the recovery harness to hang freely
4. Attach a weight to the recovery harness that is equivalent to the force exerted on the recovery harness during ejection charge firing
5. Leave the weight for at least five seconds
6. Inspect the recovery harness, for upper bulkhead, and recovery harness mounting hardware for any damage

Results / Analysis:

- There was no damage to the recovery harness, the mounting points, or the mounting hardware

#### 7.1.1.4 Avionics Bay Recovery Harness Pull Test

Goal:

- Ensure that the avionics bay recovery harness mounting points are able to withstand the forces exerted on them during ejection charge firing

Success criteria:

- There is no damage to the recovery harnesses
- There is no damage to the recovery harness mounting points
- There is no damage to the recovery harness mounting hardware

Testing variable:

- Weight

Procedure:

1. Connect both the upper and lower recovery harnesses to the avionics bay
2. Ensure that the other ends of the two recovery harnesses are not attached to anything
3. Attach the end of the upper recovery harness somewhere where there is enough space for the avionics bay and the lower recovery harness to hang freely below it
4. Attach a weight to the lower recovery harness that is equivalent to the force exerted on the recovery harness during ejection charge firing
5. Leave the weight for at least five seconds
6. Inspect the recovery harnesses, the avionics bay, and the recovery harness mounting hardware for any damage

Results / Analysis:

- There was no damage to either recovery harness, the mounting points, or the mounting hardware

#### 7.1.1.5 Altimeter Activation and Wiring

Goal:

- Ensure that both altimeters are wired correctly

Success criteria:

- Both altimeters can be turned on
- Both altimeters connect to their ejection terminals properly

Testing variable:

- N/A

Procedure:

1. Mount both altimeters to the avionics sled
2. Connect both altimeters to their batteries
3. Connect both altimeters to their switches
4. Connect both altimeters to their fore and aft ejection terminals
5. Activate one altimeter
6. Listen for the appropriate pattern of beeps (one long beep, long pause, one long beep repeated)
7. Turn off that altimeter
8. Repeat steps 5 through 7 for the other altimeter
9. Insert pieces of wire into each ejection terminal such that they complete the circuit for each charge as when prepared for a flight
10. Activate one altimeter
11. Listen for the appropriate pattern of beeps (1 long beep, long pause, 3 short beeps repeated)
12. Turn off that altimeter
13. Repeat steps 10 through 12 for the other altimeter

Results / Analysis:

- Both altimeters were able to activate successfully

#### 7.1.1.6 Altimeter Function

Goal:

- Ensure that both altimeters fire properly

Success criteria:

- Both altimeters fire both of their ejection charges
- Both altimeters fire their ejection charges at the correct times

Testing variable:

- N/A

Procedure:

1. Fly both altimeters on the subscale rocket
2. After the flight, inspect the rocket to ensure that all four ejection charges fired
3. Analysis the videos of the flight to ensure that the ejection charges fired at the correct times

Results / Analysis:

- All four ejection charges were fired
- Each ejection charge was fired at the appropriate point in the flight, the primary drogue charge fired at apogee, the secondary drogue charge fired at apogee + 2 s, the primary main charge fired at 800 ft, and the secondary main charge fired at 700 ft

#### 7.1.1.7 Experiment Data Collection

Goal:

- Ensure that the experimental payload is able to collect all of the required data

Success criteria:

- Complete data stored

Testing variable:

- Acceleration
- Velocity
- Horizontal position
- Altitude
- Angular position
- Angular velocity

Procedure:

1. Turn on experiment
2. Check for GPS acquisition
3. Run programs/data collection
4. Stop programs
5. Check collected data for completion

Results / Analysis:

- All data was present and complete

#### 7.1.1.8 Experiment Battery Life

Goal:

- Ensure that the payload is able to remain in a launch ready configuration for at least one hour without losing any functionality

Success criteria:

- After one hour in the pad ready configuration, the payload is able to perform the functions necessary during a flight

Testing variable:

- Time

Procedure:

1. Turn on experiment
2. Check for GPS acquisition
3. Run programs/data collection for one hour
4. Run reaction wheel program for a few seconds
5. Stop data collection

Results / Analysis:

- After more than an hour, the program stopped when memory ran out due to the continuous video recording. There was still enough power to run the DC motor. A change will be made to delay video collection until motor ignition.

### 7.1.1.9 Experiment Data Transmission

Goal:

- Ensure that the payload is able to transmit all of the required data

Success criteria:

- All required data is transmitted from the payload to a ground station

Testing variable:

- N/A

Procedure:

1. Turn on experiment and start data collection
2. Begin transmitting data
3. Stop data collection
4. Wait for complete transmission
5. Compare transmitted data to collected data

Results / Analysis:

- All data transmits successfully, although with some delay. A change will be made so that only critical data (position, velocity, etc.) will be transmitted.

### 7.1.1.10 Experiment Transmitter Range

Goal:

- Ensure that the payload is able to transmit over the ranges expected during flight

Success criteria:

- The payload is able to transmit all of the required data at the maximum expected range during flight

Testing variable:

- Range between the transmitter and the ground station

Procedure:

1. Turn on experiment and start data collection
2. Begin data transmission
3. Move experiment away from ground station
4. Check for continuity of transmission

Results / Analysis:

- Successful at ranges up to 500 ft. Longer range tests are still pending.

### 7.1.1.11 Roll Control

Goal:

- Determine the precision with which the payload is able to control its angular velocity

Success criteria:

- The payload is able to control its angular velocity to within 5 °/s

Testing variable:

- Initial angular velocity

Procedure:

1. Suspend experiment
2. Turn on experiment and begin flight programs
3. Jolt the experiment to simulate launch
4. Wait for rotation to start
5. Observe rotation and check for desired number of rolls
6. Wait for experiment to return to initial rotation

Results / Analysis:

- Successful with zero initial angular velocity. Tests with different initial rotations are pending.

### 7.1.1.12 Ejection System Ground Fire

Goal:

- Ensure that the ejection charges used are large enough to forcefully separate the sections of the rocket

Success criteria:

- The sections of the rocket separate with a velocity of at least 15 ft/s

Testing variable:

- Size of ejection charge

Procedure:

1. Remove the avionics sled from the avionics bay
2. Connect wires to the ejection terminal leads
3. Thread the wires through a static vent port
4. Load one ejection charge on each end of the avionics bay as for a flight

5. Connect the upper and lower sections of the rocket to the avionics bay with 4 shear pins each as for a flight
6. Place the rocket in a large open space with plenty of room in front of and behind it
7. Clear unnecessary personnel from within 50 ft of the rocket
8. Connect the clips of an ignition system to one pair of the wires coming out of the rocket, connecting it to the ejection charge on one end
9. Stand at the maximum length allowed by the length of the ignition system cables
10. Begin recording the set up with a camera
11. Fire the ignition system
12. Repeat steps 7 through 11 for the other ejection charge
13. Analyze the videos to determine the separation velocity for each section

Results / Analysis:

- The upper section separated with a velocity of 34.69 ft/s, putting it above the minimum speed
- The lower section separated with a velocity of 17.4 ft/s, putting it above the minimum speed

#### 7.1.1.13 Parachute Deployment

Goal:

- Ensure that the main parachute is able to open quickly enough to prevent the rocket from impacting the ground at a dangerously high velocity

Success criteria:

- The parachute is able to open within 3 s

Testing variable:

- Parachute folding technique

Procedure:

1. Tie an object of approximately the same mass as the rocket to the parachute's shroud lines
2. Fold the parachute as for a flight
3. Go to a high place
4. Ensure there are no people or fragile objects underneath of the drop location
5. Drop the parachute
6. Record the amount of time until the parachute is fully deployed

Results / Analysis:

- The parachute was fully deployed after 1.43 s, which, at the descent rate at main parachute deployment, means that the rocket will descent approximately 160 ft, putting it at an altitude of approximately 640 ft before the main parachute is fully deployed

#### 7.1.1.14 Experiment Electronics Shake Test

Goal:

- Ensure that none of the payload electronics will come loose during flight

Success criteria:

- None of the payload electronics come loose

Testing variable:

- Rate of vibrations
- Force of vibrations

Procedure:

1. Shake experiment

Results / Analysis:

- Nothing came loose

### 7.1.1.15 Avionics Electronics Shake Test

Goal:

- Ensure that none of the avionics electronics will come loose during a flight

Success criteria:

- None of the avionics electronics come loose

Testing variable:

- Rate of vibrations
- Force of vibrations

Procedure:

1. Mount all of the avionics electronics to the avionics sled as for a flight
2. Insert the avionics sled into the avionics bay as for a flight
3. Secure the avionics bay end caps
4. Shake the avionics bay
5. Remove the avionics bay end caps
6. Inspect the interior of the avionics bay for loose wires or electronics
7. Remove the avionics sled
8. Inspect the avionics sled for loose wires or electronics

Results / Analysis:

- All electronics, in particular the batteries, remained in position

#### 7.1.1.16 Reaction Wheel Mount Stress Test

Goal:

- Ensure that the reaction wheel is securely enough mounted to the shaft of the motor to remain attached during flight

Success criteria:

- The reaction wheel does not shift down

Testing variable:

- Force applied to the reaction wheel

Procedure:

1. Mount the payload so that there is room below it to hang a weight from
2. Attach a weight to the reaction wheel greater than or equivalent to the maximum force expected during flight
3. Leave the weight for at least ten seconds
4. Remove the weight
5. Inspect the reaction wheel to see if it has moved

Results / Analysis:

- The reaction wheel stayed attached when subjected to flight-equivalent weight

## 7.1.3 Impact on Design

### 7.1.3.1 Launch Vehicle

The launch vehicle met the success criteria for all of the tests that were done on it, so there were no changes to the design as a result.

### 7.1.3.2 Payload

Changes will be made to the payload control software to: (a) delay video recording until launch, to save storage space and (b) transmit less data, to reduce transmission latency.

## 7.2 Requirements Verification Plans

Req ID is the identifier that will be used for each requirement in this section of this document. Requirement refers to the requirement in the handbook that is being addressed for Section 7.2.1, or it is the team derived requirement for Section 7.2.2. TADI (Test, Analysis, Demonstration, or Inspection) identifies whether a test, analysis, demonstration, or inspection is required to verify the requirement.

### 7.2.1 NASA Requirements

| Req ID | Requirement | Verification Plan | TADI |
|---|---|---|---|
| 1 | 1.1 | The launch vehicle will use two altimeters to record the altitude that it reaches during test flights and the final launch | Inspection |
| 2 | 1.2 | See 1 above | N/A |
| 3 | 1.2.1 | PSLT will purchase an altimeter capable of conveying the altitude reached via a series of beeps | Demonstration |
| 4 | 1.2.3 | The altimeters will be easily accessible for marking | N/A |
| 5 | 1.2.5 | The design of the rocket will allow any electronics that produce sound to be easily disabled | N/A |
| 6 | 1.3 | Only commercially available batteries will be used for the recovery system | N/A |
| 7 | 1.4 | The launch vehicle will be designed with reusability in mind | Demonstration |
| 8 | 1.5 | The launch vehicle will have 3 independent sections | N/A |
| 9 | 1.6 | The launch vehicle will be designed to use only 1 stage | N/A |
| 10 | 1.7 | PSLT will practice preparing the launch vehicle for flight | Demonstration |
| 11 | 1.8 | The rocket and all of its components will be design to be able to remain in a launch ready configuration for at least 1 hour plus the time required for flight and recovery. Additionally, any batteries will be replaced before launch | Test |
| 12 | 1.9 | Because the launch vehicle will use a commercially available motor, a standard 12 volt firing system will be sufficient | N/A |
| 13 | 1.10 | See 12 above | N/A |

| Req ID | Requirement | Verification Plan | TADI |
|---|---|---|---|
| 14 | 1.11 | The launch vehicle will use a commercially available ammonium perchlorate composite propellant solid rocket motor | N/A |
| 15 | 1.12 - 1.12.4 | PSLT will not use any pressure vessels on the rocket | N/A |
| 16 | 1.13 | The motor used will be an L-class or less | N/A |
| 17 | 1.14 | The launch vehicle will be designed to achieve a minimum static stability margin of 2 at rail exit | Analysis |
| 18 | 1.15 | A motor powerful enough to accelerate the rocket to 52 ft/s by rail exit will be used | Analysis |
| 19 | 1.16 - 1.16.2 | A subscale rocket designed to model the full-scale design has been flown with an altimeter to measure apogee. Although the initial flight was not a success, valuable information was gathered, and a second test flight has been flown. | N/A |
| 20 | 1.17 - 1.17.7 | The full-scale rocket will be flown prior to FRR. For the flight, the recovery system will be prepared as for the final flight. The payload will be flown. The same motor used in the final flight will be flown in the test flight. The rocket will be flown with the same ballasting that will be used in the final flight | N/A |
| 21 | 1.18 | Any structural protuberances will be located aft of the burnout CG | N/A |
| 22 | 1.19 - 1.19.8 | Forward canards, forward firing motors, motors that utilize titanium sponges, hybrid motors, motor clusters, and friction fitting will not be utilized. The motor will be chosen to prevent the launch vehicle from exceeding Mach 1. Ballasting will not exceed 10% of the rocket's weight | N/A |
| 23 | 2.1 | The launch vehicle will utilize a dual deployment system with a drogue and a main parachute | N/A |
| 24 | 2.2 | Ground fire tests will be performed for both the full-scale and subscale rockets | N/A |
| 25 | 2.3 | The recovery system will be designed to keep the kinetic energy of each section of the launch vehicle below 75 ft-lbs | Analysis |
| 26 | 2.4 | The recovery system will not share any electronics with the payload | N/A |
| 27 | 2.5 | The recovery system will use 2 altimeters | N/A |
| 28 | 2.6 | Primary and secondary recovery deployment will be initiated electronically by the altimeters. | N/A |
| 29 | 2.7 | Each altimeter will be activated by a switch mounted to the exterior of the launch vehicle | N/A |
| 30 | 2.8 | The recovery system will include a separate battery for each altimeter | N/A |
| 31 | 2.9 | The switches used for the recovery system will be capable of being locked in the on position | N/A |

| Req ID | Requirement | Verification Plan | TADI |
|---|---|---|---|
| 32 | 2.10 | The parachute compartments will use removable shear pins | N/A |
| 33 | 2.11 - 2.11.2 | An electronic tracking system will be used. There will be no untethered sections of the launch vehicle | N/A |
| 34 | 2.12 - 2.12.4 | The recovery system will be shielded from all other electronics. The recovery system will be located in its own section of the launch vehicle | N/A |
| 35 | Updated experiment requirements | The experimental payload will contain an IMU to detect the roll of the launch vehicle at motor burnout. A reaction wheel will be used to induce roll. The IMU will detect when the rocket has completed 2 rotations. The reaction wheel will return the rocket to its motor burnout rotation as determined by the IMU | Test |
| 36 | 3.3.2 | The launch vehicle will not be designed to use fixed geometry to induce a roll | N/A |
| 37 | 3.3.3 | The payload will use only mechanical components to control roll | N/A |
| 38 | 4.1 | PSLT's safety officer will create launch and safety checklists | N/A |
| 39 | 4.2 | The team has appointed a safety officer | N/A |
| 40 | 4.3 - 4.3.4 | The safety officer has been made aware of his responsibilities | N/A |
| 41 | 4.4 | The team has appointed a mentor as stated in section 1 | N/A |
| 42 | 4.5 | The safety officer will ensure the team is aware of any rules relating to the local club at any launch | N/A |
| 43 | 4.6 | The safety officer will ensure that all FAA rules are followed | N/A |
| 44 | 5.1 | The student team members will do all work other than handling motors, installing electric matches, and handling black powder | N/A |
| 45 | 5.2 | PSLT's project manager will maintain a project plan | N/A |
| 46 | 5.3 | All foreign nationals have been identified | N/A |
| 47 | 5.4 - 5.4.3 | See section 1 | N/A |
| 48 | 5.5 | PSLT has completed the educational engagement requirement | Demonstration |
| 49 | 5.6 | The team has a website at http://piedmontlaunch.org, which has a page for all deliverables | N/A |
| 50 | 5.7 | See 49 above | N/A |
| 51 | 5.8 | All deliverables will be in PDF format | N/A |
| 52 | 5.9 - 5.10 | A table of contents and page numbers will be added by the team member responsible for the assembly of each document | N/A |
| 53 | 5.11 | PSLT has access to a conference room that is setup to hold teleconferences | N/A |
| 54 | 5.12 | The launch vehicle will be designed to use the available launch pads | N/A |

| Req ID | Requirement | Verification Plan | TADI |
|---|---|---|---|
| 55 | 5.13 | PSLT has a webmaster who will ensure that the website complies with all requirements | N/A |

Table 7.1 - NASA Requirement Verification Plans

| Req ID | TADI Required |
|---|---|
| 1 | Inspection, the primary altimeter in the launch vehicle will be checked after test flights and the final launch to get the official altitude reached |
| 3 | Demonstration, the method of conveying the altitude reached will be demonstrated during test flights |
| 7 | Demonstration, the reusability of the rocket will be demonstrated through test flights |
| 10 | Demonstration, the time it takes to prepare the rocket will be timed during test flights |
| 11 | Test, the rocket will be left in a launch ready configuration for at least 1 hour following which any components that might have lost functionality will be tested |
| 17 | Analysis, RockSim simulations will be used to ensure the launch vehicle is stable at rail exit |
| 18 | Analysis, RockSim simulations will be used to ensure the launch vehicle reaches at least 52 ft/s at rail exit |
| 25 | Analysis, calculations will be done for each independent section of the launch vehicle to ensure it has a low enough kinetic energy |
| 35 | Test, the rockets' ability to perform the experiment will be tested during test flights of both the subscale and full-scale rockets |
| 48 | Demonstration, reports will be submitted at the completion of each event |

Table 7.2 - NASA Requirement Verification TADIs

## 7.2.2 Team Derived Requirements

### 7.2.2.1 Project Requirements

| Req ID | Requirement | Verification Plan | TADI |
|---|---|---|---|
| 56 | Engage at least 200 females in STEM activities. | Keep track of the number of females engaged during educational engagement activities. | N/A |
| 57 | Ensure PSLT is able to continue in future years. | Set up partnerships, procedures, and community support that can be used by future teams so that they do not have to start from scratch. | N/A |
| 58 | Encourage Student Launch at other schools. | Because PVCC is a community college, many members of PSLT will transfer to other schools, where they can encourage people to start Student Launch Teams. | N/A |

Table 7.3 - Team Project Requirement Verification Plans

### 7.2.2.2 Launch Vehicle Requirements

| Req ID | Requirement | Verification Plan | TADI |
|---|---|---|---|
| 59 | The rocket reaches an altitude between 5000 ft and 5400 ft | Design the rocket to be light enough to reach the appropriate altitude without being so light that it goes too high | Analysis Demonstration |
| 60 | The rocket deploys its main parachute at 800 ft AGL | Program the main altimeter to fire the main ejection charge at 800 ft | Inspection |
| 61 | The rocket drifts less than 2500 ft | Deploy the main parachute at a low enough altitude that the rocket is not in the air long enough to drift too far with wind speeds at or below 20 mph | Analysis Demonstration |
| 62 | The rocket separates into 3 sections after the ejection charges fire | Design the rocket to have only 3 separable sections and use large enough ejection charges to ensure that those sections all separate | Demonstration |

Table 7.4 - Team Launch Vehicle Verification Plans

| Req ID | TADI Required |
|---|---|
| 59 | Analysis, simulations have been performed with the full-scale to ensure that the altitude falls within the expected range<br>Demonstration, during the full-scale test flight, the rocket reached an altitude of 5150 ft, which is within the expected range |
| 60 | Inspection, prior to each flight, the altimeters are checked to ensure that they are programmed correctly |
| 61 | Analysis, calculations have been performed to determine the drift of the rocket in a worst-case scenario. Additionally, the simulations done in RockSim were used to find the drift for a less than worst-case scenario, providing a range of expected values<br>Demonstration, the distance that the rocket drifted during the full-scale test flight was measured to be less than 2500 ft |
| 62 | Demonstration, during the full-scale test flight, the rocket successfully separated into its 3 sections |

Table 7.5 - Team Launch Vehicle TADIs

### 7.2.2.3 Payload Requirements

| Req ID | Requirement | Verification Plan | TADI |
|---|---|---|---|
| 63 | The payload shall detect motor ignition | An IMU will be included in the payload, and its accelerometer will be used to detect motor ignition | Testing |
| 64 | The payload shall detect motor burnout | The accelerometer in the payload will be used to detect motor burnout | Testing |

| Req ID | Requirement | Verification Plan | TADI |
|---|---|---|---|
| 65 | The payload shall detect the angular velocity of the rocket at motor burnout | The magnetometer in the IMU will be used to detect the angular velocity of the rocket at motor burnout | Testing |
| 66 | The rocket shall roll 3 times around its long axis | A reaction wheel will be used to induce the roll, and the magnetometer in the payload's IMU will be used to detect when the rocket has completed 3 rotations | Testing |
| 67 | The rocket shall complete its 3 rotations within 12 s | Testing and calculations will be used to determine how fast the reaction wheel will need to spin to complete the rotations in the required time | Analysis<br>Testing |
| 68 | The payload shall identify the ground targets from the target identification challenge | The payload will have a camera that will locate the ground targets while the rocket is performing its rotations | Testing |
| 69 | The rocket shall return to within 5 °/s of its angular velocity at motor burnout | The reaction wheel will be used to induce the required counter roll in the rocket, and the magnetometer in the IMU will be used to detect the angular velocity of the rocket | Testing |
| 70 | The payload shall transmit the latitude, longitude, altitude, vertical velocity, horizontal velocity, acceleration in each axis, rotation about each axis, magnetic field strength in each axis, roll position of the rocket, and whether or not the reaction wheel is spinning during the entire flight | A transmitter will be included in the payload capable of transmitting the required data at the maximum expected range for the flight | Testing |

Table 7.6 - Team Payload Requirement Verification Plans

| Req ID | TADI Required |
|---|---|
| 63 | Testing, tests have been performed to show that the IMU's accelerometer is able to detect the change in acceleration caused by motor ignition |
| 64 | Testing, tests have been performed to show that the IMU's accelerometer is able to detect the change in acceleration caused by motor burnout |
| 65 | Testing, tests have been performed to demonstrate the ability of the IMU's magnetometer to detect the angular velocity of the rocket |
| 66 | Testing, tests have been performed to show that the reaction wheel is able to rotate the rocket about its long axis |
| 67 | Analysis, calculations have been performed to determine the angular velocity needed to complete the 3 rotations within 12 s<br>Testing, tests have been performed to demonstrate the payload's ability to rotate at the required angular velocity |

| Req ID | TADI Required |
|---|---|
| 68 | Testing, the payload has been tested to show that it is able to detect the targets with its camera |
| 69 | Testing, the experiment has been tested to determine how precisely it can control its roll |
| 70 | Testing, tests have been performed to demonstrate the payload's ability to transmit all of the required data at the expected range |

Table 7.7 - Team Payload Requirement TADIs

### 7.2.3 Verified Requirements

The following table lists the requirements that have been verified and where the verification can be found in this document.

| Req ID | Location of Verification |
|---|---|
| 1 | Section 3.2.2.1 |
| 2 | Section 3.2.2.1 |
| 3 | Section 3.2.2.1 |
| 4 | Section 3.1.3.9 |
| 5 | Section 3.2.2.1 |
| 6 | Section 3.1.3.3 |
| 7 | Section 3.1.3.2 |
| 8 | Section 3.1.2 |
| 9 | Section 3.1.2 |
| 10 | Section 3.4 |
| 11 | Section 3.1.3.3 |
| 12 | Section 3.1.3.11 |
| 13 | Section 3.1.3.11 |
| 14 | Table 1.1 |
| 15 | Sections 3.1 and 4 |
| 16 | Table 1.1 |
| 17 | Table 3.3 |
| 18 | Table 3.3 |
| 19 | N/A |
| 20 | Section 3.4 |
| 21 | Sections 3.1 and 4 |
| 22 | Sections 3.1 and 4 |
| 23 | Section 3.2 |
| 24 | Section 7.1 |
| 25 | Section 3.3.5 |
| 26 | Sections 3.2 and 4 |
| 27 | Section 3.2.2.1 |
| 28 | Section 3.2.2.1 |

| Req ID | Location of Verification |
|---|---|
| 29 | Section 3.2.2.1 |
| 30 | Section 3.2.2.1 |
| 31 | Section 3.2.2.1 |
| 32 | Section 3.1.3.6 |
| 33 | Section 3.2.2.3 |
| 34 | Section 3.2.2.1 |
| 35 | Section 4 |
| 36 | Section 4 |
| 37 | Section 4 |
| 38 | Section 6 |
| 39 | N/A |
| 40 | N/A |
| 41 | Section 1.1 |
| 42 | N/A |
| 43 | N/A |
| 44 | N/A |
| 45 | Section 7.4 |
| 46 | N/A |
| 47 | N/A |
| 48 | N/A |
| 49 | N/A |
| 50 | N/A |
| 51 | N/A |
| 52 | Table of Contents |
| 53 | N/A |
| 54 | Table 1.1 |
| 55 | N/A |
| 56 | N/A |
| 57 | N/A |
| 58 | N/A |
| 59 | Section 3.3 |
| 60 | Section 3.3 |
| 61 | Section 3.3 |
| 62 | Section 3.1 |
| 63 | Section 4.2 |
| 64 | Section 4.2 |
| 65 | Section 4.2 |
| 66 | Section 4.2 |
| 67 | Section 4.2 |
| 68 | Section 4.2 |
| 69 | Section 4.2 |
| 70 | Section 4.2 |

Table 7.8 - Verified Requirements

# 7.3 Finances

## 7.3.1 Budget

### 7.3.1.1 Subscale Launch Vehicle

| Item Name | Price | Quantity | Purchased? |
|---|---|---|---|
| 4 in body tube | $14 | 2 | Yes |
| 4 in slotted body tube | $19 | 2 | Yes |
| 4 in avionics bay | $35 | 1 | Yes |
| 4 in nose cone | $22 | 1 | Yes |
| 4 in tail cone retainer | $60 | 1 | Yes |
| 3/8 in U-bolt assembly | $6 | 12 | Yes |
| 1/4 in quick link | $4 | 10 | Yes |
| 12 in parachute protector | $8 | 2 | Yes |
| 1010 rail buttons (2) | $4 | 2 | Yes |
| Ejection canisters (2) | $4 | 2 | Yes |
| Altimeter | $72 | 2 | Yes |
| Recovery harness | $61 | 1 | Yes |
| Main parachute | $127 | 1 | Yes |
| Drogue parachute | $9 | 1 | Yes |
| 54 mm body tube | $8 | 1 | Yes |
| Rotary switch | $10 | 2 | Yes |
| Terminals (2) | $4 | 2 | Yes |
| Avionics mounting posts (5) | $4 | 2 | Yes |
| Swivel | $3 | 6 | Yes |
| Motor | $200 | 4 | Yes |
| Subtotal | | | $1530 |

Table 7.9 - Subscale Launch Vehicle Budget

### 7.3.1.2 Subscale Payload

| Item Name | Price | Quantity | Purchased? |
|---|---|---|---|
| 4 in coupler | $5 | 1 | Yes |
| Raspberry Pi | $40 | 2 | Yes |
| Accelerometer / Gyroscope | $12 | 2 | Yes |
| GPS module | $40 | 1 | Yes |
| Antenna base | $25 | 1 | Yes |
| Antenna base dongle | $25 | 1 | Yes |
| Antenna | $8 | 2 | Yes |

| Item Name | Price | Quantity | Purchased? |
|---|---|---|---|
| Radio module | $40 | 2 | Yes |
| SD card | $10 | 1 | Yes |
| USB flash drive | $28 | 1 | Yes |
| Camera | $40 | 1 | Yes |
| AA battery box | $7 | 2 | Yes |
| UBEC | $10 | 1 | Yes |
| 1/4 in -20 bolts (100) | $10 | 1 | Yes |
| Mounting hub | $14 | 2 | Yes |
| A23 battery holders (2) | $6 | 2 | Yes |
| Motor | $14 | 2 | Yes |
| Power supply | $8 | 1 | Yes |
| IMU | $23 | 1 | Yes |
| Motor controller | $14 | 2 | Yes |
| Mini-USB cable | $3 | 1 | Yes |
| 1/4 in -20 nuts (100) | $6 | 1 | Yes |
| Subtotal | | | $503 |

Table 7.10 - Subscale Payload Budget

### 7.3.1.3 Full-scale Launch Vehicle

| Item Name | Price | Quantity | Purchased? |
|---|---|---|---|
| 54 mm body tube | $43 | 1 | Yes |
| 5.5 in body tube | $134 | 2 | Yes |
| 5.5 in nose cone | $85 | 1 | Yes |
| 5.5 in coupler | $63 | 1 | Yes |
| Rotary switch | $10 | 2 | Yes |
| 1/4 in Threaded rod | $8 | 1 | Yes |
| 1/4 in Tube | $11 | 1 | Yes |
| 1/4 in U-bolt assembly | $5 | 8 | Yes |
| Drogue parachute | $9 | 1 | Yes |
| Main parachute | $146 | 1 | Yes |
| Avionics mounting posts (5) | $4 | 2 | Yes |
| Terminals (2) | $4 | 2 | Yes |
| Tail cone | $9 | 1 | Yes |
| 1515 rail button (2) | $5 | 1 | Yes |
| Ejection canisters (2) | $4 | 2 | Yes |
| 1/4 in quick link | $4 | 10 | Yes |
| 18 in parachute protector | $11 | 2 | Yes |
| Recovery harness | $100 | 1 | Yes |
| Swivel | $3 | 6 | Yes |
| Motor | $200 | 3 | Yes |

| Item Name | Price | Quantity | Purchased? |
|---|---|---|---|
| Subtotal | | | $1511 |

Table 7.11 - Full-scale Launch Vehicle Budget

### 7.3.1.4 Full-scale Payload

| Item Name | Price | Quantity | Purchased? |
|---|---|---|---|
| Raspberry Pi | $40 | 1 | Same as subscale |
| GPS module | $40 | 1 | Same as subscale |
| Antenna base | $25 | 1 | Same as subscale |
| Antenna base dongle | $25 | 1 | Same as subscale |
| Antenna | $8 | 2 | Same as subscale |
| Radio module | $40 | 2 | Same as subscale |
| SD card | $10 | 1 | Same as subscale |
| USB flash drive | $28 | 1 | Same as subscale |
| Camera | $40 | 1 | Yes |
| AA battery box | $7 | 1 | Yes |
| UBEC | $10 | 1 | Same as subscale |
| 1/4 in -20 bolts (100) | $10 | 1 | Same as subscale |
| Mounting hub | $14 | 1 | Same as subscale |
| A23 battery holders (2) | $6 | 1 | Yes |
| Motor | $14 | 1 | Same as subscale |
| Power supply | $8 | 1 | Same as subscale |
| IMU | $23 | 1 | Same as subscale |
| Motor controller | $14 | 1 | Same as subscale |
| Mini-USB cable | $3 | 1 | Same as subscale |
| 1/4 in -20 nuts (100) | $6 | 1 | Same as subscale |
| Subtotal | | | $53 |

Table 7.12 - Full-scale Payload Budget

### 7.3.1.5 Educational Engagement

| Item Name | Price | Quantity | Purchased? |
|---|---|---|---|
| Model rocket kit | $22 | 2 | Yes |
| Model rocket bulk pack (24) | $100 | 4 | Yes |
| Model rocket motor (24) | $52 | 5 | Yes |
| Subtotal | | | $704 |

Table 7.13 - Educational Engagement Budget

### 7.3.1.6 PPE

| Item Name | Price | Quantity | Purchased? |
|---|---|---|---|
| Safety glasses | $4 | 5 | Yes |
| Dust masks (10) | $21 | 1 | Yes |
| Glove | $10 | 5 | Yes |
| Subtotal | | | $91 |

Table 7.14 - PPE Budget

### 7.3.1.7 Tools and Construction Materials

| Item Name | Price | Quantity | Purchased? |
|---|---|---|---|
| Wood screws (100) | $10 | 1 | Yes |
| Epoxy clay | $20 | 1 | Yes |
| Epoxy | $16 | 4 | Yes |
| Plywood | $16 | 1 | Yes |
| Fiberglass sheet | $20 | 5 | Yes |
| Screws (120) | $12 | 4 | Yes |
| Lexan sheet | $8 | 2 | Yes |
| #4-40 bolts (100) | $6 | 1 | Yes |
| Spray paint | $4 | 10 | Yes |
| Subtotal | | | $320 |

Table 7.15 - Tools and Construction Materials Budget

### 7.3.1.8 Travel

| Item Name | Price | Quantity | Purchased? |
|---|---|---|---|
| Hotel room | $495 | 7 | Yes |
| Food | $1700 | 1 | No |
| Transport | $250 | 1 | No |
| Subtotal | | | $5415 |

Table 7.16 - Travel Budget

### 7.3.1.9 Miscellaneous

| Item Name | Price | Quantity | Purchased? |
|---|---|---|---|
| 9 volt batteries (20) | $10 | 2 | Yes |
| Shear pins (20) | $4 | 2 | Yes |
| Removable rivets (10) | $4 | 4 | Yes |
| Wires | $12 | 1 | Yes |

| Item Name | Price | Quantity | Purchased? |
|---|---|---|---|
| Ignitors (100) | $60 | 1 | Yes |
| Black powder | $18 | 2 | Yes |
| Masking tape | $4 | 2 | Yes |
| AA batteries (20) | $13 | 2 | Yes |
| A23 batteries (12) | $9 | 2 | Yes |
| Electrical tape | $6 | 2 | Yes |
| Subtotal | | | $200 |

Table 7.17 - Miscellaneous Budget

#### 7.3.1.10 Total

$10327

### 7.3.2 Funding Plan

Funding for PSLT comes from corporate sponsors, individual donors, and PVCC. Below is a table showing how much PSLT has received from each donor.

| Source | Amount Donated |
|---|---|
| Individual donors | $4500 |
| PVCC | $5500 |
| Corporate sponsors | $1000 |
| Total | $11000 |

Table 7.18 - Sources of Funding

### 7.3.3 Allocation of Funds

| Allocated To | Amount |
|---|---|
| Subscale | $2200 |
| Full-scale | $2200 |
| Travel | $5500 |
| Educational engagement | $1000 |
| Other expenses | $1000 |
| Motors | $1000 |

Table 7.19 - Allocation of Funds

# 7.4 Timeline

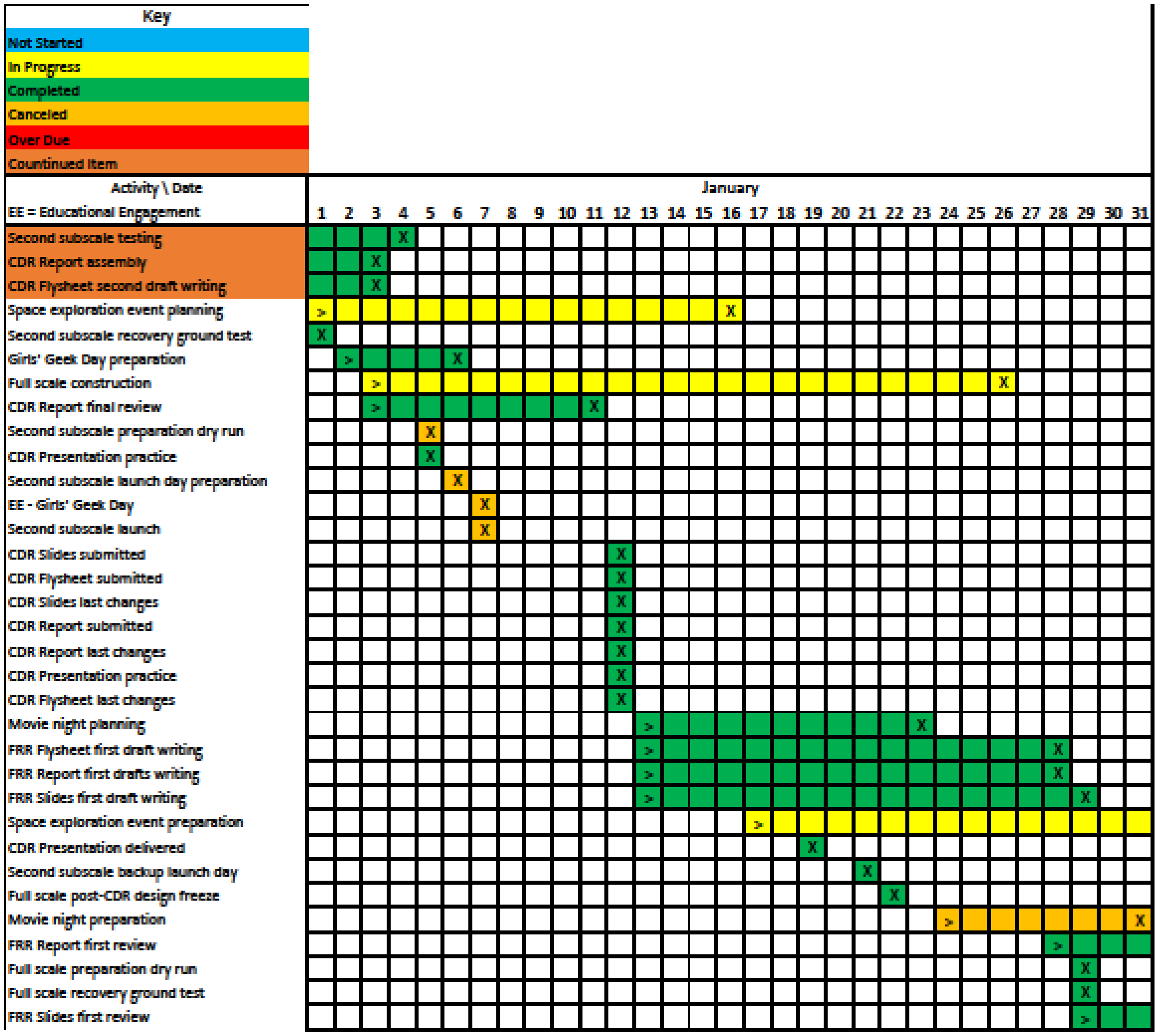


Figure 7.1 - Timeline January

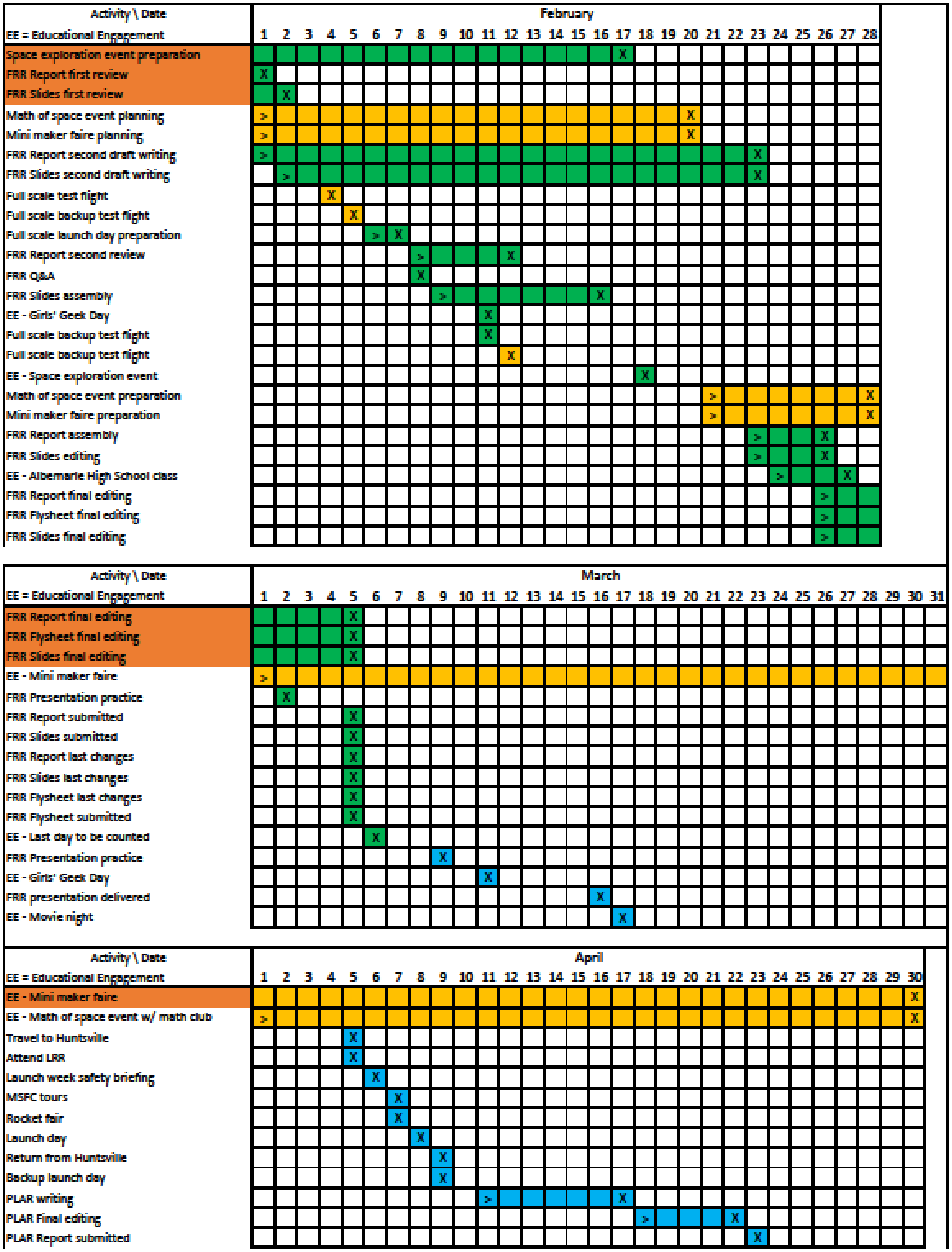


Figure 7.2 - Timeline February through April