Piedmont Student Launch Team
Critical Design Review

2017 NASA Student Launch

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

December 13, 2016

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Glossary of Acronyms

ABS	Acrylonitrile Butadiene Styrene
AGL	Above Ground Level
APCP	Ammonium Perchlorate Composite Propellant
CG	Center of Gravity
CP	Center of Pressure
GPS	Global Positioning System
IMU	Inertial Measurement Unit
NAR	National Association of Rocketry
PPE	Personal Protective Equipment
PSLT	Piedmont Student Launch Team
STEM	Science, Technology, Engineering, and Math
TADI	Test, Analysis, Demonstration, or Inspection
TRA	Tripoli Rocketry Association

UBEC	Universal Battery Eliminator Circuit
USB	Universal Serial Bus

1 General Information

1.1 Team Contacts

Name	Title	Email	Telephone
Dr. Yana Goddard	Associate Professor of Physics	ygoddard@pvcc.edu	434-961-5341
Andrew Oxford	Team Leader	leader@piedmontlaunch.org	434-996-4658
Nicolas Gutkowski	Safety Officer	safety@piedmontlaunch.org	434-806-6980

Table 1.1 - Team Contacts

1.2 Team Organization and Members

Name	Going to Launch Week?	Role	Project Teams	Functional Teams
Andrew	Yes	Launch Vehicle Lead	Launch Vehicle, Admin	Structural
Sander	Yes	Experiment Lead	Experiment, Admin	Electrical, Structural
Nick	Yes	Safety Officer	Launch Vehicle, Admin	Programming
Alex	Yes	Deputy Safety Officer	Experiment, Admin	Programming
David	Yes	Mentor	Admin	–

Table 1.2 - Key Team Members

Name	Going to Launch Week?	Project Teams	Functional Teams
Nathan	Yes	Launch Vehicle, Experiment	Electrical
Collins	Yes	Launch Vehicle, Admin	Programming, Electrical
Rodney	Yes	Experiment	Programming
Haochen	Yes	Launch Vehicle	Structural
Rachel	Yes	Launch Vehicle	Structural
Daniel	Yes	Launch Vehicle	Electrical, Structural
Cayla	Yes	Launch Vehicle	Structural
Jack	Yes	Experiment	Electrical
Jeffery	Yes	Launch Vehicle	Structural, Electrical

Table 1.3 - Other Team Members

1.3 NAR / TRA Section Assistance

For purposes of mentoring, design / documentation review, and launch assistance, PSLT will be working primarily with the Valley AeroSpace Team (VAST) – NAR Section #687 / Tripoli Western Virginia #36.

PSLT will also be working with the Northern Virginia Association of Rocketry (NOVAAR) – NAR Section #205.

2 CDR Summary

2.1 Team Summary

The group 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 level 2.

2.2 Launch Vehicle Summary

Launch Vehicle Information	Details
Weight without motor	29.77 lbs
Weight with motor	37.27 lbs
Motor choice	AeroTech L1150R
Recovery system	18 in drogue parachute, 84 in main parachute
Rail Size	1515 / 12 ft
Length	108.8 in
Body diameter	5.5 in
Fin span	20.3 in

Table 2.1 - Launch Vehicle Summary

2.3 Payload Summary

PSLT's experimental payload is designed to rotate the rocket around its roll axis using a reaction wheel. The payload consists of an electronics sled mounted in the fore end of the upper section of the rocket with a reaction wheel mounted below the sled. On the electronics sled, there is a Raspberry Pi that controls the experiment, an Inertial Measurement Unit (IMU) to detect the roll of the rocket, and the other electronics necessary for the payload.

Additionally, the experiment has a camera mounted to detect the ground targets from the target identification challenge.

3 Changes Since PDR

3.1 Vehicle Criteria

Change	Reason
Increased the length of the upper body tube by 8 in	To add more space for the main parachute
Changed from a 54 mm motor to a 75 mm motor	There are not any 54 mm motors with sufficient impulse to reach the target altitude available
Increased the length of the coupler by 2 in	To increase the length of the shoulders to be greater than the body diameter of the rocket
Changed from a 30 in drogue parachute to a 12 in one	To reduce drift during descent under the drogue
Changed method of attachment for recovery harnesses so that there are not additional sections of Kevlar between the main piece and the mounting points	To reduce the number of points of failure in the recovery system and to reduce the chance of twisting the recovery harnesses

Table 3.1 - Changes to Vehicle Criteria

3.2 Payload Criteria

Change	Reason
Replaced the two accelerometer/gyroscopes with an IMU	Better able to measure rotation
Removed the team derived goal of transmitting live video	Bandwidth limitations
The rocket will not roll to aim at the ground targets	Not enough time during ascent to ensure the ability to aim at all of the targets and still complete the primary objectives of the mission
Changed reaction wheel from solid metal ring to fiberglass circles with bolts and nuts for weight	Allows weight to be adjusted more easily

Table 3.2 - Changes to Payload Criteria

3.3 Project Plan

Change	Reason
Added subscale test flight on 2017-01-21	Failure of the initial subscale rocket and weather preventing an earlier relaunch
Added several educational engagement activities	To be able to engage more people

Table 3.3 - Changes to Project Plan

4 Vehicle Criteria

4.1 Design and Verification of Launch Vehicle

4.1.1 Mission Statement and Success Criteria

4.1.1.1 Mission Statement

Create a high-power rocket capable of lifting an experimental payload to 5280 ft, landing safely, and being reusable.

4.1.1.2 Mission Success Criteria

- Launch vehicle and payload are prepared for flight in less than four hours
- Launch vehicle and payload remain functional while on the launch pad
- Rocket launches vertically
- After motor burnout, rocket rotates 3 times around its roll axis with a precision of 10 °
- Rocket detects the ground targets from the target identification challenge
- Rocket returns to post motor burnout angular velocity with a precision of 5 °/s
- Rocket successfully deploys drogue parachute before apogee
- Rocket reaches apogee between 5000 ft and 5400 ft
- Rocket successfully deploys main parachute at 800 ft AGL
- Rocket drifts less than 2500 ft
- Rocket lands with less than 75 ft-lbf of kinetic energy in each independent section
- Rocket is undamaged by flight

4.1.2 Launch Vehicle Design

4.1.2.1 Launch Vehicle

The launch vehicle is designed to have enough room to mount all of the components necessary for safe, stable flight to the target altitude, as well as the experimental payload.

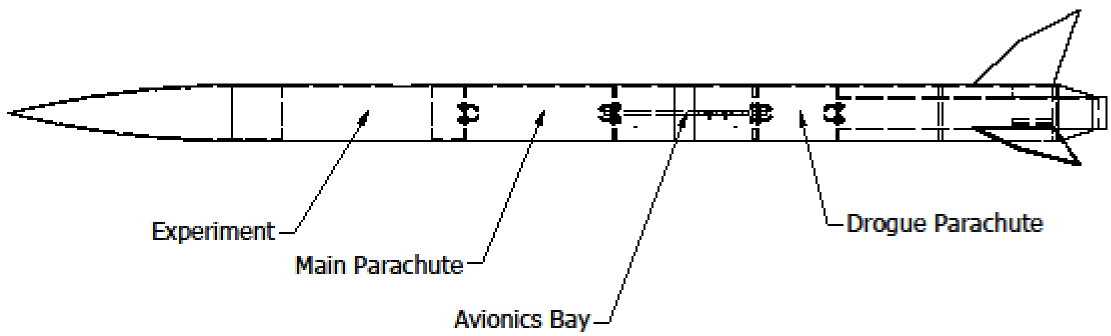

Figure 4.1 - Launch Vehicle Sections

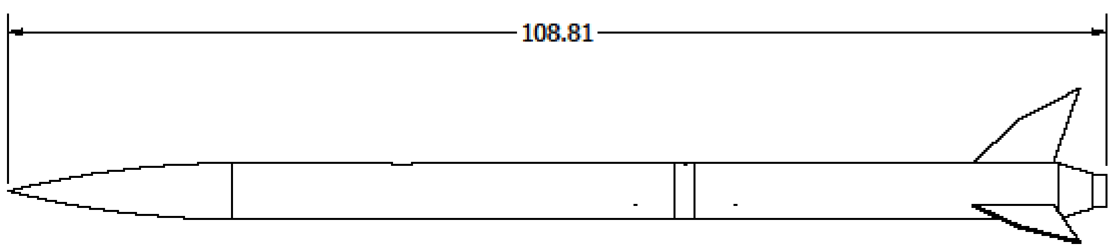

Figure 4.2 - Launch Vehicle Length

4.1.2.2 Material

All structural components of the launch vehicle and experiment will be made from fiberglass to maximize strength without introducing significant additional complexity for manufacturing or being prohibitively expensive.

4.1.2.3 Connections

All connections between parts are made using epoxy except where otherwise noted.

4.1.2.4 Body Sections

The launch vehicle is comprised of three sections which are, from top to bottom, the upper section, the avionics bay, and the lower section. This allows enough points of separation to use a standard dual deployment recovery system, eliminating the need to use a more complex system that would have a higher risk of failing. It also allows the recovery system electronics to be housed in a separate compartment from the experiment and the tracking system transmitter.

The upper and lower sections fit over the avionics bay and are connected to it by 4 shear pins each.

The upper section houses the experimental payload, tracking system, and the main parachute, and it is where the nose cone attaches.

Figure 4.3 - Upper Section External

The avionics bay houses all of the recovery system electronics and the ejection charges.

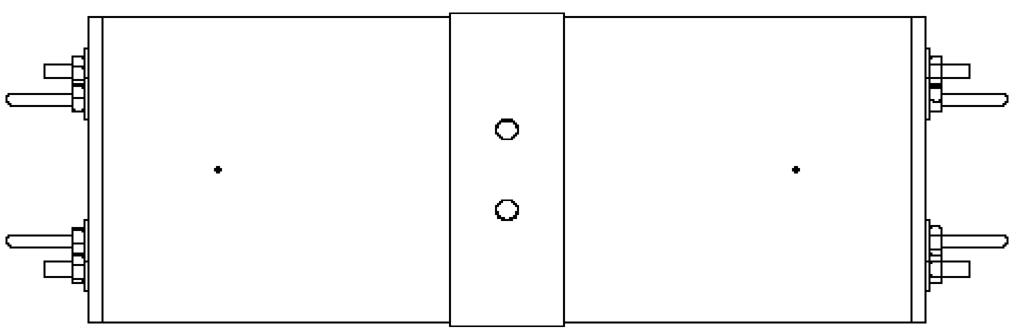

Figure 4.4 - Avionics Bay External

The lower section houses the motor and the drogue parachute.

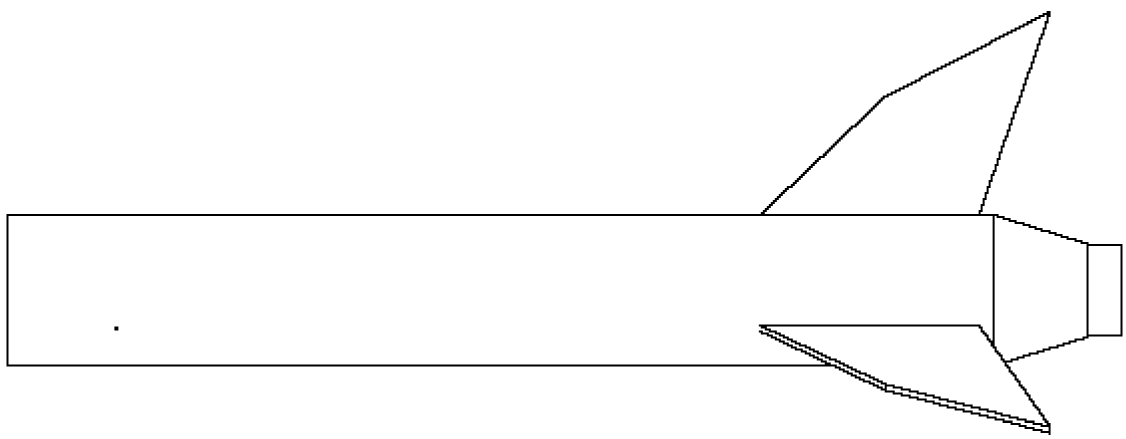

Figure 4.5 - Lower Section External

4.1.2.5 Nose Cone

An ogive nose cone will be used because nose cones of that shape are easily commercially available and provide good aerodynamics at subsonic speeds.

4.1.2.6 Upper Section

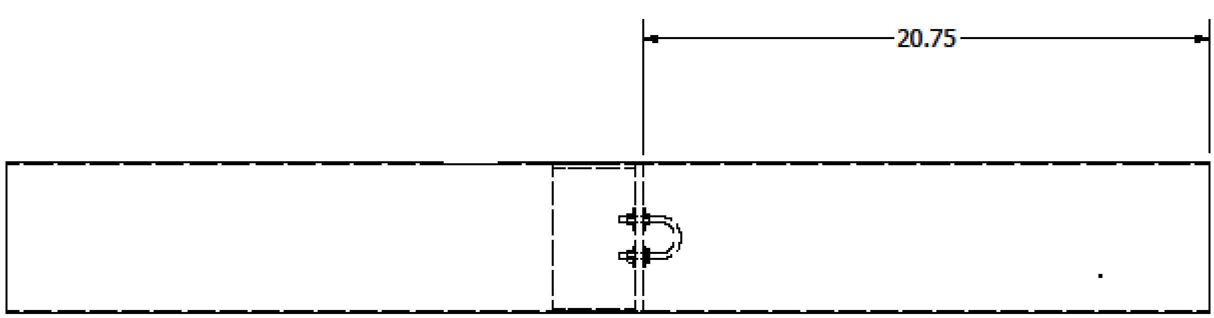

Figure 4.6 - Upper Section Internal

4.1.2.6.1 Nose Cone Attachment

There are three holes at the top of the upper section are for attaching the nose cone to it with removable rivets. Using removable rivets allows the nose cone to be removed, allowing for access to the payload compartment of the rocket.

4.1.2.6.2 Camera Mounting Hole

The rectangular hole in the upper section is for mounting the camera for the experiment. It allows the camera to be removed with the experiment, while allowing it to have a view outside of the rocket.

4.1.2.6.3 Upper Bulkhead

The bulkhead in the upper section provides a mounting point for the upper recovery harness. It also separates the main parachute compartment from the payload compartment of the upper section.

There is a section of coupler attached to the back of the upper bulkhead which acts as a rest for the payload to sit against, allowing it to be easily aligned when being put in the rocket as well as allowing force to be transferred from the experiment to the launch vehicle through a sturdier mechanism than rivets.

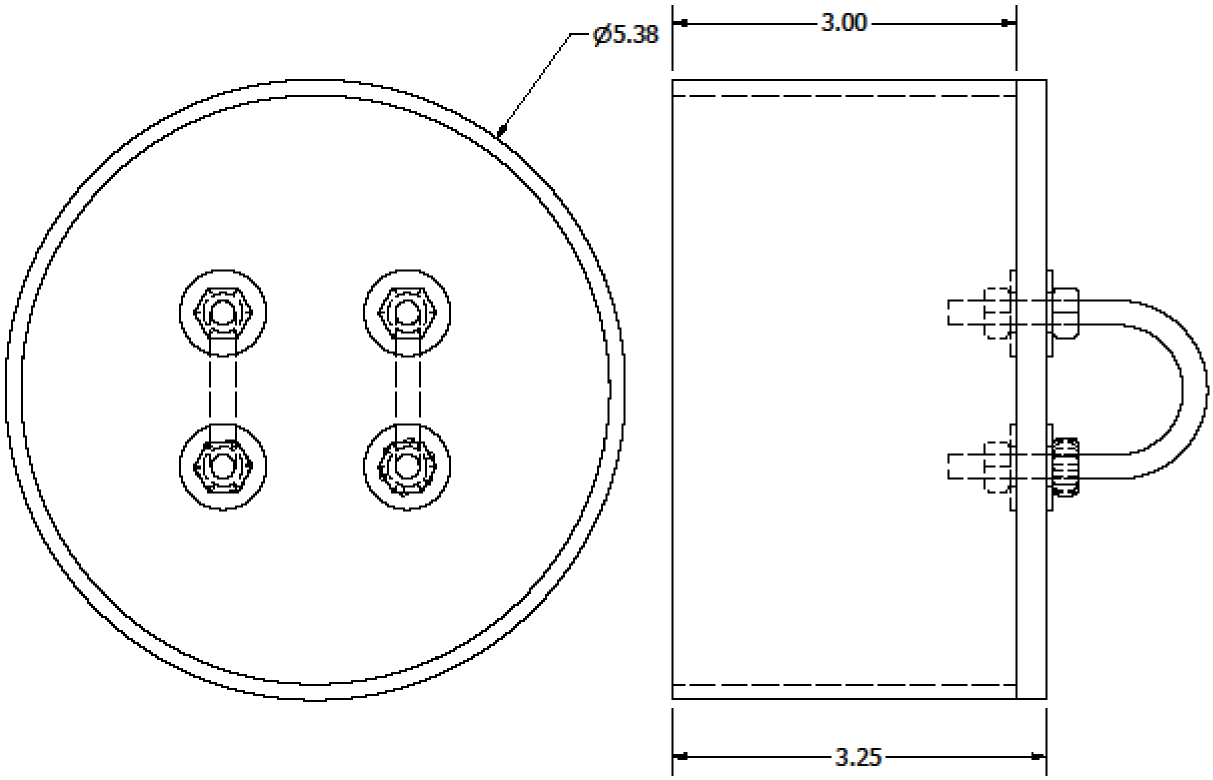

Figure 4.7 - Upper Bulkhead

4.1.2.7 Avionics Bay

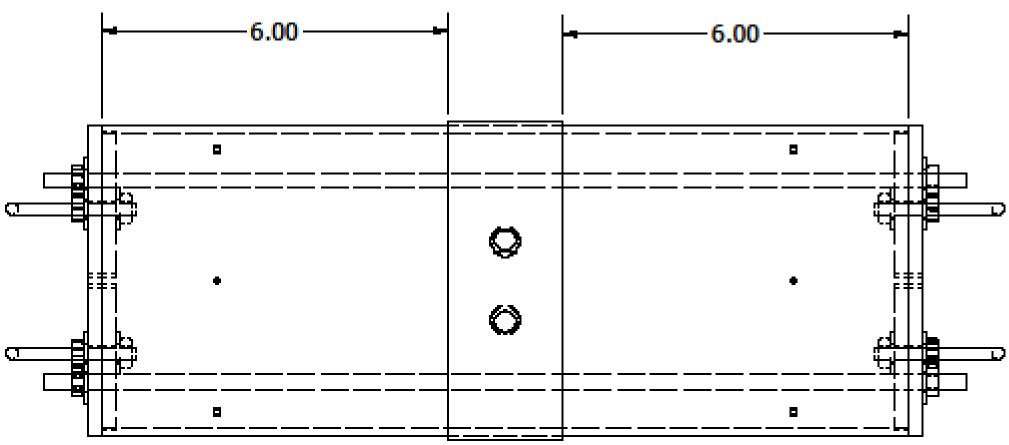

Figure 4.8 - Avionics Bay Internal

4.1.2.7.1 End Caps

Each end of the avionics bay has two bulkheads attached to each other to make an end cap. Each end cap has mounting points for two U-bolts, which act as mounting points for the upper and lower recovery harnesses; two threaded rods, which run through the avionics bay and are what the avionics sled is mounted on; two terminals for the ejection charges; and two ejection cups. The hole in the center of each end cap allows the wires for the ejection charges to be run to the terminals from the altimeters on the inside of the avionics bay.

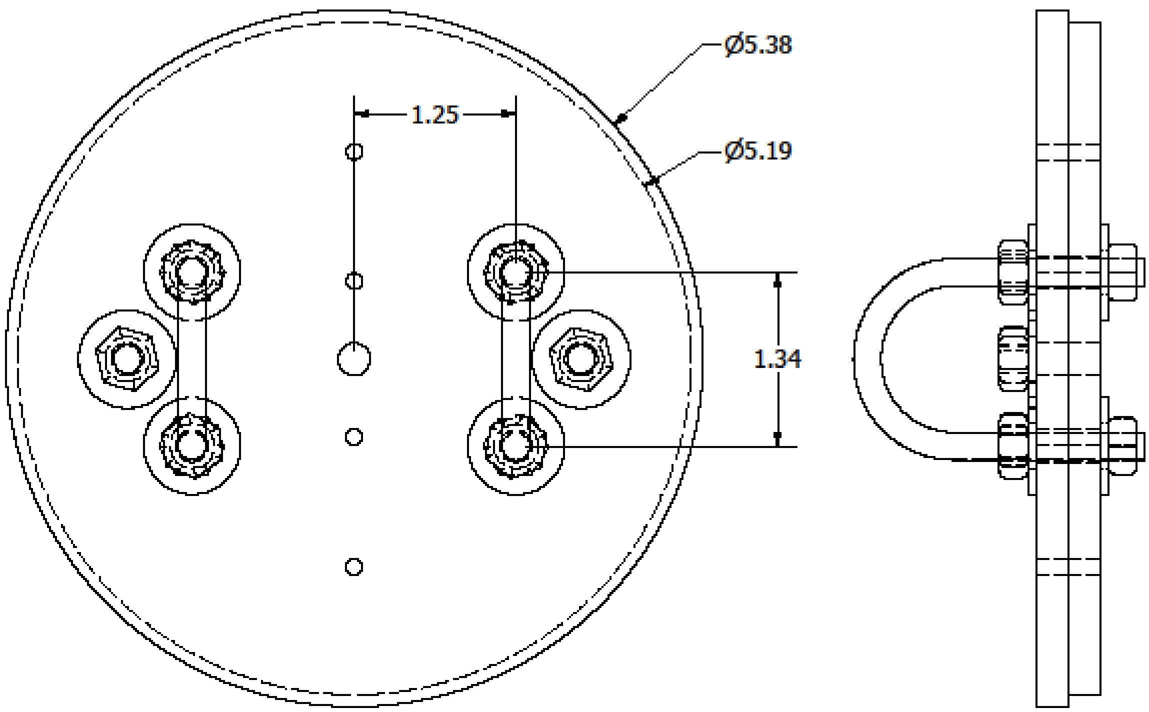

Figure 4.9 - Avionics End Cap

4.1.2.7.2 Avionics Sled

The avionics sled is used to mount the altimeters and their batteries. The sled is attached to the avionics bay by sliding it onto the two threaded rods that run through the avionics bay; it is secured in place by nuts on the threaded rods at each end of the sled. Both altimeters are mounted to one side of the sled, and the batteries are both mounted to the other side so that if either battery breaks loose during flight, it is less likely to damage the altimeters.

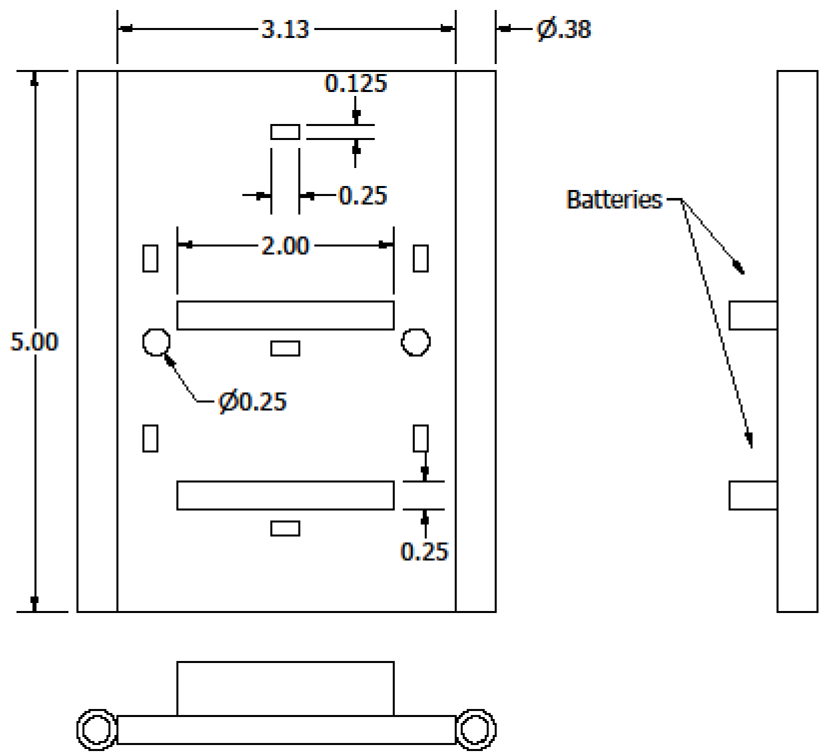

Figure 4.10 - Avionics Sled

4.1.2.8 Lower Section

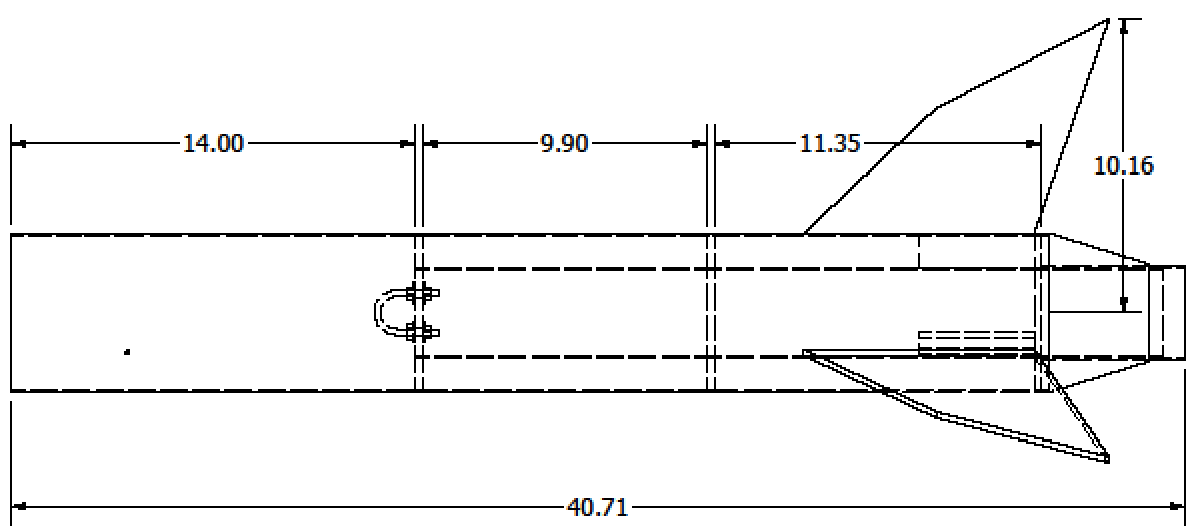

Figure 4.11 - Lower Section Internal

4.1.2.8.1 Rail Attachment

The launch vehicle is attached to the launch rail by two 1515 rail buttons located on the lower section. 1515 rail buttons were chosen to ensure that the connection between the launch vehicle and launch rail will be sturdy enough to support the weight of the rocket.

4.1.2.8.2 Fins

The launch vehicle uses three fins which are mounted using through-the-wall mounting to provide additional strength for the fins and to provide an additional path for force from the motor to be transferred to the airframe. Additionally, each fin will have an epoxy clay filet where it connects to the outside of the body tube of the lower section to improve the strength of the connection and improve the aerodynamics around the base of the fins.

The size of the fins is based on simulations done in RockSim to allow stable flight without causing the rocket to be over-stable.

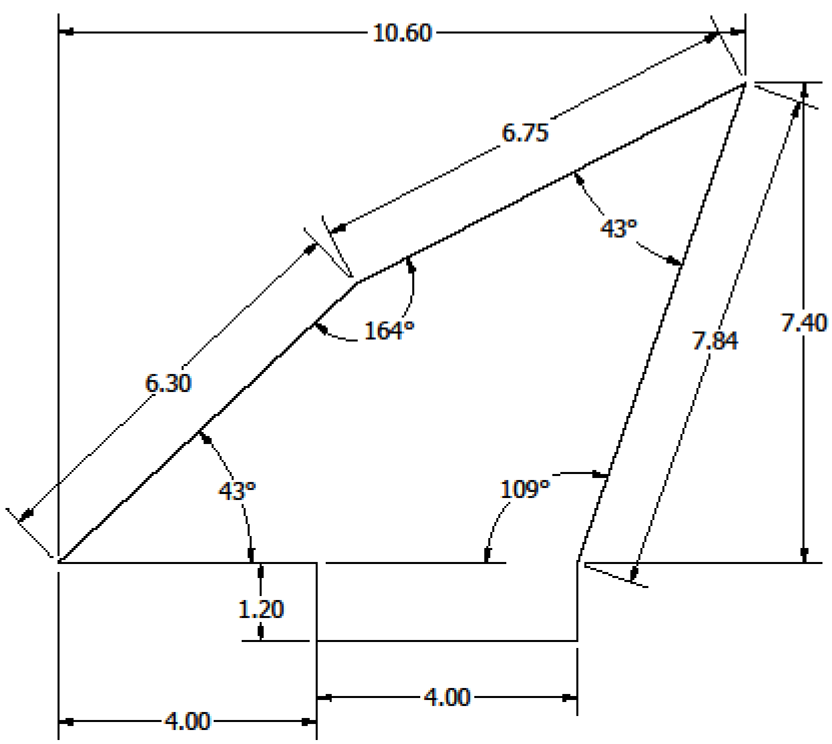

Figure 4.12 - Fins

4.1.2.8.3 Tail Cone

A tail cone will be used both to make the launch vehicle more aerodynamic and to reduce the risk of damage to the motor mount at landing.

The tail cone is 3D printed from ABS plastic.

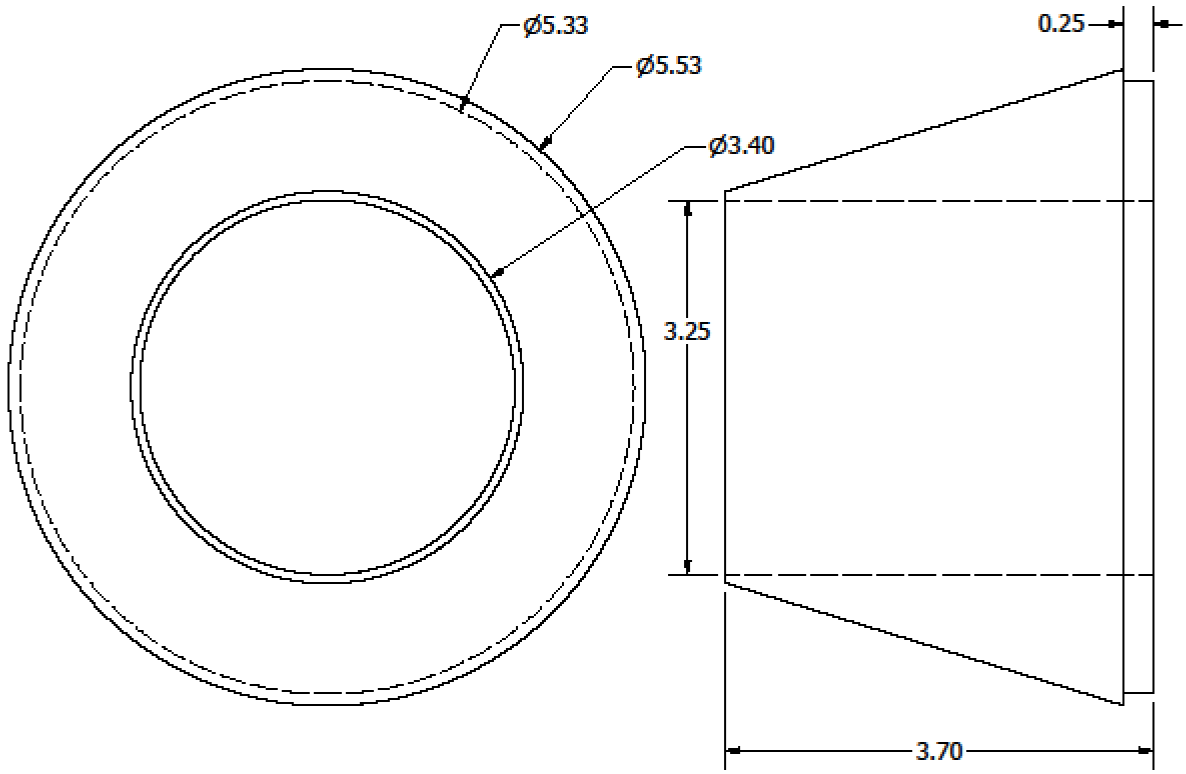

Figure 4.13 - Tail Cone

4.1.2.9 Motor Mount

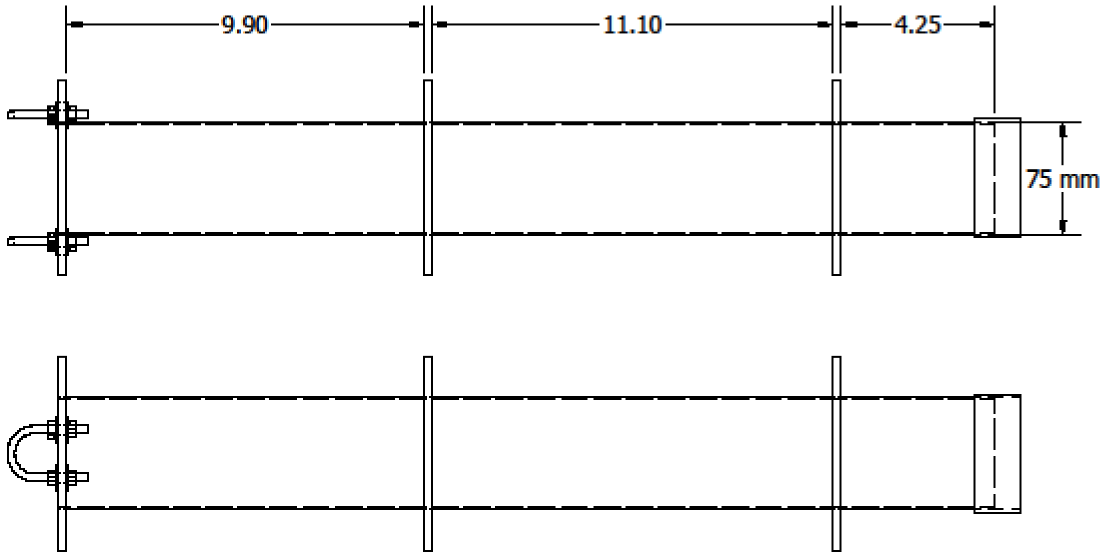

Figure 4.14 - Motor Mount

4.1.2.9.1 Motor Retention

A screw-on retainer will be used for motor retention because it provides a simple mechanism for installing and removing motors, while being secure enough to withstand the forces from a motor of the class necessary to lift the rocket to the target altitude. The motor retainer will be connected to the motor tube using high heat epoxy.

4.1.2.9.2 Centering Rings

The motor mount will utilize three centering rings to ensure a strong connection between the motor tube and the lower section of the launch vehicle.

The foremost of the three centering rings will have two U-bolts to allow it to be used as a mounting point for the lower recovery harness.

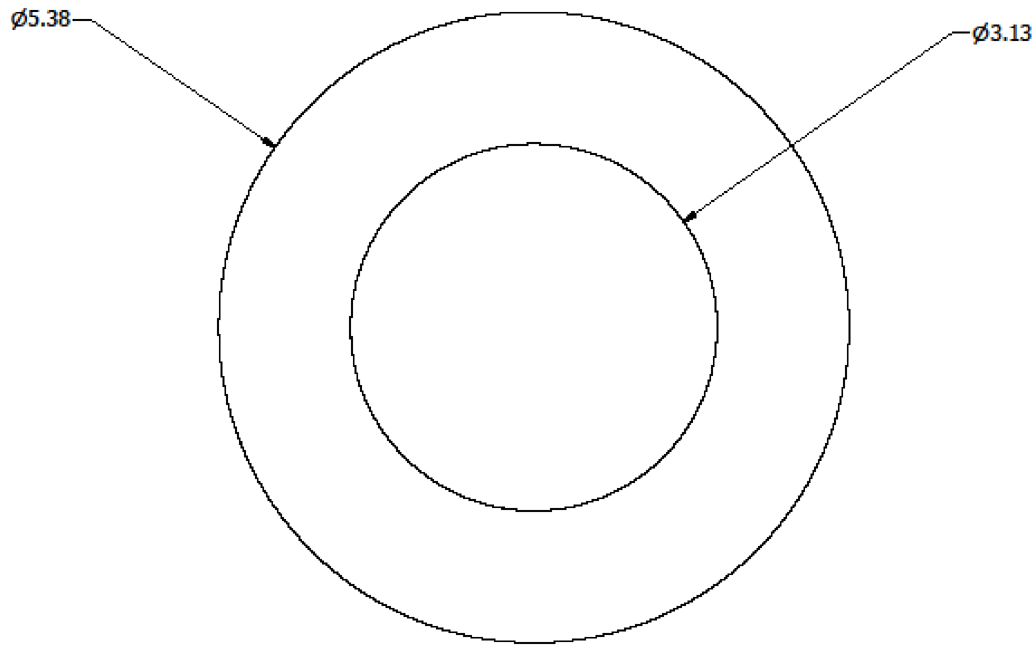

Figure 4.15 - Centering Rings

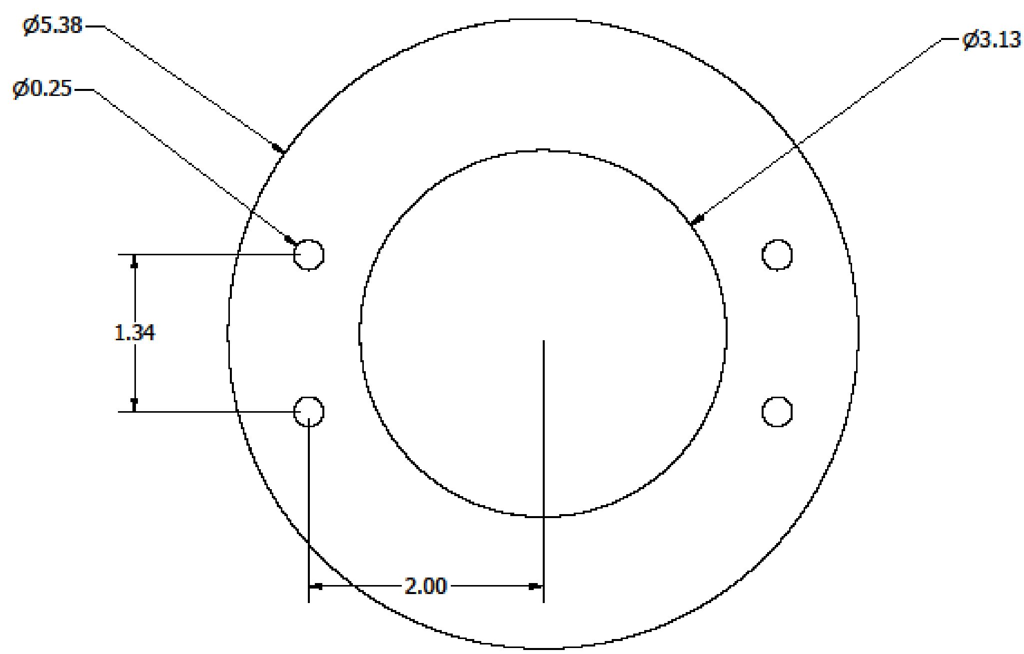

Figure 4.16 - Fore Centering Ring

4.1.2.10 Ballasting

The rocket will use ballasting to avoid going over the target altitude. The ballasting will be done with 2 lbs of epoxy clay located in the nose cone of the rocket.

The amount of ballasting was determined using simulations done in RockSim.

4.1.3 System Requirements and Risks

4.1.3.1 Altitude

The rocket is light enough with low enough drag to reach the target altitude using a motor that does not exceed L-class.

4.1.3.2 Reusability

All major structural components are made from fiberglass to ensure that the rocket is able to be reused after flight. The increased weight of fiberglass does increase 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 decreases the risk of something going wrong during flight.

4.1.3.3 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 two 1/4 in threaded steel rods with nuts and washers 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.

4.1.3.4 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.

4.1.3.5 Preparation

The designs of the launch vehicle and payload are simple enough that they can be prepared for flight within four hours.

4.1.3.6 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 sufficient power to remain in the launch ready configuration for at least one hour. Additionally, they will be replaced before each flight.

4.1.3.7 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.

4.1.3.8 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.

4.1.3.9 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 except when the ejection charges are fired.

4.1.3.10 Recovery System Activation

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

4.1.3.11 Recovery System Power

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

4.1.3.12 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.

4.1.3.13 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 will be placed in the upper section of the rocket to prevent any electromagnetic interference with the recovery system from the payload.

4.1.4 Integrity of Design

4.1.4.1 Fin Shape

The shape of the fins does not increase drag on the rocket so much that it cannot reach the required altitude, and they still provide enough stabilization for the rocket to be stable during flight. Although there are other shapes, such as elliptical, that would achieve the same effect with even lower drag, the design used makes the fins simpler to manufacture, reducing the risk of mistakes that could cause unstable flight.

4.1.4.2 Materials

The fins, body tubes, nose cone, bulkheads, centering rings, coupler, motor tube, avionics sled, and all structural components of the payload will be made out of fiberglass. This will allow them to withstand any forces from the flight or landing without cracking or breaking. This does increase the weight of the rocket, which in turn increase the impulse and thrust needed from the motor, but it is still able to reach the required altitude using a motor that does not exceed L-class and improves the ability of the rocket to be flown more than once.

The tail cone will be made out of ABS plastic, which is not as strong as fiberglass; however, it will not have to withstand a direct impact, so ABS will be sufficient to prevent it from breaking.

4.1.4.3 Motor Mounting and Retention

The motor retainer is designed by a commercial manufacturer to be sufficient to hold a motor of the class being used in the motor tube during the flight. Additionally, the motor retainer will be connected to the motor tube using a high heat epoxy to ensure that it stays on during and after multiple flights.

4.1.4.4 Mass

System	Mass (lbs)
Overall	29.77
Upper section	4.53
Avionics bay	4.57
Lower section	7.53
Motor mount	1.77
Nose cone	2.59
Ballast	2.00
Recovery harness (each, with swivels and quick links)	1.22
Parachutes (both)	1.60
Centering rings (each)	0.14
Bulkheads (each)	0.39
Upper body tube	3.85
Lower body tube	3.15
Motor tube	1.03
Avionics bay tube	1.86
Avionics sled, mounting hardware, and altimeter	0.64
Fins (each)	0.70
Tail cone	0.44

Table 4.1 - System Masses

4.2 Subscale Flight Results

4.2.1 Design

The airframe was 73% scale because the next standard size of body tube has a 73% smaller diameter than the body tubes used for the full scale rocket. It also allows enough space to fit the experiment without having to make significant design modifications. The reaction wheel was scaled to 29% mass because the rocket was made of phenolic reinforced paper, rather than fiberglass, so a smaller reaction wheel was needed to achieve the same effect. The subscale rocket was flown with a fully functional experiment.

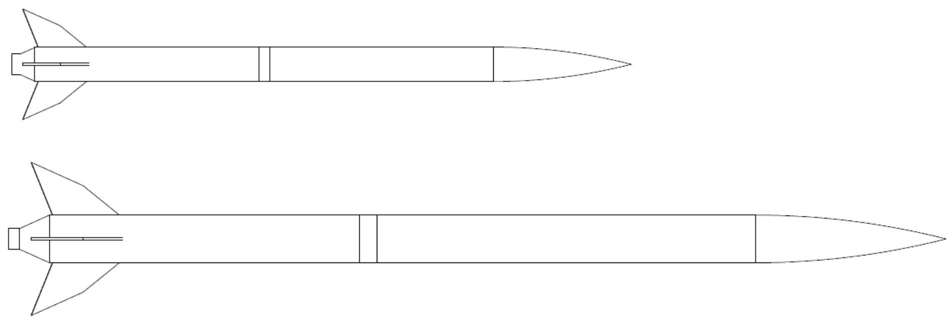

Figure 4.17 - Subscale Compared to Full Scale

4.2.2 Simulations

A simulation of the subscale test flight was performed in RockSim using the predicted temperature and wind speed at the launch site before the launch, results are shown below.

Value	Expected Result
Apogee	2319 ft
Time to apogee	12.8 s
Flight time	51 s
Rail exit velocity	53 ft / s

Table 4.2 - Pre-Subscale Launch Simulation

An additional simulation was run after the flight using the same conditions as on the day of the launch, results are shown below.

Value	Expected Result
Apogee	2348 ft
Time to apogee	12.8 s

Value	Expected Result
Flight time	48 s
Rail exit velocity	53 ft/s

Table 4.3 - Post-Subscale Launch Simulation

The conditions at the launch are shown below.

Condition	Value
Temperature	27 °F
Pressure	1.01 Bar
Humidity	50%
Elevation	400 ft
Wind speeds	3 - 6 MPH

Table 4.4 - Subscale Launch Day Conditions

4.2.3 Flight

The subscale test flight occurred on December 10th at the NOVAAR launch site in Great Meadow, VA. Approximately 0.77 seconds after liftoff the APCP motor detonated, ejecting the fuel grains out of the rocket and propelling the ejection charge into the drogue parachute compartment and then out through the side of the rocket. Because the rocket did not reach the altimeter arming altitude of 300 ft, the main parachute did not deploy and the rocket crash landed. The Raspberry Pi that controls the experiment was damaged in the crash, destroying much of the data it had collected.

The table below lists the data that was recovered from the flight. Most of the values come from analyzing videos of the flight, the others are from data that was collected from the payload prior to the failure.

Value	Result
Apogee	154 ft
Anomaly altitude	42 ft
Rail exit angle	<5°
Time to apogee	2.6 s
Flight time	9.5 s
Rail exit velocity	46 ft / s

Table 4.5 - Subscale Launch Analysis Data

4.2.4 Comparison of Flight and Simulation

The main value that was recovered from the flight that can be compared with the simulation is the rail exit velocity. In both the simulation run before the flight and the one run after it, the rail exit velocity is 7 ft/s higher than it was in the actual flight. It is believed that this is a result of the motor failure, as that may have affected the initial thrust of the motor.

4.2.5 Drag Coefficient

There was not enough data gathered to be able to estimate the drag coefficient for the full scale; however, that value will be estimated as soon as possible after the flight of the second subscale rocket, which will provide a more accurate value than the first subscale would have as the second one includes the design changes made after the first subscale.

4.2.6 Impact on Full Scale Design

Change	Reason
Extended upper body tube	To allow for a larger parachute and experiment
Reduced altimeter arming altitude to 100 ft	More likely to deploy parachute in the event of an anomaly
Rearranged the experiment electronics	More secure mounting and connections in case of a crash
Changed the experiment code to write data more often	To save as much data as possible in the event of a crash

Table 4.6 - Subscale Impact on Full Scale Design

4.2.7 Second Subscale

A new subscale rocket has been constructed and is ready to fly; however, all of the January launches in Virginia have either been cancelled due to dangerous weather conditions or are after the CDR deadline. The replacement subscale will be launched at the next NOVAAR launch on January 21st.

4.3 Recovery Subsystem

4.3.1 Chosen Design Alternatives

4.3.1.1 Parachutes

Both the main and drogue parachutes will be nylon. This will provide sufficient strength to prevent the parachutes from being damaged.

The main parachute will have a diameter of 84 in and the drogue parachute will have a diameter of 18 in to ensure a low enough speed to prevent damage to the rocket on landing and at main deployment without causing the rocket to drift unduly during descent.

4.3.1.2 Recovery Harnesses

The recovery harnesses will be Kevlar to withstand the forces from the ejection charges.

Both the upper and lower recovery harnesses will be 27 ft long.

4.3.1.3 Mounting Points

Both recovery harnesses will be mounted to the launch vehicle using U-bolts to ensure the force from the ejection charges is distributed evenly across the relevant bulkheads and centering ring.

4.3.1.4 Recovery Harness Attachment

The recovery harnesses will be attached to their mounting points with a combination of quick links and swivels. This will allow the sections of the rocket to be easily separated for transport and reconnected for launch, and it will help prevent the recovery harnesses from twisting.

4.3.1.5 Altimeters

Both altimeters used will be barometric altimeters. This is required for one of them, and it simplifies the design of the recovery system to use the same type of altimeter for both the primary and secondary, reducing the risk of errors being made.

4.3.1.6 Ejection Method

The ejection charges used will use black powder. The mentor is most familiar with black powder ejection charges, so using them decreases the risk of making a mistake.

There will be a total of 4 ejection charges used, 2 for the main parachute and 2 for the drogue parachute. Each altimeter controls 1 of the ejection charges on each end, so each altimeter is independently capable of firing both parachutes.

4.3.2 Recovery Hardware

The main parachute has a diameter of 84 in; the drogue parachute has a diameter of 18 in. The shroud lines of each parachute are tied to a swivel, which is in turn connected to a quick link. The quick link is attached to a knot in each recovery harness. Each end of each recovery harness is tied to a swivel. Those swivels each have two quick links attached to them, which are then each attached to one U-bolt on a centering ring or bulkhead. See figures 4.7, 4.8, 4.9, and 4.14 for the placement of U-bolts.

4.3.3 Recovery Electronics

4.3.3.1 Altimeter Circuits

The primary electronics in the recovery system are the two altimeters, a primary and secondary. Each altimeter is connected to its own battery and switch, and each one controls its own main and drogue ejection charges. The only points where the two altimeters are not completely independent of each other are two quick connectors; however, the altimeters' circuits do not interact in the quick connectors, and the quick connectors are keyed to prevent accidental crossing of the circuits.

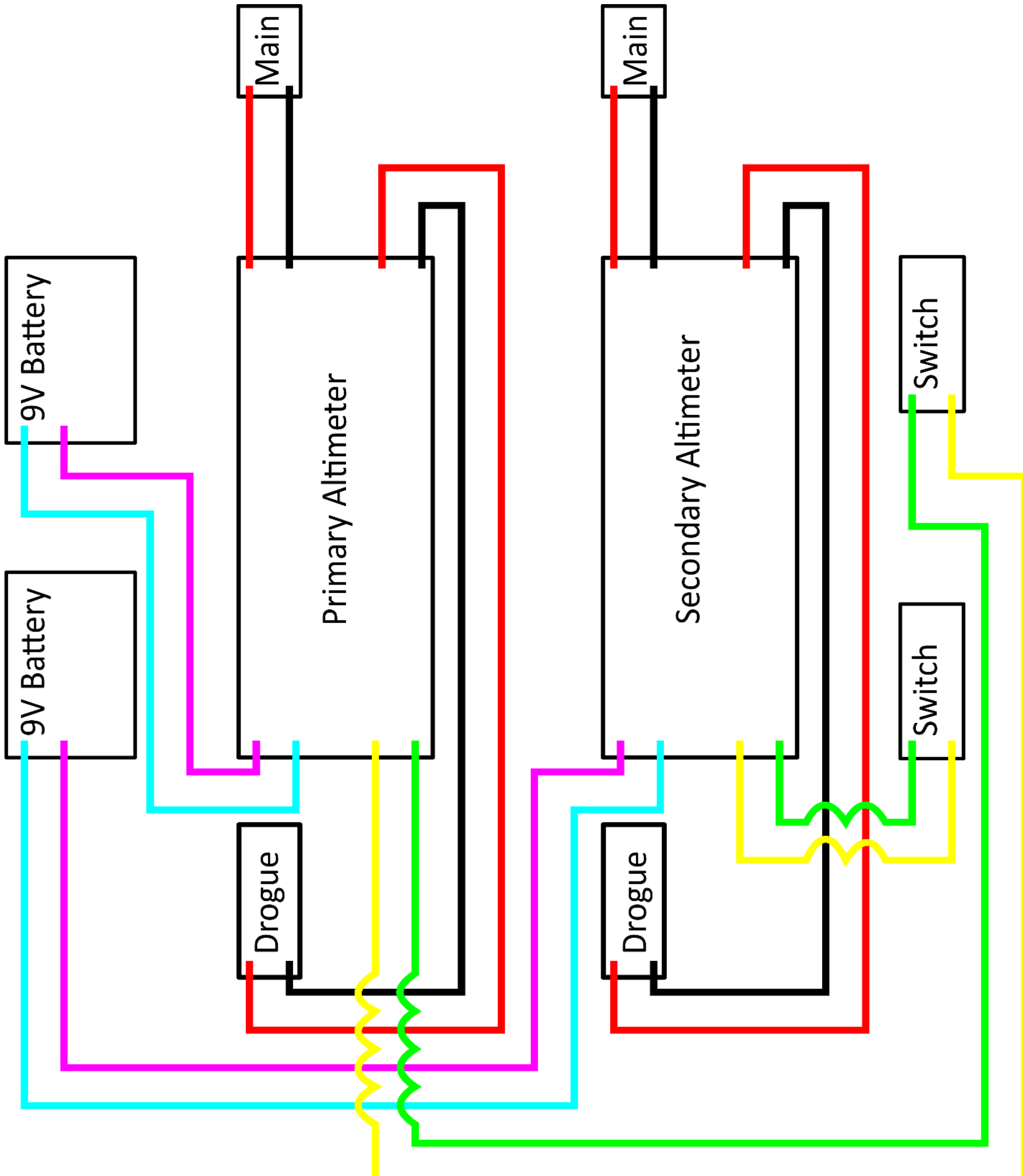

Figure 4.18 - Recovery System Electronics

4.3.3.2 Tracking System

The tracking system is built into the payload so that data from the experiment can be transmitted alongside the location of the rocket.

The tracking system includes a GPS module and a 900 MHz transmitter, both of which are located in the top of the upper section of the rocket. The choice of a 900 MHz transmitter was made to avoid interference with or from most other public radio sources.

The tracking system will transmit the location of the rocket to a ground station during the entire flight and after landing.

4.3.3.3 Power

The power for the tracking system is covered in Section 6, Payload Criteria. Each altimeter is powered by one 9 V battery. On a fully charged battery, each altimeter should be able to remain in a launch ready configuration for approximately 83 hr.

4.4 Mission Performance Predictions

4.4.1 Flight Simulations

Simulations were made for the full scale flight using RockSim to choose which motor to use, what size parachutes to use, and to ensure that the rocket will be able to meet all of its requirements.

4.4.1.1 Key Flight Data

Value	Result
Apogee	5282 ft
Maximum velocity	599 ft/s
Maximum acceleration	1174 ft/s^2
Time to apogee	18.78 s
Flight time	89 s
Static stability margin	2.26
Rail exit velocity	71 ft/s
Descent time	70.2 s
Average thrust-to-weight ratio	6.9:1
Velocity at main deployment	112 ft/s
Velocity at landing	18.8 ft/s

Value	Result
Maximum Mach number	0.55

Table 4.7 - Simulated Flight Data for Full Scale

4.4.1.2 Motor Choice

The motor chosen is the Aerotech L1150R. The simulated thrust curve for that motor is shown below.

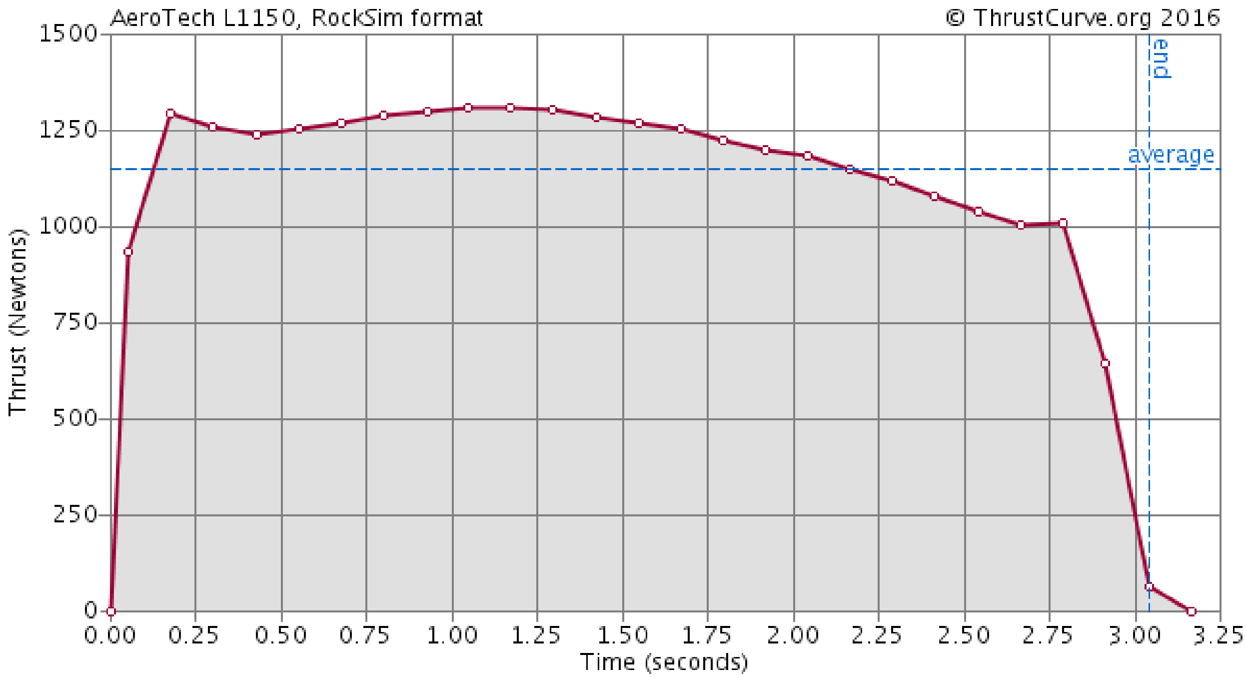

Figure 4.19 - Aerotech L1150R Thrust Curve

4.4.1.3 Analysis

The simulations show that the rocket meets all flight requirements. The predicted apogee is close to the target altitude, and while it may shift due to discrepancies in the model or manufacturing errors during the construction of the rocket, it is likely to remain close to the target, and is very unlikely to go over the 5600 ft limit stated in the handbook. Additionally, simulations were done with higher wind speeds to get low end drift predictions as well as predicted apogees, and even with a wind speed of 20 mph, the predicted apogee was approximately 5130 ft, still close to the target altitude.

The rail exit velocity is well above the required 52 ft/s, which also helps to make the rocket more stable at rail exit and less likely to veer off course during the initial stage of the flight.

The average thrust-to-weight ratio is above the 5:1 recommended by NAR, and again helps the rocket remain stable.

The maximum Mach number, 0.55, is well below the limit of 1 imposed by the handbook, leaving a significant margin.

4.4.2 Stability Data

The rocket has a stability margin of 2.26 while stationary, above the requirement of 2 set forth in the handbook while still below the NAR guide line of 4, giving a stable launch and flight.

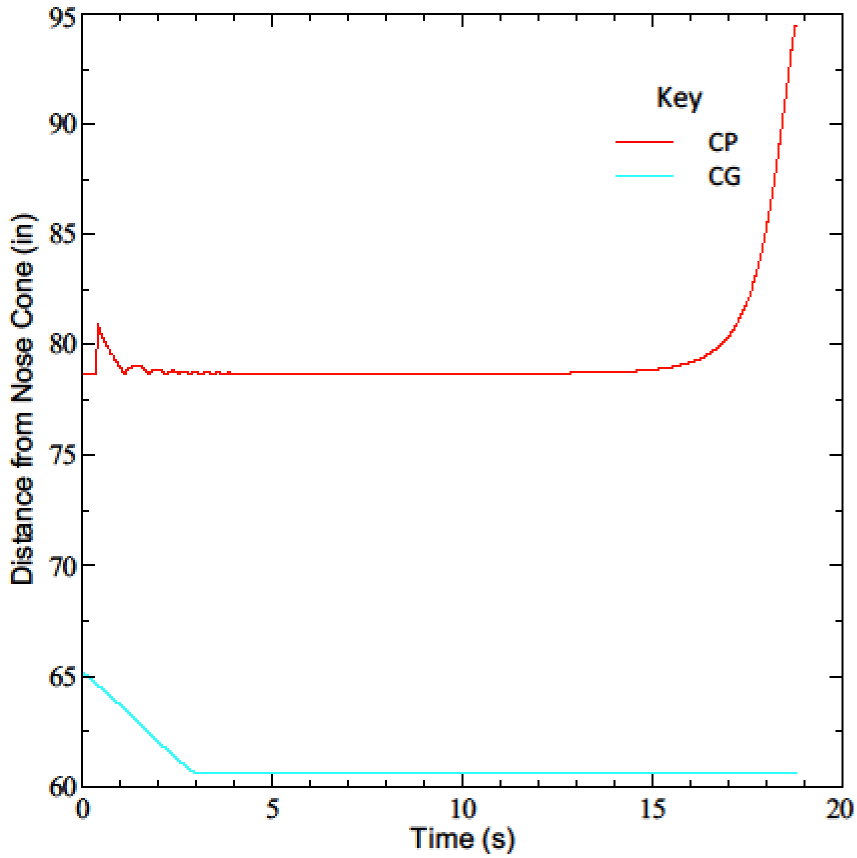

Figure 4.20 - CG, CP Relationship Over Time

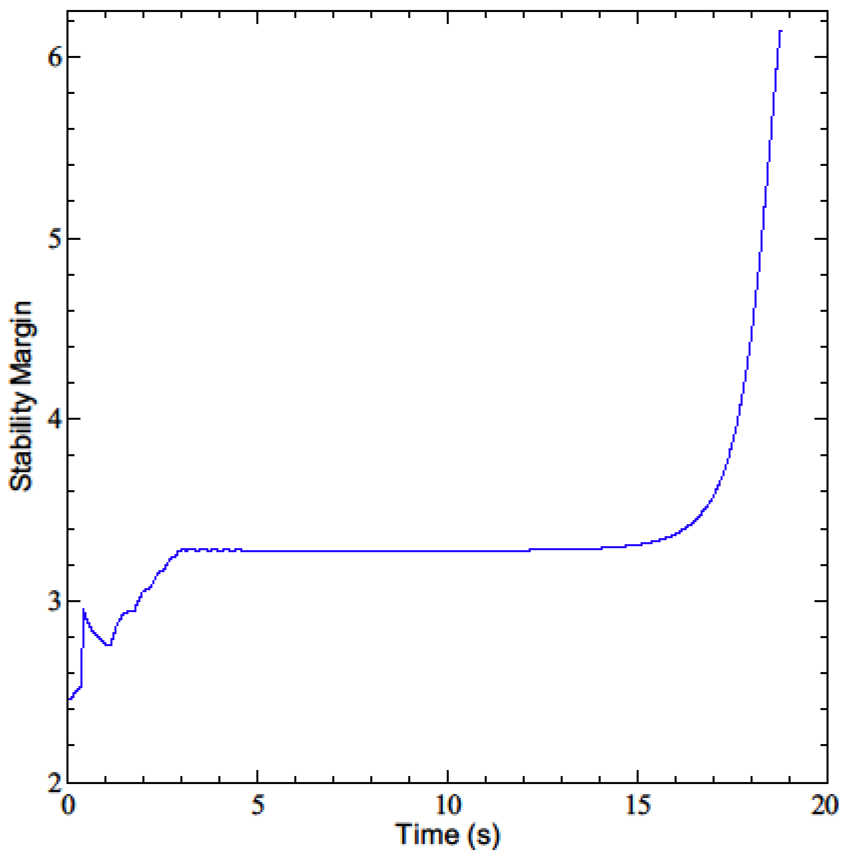

Figure 4.21 - Stability Margin Over Time

4.4.3 Energy at Landing

The highest kinetic energy at landing for any section of the rocket is 41.4 ft-lbf, below the 75 ft-lbf maximum limit. Additionally, there is enough of a margin that if the weight of any section increases due to a manufacturing error, unless it is an error so significant that it entirely invalidates the design, the kinetic energy at landing will remain below the limit.

Section	Kinetic Energy (ft-lbf)
Upper section (with nose cone)	24.9
Avionics bay	25.1
Lower section	41.4

Table 4.8 - Kinetic Energy at Landing

4.4.4 Drift Predictions

The worst cast rift predictions, the first of the below tables, are the descent time multiplied by the wind speed. None of the drift distances are at or above 2500 ft, the maximum allowed drifting distance. Additionally, all of the calculations are for a worst case scenario, and the RockSim predictions are likely an under estimate, the actual drift is expected to fall between the two ranges.

Wind Speed (mph)	Drift (ft)
0	0
5	515
10	1030
15	1545
20	2060

Table 4.9 - Worst Case Drift Predictions

Wind Speed (mph)	Drift (ft)
0	0
5	171
10	352
15	526
20	708

Table 4.10 - RockSim Drift Predictions

5 Safety

5.1 Launch Concerns and Operation Procedures

5.1.1 Recovery and Motor Preparation

5.1.1.1 Recovery System Preparation

1. Strap both batteries to avionics sled in both directions with zip ties
2. Connect battery to primary altimeter
3. Connect battery to secondary altimeter
4. Pull-test all wiring connections on avionics sled
5. Ensure rotary switches are in “220” (off) position
6. Connect switch to sled (blue/white wires with mini clamp)
7. Load sled onto rods
8. Secure on rods with nuts
9. Insert into coupler
10. Connect aft terminals to sled (red/black wires with mini clamp)
11. Inspect interior of avionics bay to ensure nothing is snagged
12. Ensure static vent holes are clear
13. Install aft bulkhead, securing with 2 nuts and 2 washers using 7/16 in wrench
14. Connect forward ejection charge ignitor to forward terminals and pull test
15. Insert ignitor tip to bottom of forward ejection cup
16. Load powder and wadding in forward ejection cup, securing with masking tape
17. Connect aft ejection charge ignitor to aft terminals and pull test
18. Insert ignitor tip to bottom of aft ejection cup
19. Load powder and wadding in aft ejection cup, securing with masking tape
20. Fold main parachute
21. Place rubber band on main parachute
22. Ensure rubber band is on upper recovery harness
23. Z-fold upper recovery harness and secure with rubber band
24. Connect upper recovery harness to upper body tube with 2 quick links
25. Connect main parachute to upper recovery harness loop

26. Ensure main parachute swivel rotates freely
27. Ensure blast protector is on upper recovery harness below the parachute
28. Connect upper recovery harness to forward end of avionics bay with 2 quick links
29. Ensure all 5 upper recovery harness quick links are tight
30. Load recovery harness into upper body tube
31. Remove rubber band from main parachute
32. Insert main parachute into upper body tube
33. Insert blast protector below main parachute
34. Insert forward end of avionics bay into upper body tube, aligning registration marks
35. Secure avionics bay to upper body tube with 4 shear pins
36. Ensure rubber band is on lower recovery harness
37. Z-fold lower recovery harness and secure with rubber band
38. Ensure blast protector is on lower recovery harness above the parachute
39. Fold drogue parachute
40. Connect drogue parachute to lower recovery harness loop
41. Ensure drogue parachute swivel rotates freely
42. Connect lower recovery harness to lower body tube with 2 quick links
43. Connect lower recovery harness to aft end of avionics bay with 2 quick links
44. Ensure 5 lower recovery harness quick links are tight
45. Load recovery harness in lower body tube
46. Wrap parachute in blast protector and insert into lower body tube
47. Insert aft end of avionics bay into top of lower body tube, aligning registration marks
48. Secure avionics bay to lower body tube with 4 shear pins

5.1.1.2 Motor Preparation

1. Set delay timing if necessary
2. Assemble motor according to manufacturer’s instructions
3. Measure ignitor against motor (do not insert into motor!)
4. Install motor in motor mount and secure with retaining ring
5. Tape ignitor to fin for transport to pad

5.1.2 Setup and Ignitor Installation

1. Disconnect ignition system from power (if possible)
2. Ensure all unnecessary personnel are in a safe location
3. Load rocket on launch rail
4. Secure launch rail in vertical position
5. Insert and secure ignitor (ensure it is fully inserted)
6. Confirm ignition system unpowered
7. Connect ignition leads to ignitor
8. Ensure solid, secure connection between ignition leads and ignitor
9. Secure ignition lead wire to pad
10. Switch on altimeter
11. Confirm one long beep, a several second pause, and six short beeps every few seconds
12. Final visual inspection
13. Clear pad area
14. Connect ignition system power
15. Alert LCO / RSO that rocket is ready for launch

5.1.3 Troubleshooting

Error	Solutions
Misfire	Wait 60 seconds to approach, check firing system power, then check firing system lead connection. If neither of those are the issue, replace the ignitor If replacing ignitor, follow procedures for installing ignitor
Altimeter does not beep	Turn altimeter off, open avionics bay, check battery connectors, check altimeter for damage
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

Table 5.1 - Troubleshooting

5.1.4 Post-Flight Inspection

5.1.4.1 Successful Flight

1. If in safe location, retrieve the rocket
2. Check for non-discharged pyrotechnics; mentor should remove any non-discharged pyrotechnics
3. Report to NASA official to have the official altitude recorded
4. Disassemble rocket and check for any damage
5. Analyze data gained from experiment

5.1.4.2 Unsuccessful Flight

1. Retrieve rocket. Collect any parts that may have broken off
2. Determine when failure occurred
3. Inspect rocket for damage
4. If recovery system failure, check code and avionics bay for cause
5. Determine most likely cause of failure

5.2 Safety and Environment

5.2.1 Personnel Hazard Analysis

Hazard	Causes	Effects	Mitigation ID
Accidental black powder ignition	Mishandling or improper storage	Moderate injury (Burns, concussion)	1
Power tools	Improper use. Distractions	Minor to severe injury	2
Fiberglass	Fiberglass dust on skin, in eyes, or in lungs	Irritation	3
Rocket flies into personnel	Rocket goes off course	Severe injury or death	4, 5, 6, 7, 12, 14
Motor flies into personnel	Motor comes out of rocket	Severe injury or death	10
Falling debris	Rocket breaks. Recovery system fails. Top of Motor not capped. Too much black powder. Motor failure	Moderate to severe injury	9, 14, 15, 33

Table 5.2 - Personnel Hazard Analysis

5.2.2 Failure Modes and Effects Analysis

Hazard	Causes	Effects	Mitigation ID
Motor fails to ignite	Bad ignitor	Recycle/delay of launch	None
Rocket goes off course	Launch rail not vertical. Incorrectly aligned fins. Offset CG. Misaligned motor/motor 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 wrong place. Failure to reach sufficient altitude for recovery system	4, 5, 6, 7, 12, 14
Internal damage	High acceleration	Damage to rocket. Experiment failure. Recovery system failure	8
Motor ejects from rocket while burning	Top of motor not capped. Motor mount fails. Motor retainer fails	Falling debris. Damage to rocket. Motor flies into crowd	9, 10
Reaction wheel does not start	Payload electronics failure. Reaction wheel is jammed	Experiment failure	13
Reaction wheel breaks off	Too much angular acceleration. Too much acceleration	Rocket goes off course. Experiment failure	8, 12
Vibration	Reaction wheel off center	Damage to electronics	13
Rotation breaks fins	Rotational forces	Rocket goes off course. Falling debris	14
Reaction wheel spins at wrong speed	Electronic subsystem failure	Experiment failure	25
Ejection charge does not ignite	Bad ignitor. Altimeters not turned on. Altimeters not programmed correctly. Batteries not charged. Wires come loose	Rocket returns ballistically. Damage to rocket. Potential injury	18
Ejection charge fires but drogue parachute does not deploy	Not enough black powder	Drogue parachute does not deploy	15
Rocket hits ground too hard	Parachute is too small. Recovery system fails. Motor failure	Damage to rocket	20
Rocket lands in undesirable place	Wind	Rocket falls on people. Damage to rocket	4, 21, 22, 23
Reaction wheel control failure	Physical failure. Electrical subsystem failure	Experiment failure. Rocket rotates too fast and causes damage.	25, 27
Data collection failure	Physical failure. Electrical subsystem failure	Data transmission failure. Experiment failure. Data lost: No proof of veracity, design improvements, and PLAR	25, 27

Hazard	Causes	Effects	Mitigation ID
Data transmission failure	Physical failure. Electrical subsystem failure	No ground based data backup. Tracking failure.	25, 27
Physical failure	Batteries come loose. Wires come loose. Batteries not charged	All other payload electronics fail	27
Main parachute recovery harness breaks	Too much black powder. Damaged recovery harness. Rocket is moving too fast.	Falling debris. Destruction of rocket	15, 16, 17
Drogue parachute recovery harness breaks	Too much black powder. Damaged recovery harness. Rocket is moving too fast.	Falling debris. Destruction of rocket	15, 16, 17
Motor Failure	Manufacturer error	Falling debris. Destruction of rocket	33

Table 5.3 - Failure Modes and Effects Analysis

5.2.3 Environmental Hazard Analysis

Hazard	Causes	Effects	Mitigation ID
Direct sunlight/high temperatures	Weather	Overheating of electronic components, affecting efficiency. Possible distortion of airframe	28
Humidity	Weather	Swelling of airframe components. Wet rocket and electrical components	29
Wind	Weather	Rocket goes off course. Drifts further after parachute deployment	30
Grass fire	Rocket crashes while motor is still burning	Burnt vegetation. Potential injury	31
Scattered rocket components	Rocket breaks during flight. Recovery system fails. Motor failure	Potentially harmful chemicals and materials released into environment	9, 14, 15, 33
Harming wildlife	Animals wander onto launch field	Injured wildlife	32

Table 5.4 - Environmental Hazard Analysis

5.2.4 Mitigations and Verifications

Mitigation ID	Mitigation	Verification
1	Black powder will be properly stored and handled only by the mentor	It will be clearly explained only the NAR certified mentor shall handle black powder
2	All team members involved in the fabrication of the rocket will be briefed on how to safely use all 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 tools. No work shall be completed without the safety officer or deputy safety officer present
3	Gloves, masks, and safety glasses will be worn when working with fiberglass. Any fiberglass dust will be cleaned up	Safety officer or deputy safety officer will ensure everyone wears gloves, masks, and safety glasses
4	Check launch rail direction before launch	Pre-flight checklist
5	Visually inspect the fins during construction to ensure they are aligned	Testing
6	Use ballast to ensure the CG is centered	The CG will be calculated after rocket is constructed
7	Double check all parts of the motor mount before it is assembled to ensure they have been precisely manufactured	Visual inspection by the safety officer or deputy safety officer
8	Ensure all points of failure are strong enough to withstand the maximum expected acceleration with a margin of safety	Design analysis
9	Ensure the motor is capped with something that can withstand the exhaust	Design analysis
10	Ensure the motor mount is strong enough to withstand the force from the motor	Design analysis
11	Make sure there are no loose wires or other obstructions near the reaction wheel	Pre-flight checklist
12	Test starting and stopping the experiment on the ground; if the acceleration causes damage, the reaction wheel can spin up and spin down more slowly	Testing
13	Make sure the reaction wheel is centered; run the experiment on the ground to ensure vibrations are at safe levels	Testing
14	Ensure the rocket will not spin fast enough to cause damage	Testing
15	Repeated tests of the ejection system on the ground	Testing
16	Inspect the recovery harness before launch	Pre-flight checklist

Mitigation ID	Mitigation	Verification
17	Choose the motor and ballast such that the rocket is moving at a safe velocity when the drogue parachute deploys	Design analysis
18	Redundant ignitors and ejection cups	Follow pre-launch checklist. Have the mentor and safety officer inspect the ejection system before launch
19	Choose the size of the drogue parachute such that the rocket is moving at a safe velocity when the main parachute deploys	Design analysis
20	Run simulations to ensure the main parachute is the correct size for the rocket	Simulations
21	Do not launch when there is too much wind	Check wind speed before launch
22	Angle the launch rail to account for wind	Pre-flight checklist
23	Use the smallest possible drogue that will allow safe deployment of the main parachute	Design analysis
24	Choose suitable launch sites for rocket size	Inspect launch site before launches for hazards
25	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
26	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
27	Do ground tests to find out how long the batteries will last. Replace batteries frequently	Testing of batteries.
28	Assemble and store rocket in shaded areas	Safety officer or deputy safety officer will ensure assembly takes place in proper conditions
29	Inspect rocket before launch for airframe swelling	Pre-flight checklist
30	Minimize time on main parachute to ensure minimal drift while maintaining safe landing speed	Simulations
31	Fire extinguishers shall be ready during launch	Packing checklist
32	Inspect launch field for potential wildlife	Pre-flight checklist
33	Inspect motor before launch	Pre-flight checklist

Table 5.5 - Mitigations and Verifications

6 Payload Criteria

6.1 Payload Design

6.1.1 Overall

The payload will induce a roll in the rocket using a reaction wheel. This allows a simple method of controlling the roll of the rocket that also gives a high degree of precision. Additionally, it allows all of the moving components of the payload to be on the inside of the rocket, eliminating complex external interfaces.

The sled is designed to be placed on a section of coupler in the upper body tube of the rocket and to be secured in place with six removable rivets. This allows the payload to be taken out of the rocket easily, while keeping it securely in place and allowing it to rotate the rocket without slipping.

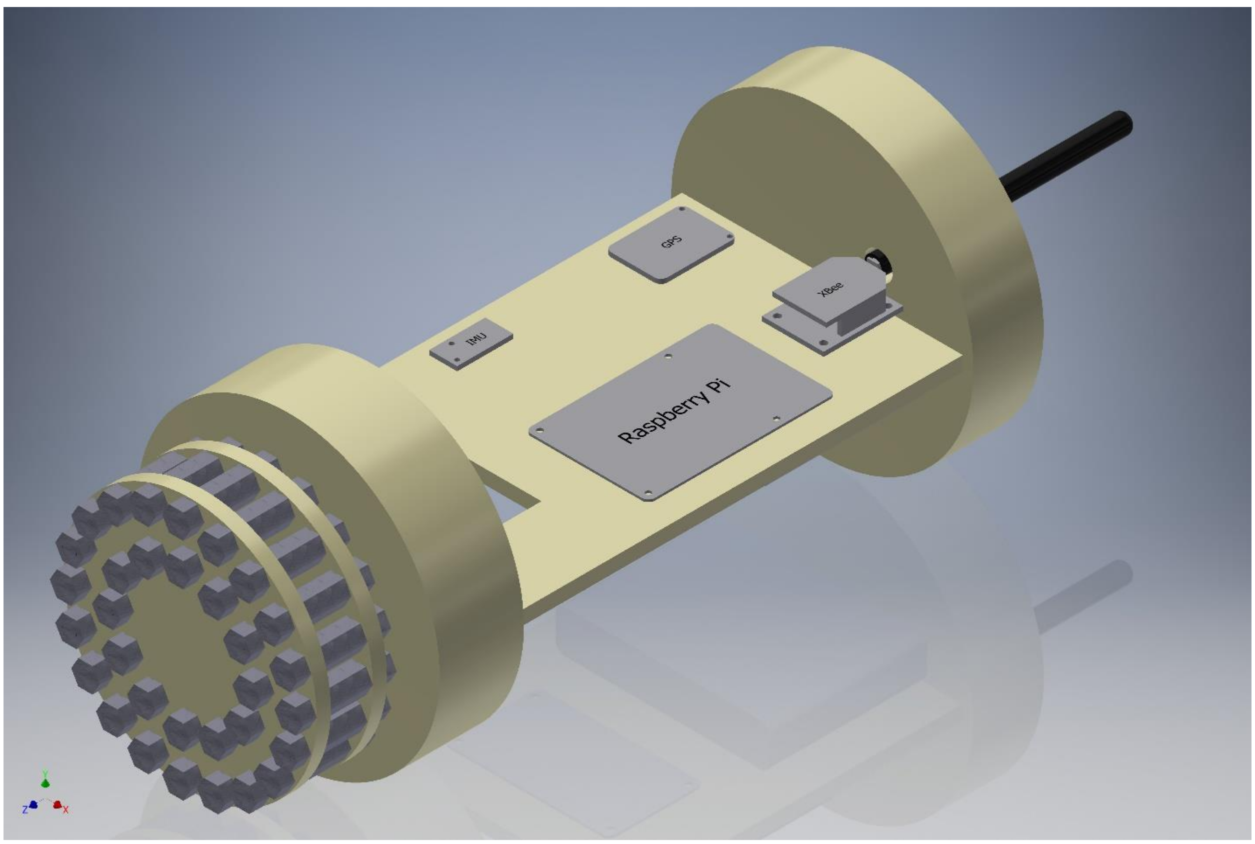

Figure 6.1 - Payload

6.1.2 Reaction Wheel

The reaction wheel will consist of two fiberglass disks connected by 32 bolts. Each bolt will have 4 nuts on it; 3 between the disks and 1 on the end. The large number of bolts and nuts is to provide addition mass to the reaction wheel, allowing it to turn slower. The reason for using this design, instead of the solid metal ring proposed in the PDR, is that the nuts and bolts are cheaper and allow for flexibility in the mass of the reaction wheel.

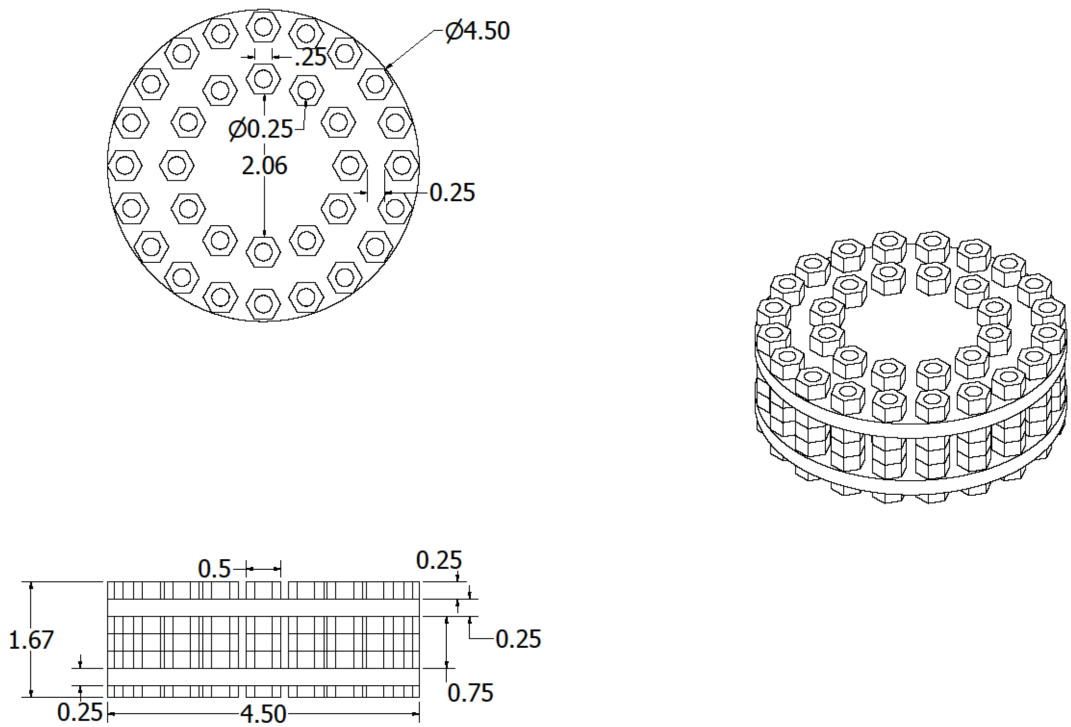

Figure 6.2 - Reaction Wheel

6.1.3 Electronics

6.1.3.1 Sensors

The main payload sensor will be a 10 DOF IMU, which combines an accelerometer, a gyroscope, a barometer, and a magnetometer. The accelerometer will be used to detect motor burnout, and the magnetometer will be used to detect the roll position of the rocket, which is used to determine its angular velocity and the number of rolls completed. Additionally, the payload will have a camera to be used to locate the ground targets and a GPS module to track the location of the rocket.

6.1.3.2 Computer

A Raspberry Pi will be used to collect and store the data from the sensors, process the video to identify the targets, send commands to the motor driver, and send data to the transceiver to transmit to the ground.

6.1.3.3 Motor and Driver

The reaction wheel will be turned using a 24 V DC motor. The motor will be controlled by a motor driver that is connected to the Raspberry Pi.

6.1.3.4 Transceiver

The table below lists the data that will be transmitted during the flight and its source. The data will be transmitted by a 900 MHz radio.

Data	Source of data
Location (latitude and longitude)	GPS
Altitude	GPS
Climb	GPS
Horizontal velocity	GPS
Acceleration (3-axes)	IMU
Rotation (3-axes, based on gyroscope)	IMU
Magnetic field magnitude (3-axes)	IMU
Roll (based on magnetometer)	IMU
Motor speed	Raspberry Pi

Table 6.1 - Data Transmitted by the Payload

6.1.3.5 Power

The IMU, GPS, camera, and radio will be powered by the Raspberry Pi. The Raspberry Pi will be powered by a battery pack containing 6 AA batteries. The battery pack provides 9 V, which is reduced to 5 V through the use of a step-down converter (also known as a UBEC). The battery pack has a capacity of 14.4 Ah. The maximum expected power usage of the Raspberry Pi is 1 A, meaning it can run for 14+ hours.

The DC motor is powered by the motor driver (or motor controller), which is powered by 2 A23 (12 V) batteries. These batteries have a capacity of 55 mAh. The maximum expected power usage of the motor is 1.5 A, meaning it can run for about 130 s, much more than the 12 s run time needed.

6.1.3.6 Specifications

Part	Model	Notes
Raspberry Pi	3 B+	
Transceiver	XBee Pro 900 HP	900 MHz, 200 kbps
IMU	AltIMU-10	10DOF
GPS	Adafruit Ultimate GPS	
Camera	Adafruit Spy Camera	5MP, 1080p30
Motor Driver	MD10C R3	5-30 v, 13 A
Step-down Converter	Adafruit UBEC	5 V, 3 A
Motor	Uxcell DC Micro Gear Box Motor	24 V, 1000RPM

Table 6.2 - Payload Components Specifications

6.1.3.7 Diagrams

The following diagram shows the positioning of the electronics on the payload electronics sled.

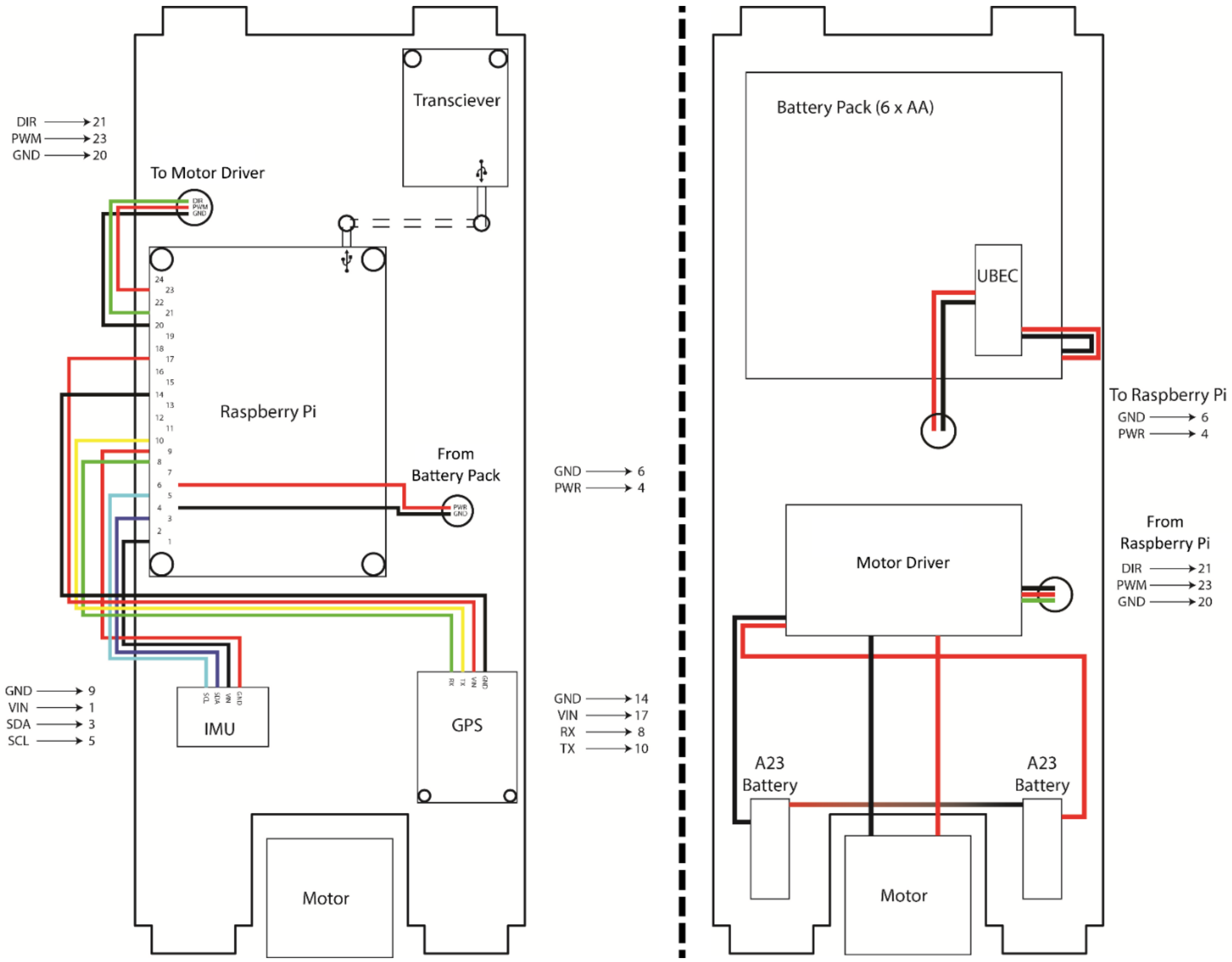

Figure 6.3 - Payload Electronics

6.1.4 Mounting Hardware

The electronics sled, upper bulkhead, and lower bulkhead will be made from fiberglass.

6.1.4.1 Electronics Sled

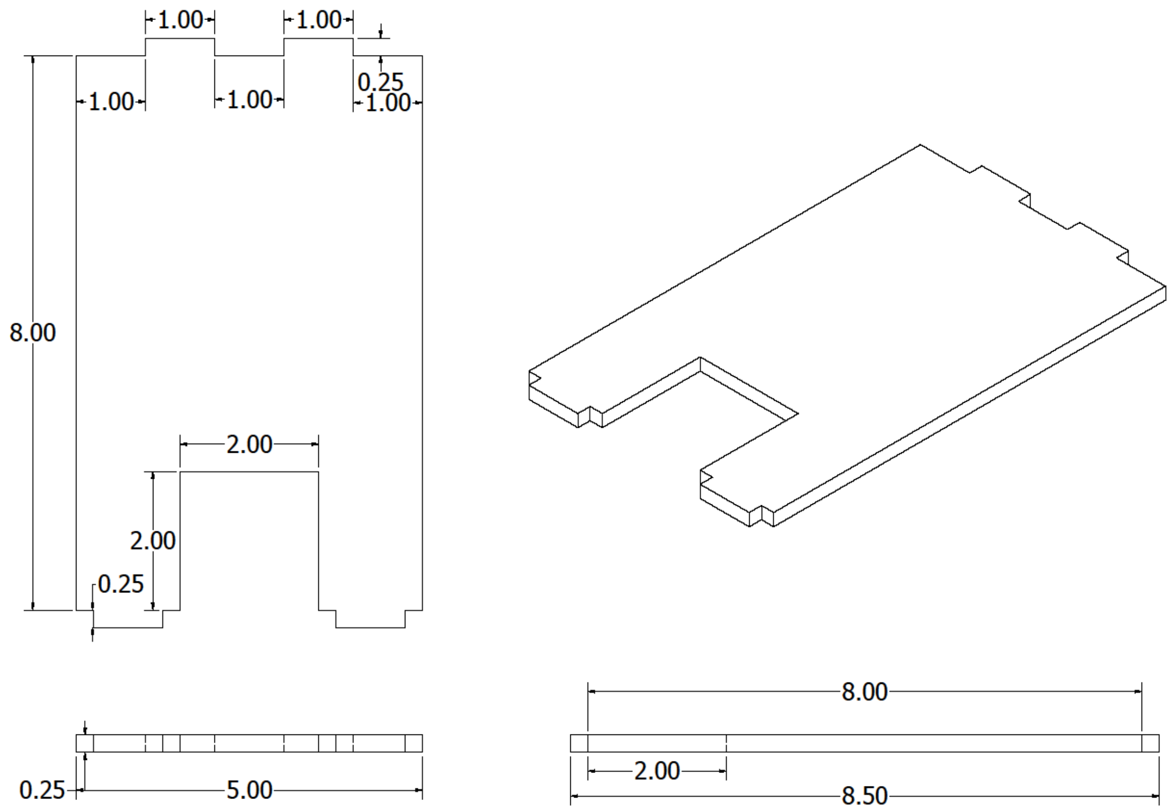

Figure 6.4 - Electronics Sled

6.1.4.2 Lower Bulkhead

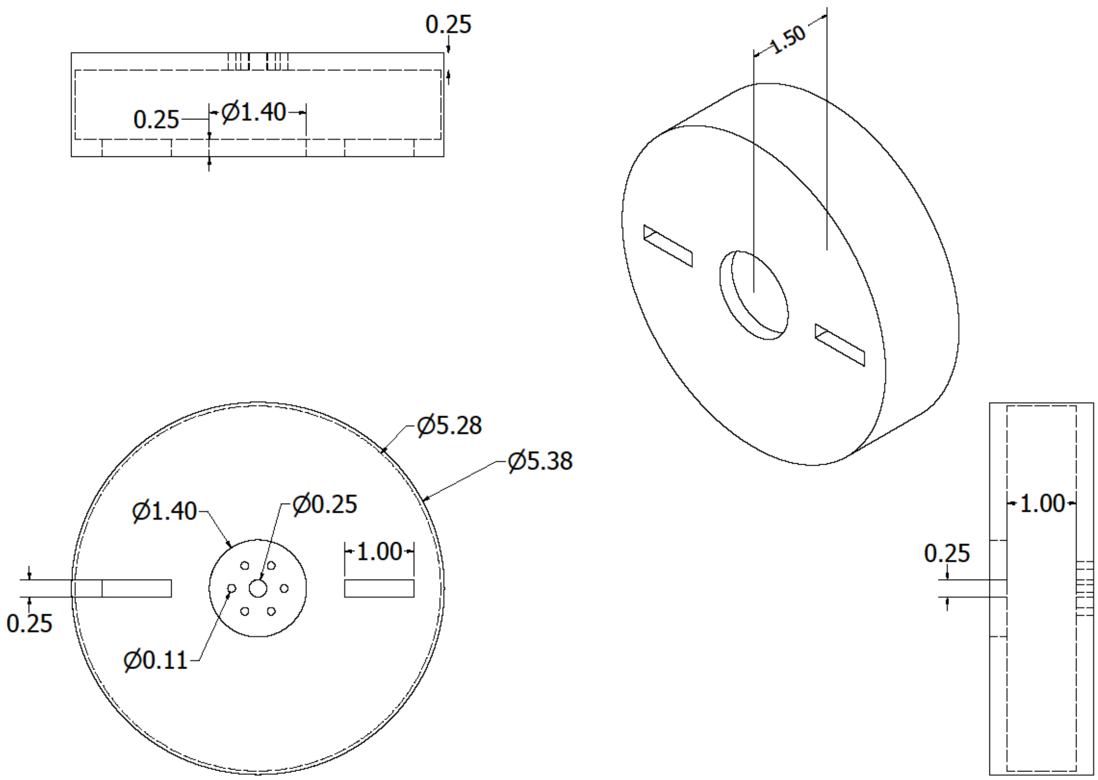

Figure 6.5 - Lower Payload Bulkhead

6.1.4.3 Upper Bulkhead

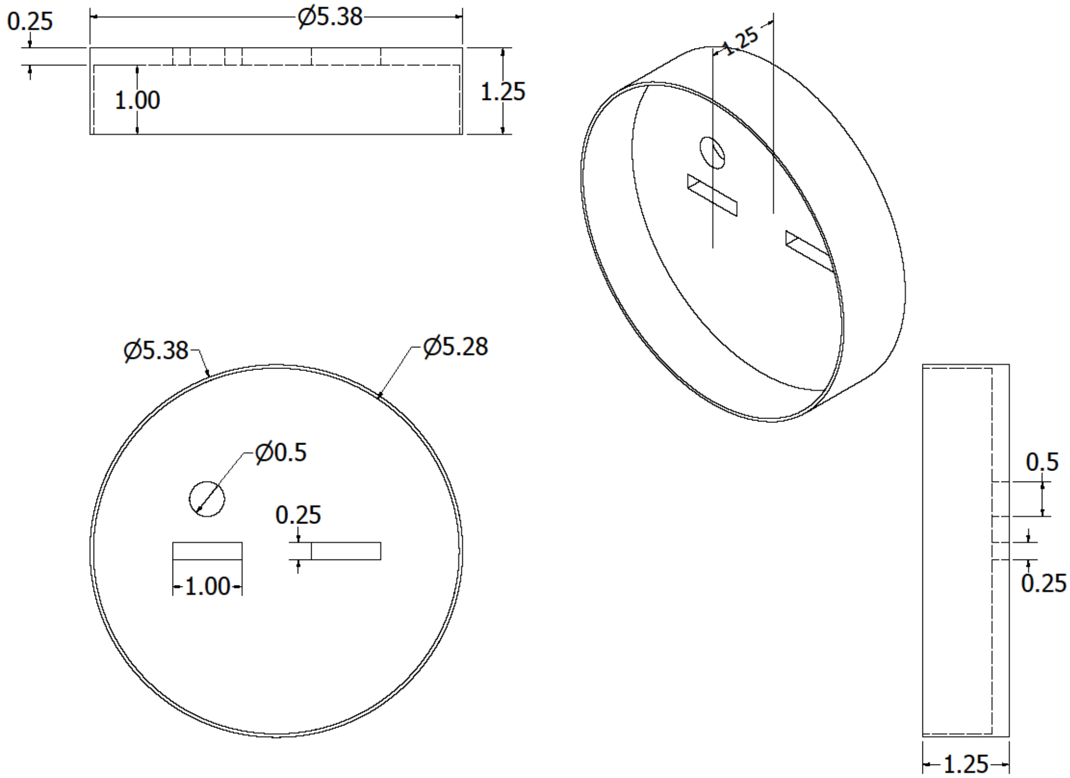

Figure 6.6 - Upper Payload Bulkhead

6.2 Requirements and Risk

6.2.1 Measuring Rotation Rate

The payload must be able to measure its rate of rotation after motor burnout and again later when attempting to return to the post-burnout rotation rate. Based on the specifications for the IMU, as well as testing, it seems to be able to detect rotation rates to within 5°/s. This is accurate enough for the purposes of the experiment.

6.2.2 Rotating The Rocket

The payload must be capable of making the rocket rotate at a rate of at least 16 RPM or 0.27 rotations per second. To achieve this speed, the reaction wheel will have to spin at 640 RPM. This is well below the motor's rating of 1000 RPM.

6.2.3 Target Identification

The payload camera must have a high enough resolution to identify the targets from nearly a mile in altitude. We have calculated, based on the field-of-view and resolution of the camera, that a 40 ft X 40 ft target will be visible.

6.2.4 Precise Roll Control

When returning to the post-burnout rotation rate the payload must be able to precisely control the rotation of the rocket. This requires the ability to control the speed and direction of the reaction wheel, and therefore of the motor. The motor driver that has been selected is capable of running the motor in either direction at 10-100% power.

6.2.5 Data Transmission

The payload must be able to transmit all of the data listed in section 6.1.3.4 as fast as the data is generated. The data is generated at a rate of about 10 Kbps, while the radio has a speed of 200 Kbps. Additionally, the signal must be strong enough to reach the ground station from the maximum expected distance of the rocket. This distance is less than 2 miles, while the radio has a range of 4 miles.

7 Launch Operations Procedures

7.1 Recovery Preparation

7.1.1 Lower body section

☐ Separate lower body section completely

☐ Ensure both quick links at the bottom end of the recovery harness are attached to the U-bolts on the lower section

☐ Ensure the quick links are tight

☐ WARNING, failure to secure quick links can result in recovery harness detaching during flight

☐ Pull test lower recovery harness

☐ Fold drogue parachute

☐ Put rubber band on lower recovery harness

☐ Z-fold lower recovery harness

☐ Attach drogue parachute to lower recovery harness

☐ Ensure blast protector is on lower recovery harness

☐ Wrap drogue in blast protector

☐ WARNING, failure to wrap drogue can result in igniting the drogue

☐ Insert lower recovery harness and drogue into lower body tube

7.1.2 Upper body section

☐ Separate upper body section completely

☐ Ensure both quick links at the end of the upper recovery harness are attached to the U-bolts on the upper section

☐ Ensure the quick links are tight

☐ WARNING, failure to secure quick links can result in recovery harness detaching during flight

☐ Pull test upper recovery harness

☐ Fold main parachute

☐ Put rubber band on main parachute

☐ Put rubber band on upper recovery harness

- ☐ Z-fold upper recovery harness
- ☐ Attach main parachute to upper recovery harness
- ☐ Ensure blast protector is on upper recovery harness
- ☐ Remove rubber band from main parachute
- ☐ WARNING, failure to remove rubber band from main parachute can result in main parachute not opening
- ☐ Insert upper recovery harness and main parachute into upper body tube
- ☐ Insert blast protector into upper body tube

7.1.3 Avionics bay

- ☐ Remove aft nuts and washers with 7/16 in wrench
- ☐ Remove aft bulkhead, unclipping red/black connector
- ☐ Remove sled and forward bulkhead, unclipping blue/white connector
- ☐ Pull test all wires on altimeters (2 main + 2 drogue + 2 switch + 2 battery per altimeter)
- ☐ Put 2 fresh 9 volt batteries on battery shelves
- ☐ Attach battery connector to both batteries
- ☐ Strap in each battery with one vertical and one horizontal zip-tie each
- ☐ Ensure batteries are secure
- ☐ Connect switch connector (blue/white)
- ☐ Turn on primary altimeter and wait for one long beep followed by six short beeps, repeated
- ☐ Turn off primary altimeter
- ☐ Turn on secondary altimeter and wait for one long beep followed by six short beeps, repeated
- ☐ Turn off secondary altimeter
- ☐ Insert sled into fore end of avionics bay
- ☐ Connect drogue connector (red/black)
- ☐ Attach aft bulkhead with 2 washers and 2 nuts (use 7/16 in wrench)
- ☐ Ejection charges (for mentor)
    - ☐ Connect ignitor leads to aft primary terminal block
    - ☐ Insert ignitor tip into bottom of primary ejection cup
    - ☐ Pour in pre-measured black powder (1.6 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 (1.6 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 (2.8 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 (2.8 g)
- ☐ Insert wadding
- ☐ Secure with masking tape
- ☐ Take altimeter outside
- ☐ Making sure ejection cups are pointed away from people, turn on primary altimeter and wait for 1 long beep then 6 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 6 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

☐ 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

☐ 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

7.2 Experiment Procedures

- ☐ Turn on power
- ☐ Pull test connections on motor controller
- ☐ Check GPIO connections (power, GPS, IMU, and motor controller)
- ☐ Check USB connections (flash drive and Xbee)
- ☐ Attach antenna
- ☐ Attach camera
- ☐ 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

7.3 Motor Preparation

- ☐ Set delay timing if necessary
- ☐ Assemble motor according to manufacturer’s instructions
- ☐ Measure ignitor against motor (do not insert into motor!)
- ☐ Install motor in motor mount and secure with retaining ring
- ☐ Tape ignitor to fin for transport to pad

7.4 Set Up on Launcher

- ☐ Take rocket, laptop 1, laptop 2, and Wi-Fi hotspot to launcher

- ☐ Disconnect ignition system power
- ☐ Lower launch rail
- ☐ Slide rocket onto launch rail
- ☐ Raise launch rail
- ☐ Secure launch rail in vertical position
- ☐ If possible, spray down launch area
- ☐ Clear launch area of unnecessary personnel

7.5 Ignitor Installation

- ☐ 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)
- ☐ Connect ignition system leads to ignitor leads

7.6 Launch Procedure

- ☐ On Pi (via laptop 1 ssh connection) run “vncserver :1”
- ☐ On laptop 1, connect to virtual desktop (192.168.1.35:1)
- ☐ Open terminal in VNC
- ☐ Enter “cd Desktop/PSLT-Fullscale”
- ☐ Enter “sudo python Driver.py”
- ☐ Wait 11 seconds for confirmation that all programs are running
- ☐ On laptop 1, open a command prompt
- ☐ Enter “cd Documents/Github/PSLT-Fullscale”
- ☐ Enter “python ReceiveData.py”
- ☐ Ensure exData.csv is being written to
- ☐ Open another command prompt
- ☐ Enter “cd Documents/Github/PSLT-Fullscale”
- ☐ Enter “python FullscaleGUI.py”
- ☐ Ensure GUI is working

- ☐ On laptop 2, enter “cd Documents/Github/PLOTLOCATION.PY”
- ☐ Ensure the location is being plotted correctly
- ☐ Clear launch area
- ☐ Reconnect ignition system power
- ☐ Inform RSO that the rocket is ready for launch

7.7 Troubleshooting

7.7.1 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

7.7.2 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

7.8 Post-flight Inspection

7.8.1 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
- ☐ On laptop 1, reconnect to virtual desktop (192.168.1.35:1)
- ☐ If necessary, end Driver.py (ctrl-c, wait a second, ctrl-c again) and wait for confirmation of shutdown
- ☐ Connect laptop 1 to Pi with ssh

- ☐ Disconnect from the virtual desktop
- ☐ Connect laptop 1 to Pi with an FTP client (e.g. FileZilla)
- ☐ Copy “/home/pi/Desktop/PSLT-Fullscale/” to a data recovery folder on laptop 1
- ☐ 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
- ☐ Copy the data recovery folder onto laptop 2
- ☐ Disconnect the FTP client
- ☐ On laptop 1, in the ssh shell, run “sudo shutdown now”
- ☐ Turn off experiment power

7.8.2 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

8 Project Plan

8.1 Testing

All of the tests described below will be or have been performed on both the subscale and full scale rockets.

8.1.1 Design Integrity

Test Name	Test Objective(s)
Altimeter activation	Ensure that the wiring for the switches, terminals, and batteries for both altimeters is functional. Ensure that both altimeters are functional
Assembled inspection	Ensure that there are no issues with the launch vehicle, particularly with the airframe
Avionics wire pull test	Ensure all of the wires for the avionics are secure
Avionics wiring check	Ensure all wires for the avionics are connected properly
Data collection	Ensure the payload can collect data from all of its sensors
Data transmission	Ensure the payload can transmit data to a ground station
Disassembled damage inspection	Ensure there is no damage to any of the components of the rocket, either internal or external.
Ejection charge ground fire	Ensure that the wiring for the ejection system is functional. Ensure that the quantity of black powder used is sufficient to separate the sections of the launch vehicle
Experiment controller activation	Ensure the controller for the experimental payload can be activated and functions correctly.
Flight simulation	Ensure that the main and drogue parachutes are large enough to allow a soft landing. Ensure the rocket reaches a sufficiently high rail exit velocity. Ensure stable flight. Ensure that the rocket can reach the desired altitude.
Parachute deployment	Ensure that both the drogue and main parachutes are able to open without issue
Payload electronics sled shake test	Ensure all payload electronics are strongly enough mounted to withstand significant vibrations
Pull test for reaction wheel mount	Ensure reaction wheel can withstand large forces without coming off of its mounting
Push / Pull test for all bulkheads / centering rings	Ensure all bulkheads are firmly attached and able to withstand large forces
Push / Pull test for all non-permanently mounted components	Ensure all components that are intended to be removable are secured firmly enough to withstand large forces
Reaction wheel control	Ensure the controller for the reaction wheel works. Ensure the reaction wheel motor can be controlled accurately.
Recovery harness pull test	Ensure that both recovery harnesses are secure and that their mounting points are able to withstand large forces

Test Name	Test Objective(s)
Shake test for avionics	Ensure all payload electronics are strongly enough mounted to withstand significant vibrations

Table 8.1 - Design Tests Overview

8.1.1.1 Altimeter Activation

- Success Criteria
  - Primary and secondary altimeters turn on
  - Primary and secondary altimeters produce the expected sounds
- Testing Variable
  - Altimeter switch position
  - Wires in ejection charge terminals
- Testing Methodology
  - Part one
    - Mount altimeters and batteries onto avionics sled
    - Load avionics sled into avionics bay as for a launch
    - Ensure there are no wires in any of the ejection charge terminals
    - Turn switch for primary altimeter to “on” position
    - Listen for one long beep, a long pause, and one long beep repeated
    - Turn switch for primary altimeter to “off” position
    - Turn switch for secondary altimeter to “on” position
    - Listen for one long beep, a long pause, and one long beep repeated
    - Turn switch for secondary altimeter to “off” position
  - Part two
    - Mount altimeters and batteries onto avionics sled
    - Load avionics sled into avionics bay as for a launch
    - Ensure there are wires in all of the ejection charge terminals to close the circuit
    - Turn switch for primary altimeter to “on” position
    - Listen for one long beep, a long pause, and six short beeps repeated
    - Turn switch for primary altimeter to “off” position
    - Turn switch for secondary altimeter to “on” position
    - Listen for one long beep, a long pause, and six short beeps repeated

        - Turn switch for secondary altimeter to “off” position
- What can be Learned from Failure
    - Overall
        - If the either altimeter does not beep initially
            - There is a break in the wires to the battery for that altimeter or,
            - There is not a battery connected to the battery terminal for that altimeter or,
            - The battery wires are not connected to that altimeter or,
            - The battery connected to that altimeter does not have sufficient charge to power the altimeter or,
            - There is a break in the wires to the switch for that altimeter or,
            - There is a fault in the switch for that altimeter or,
            - The switch wires are not connected to the switch for that altimeter or,
            - The switch wires are not connected to that altimeter or,
            - There is a fault in the quick connector for the switches or,
            - The quick connector for the switches in not connected or,
            - The wire leads going into or out of the quick connector for the switches are not properly connected to the quick connector or,
            - There is a fault in that altimeter or,
            - The avionics bay is too insulated for sound to get out
        - If either altimeter indicates an error with its initial beeps
            - There is a short circuit on that altimeter or,
            - That altimeter was left in programming mode
    - Part one
        - If either altimeter does not repeat one long beep
            - A wire has been shaken loose or,
    - Part two
        - If either altimeter does not repeat three short beeps
            - There is too much insulation on the wires going into the ejection charge terminals, preventing that altimeter from closing the circuit or,
            - A wire has been shaken loose or,

8.1.1.2 Assembled Inspection

- Success Criteria
    - There are no structural defects with the launch vehicle that would be cause for concern for a launch
- Testing Variable
    - N/A
- Testing Methodology
    - Inspect the nose cone for cracks or dents
    - Inspect the upper body tube for cracks, dents, creases, unintentional holes, or frayed edges
    - Inspect the avionics bay for cracks, dents, creases, unintentional holes, or frayed edges
    - Inspect the lower body tube for cracks, dents, creases, unintentional holes, or frayed edges
    - Inspect the fins for correct alignment cracks, or bends
    - Pull on the fins to check for loose attachment
    - Inspect the motor retainer for cracks, dents, damaged threads, or heat damage
    - Pull on the motor retainer to check for loose attachment
    - Inspect accessible bulkheads and centering rings for cracks, dents, or loose attachment
    - Inspect all rivets for proper attachment
- What can be Learned from Failure
    - If a part is damaged
        - The part needs to be repaired or,
        - The part needs to be replaced
    - If a part is loose
        - The part needs to be reattached or
        - The part's attachment needs to be reinforced
    - If a rivet is not properly attached
        - The rivet needs to be attached properly

8.1.1.3 Avionics Wire Pull Test

- Success Criteria
    - None of the wires in the avionics system pull loose

- Testing Variable
    - Force applied to the wire connection
- Testing Methodology
    - Pull on main parachute connections to primary and secondary altimeters
    - Pull on drogue parachute connections to primary and secondary altimeters
    - Pull on switch connections to primary and secondary altimeters
    - Pull on battery connections to primary and secondary altimeters
    - Pull on wire connections to both switches
    - Pull on wire connections to both batteries
    - Pull on wire connections to quick connectors
    - Pull on wire connections to ejection charge terminals
- What can be Learned from Failure
    - If any wires come loose
        - Those wires need to be reattached more strongly
    - If any wires break
        - Those wires need to be replaced

8.1.1.4 Avionics Wiring Check

- Success Criteria
    - All wires in the avionics system are connected where they are supposed to be
- Testing Variable
    - N/A
- Testing Methodology
    - Inspection of battery wires
    - Inspection of switch wires
    - Inspection of main parachute wires
    - Inspection of drogue parachute wires
- What can be Learned from Failure
    - If any wires are not connected
        - Those wires need to be connected
    - If any wires are connected to the wrong place

        - Those wires need to be reconnected to the appropriate place
    - If any wires are damaged
        - Those wires need to be replaced
    - If any wires are not properly insulated
        - Those wires need to be replaced

8.1.1.5 Data Collection

- Success Criteria
    - The payload receives data from all of its sensors
- Testing Variable
    - Position of payload
    - Altitude of payload
    - Orientation of payload
    - Acceleration of payload
- Testing Methodology
    - Part one
        - Activate the payload for data collection
        - Move the payload horizontally
        - Check for data
        - Turn the payload off
    - Part two
        - Activate the payload for data collection
        - Move the payload vertically
        - Check for data
        - Turn the payload off
    - Part three
        - Activate the payload for data collection
        - Rotate the payload
        - Check for data
        - Turn the payload off
    - Part four

        - Activate the payload for data collection
        - Accelerate the payload
        - Check for data
        - Turn the payload off
- What can be Learned from Failure
    - If the payload does not activate
        - There is fault in the experiment controller or,
        - The batteries are not connected or,
        - The batteries do not have sufficient charge to power the experiment or,
        - There is an issue with the control program on the experiment controller
    - If any sensors do not activate
        - There is a fault in the sensor or,
        - The sensor is not connected to power or,
        - The sensor is connected to the wrong place on the experiment controller or,
        - The connection to the sensor goes to the wrong place
    - If data is not collected
        - The sensor is connected to the wrong place on the experiment controller or,
        - The connection to the sensor goes to the wrong place or,
        - There is an issue with the control program on the experiment controller or,
        - There is nowhere for data to be stored or,
        - The sensor is not sensitive enough to detect the change in the test variable or,
        - There is a fault in the sensor

8.1.1.6 Data Transmission

- Success Criteria
    - Data is transmitted from the payload to a ground station
- Testing Variable
    - Distance between payload and ground station
- Testing Methodology
    - Activate the payload for data transmission
    - Activate a ground station for data reception

- Transmit data from the payload
- Check for reception of data on the ground station

- What can be Learned from Failure
  - If the payload does not activate
    - There is fault in the experiment controller or,
    - The batteries are not connected or,
    - The batteries do not have sufficient charge to power the experiment or,
    - There is an issue with the control program on the experiment controller
  - If data is not transmitted
    - The transmitter is not connected to power or,
    - The antenna is not properly connected to the transmitter or,
    - There is an issue with the control program on the experiment controller or,
    - The transmitter is not connected to the experiment controller or,
    - There is a fault in the transmitter or,
    - There is a fault in the antenna
  - If data is transmitted but not received
    - There is an issue with the program on the ground station that receives the data or,
    - There is a fault in the receiver or,
    - There is a fault in the receiver’s antenna or,
    - There is a fault in the connection from the receiver to the ground station or,
    - The antennas do not have sufficient range or,
    - There was some kind of interference or blockage between the transmitter and the receiver

8.1.1.7 Disassembled Damage Inspection

- Success Criteria
  - There is no damage to any components that would be cause for concern for a flight
- Testing Variable
  - N/A
- Testing Methodology
  - Completely disassemble the rocket

- Inspect the nose cone for damage
- Inspect the upper body tube for damage
- Inspect the upper recovery harness mounting point for damage
- Inspect the avionics bay for damage
- Inspect the avionics bay bulkheads for damage
- Inspect the avionics bay recovery harness mounting points for damage
- Inspect the ejection charge terminals for damage
- Inspect the ejection cups for damage
- Inspect the avionics sled mounting rods for damage
- Inspect the avionics sled for damage
- Inspect the lower body tube for damage
- Inspect the lower recovery harness mounting point for damage
- Inspect the fins for damage
- Inspect the centering rings for damage
- Inspect the motor mount tube for damage
- Inspect the motor retainer for damage
- Inspect the recovery harnesses for damage
- Inspect the main parachute for damage
- Inspect the drogue parachute for damage

- What can be Learned from Failure
  - If a part is damaged
    - That part needs to be repaired or,
    - That part needs to be replaced

8.1.1.8 Ejection Charge Ground Fire

- Success Criteria
  - Both ends of the launch vehicle separate energetically
- Testing Variable
  - Quantity of black powder
- Testing Methodology
  - Pull the wires for the ejection charge terminals through the vent holes in the avionics bay

    - Have the team mentor load the ejection charges in the ejection cups as for a flight
    - Connect all three sections of the launch vehicle with shear pins
    - Part one
        - Attach the leads of an ignition system to the wires for the primary drogue ejection charge
        - Fire the ignition system
    - Part two
        - Attach the leads of an ignition system to the wires for the primary main ejection charge
        - Fire the ignition system
    - Reconnect the three sections of the rocket
    - Part three
        - Attach the leads of an ignition system to the wires for the secondary drogue ejection charge
        - Fire the ignition system
    - Part four
        - Attach the leads of an ignition system to the wires for the secondary main ejection charge
        - Fire the ignition system
- What can be Learned from Failure
    - If an ejection charge does not ignite
        - The ignitor used was faulty or,
        - There is a break in the wires for the ejection system or,
        - There is an issue with the ejection terminals or,
        - The ends of the electric matches used were not stripped properly to allow contact in the ejection terminals or,
        - The wires in the ejection terminals were not secured properly
    - If an ejection charge ignites but does not separate the launch vehicle sections
        - There is not enough black powder or,
        - There are too many shear pins or,
        - The ejection charges were not packed tightly enough or,
        - There is another path for pressure to be released

- If the sections separate but not energetically
    - There is not enough black powder or,
    - There are too many shear pins or,
    - The ejection charges were not packed tightly enough

8.1.1.9 Experiment Controller Activation

- Success Criteria
    - The experiment controller activates and functions correctly
- Testing Variable
    - N/A
- Testing Methodology
    - Turn on the experiment controller
- What can be Learned from Failure
    - There is an issue with the wires that connect the experiment controller to its batteries or,
    - The wires that connect the experiment controller to its batteries are not connected to the experiment controller or,
    - The wires that connect the experiment controller to its batteries are not connected to the batteries or,
    - The batteries used to not have sufficient charge to power the experiment controller or,
    - The batteries used to not supply enough voltage to power the experiment controller or,
    - There is a fault in the experiment controller

8.1.1.10 Flight Simulation

- Success Criteria
    - The simulation shows safe speeds for main parachute deployment and landing
    - The simulation shows a rail exit velocity of greater than 52 ft/s
    - The simulation shows that the stability margin of the rocket throughout the entire flight is high enough to be stable but not high enough to be over stable
    - The simulation shows that the rocket reaches its target altitude

- Testing Variable
    - Ballast
    - Motor
    - Main parachute size
    - Drogue parachute size
- Testing Methodology
    - Create a model of the rocket in RockSim that accurately simulates the actual launch vehicle
    - Add a ballast mass object to adjust as needed
    - Run a simulation with the intended motor
    - Check results
- What can be Learned from Failure
    - If the target altitude is not reached
        - There is too much ballast or,
        - The motor used is not powerful enough or,
        - The rocket produces too much drag
    - If the speed at landing is too high to be safe
        - The rocket has too much mass or,
        - The main parachute is not large enough
    - If the speed at main parachute deployment is too high to be safe
        - The rocket has too much mass or,
        - The drogue parachute is not large enough
    - If rail exit velocity is below 52 ft/s
        - The rocket has too much mass or,
        - The motor used is not powerful enough or,
        - The rail used is too short
    - The stability margin of the rocket is too low
        - There is too much mass toward the aft end of the rocket or,
        - The fins are not large enough or,
        - There is too much drag caused by components toward the fore end of the rocket
    - The stability margin of the rocket is too high
        - There is too much mass toward the fore end of the rocket or,
        - The fins are too large or,

        - There is too much drag caused by components toward the aft end of the rocket

8.1.1.11 Parachute Deployment

- Success Criteria
    - The main parachute opens easily
    - The drogue parachute opens easily
- Testing Variable
    - Folding technique
- Testing Methodology
    - Detach the main parachute from recovery harness, leaving a swivel and quick link at the end of the shroud lines
    - Fold the main parachute as for a flight
    - Drop the main parachute from a high place
    - Detach the drogue parachute from recovery harness, leaving a swivel and quick link at the end of the shroud lines
    - Fold the drogue parachute as for a flight
    - Drop the drogue parachute from a high place
- What can be Learned from Failure
    - If a parachute did not start to deploy
        - The folding technique needs to be changed
    - If a parachute started to deploy but did not open all of the way
        - The folding technique needs to be changed or,
        - The test needs to be repeated from a higher location

8.1.1.12 Payload Electronics Sled Shake Test

- Success Criteria
    - All of the payload electronics stay properly mounted to the payload electronics sled without damage
- Testing Variable

- Speed of vibrations
- Testing Methodology
    - Mount all of the payload electronics to the payload electronics sled as for a flight
    - Vibrate the payload electronics sled
    - Inspect all components for integrity of mounting and damage
- What can be Learned from Failure
    - If any components break off
        - Those components need to be mounted more securely
    - If any components are damaged
        - There are loose parts shaking around on the payload electronics sled or,
        - Those parts need shock absorbers or,
        - Those parts need to be mounted differently

8.1.1.13 Pull Test for Reaction Wheel Mount

- Success Criteria
    - The reaction wheel does not move
- Testing Variable
    - Force on the reaction wheel
- Testing Methodology
    - Mount the reaction wheel on its motor
    - Mark where the reaction wheel is
    - Pull on the reaction wheel
    - Check to see if the reaction wheel has moved
- What can be Learned from Failure
    - The reaction wheel's mounting needs to be improved

8.1.1.14 Push / Pull Test for all Bulkheads / Centering Rings

- Success Criteria
    - No bulkheads or centering rings move

- No bulkheads or centering rings deform significantly

- Testing Variable
    - Force on the bulkheads and centering rings
- Testing Methodology
    - Push on upper recovery harness mounting point
    - Pull on upper recovery harness mounting point
    - Push on avionics bay bulkheads
    - Pull on avionics bay bulkheads
    - Push on lower recovery harness mounting point
    - Pull on lower recovery harness mounting point
    - Push on motor tube
    - Pull on motor tube
- What can be Learned from Failure
    - If a bulkhead or centering ring moves
        - That bulkhead or centering ring needs to be mounted more strongly
    - If a bulkhead or centering ring deforms significantly
        - A stronger material is need for that bulkhead or centering ring or,
        - That bulkhead or centering ring needs to be thicker

8.1.1.15 Push / Pull Test for all Non-Permanently Mounted Components

- Success Criteria
    - No non-permanently mounted components move
- Testing Variable
    - Force on the components
- Testing Methodology
    - Push on avionics sled
    - Pull on avionics sled
    - Push on payload electronics sled
    - Pull on payload electronics sled
- What can be Learned from Failure
    - That component needs to be mounted more strongly

8.1.1.16 Reaction Wheel Control

- Success Criteria
    - The reaction wheel spins at a desired rate
- Testing Variable
    - N/A
- Testing Methodology
    - Set up payload as for a flight, but leave it outside of the launch vehicle
    - Activate the experiment controller
    - Command the experiment controller to spin the reaction wheel motor at a desired rate
    - Command the experiment controller to stop spinning the reaction wheel motor
    - Turn the experiment controller off
- What can be Learned from Failure
    - If the motor does not spin
        - There is a fault in the motor or,
        - There is a fault in the motor controller or,
        - The motor is not connected to the motor controller or,
        - The motor controller is not connected to the experiment controller or,
        - The motor is not connected to power or,
        - The motor is not connected correctly to the motor controller or,
        - The motor controller is not connected correctly to the experiment controller or,
        - The batteries used for the motor are not powerful enough to power it or,
        - The batteries used for the motor do not have sufficient charge to power the motor
    - If the motor spins but not at the desired rate
        - There is an issue with the control program or,
        - The batteries used for the motor do not provide enough voltage

8.1.1.17 Recovery Harness Pull Test

- Success Criteria
    - Both ends of both recovery harnesses remain mounted to the airframe
    - The recovery harnesses remain intact

- Testing Variable
    - Force on the recovery harnesses
- Testing Methodology
    - Pull on the upper recovery harness at both ends
    - Pull on the lower recovery harness at both ends
- What can be Learned from Failure
    - If a mounting point fails
        - That end of that recovery harness needs to be mounted more strongly
    - If a recovery harness breaks
        - A stronger material is needed for that recovery harness

8.1.1.18 Shake Test for Avionics

- Success Criteria
    - All components for the avionics system remain mounted
    - No components for the avionics system are damaged
- Testing Variable
    - Speed of vibrations
- Testing Methodology
    - Mount all components in the avionics bay as for a flight
    - Vibrate the avionics bay
    - Inspect all avionics system components for integrity of mounting and damage
- What can be Learned from Failure
    - If a component comes loose
        - That component needs to be mounted more strongly
    - If a component is damaged
        - There is a loose component in the avionics bay or,
        - That component needs shock absorbers or,
        - That component needs to be mounted differently

8.1.2 Completed Tests

Of the tests presented in the preceding section, all have been performed on the subscale rocket. Each test was successful except for Reaction Wheel Control and Assembled Inspection; however, neither one showed a major issue with the design.

The Reaction Wheel Control test showed an issue with the motor controller related to the power source. The Assembled Inspection showed that the original size of the main parachute compartment was not sufficient to pack a parachute of the intended size.

8.2 Requirements Compliance

8.2.1 NASA Requirements

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. TADI (Test, Analysis, Demonstration, or Inspection) identifies whether a test, analysis, demonstration, or inspection is required to verify the requirement.

Req ID	Requirement	Verification Plan / Status	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	Test

Req ID	Requirement	Verification Plan / Status	TADI
		recovery. Additionally, any batteries will be replaced before launch	
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
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 flight was not a success, valuable information was gathered, and a second test flight is planned	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

Req ID	Requirement	Verification Plan / Status	TADI
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
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 as stated in section 1	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	There are no foreign nationals on the team	N/A
47	5.4 - 5.4.3	See section 1	N/A
48	5.5	PSLT has completed several educational activities and has plans for more	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

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

Table 8.2 - Requirement Verification Plans

Req ID	TADI Required
1	The primary altimeter in the launch vehicle will be checked after test flights and the final launch to get the official altitude reached
3	The method of conveying the altitude reached will be demonstrated during test flights
7	The reusability of the rocket will be demonstrated through test flights
10	The time it takes to prepare the rocket will be timed during test flights
11	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	RockSim simulations will be used to ensure the launch vehicle is stable at rail exit
18	RockSim simulations will be used to ensure the launch vehicle reaches at least 52 ft/s at rail exit
25	Calculations will be done for each independent section of the launch vehicle to ensure it has a low enough kinetic energy
35	The rockets' ability to perform the experiment will be tested during test flights of both the subscale and full scale rockets
48	Reports will be submitted at the completion of each event

Table 8.3 - Requirement Verification TADIs

8.2.2 Team Derived Requirements

Requirement	Verification Plan
Project	
Engage at least 200 females in STEM activities.	Keep track of the number of females engaged during educational engagement activities.
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.
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.

Requirement	Verification Plan
Experiment	
The payload shall detect motor ignition	An IMU will be included in the payload, and it will use its accelerometer to detect motor ignition
The payload shall detect motor burnout	The IMU in the payload will also use its accelerometer to detect motor burnout
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
The rocket shall roll 3 times around its long axis	The reaction wheel will be used to induce the roll, and the IMU in the payload will use its magnetometer to detect when the rocket has completed 3 rotations
The rocket shall complete its 3 rotations within 12 s	Testing will be done to determine how fast the reaction wheel will need to spin to complete the rotations in the required time
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
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 roll in the rocket, and the magnetometer in the IMU will be used to detect the angular velocity of the rocket
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	Testing will be done to ensure the payload is able to transmit the required statistics at the maximum range that the rocket will be from the ground station

Table 8.4 - Team Derived Requirements

8.2.3 Verified Requirements

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

Requirement ID	Location of Verification
1.1	Section 4.4
1.2 - 1.2.6.4	Section 4.3
1.3	Section 4.3
1.4	Sections 4.1, 4.3
1.5	Section 4.1
1.6	Section 4.1
1.8	Sections 6.1, 4.3

Requirement ID	Location of Verification
1.9	Section 4.4
1.10	Section 4.4
1.11 - 1.11.2	Section 4.4
1.12 - 1.12.4	Sections 4, 6
1.13	Section 4.4
1.14	Section 4.4
1.15	Section 4.4
1.16 - 1.16.2	Section 4.2
1.18	Section 4.1
1.19 - 1.19.8	Sections 4.1, 4.4
2.1	Section 4.3
2.3	Section 4.4
2.4	Section 4.3
2.5	Section 4.3
2.6	Section 4.3
2.7	Section 4.3
2.8	Section 4.3
2.9	Section 4.3
2.10	Section 4.1
2.11 - 2.11.2	Sections 4.3, 6.1
Updated experiment requirements	Section 6
3.3.2	Section 6.1
3.3.3	Section 6.1
4.1	Section 5.1
4.2	Section 1.1
4.4	Section 1.1
5.4	Section 1.2
5.12	Section 4.1

Table 8.5 - Verified Requirements

8.3 Budgeting and Timeline

8.3.1 Budget

Numbers in parentheses indicate number of item per package; quantity is the number of packages.

8.3.1.1 Subscale Launch Vehicle

Item Name	Price	Quantity	Purchased?
4 in body tube	$14	2	Yes
4 in slotted body tube	$19	2	Yes

Item Name	Price	Quantity	Purchased?
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 8.6 - Subscale Launch Vehicle Budget

8.3.1.2 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
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

Item Name	Price	Quantity	Purchased?
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 8.7 - Subscale Payload Budget

8.3.1.3 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
Subtotal			$1511

Table 8.8 - Full Scale Launch Vehicle Budget

8.3.1.4 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 8.9 - Full Scale Payload Budget

8.3.1.5 Educational Engagement

Item Name	Price	Quantity	Purchased?
Model rocket kit	$22	2	Yes
Model rocket motor (24)	$52	1	Yes
Subtotal			$96

Table 8.10 - Educational Engagement Budget

8.3.1.6 PPE

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

Table 8.11 - PPE Budget

8.3.1.7 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 8.12 - Tools and Construction Materials Budget

8.3.1.8 Travel

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

Table 8.13 - Travel Budget

8.3.1.9 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 8.14 - Miscellaneous Budget

8.3.1.10 Total

$9719

8.3.2 Funding

8.3.2.1 Sources of Funding

Funding for PSLT comes from two major sources, corporate sponsors and individual donors. The team has also received funding from PVCC.

8.3.2.2 Allocation of Funds

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

Table 8.15 - Allocation of Funds

8.3.3 Timeline

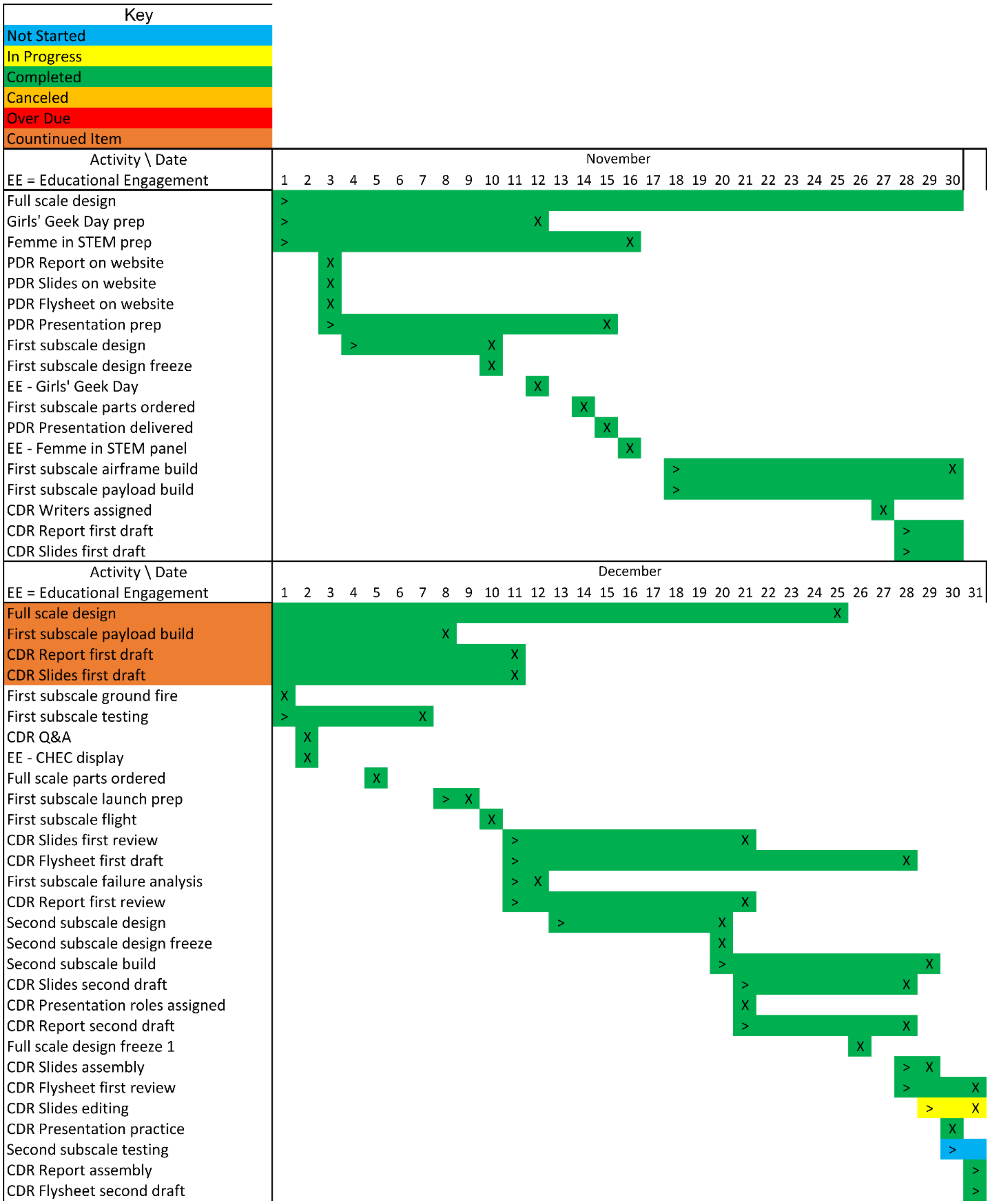

Figure 8.1 - Timeline, November through December

Activity \ Date	January																														
EE = Educational Engagement	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
Second subscale testing				X																											
CDR Report assembly			X																												
CDR Flysheet second draft			X																												
Space explor. event planning	>															X															
Second subscale ground fire	X																														
Girls' Geek Day prep		>				X																									
Full scale build			>																							X					
CDR Report final review			>								X																				
Second subscale prep dry run					X																										
CDR Presentation practice					X																										
Second subscale launch prep						X																									
EE - Girls' Geek Day							X																								
Second subscale launch							X																								
CDR Slides submitted												X																			
CDR Flysheet submitted												X																			
CDR Slides last changes												X																			
CDR Report submitted												X																			
CDR Report last changes												X																			
CDR Presentation practice												X																			
CDR Flysheet last changes												X																			
Movie night planning													>										X								
FRR Flysheet first draft													>															X			
FRR Report first drafts													>															X			
FRR Slides first draft													>																X		
Space explor. event prep																	>														
CDR Presentation delivered																	>														
Full scale ground fire																					X										
Second subscale backup launch																					X										
Full scale design freeze 2																						X									
Movie night prep																								>							X
Full scale prep dry run																										X					
FRR Report first review																												>			
FRR Slides first review																													>		

Figure 8.2 - Timeline, January

Activity \ Date	February																											
EE = Educational Engagement	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28
Space explor. event prep																	X											
CDR Presentation delivered			X																									
FRR Report first review	X																											
FRR Slides first review		X																										
Math of space event planning	>																			X								
Mini maker faire planning	>																			X								
FRR Report second draft	>							X																				
FRR Slides second draft		>							X																			
Full scale launch prep		>	X																									
Full scale test flight				X																								
Full scale backup test flight					X																							
FRR Report second review								>				X																
FRR Q&A								X																				
FRR Slides assembly									>							X												
EE - Girls' Geek Day											X																	
Full scale backup test flight											X																	
FRR Report third draft												>							X									
Full scale backup test flight												X																
FRR Slides editing																>							X					
FRR Presentation practice																X												
EE - Movie night																	X											
EE - Space explor. event																		X										
FRR Report assembly																			>							X		
EE - High School class																				>								X
Math of space event prep																					>							X
Mini maker faire prep																					>							X
FRR Presentation practice																							X					
FRR Slides editing																							>			X		
FRR Report final editing																										>		
FRR Flysheet final editing																										>		
FRR Slides final editing																										>		

Activity \ Date	March																														
EE = Educational Engagement	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
FRR Report final editing					X																										
FRR Flysheet final editing					X																										
FRR Slides final editing					X																										
EE - Mini maker faire	>																														
FRR Presentation practice		X																													
FRR Report submitted					X																										
FRR Slides submitted					X																										
FRR Report last changes					X																										
FRR Slides last changes					X																										
FRR Flysheet last changes					X																										
FRR Flysheet submitted					X																										
EE - Last day to be counted						X																									
FRR presentation delivered								>																X							
EE - Girls' Geek Day											X																				

Figure 8.3 - Timeline, February through March

Activity \ Date	April																													
EE = Educational Engagement	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
EE - Mini maker faire																														X
EE - Math of space w/ math club	>																													X
Travel to Huntsville					X																									
Attend LRR					X																									
Launch week safety briefing						X																								
MSFC tours							X																							
Rocket fair							X																							
launch								X																						
Return from Huntsville									X																					
Backup launch									X																					
PLAR											>						X													
PLAR Final editing																		>				X								
PLAR Report submitted																							X							

Figure 8.4 - Timeline, April