Piedmont Student Launch Team

2018 NASA Student Launch

Critical Design Review

Piedmont Virginia Community College

501 College Drive, Charlottesville, Virginia 22902

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Glossary of Terms

ABS	-	Acrylonitrile Butadiene Styrene
ACS	-	Altitude Control System
AGL	-	Above Ground Level
APCP	-	Ammonium Perchlorate Composite Propellant
APCP	-	Ammonium Perchlorate Composite Propellant
Cd	-	Coefficient of Drag
CG	-	Center of Gravity
CHEC	-	Community Homeschool Enrichment Center
CP	-	Center of Pressure
DOF	-	Degrees Of Freedom
FAA	-	Federal Aviation Administration

FMEA	-	Failure Modes and Effects Analysis
FSEE	-	Family Space Exploration Event
GPS	-	Global Positioning System
I/O	-	Input / Output
IMU	-	Inertial Measurement Unit
IR	-	Infrared
IRC	-	International Rescue Committee
IRC	-	International Rescue Committee
JIM	-	Joining Intermediary Member
LiDAR	-	Light Detection And Ranging
NAR	-	National Rocketry Association
NOVAAR	-	Northern Virginia Association of Rocketry
PSLT	-	Piedmont Student Launch Team
PVCC	-	Piedmont Virginia Community College
STEM	-	Science, Technology, Engineering, and Mathematics
TRA	-	Tripoli Rocketry Association
VAST	-	Valley AeroSpace Team

1 General Information

1.1 Team Contacts

Name	Title	Email	Telephone	Going to Huntsville
Dr. Yanina Goddard	Professor of Physics	ygoddard@pvcc.edu	434-961-5341	No
David Oxford	Team Mentor	david@oakhaven.org	434-996-9131	Yes
Andrew Oxford	Team Leader	leader@piedmontlaunch.org	434-996-4658	Yes
Troy Dodd	Safety Officer	safety@piedmontlaunch.org	434-953-6901	Yes

Table 1.1 - Team Contacts

All deliverables due to NASA throughout the period of performance will be provided on the team website at piedmontlaunch.org.

1.2 Team Organization and Members

PSLT currently consists of 18 students, one team mentor, and one faculty advisor.

The team is organized into five project areas with area leaders:

- Administrative
- Engagement & Outreach
- Launch Vehicle
- Payload
- Safety

In addition to major project areas, there are functional areas to categorize the work team members do, based on their interests and skills. Functional areas do not have leaders:

- Analysis
- Communications

- Education
- Electronics
- Graphic Arts
- Outreach
- Programming
- Structural

There are several key roles on the team for people who are in charge of a project area, who direct a major function within a project area, or are required under the statement of work.

Name	Role	Project Areas	Functional Areas	Going to Huntsville
Alex	Deputy Safety Officer Webmaster	Safety Payload Launch Vehicle	Electronics Programming Structural Analysis	Yes
Andrew	Team Leader & Project Manger	Administrative	None	Yes
Anna	Director of Testing & Analysis	Launch Vehicle Payload	Analysis	Yes
Branson	Launch Vehicle Leader	Launch Vehicle	Structural	Yes
Lu	Treasurer	Administrative Engagement & Outreach	Structural Education Outreach Communications	Yes
Sander	Payload Leader	Payload	Electronics	Yes
Troy	Safety Officer Director of Art	Safety Launch Vehicle	Structural Graphic Arts	Yes
Victoria	Director of Social Media	Launch Vehicle Engagement & Outreach Administrative	Structural Analysis Education	Yes

Table 1.2 - Key Positions

In addition to the key roles, other team members work in one or more project areas, and in many cases, perform multiple functions within those areas.

Name	Project Areas	Functional Areas	Going to Huntsville
Carl	Launch Vehicle Payload	Electronics Structural	Yes
Chris	All	Graphic Arts	Yes
Daniel	Launch Vehicle Payload	Electronics Structural	No
James	Launch Vehicle Administrative	Electronics Structural	Yes
Michael	Launch Vehicle	Structural Analysis	Yes
Nelly	Launch Vehicle	Communications	Yes
Shane	Launch Vehicle Payload	Electronics Programming Structural	Yes
Sophia	Launch Vehicle Payload Engagement & Outreach	Structural Analysis Education Outreach Communications	No

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 Tripoli Central Virginia TRA #25 (also known as Battle Park). The Battle Park launch field near Culpeper, VA (approximately 40 minutes from PVCC) has a nominal flight ceiling of 16,000 ft AGL based on their FAA waiver, with frequent flights to 6,000 ft AGL or more being safely recovered. With this capability, PSLT will be able to perform full-scale test flights using the full-scale motor.

As a backup launch site, PSLT will be working with the Valley AeroSpace Team (VAST) (NAR Section #687 / Tripoli Western Virginia #36). The VAST launch field near Monterey, VA (approximately an hour and a half from PVCC) has a nominal flight ceiling of 10,000 feet AGL and can support launches to at least 6,000 ft AGL.

Additionally, PSLT will be working with the Northern Virginia Association of Rocketry (NOVAAR) (NAR Section #205). The NOVAAR launch field near Warrenton, VA (approximately an hour and a half from PVCC) has a nominal ceiling of only 4,500 ft AGL so it will not be used for full-scale test flights unless other options are not available; however, it may still be used for subscale test flights.

2 Summary

2.1 Team

The Piedmont Student Launch Team (PSLT), representing Piedmont Virginia Community College (PVCC), is working with David Oxford, NAR number 101883, as the mentor for high-power rocketry. David Oxford has level 2 high-power certifications with the NAR and TRA. See section 1.1 Team Contacts for contact information.

PVCC mailing address: 501 College Drive, Charlottesville, VA 22902

2.2 Launch Vehicle

Statistics	Value
Diameter (in.)	6
Length (in.)	105
Mass without motor (lbs)	33.5
Mass with motor (lbs)	43.6
Motor	Aerotech L1420
Rail button size	1515
Rail exit velocity (ft/s)	63
Static stability margin	3.5
Parachute diameter (ft)	14
Recovery harness length (ft)	26
Primary ejection charge size (g)	3.8
Altitude control system gas	Nitrogen
Cd	0.616
Apogee (ft)	5252

Table 2.1 - Launch Vehicle Summary

2.3 Payload

PSLT has chosen the deployable rover challenge. To complete this challenge, PSLT has designed a rover which will be housed within the nosecone of the rocket. Once the rocket has landed, the nosecone will be ejected with the rover. Then, it will open, releasing the rover. The rover utilizes six infinity wheels to allow it to maneuver over rugged terrain. It has a solar panel mounted to a backplate which can be folded out by the rover when it has moved the necessary distance. This panel can also be used as a mechanism to flip the rover should it become inverted.

3 Changes Made Since PDR

3.1 Launch Vehicle

- The avionics electronics and ejection charges have been moved to the fore end of the parachute tube to prevent deployment issues

3.2 Payload

- A single power supply will be used for the camera system and all motors and actuator
- That power supply will be enabled / disabled with a relay
- The power supply will be 8 AAs
- Each motor and the actuator will have its own driver

3.3 Project Plan

- The launch dates for the full-scale test launch and backup launches have been moved due to changes in the Battle Park TRA prefecture's launch schedule

4 Vehicle Criteria

4.1 Design and Verification of Launch Vehicle

4.1.1 Mission Statement

Build a launch vehicle that will safely carry a payload and altimeter to a target altitude of 5,280 ft, utilizing thrusters to control apogee, while allowing the rocket to safely return to the ground in a way such that the payload may be safely deployed.

4.1.2 Design

4.1.2.1 Upper Section

The upper section of the launch vehicle is composed of the nosecone and the payload bay.

The nosecone will be 3D printed using ABS plastic because it is an easily accessibly material, can be recreated easily in the event of damage, and allows for a flexible design suitable for the payload. Because the design of the nosecone is critical to the operation of the payload, it is discussed in more detail in that section. It will be ellipsoid in shape so that, if the separated launch vehicle lands nose-first, it is less likely to embed into soft ground, and it is more likely that the launch vehicle will be on its side before the rover is deployed.

The lower portion of the payload tube will house the recovery system electronics. The aft end bulkhead of the payload tube will have four ejection cups attached to it in addition to two U-bolts which will be the attachment points for the upper end of the recovery harness. Each ejection cup will be bolted and epoxied in place. The bulkheads will have two, 1/4 in. holes for 15.5 in. long threaded rods as well as four, 1/4 in. holes for electrical terminals for the ejection system.

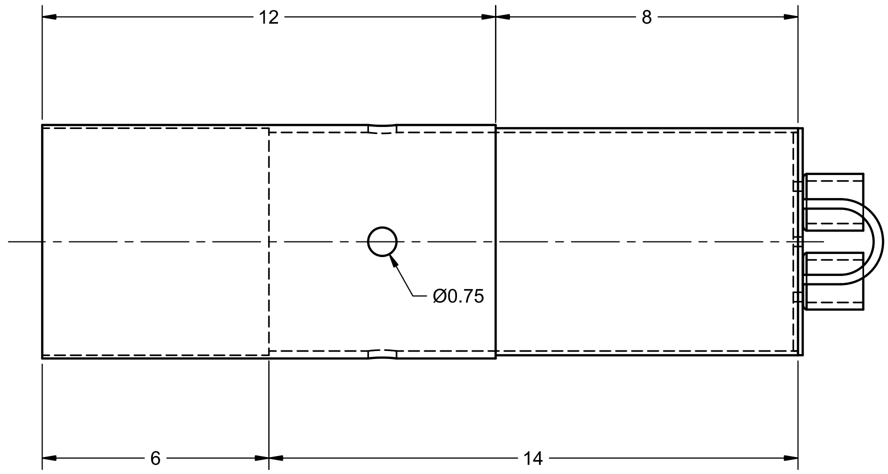

Figure 4.1 – Payload Bay Side Profile

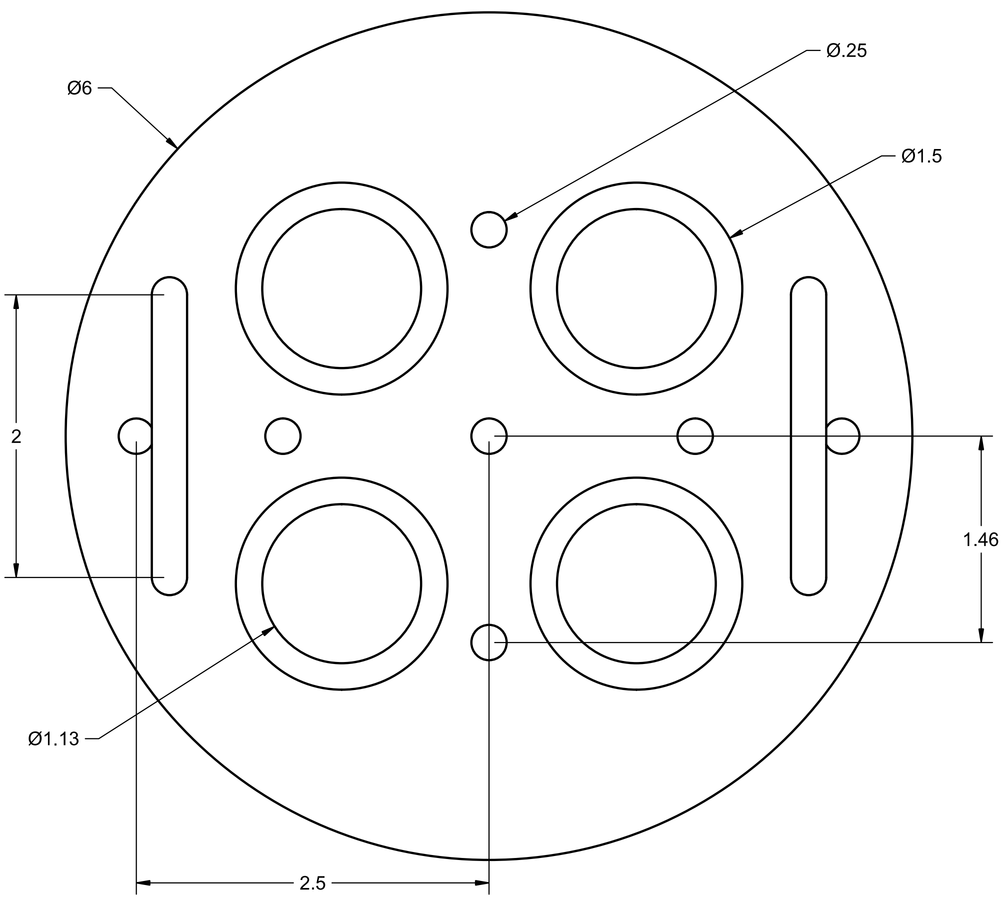

Figure 4.2 – Payload Bay Aft Bulkhead

4.1.2.2 Parachute Tube

The parachute tube will be constructed of G12 fiberglass because of an excellent strength to weight ratio as well as being relatively easy to work with and commercially available in the desired 6 in. diameter. A 36-in. long parachute tube allows for sufficient space to house a 14 ft diameter main parachute and the 26 ft recovery harness. A flame retardant parachute protector will be placed between the ejection charges and parachute to protect the it from the blast of the ejection charges.

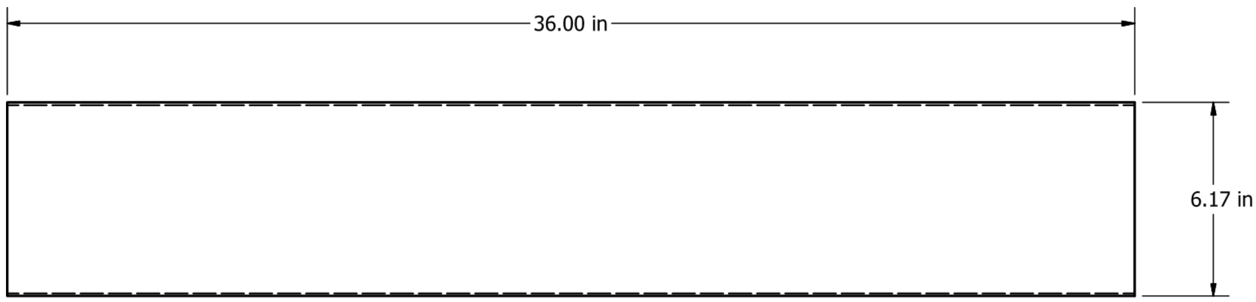

Figure 4.3 – Parachute Tube Side Profile

4.1.2.3 Joining Intermediary Member (JIM)

The fore bulkhead will have three 1/4 in. holes for threaded rods which connect the JIM to the booster section. The threaded rods will also be used to mount the ACS hardware and an electronics sled for the ACS electronics. The fore bulkhead will also have two U-bolts which will serve as the lower attachment for the recovery harness. There is no rear bulkhead on the JIM, so the inside of it continues into the fore end of the booster section to provide more room for the ACS hardware.

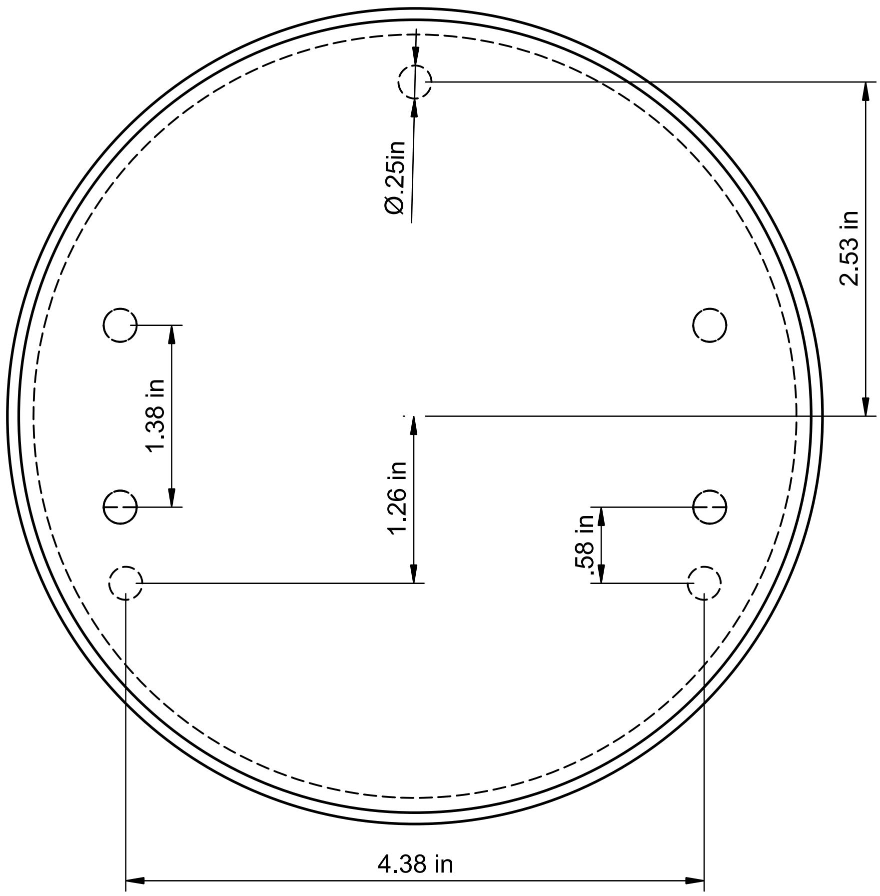

Figure 4.4 – JIM Top View

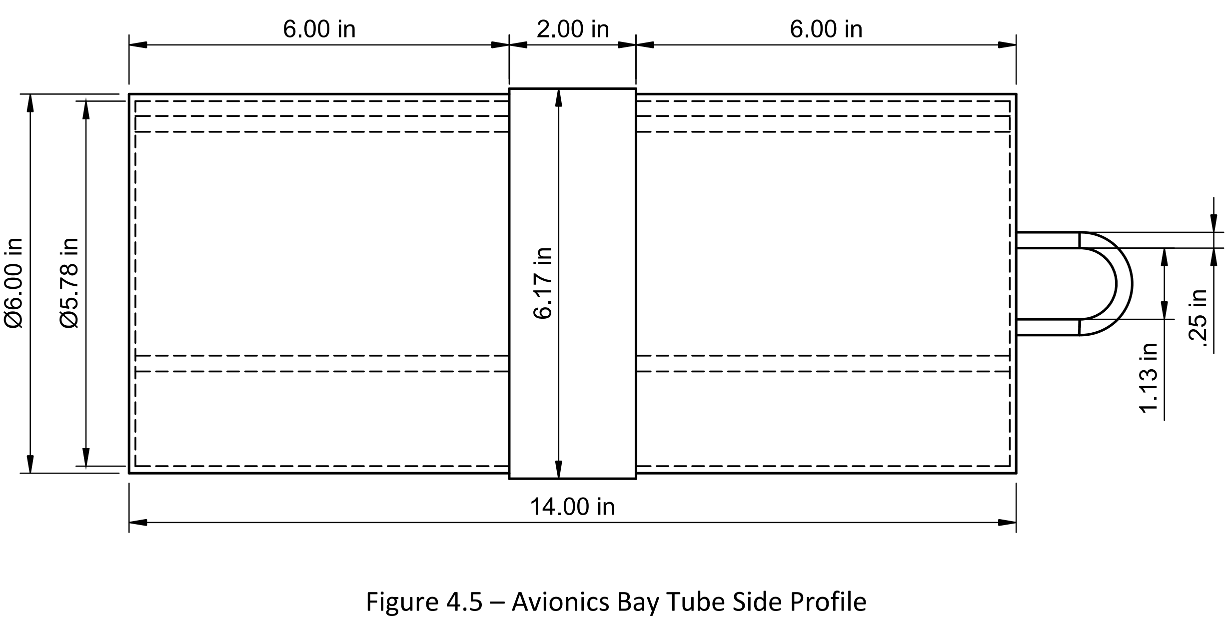

Figure 4.5 – Avionics Bay Tube Side Profile

4.1.2.4 Booster Section

Attached to the booster section will be two 1515 rail buttons which will allow for a safe and secure connection between the launch vehicle and launch rail during takeoff. Four, 8.5 in. long cuts will be made equally spaced around the booster section to allow for through-the-wall fin mounting. The gap between the motor tube and booster section will be filled with an expanding foam after the fins are mounted to provide additional strength and rigidity to the fins and the motor mount. The ACS hardware will be housed in the fore end of the booster section.

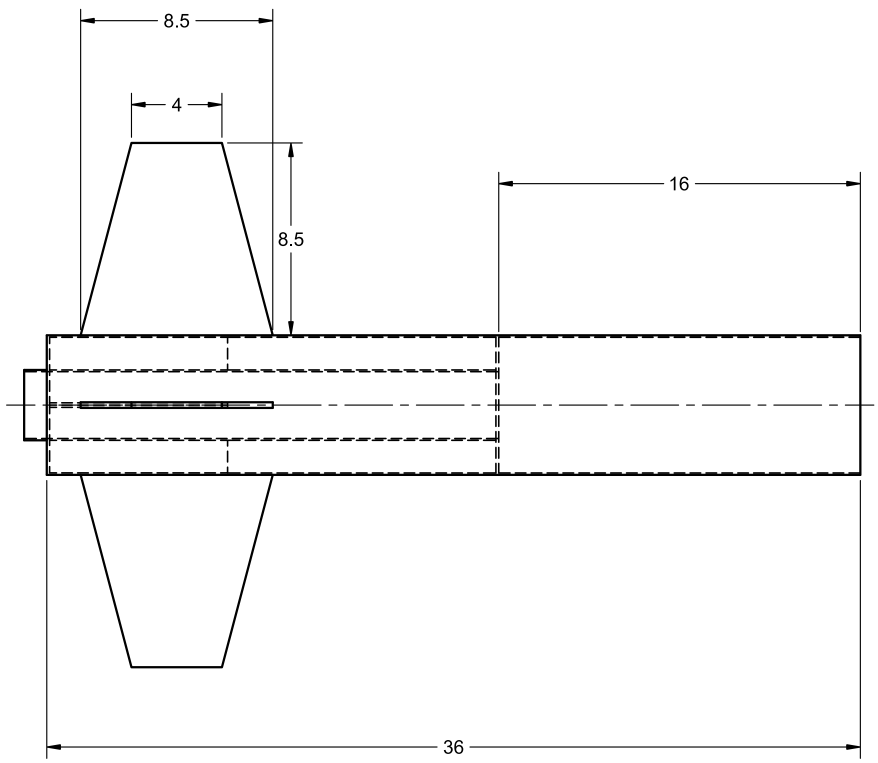

Figure 4.6 – Booster Section Side Profile

4.1.2.4.1 Motor Tube and Retention

A 75 mm AeroPack retainer will be attached to the aft end of the motor mount tube to secure the motor during flight. A screw-on retainer was chosen because it is a simple yet effective method to ensure the motor remains secure throughout the flight. The motor tube will be attached to the airframe by two centering rings, one flush with the fore end, the other somewhat fore of the aft end to make room for the motor retainer. The fore centering ring will have three holes for threaded rods that will extend to the fore end of the JIM.

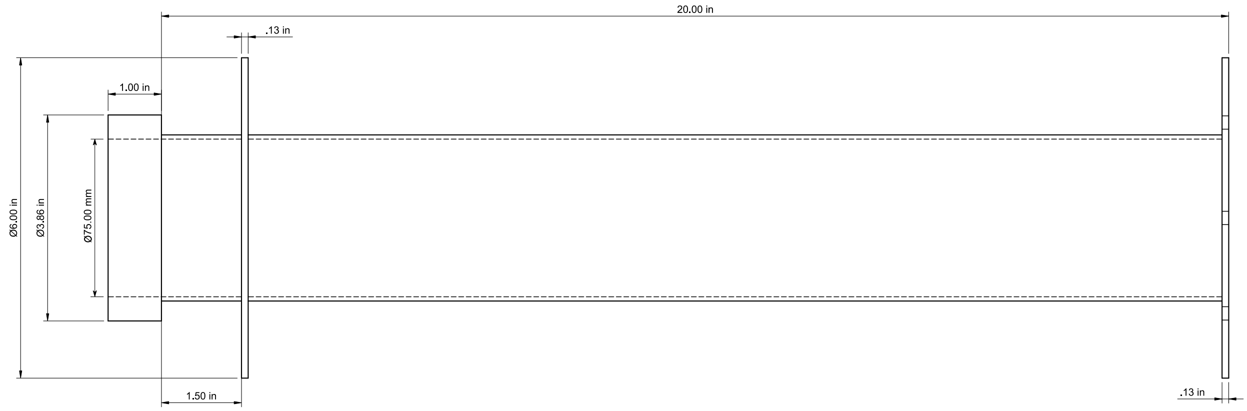

Figure 4.7 – Motor Tube Side Profile

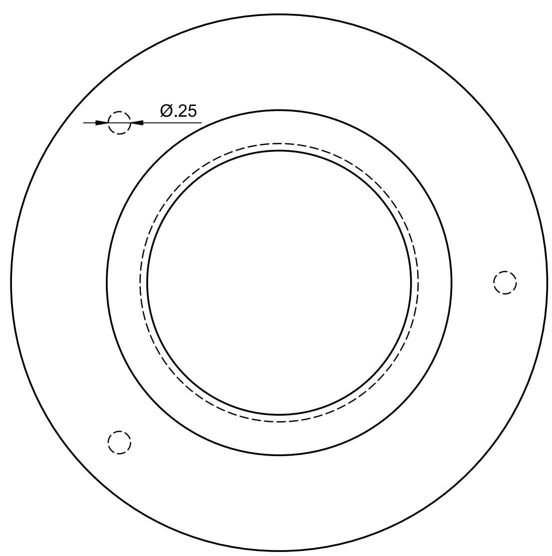

Figure 4.8 – Motor Tube Top View

4.1.2.4.2 Fins

There will be four, trapezoidal fins mounted through-the-wall to the motor tube. Fiberglass fins will be used because of their durability and low cost compared to other viable options. Each fin will be made of two, 1/8 in. pieces laminated together to create a 1/4 in. thick fin to prevent any flapping during flight.

Four fins allow for simple alignment around the booster section and when setting the rocket down without a stand, it reduces the stress on the fins. After installing the fins through-the-wall, the remaining space between the motor tube and booster section will be filled in with an expanding foam to further strengthen the fins. On both sides of each fin, there will be an epoxy clay fillet along the root chord that connects the fin to the booster section to improve attachment strength and the aerodynamics of the launch vehicle.

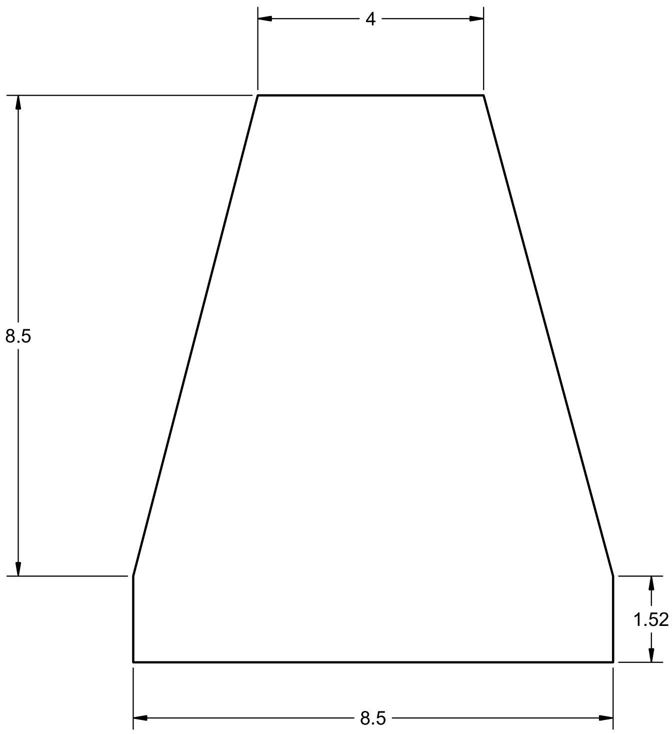

Figure 4.9 – Fin Face Profile

4.1.2.5 Altitude Control System (ACS)

4.1.2.5.1 Overview

The rocket will utilize a system of thrusters, half facing forward and half backward. The two sets of four thrusters, positioned at 90 ° intervals around the airframe, allow the system to either increase or decrease the apogee of the rocket. An altimeter will be used to provide a microcontroller the altitude and vertical velocity of the rocket. The microcontroller will fire the forward or rear facing thrusters as appropriate to adjust the velocity of the rocket.

4.1.2.5.2 Propellant Tank

A Ninja Paintball 45 in.^3 carbon fiber tank will be used to store the nitrogen gas propellant for the ACS. This tank is intended to operate at 4,500 PSI, with a minimum burst pressure of 13,500 PSI. The regulator on the tank also has a built-in burst disk to release the gas if the pressure becomes too high. It is rated to burst at 7,500 PSI. To maintain a safety factor of at least 4:1, the tank will never be filled above 3,375 PSI; however, due to the availability of filling tanks for N2, the tank will normally be filled to 2,100 PSI. The tank has a regulator attached at the top, which reduces the output pressure to 800 PSI.

At 2,100 PSI and 70 °F, the tank will hold approximately 122 g of propellant. With that much propellant, to reach the minimum burst pressure, the gas in the tank would need to be heated to around 2,950 °F, and to 1,430 °F to reach the rated pressure of the burst disk, so there should not be any issues with the tank over pressuring due to over-heating of the propellant.

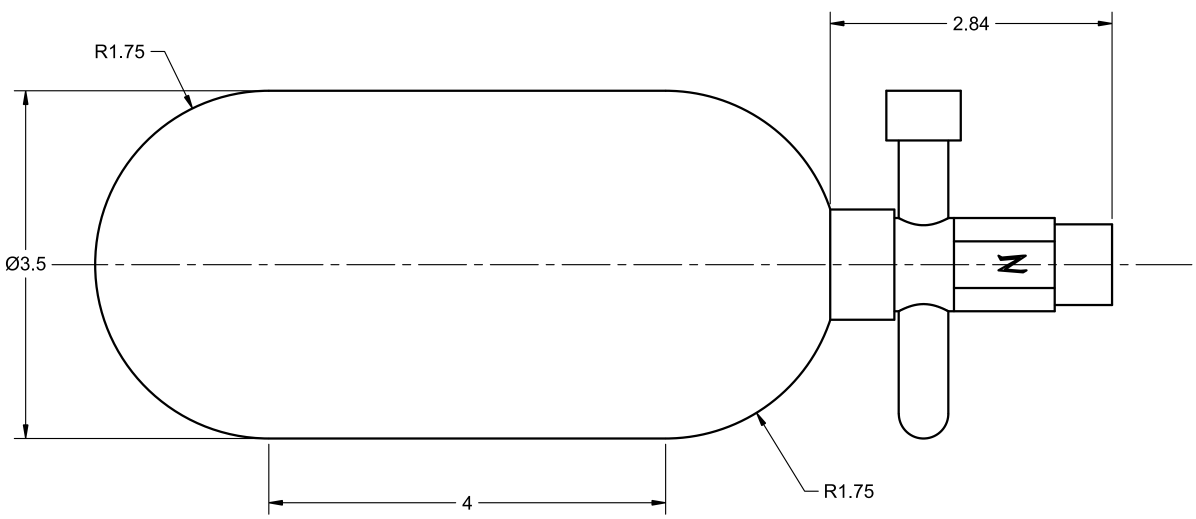

Figure 4.10 – Propellant Tank

Statistic	Value
Tank volume (in.^3)	45
Minimum burst pressure (PSI)	13,500
Burst disk pressure (PSI)	7,500
Maximum pressure tank will be fill to (PSI)	2,100
Output pressure (PSI)	800
Propellant	N2
Propellant mass (g)	122

Table 4.1 - Key Propellant Tank Statistics

Figure 4.11 – Ninja Tank Side Profile

4.1.2.5.3 Solenoids

The solenoids are used to control whether propellant flows to the forward or rear facing thrusters; each direction is controlled by one solenoid. Solenoids valves were chosen to provide a very short opening / closing time to allow for more accurate pluses to finetune the velocity of the rocket. The particular solenoids being used are normally closed, so that if the system loses power at any point, the thrusters will stop firing.

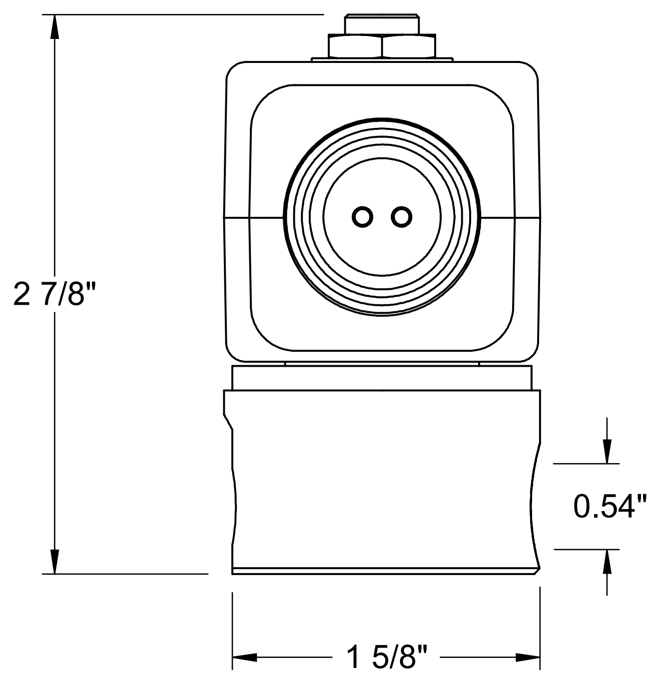

Figure 4.12 – Solenoid Rear

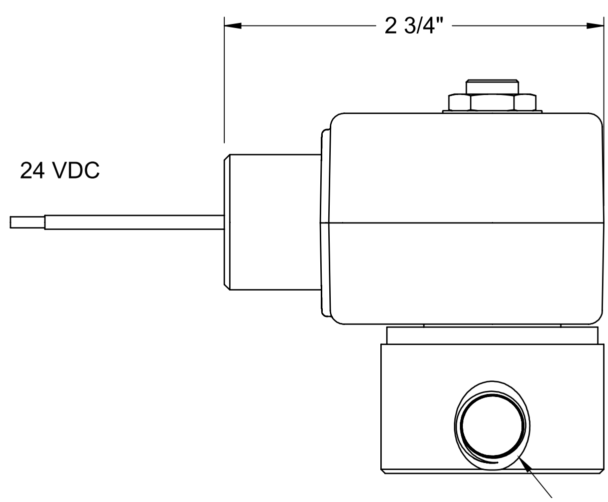

Figure 4.13 – Solenoid Side

Statistic	Value
Input voltage (V)	24
Input current (A)	0.41
Current type	DC
Rated pressure (PSI)	1,000
Body material	Steel
Unenergized position	Normally closed

Table 4.2 - Key Solenoid Statistics

4.1.2.5.4 Tubing and Hardware

The propellant is feed through the ACS through brake line with various fittings and tee junctions. The brake line is rated for up to 10,000 PSI, and the highest pressure that will pass through it will be 800 PSI.

4.1.2.5.5 Electronics

The ACS is controlled from onboard the rocket in real-time. The electronics used in the control system are listed below.

- Two 12 V, A23 batteries
- One 6 V Lipo battery
- One Arduino Nano microcontroller
- One altimeter
- One 2-channel 24 V relay

The following figure shows how the electronics are connected. The altimeter feeds data to the controller, which sends a command to the relay to send power to the appropriate solenoid, or to neither, as needed.

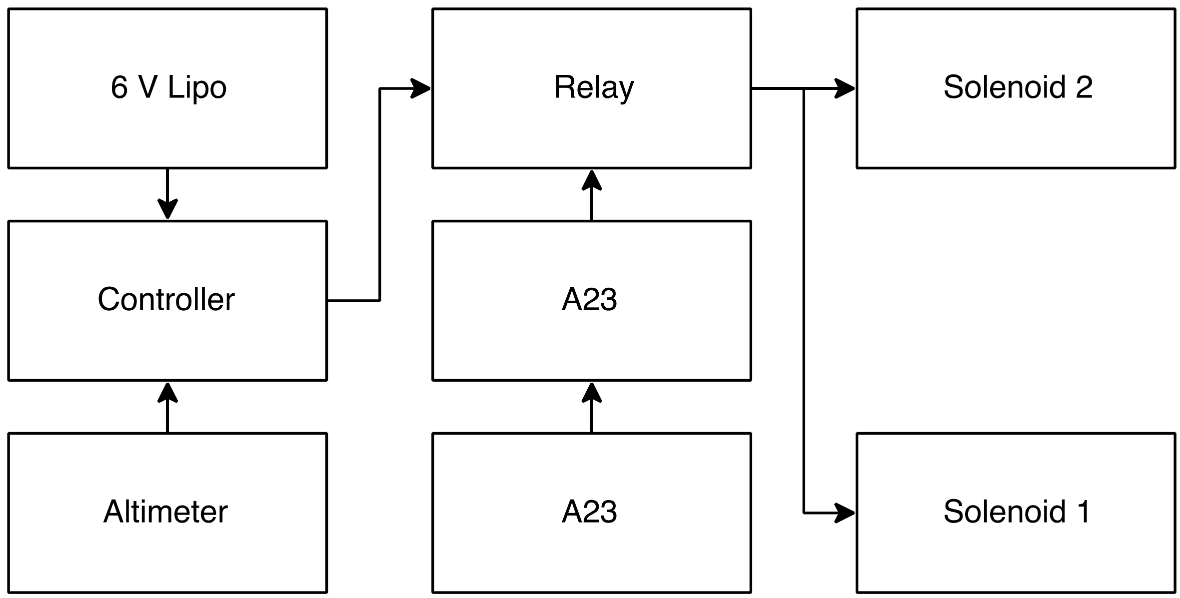

Figure 4.14 – Electronics Connection Diagram

4.1.2.6 Integrated Design

4.1.2.6.1 Connections

The nosecone will be attached to the payload bay by shear pins. The payload bay will be connected to the parachute tube by eight removable rivets. The parachute tube will be attached to the JIM by four, #4-40 shear pins. The JIM will be connected to the booster section by the three threaded rods that run through that section. The motor mount will be epoxied to the booster section, with the fins epoxied to it and connected by epoxy clay fillets to the booster section airframe. The motor retainer is connected to the motor mount by high heat epoxy.

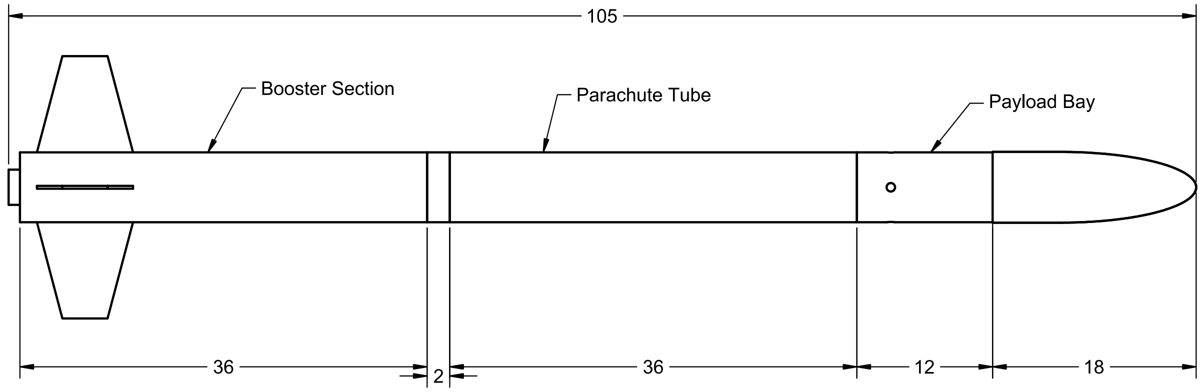

Figure 4.15 – Assembled Launch Vehicle

4.1.2.6.2 Section Masses

All masses other than the nosecone with payload are measured from the as-built components.

Section	Mass (lbs)
Payload Bay	3.4
Nosecone with payload	4
Parachute Tube	4.5
JIM	2.2
Booster Section (without fins)	6.6
Fins	4.5
Gas Tank	2.2
Solenoids	2.6
Tubing and Hardware	1.3
Electronics	2.2
Total (without motor)	33.5

Table 4.3 – Mass of Launch Vehicle

4.1.3 Construction Readiness

All major components of the launch vehicle are now designed, with only a few small aspects that are not specified. Those aspects will be determined during construction, such as the exact routing and length of the propellant feedline. Additionally, most of the airframe has already been constructed. The major parts that remain to be built are the ACS and the payload.

4.2 Subscale Flight Results

4.2.1 Observations

Visual observations of the flight showed a good, stable ascent and proper flight to apogee; however, at apogee, the recovery system did not deploy as expected, and the rocket returned ballistically.

Analysis of the recovered components of the rocket suggests that the issue stemmed from the parachute and blast protector being forced onto exposed threaded rods at the base of the parachute tube and becoming wedged between them. Because the ejection charges on the subscale were located at the bottom of the parachute tube, the blast was not able to apply any force to the bulkhead at the end of the parachute tube that was designed to separate, and so the deployment did not occur.

Analysis of the data from the altimeters and inspection of the rocket post-flight confirmed that all four ejection charges fired at the correct times during flight.

4.2.2 Data Gathered

The following table shows the key flight data that was recovered from the subscale flight.

Value	Result
Apogee (ft)	3248
Maximum Velocity (ft/s)	591
Time to Apogee (s)	14.45
Descent Time (s)	15.25
Flight Time (s)	29.85
Rail Exit Velocity (ft/s)	39.24

Table 4.4 - Key Subscale Flight Data

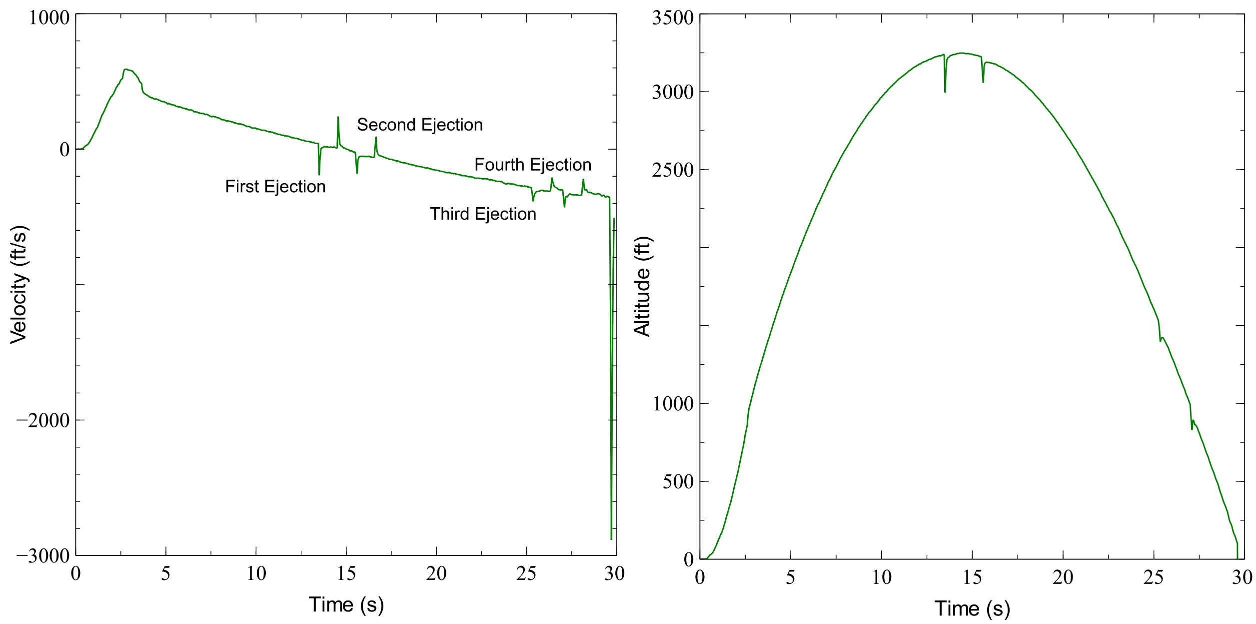

Figure 4.16 - Subscale Velocity and Altitude

4.2.3 Scaling

The subscale was built at 3/4 the size of the full-scale rocket, giving it a diameter of 4 in. This was done because the it allowed it to be small enough to be less expensive while still being large enough to work in easily. The airframe was the same as the full-scale design, but the CG was 2 in. off where it would be in an exact scaling, largely due to the fact that neither a subscale payload nor a subscale ACS were flown. It was decided that, because the CG of the full-scale was being estimated in any case, it would be better to leave that and adjust the CG in the full-scale with ballasting once a final CG is located.

4.2.4 Launch Conditions and Simulations

The following are the conditions and results of the simulations that were run before the flight of the subscale rocket.

Condition	Value
Temperature (°F)	46.4
Humidity	40%
Elevation (ft)	600
Wind speeds (MPH)	2 - 15

Table 4.5 - Initial Subscale Simulation Conditions

Value	Expected Result
Apogee (ft)	4964
Time to apogee (s)	17
Flight time (s)	58
Rail exit velocity (ft/s)	76.6

Table 4.6 - Initial Subscale Simulation Results

4.2.5 Drag Coefficient

An estimate for the drag coefficient was calculated by hand and through RockSim. Using velocity and pressure data from the altimeter, acceleration and drag force were calculated. The coefficient of drag was calculated with the formula below.

$$Cd = \frac{2 * F_d}{A * \rho * V^2}$$

Where F_d is the drag force, A is the frontal area of the subscale, ρ is the density of air, and V is the rockets velocity.

This equation was used with data from several points in the flight and their average was taken. The resulting Cd was 0.634. The Cd was also estimated using RockSim by adjusting it until the flight profile matched closely with the actual data. The result was a Cd of 0.598. For the simulations in section 4.4 Mission Performance Predictions, the average of these two values, 0.616, was used.

4.2.6 Full-Scale Design Implications

The primary change to the full-scale design that resulted from the subscale flight was to move the avionics electronics, and more importantly, the ejection charges, to the rear end of the payload bay. Doing this does several things to prevent the deployment anomaly that occurred in the subscale flight.

The force from the motor drives the parachute toward the bottom of the parachute tube, which is now the end that separates at deployment, so the parachute is directly adjacent to the point of separation, allowing for easy deployment. That also means that, even if the parachute becomes caught on the hardware on the bulkhead at that end of the tube, the force of the ejection charge is still transmitted through the parachute and into that bulkhead, ensuring separation. Additionally, there were significantly more threaded rods protruding into the parachute tube in the subscale as a result of a design change that was made because of its size that are not present in the full-scale. All of the threaded rods that do extend into the parachute tube are now capped by acorn nuts to eliminate any sharp edges for the parachute or blast protector to become caught on.

4.3 Recovery Subsystem

4.3.1 Hardware Design

4.3.1.1 Parachute

A 14 ft main parachute was chosen to provide a low enough velocity at landing to prevent the kinetic energy of any section from going over 75 ft-lbf. This size limited other options for a commercially available parachute; however, the chosen parachute is of the desired design, rip-stop nylon with only four shroud lines.

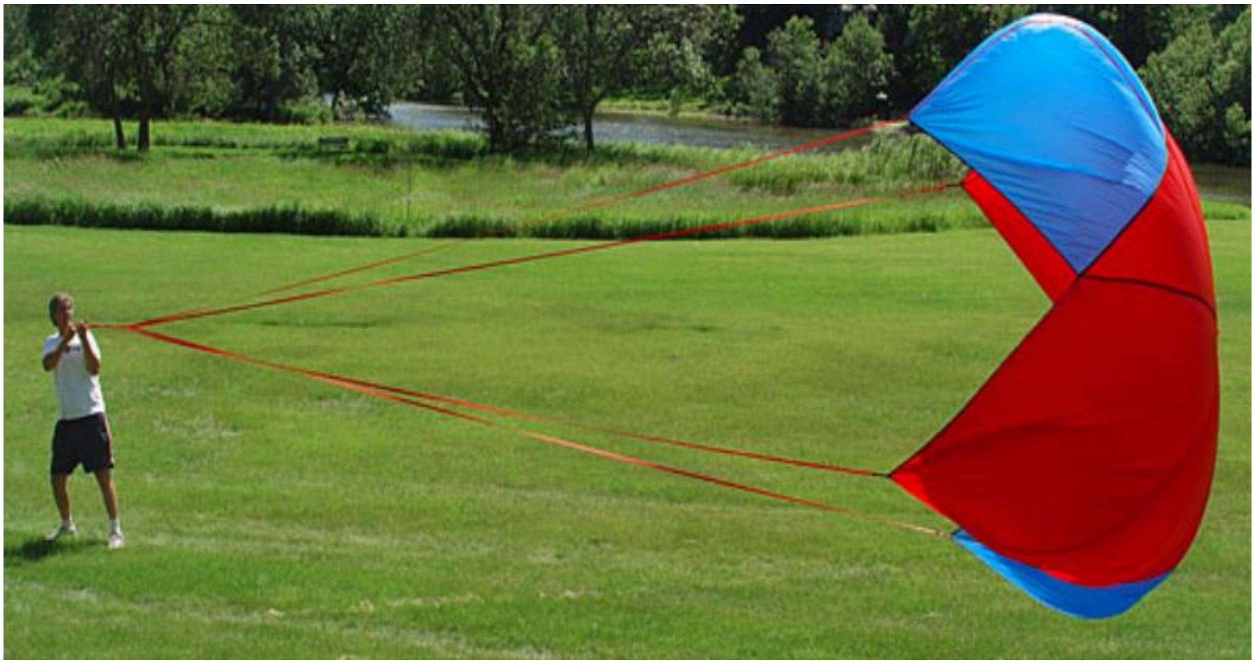

Figure 4.17 - Parachute

The parachute will be held closed by two, redundant Jolly Logic chute releases connected in series during flight until the desired altitude. One will be set for an altitude of 800 ft, the other for 500 ft.

The use of chute releases eliminates the need for a drogue parachute compartment or second separate of the airframe, which allowed for greater design flexibility, an important consideration with the chosen payload challenge.

The parachute will be connected to the recovery harness 6 feet from the booster section. This off-center placement means the upper section of the launch vehicle will hang below the lower section, reducing the probability of them colliding. The parachute will be attached to the recovery harness with a quick link for easy removal and a swivel to prevent the shroud lines from tangling.

4.3.1.2 Recovery Harness

The recovery harness will be 26 ft in overall length. This length is three times the length of the rocket, the typically recommended length. The recovery harness will be made of 1/2 in. tubular Kevlar. Kevlar was chosen for its strength and fire-retardant qualities. At each end of the harness, there will be a swivel to decrease the chance of the harness getting twisted during deployment and descent. Each swivel will be connected to two quick links.

4.3.1.3 Mounting Points

The recovery harness is mounted to the lower section of the rocket at the fore bulkhead on the JIM and the upper section at the aft bulkhead on the payload bay. Each bulkhead will have two U-bolts that the quick links on each end of the recovery harness will be attached to.

4.3.1.4 Ejection

There will be four ejection cups attached on the bulkhead at the rear of the payload bay; two ejections cups will be fired by the primary altimeter, and the other two will be fired by the secondary altimeter.

The first charge will have 3.8 g of black powder. The remaining charges will each have 4.7 g, approximately 25% larger than the initial charge, to ensure separation.

4.3.2 Electronics Design

4.3.2.1 Altimeters

The primary altimeter will be an Altus Metrum EasyMega. This altimeter was chosen because it is able to be programmed to fire under a wide variety of conditions, including at a particular altitude on ascent. This feature is crucial for the altitude control system.

Figure 4.18 - Primary Altimeter

An RRC3 will be used as the secondary altimeter. It is a reliable altimeter, which is simple to program, reducing the risk of it being incorrectly programmed.

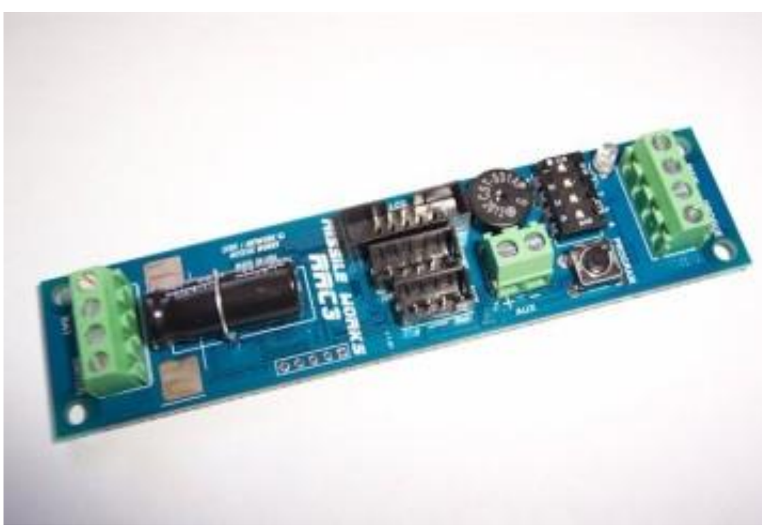

Figure 4.19 - Secondary Altimeter

4.3.2.2 Chute Releases

Two chute releases, connected in series, will be used to secure the parachute until the desired deployment altitude. The pin on the first one will be connected to the attachment point on the second, and the pin on the second will be connected to the attachment point on the first. With this setup, even if one chute release fails to disconnect properly, the other will be able to release the parachute.

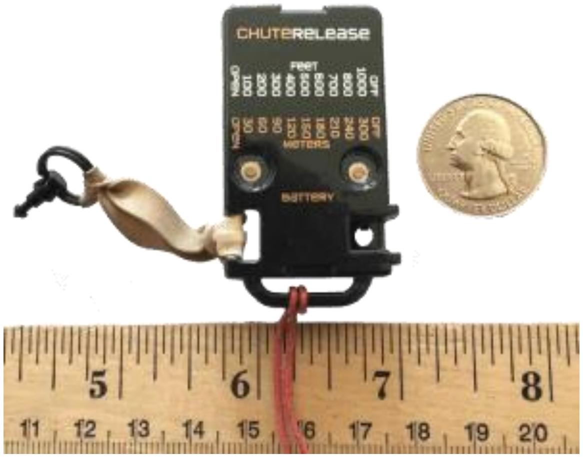

Figure 4.20 - Chute Release

4.3.2.3 Power Supply

Each altimeter is separately powered by a 1S lipo battery. This provides 3.7 V, which is enough for both altimeters. They each store 800 mAh, which will power both altimeters for the entire pad time plus flight time.

4.3.2.4 Switches

Each altimeter is connected to a separate, rotary switch. Both of the switches are keyed to prevent inadvertent deactivation of the altimeters.

4.3.2.5 Integrated Electronics

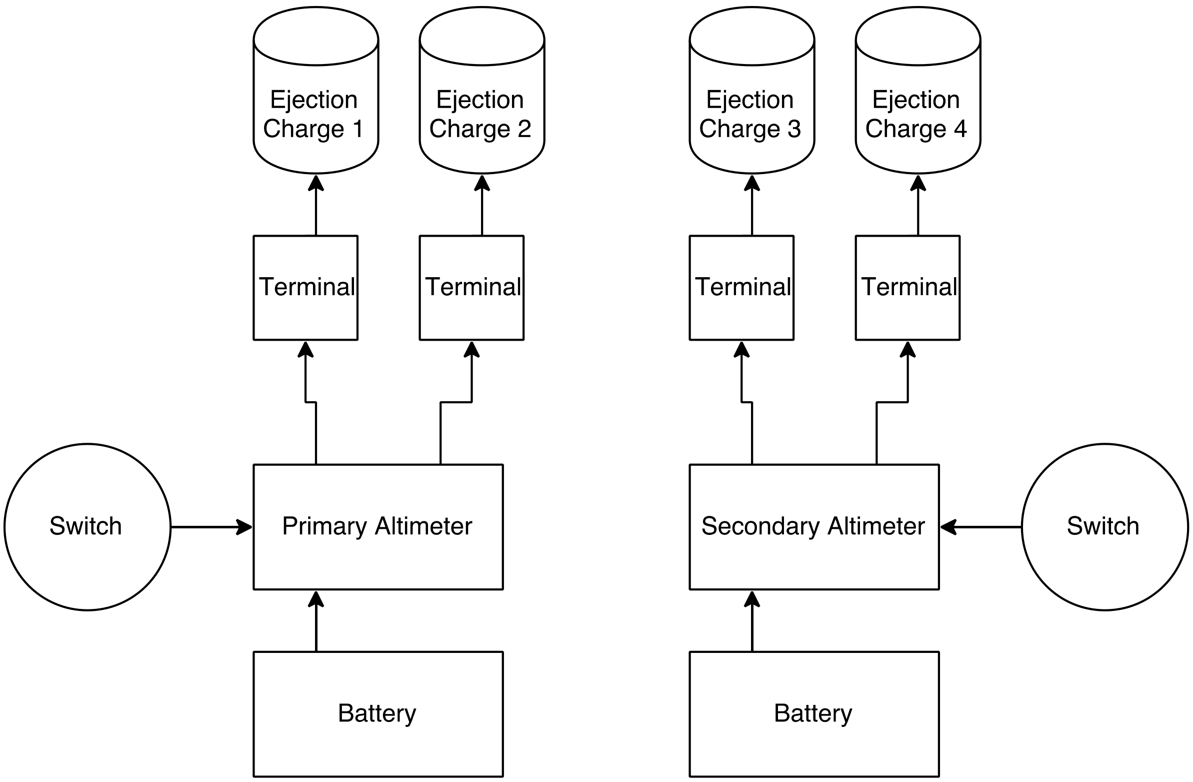

Figure 4.21 - Recovery System Electronics

4.4 Mission Performance Predictions

Full-scale flight simulations were made to choose which motor to use, what size parachutes to use, and to ensure the rocket will be able to meet all requirements. The Cd was taken from the data from the subscale flight, and the mass of the rocket is largely from the measured mass of the as-built components.

4.4.1 Simulation Conditions and Settings

4.4.1.1 Motor Choice

The motor originally chosen was an Aerotech L1150, but through analysis it was determined the Aerotech L1420 would better allow the rocket to meet all requirements. The simulated thrust curve for that motor is shown below.

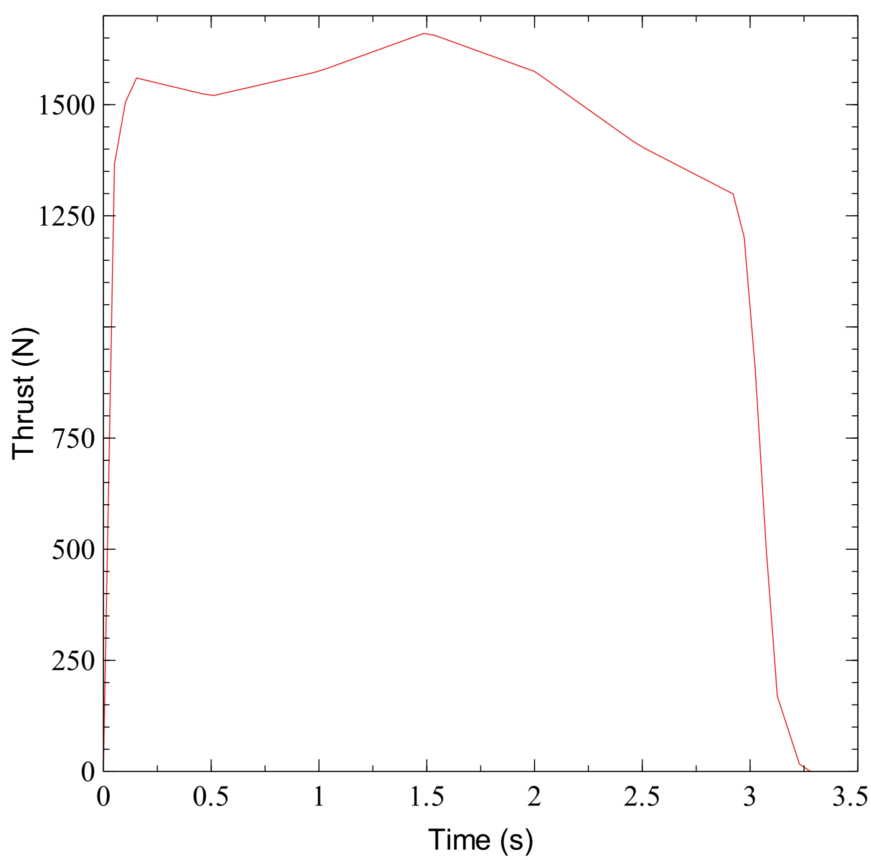

Figure 4.22 - L1420 Thrust Curve

4.4.1.2 Conditions

Conditions	Value
Temperature (°F)	40
Humidity	56%
Elevation ASL (ft)	600
Wind speed (MPH)	0 - 20
Pressure (bar)	1.010

Table 4.7 - Simulation Conditions

4.4.2 Simulation Results

Value	Result
Apogee (ft)	5252
Maximum Velocity (ft/s)	717.76
Time to Apogee (s)	18
Flight Time (s)	117.6
Static Stability Margin	3.51
Rail Exit Velocity (ft/s)	63
Descent Time (s)	99.6
Average Thrust-to-Weight Ratio	7.5:1
Velocity at Main Deployment (ft/s)	119.3
Velocity at Landing (ft/s)	15.3
Maximum Mach Number	0.65

Table 4.8 - Key Full-Scale Simulation Results

4.4.2.1 Analysis

The simulations show that the rocket meets all flight requirements. The predicted apogee is below the target altitude, but close enough for the ACS to bring up to an appropriate value. The average thrust-to-weight ratio is above the 5:1 recommendation by NAR. The maximum Mach number, 0.65, is below the limit imposed by the handbook, leaving a significant margin for variation in motor performance.

4.4.2.1.1 Stability Data

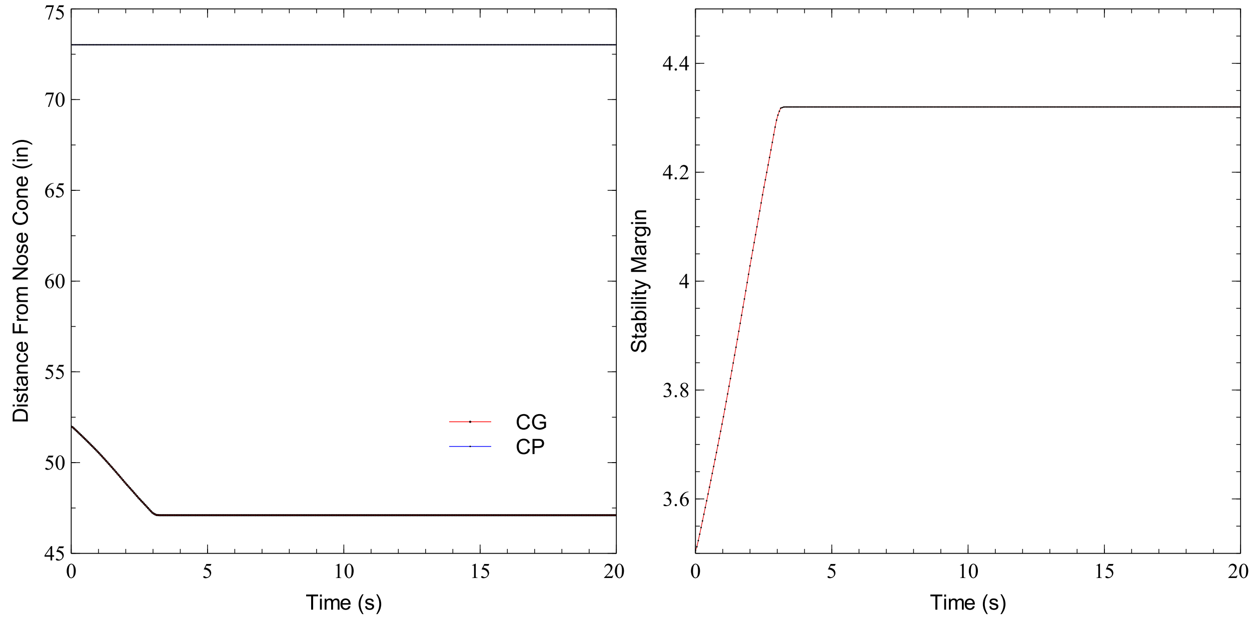

Figure 4.23 - Full-Scale CP / CG Relation and Stability Margin

4.4.2.1.2 Energy at Landing

The highest kinetic energy at landing for either section of the rocket is 70.2 ft-lbf.

Section	Kinetic Energy (ft-lbf)
Upper Section (with nose cone)	44.9
Lower Section	70.2

Table 4.9 - Kinetic Energy at Landing by Section

4.4.2.1.3 Drift Predictions

The calculations for worst-case scenario were calculated by multiplying wind speed by descent time. The best-case scenarios were taken from RockSim predictions. The actual drift is expected to fall between these two ranges.

Wind Speed (MPH)	Drift (ft)
0	0
5	511
10	985
15	1453
20	1939

Table 4.10 - Worst Case Drifts

Wind Speed (MPH)	Drift (ft)
0	0
5	40
10	64
15	120
20	248

Table 4.11 - Best Case Drifts

5 Safety

5.1 Culture of Safety

The Piedmont Student Launch Team is fully committed to maintaining a culture of safety. The team takes safety very seriously, and will not compromise safety at any point for any reason. The PSLT working environment will maintain high safety standards, where no conflict exists between safety and getting the job done, and team members will always feel safe speaking up if they see something that they feel is dangerous. Team members will continue to follow all safety rules including all team safety rules stated in the student handbook, all safety instructions given during all safety briefings, all instructions given by NAR and TRA range safety officers and their respective rocketry safety codes, all National Fire Protection Agency codes for rocketry as set forth in NFPA code 1127, all Federal Aviation Administration rules as set forth in 14 CFR 101 subpart C, all Bureau of Alcohol, Tobacco, Firearms, and Explosives regulations as set forth by U.S.C. Chapter 40 and 27 CFR Part 555, and they understand that violations of the safety rules will result in dismissal from the team. Team members also understand that hazards are present and that even with safe procedures being followed, accidents may still occur.

5.1.1 Following P.I.C.A.R.D.

While building in the shop, testing components, and attending launch events, being safe and avoiding hazards will need to be at the front of everyone's minds. To help with this, the acronym P.I.C.A.R.D. was created to help team members remember general safety rules. P.I.C.A.R.D. stands for:

- *Plans & Procedures* – They are in place to give safe guidelines for performing tasks. These should always be followed to the letter no matter how many times a team member has performed the task in the past.
- *Investigate* – Investigate your surroundings whether in the shop working, at a launch event, at a public outreach event, or even testing components. Knowing your surroundings and what others around you are doing is important in case you recognize a potential hazard that someone else doesn't notice.
- *Caution* – Use caution, take your time, and plan out your task before performing the task. Never work in a rush, and think about what you are doing.
- *Ask* – Ask for help from someone else if you are unsure about what you are about to do, or if you cannot perform a task by yourself. There is no shame in getting help.

- *Report* – Report any accident or hazard, no matter how harmless it may seem. Even if a team member gets a small cut from a performing a task, if another team member does the same task without knowledge of the hazard, they may hurt themselves even worse.
- *Devotion to safety* – Protecting ourselves and others from hazards requires committing ourselves to having safe practices and being aware of potential risks. Safety isn't just a 9-to-5, it's 365.

5.2 Launch Concerns and Procedures

5.2.1 Launch Vehicle Exterior Inspection

Must be observed and checked off by either the Safety Officer, or the Deputy Safety Officer.

☐ Carefully place the rocket down on the preparation table with the fins over the edge of the table so that there is no pressure put on fins. WARNING: Pressure placed on the fins can cause the fins to warp, and become loose or break off from the airframe.

☐ Examine the rocket, making sure the airframe has not warped. WARNING: Warping of the airframe will result in the rocket not passing flight readiness inspection, and the rocket will not fly. If a rocket does fly with warping of the airframe, it can result in the rocket flying off course and crashing.

☐ Examine the rocket making, sure there are no cracks or holes in the airframe. WARNING: If there are any cracks or holes in the airframe, the rocket will not pass flight readiness inspection and will not fly. Holes or cracks in the airframe can cause the rocket to fly off course and crash, and the force of flight can cause damage to the internal components of the rocket.

☐ Examine the nosecone, making sure there are no cracks or holes in the nosecone. WARNING: If there are any cracks or holes in the nosecone, the rocket will not pass flight readiness inspection and will not fly. If there are any cracks or holes in the nosecone during flight, the force of flight can cause the nosecone to break off and result in the rocket crashing.

☐ Examine both rail buttons, making sure they can rotate freely, and that they are mounted securely to the airframe. WARNING: If the rail buttons are not secured, they can separate during rail exit which can cause the rocket to fly off course.

☐ Examine the fins, making sure they are on securely, and that there are no cracks or holes in the fins. WARNING: Loose fins will result in the rocket not passing flight readiness inspection and will not fly. If the fins are loose during a flight they could separate from the airframe causing the rocket to fly off course and crash.

☐ Examine the fillets that bond the fins to the airframe making sure there are no cracks. WARNING: If the fillets do not seal the fins to the airframe the rocket will not pass flight readiness inspection and the rocket will not fly. If the fillets were compromised during flight the fins could separate from the airframe causing the rocket to fly off course and crash.

☐ Examine the motor mount to make sure it is secured. WARNING: If the motor mount is not secured during flight the motor could eject causing injuries and damage to the rocket.

I have observed and verified that all the above procedures were followed.

Signature____ Print Name____________________________ Date_________________

5.2.2 Altitude Control System (ACS)

Must be observed and checked off by either the Safety Officer, or the Deputy Safety Officer.

PUT ON SAFETY GLASSES BEFORE WORKING WITH THE ACS. WARNING: Failure to put on safety glasses could lead to injuries if any pressurized gases or objects were to fly into a team member's eyes while working on the ACS.

☐ Check to ensure that the lipo battery has been charged and the A23s have been replaced before every use. WARNING: If the batteries die before or during flight, the ACS will fail.

☐ The (tank's) system's regulator will be double checked to ensure safe and proper pressurization of the vessel, which should lie within ±25 psi of 800. WARNING: If the tank is over pressurized and the rocket sits out in the sun for too long, the gases can expand and potentially vent or rupture the gas tank.

☐ The tank's connection to the tubing structure (already secured in the rocket tube by foam) will be checked to ensure that it is secure. WARNING: If the connections aren't secured they could come loose during flight and get damaged.

☐ Check to ensure the insulation is not damaged. WARNING: Damaged insulation could lead to dangerous temperature fluctuations in the tank.

☐ The tank will be tested by opening the fore thrusters temporarily (using the electronics to simultaneously test the electronics). The system is only needed to be opened enough to allow air through to ensure that air can successfully flow through the system at an appropriate pressure. While air is flowing, carefully listen for any leaks. Repeat this test with the rear firing thrusters. WARNING: Failure to test the gas flow before launch could result in unfixed gas leaks inside the airframe causing damage to electronics.

WARNING: When listening for leaks keep your head clear of the nozzles and other points where high-speed gas may exit!

- ☐ Ensure all electronics are on and functioning. WARNING: If the electronics aren't functioning the ACS will fail during flight.
- ☐ Remove and refill the tank to the appropriate pressure and again have two separate people check that the pressurization of the vessel is within ±25 psi of 800. WARNING: If the tank is over pressurized and the rocket sits out in the sun for too long, the gases can expand and potentially vent or rupture the gas tank.
- ☐ Securely reattach the tank and electronics checking that all parts are securely attached as this will be the final time the system is checked before flight. WARNING: Failure to securely attach the components could result in parts coming loose during flight and getting damaged.

I have observed and verified that all the above procedures were followed.

Signature_________________________ Print Name_________________________ Date_______________

5.2.3 Recovery System Preparation

5.2.3.1 Parachute

Must be observed and checked off by either the Safety Officer, or the Deputy Safety Officer.

- ☐ Pull parachute out and inspect it for any holes or tears in the fabric. WARNING: Failure to follow this step could lead to the parachute ripping during descent if it has any holes and / or tears in it.
- ☐ Inspect the parachute chords for any tears or fraying. WARNING: Failure to follow this step could result in the chords breaking during descent if there are any tears in them.
- ☐ Lay the parachute on the prep table. Gather the support lines in both hands at the bottom of the canopy and the bottom of the shroud lines. Remove any twists in the lines. Stretch the lines out so they are taut. On larger parachutes with long support lines, use a weight to hold the steel connector link while you work with the support lines from the canopy end.

☐ Arrange the canopy so it lays flat on the table. Neatly tuck in the nylon fabric from the multiple parachute panels (the material between the support lines) in towards the center line of the canopy.

☐ Fold the top of the parachute down to the bottom of the parachute where the shroud lines attach.

☐ Fold the parachute in thirds by folding the top corners in towards the center of the parachute.

☐ Using one hand to hold the parachute down, fold the top half of the parachute down over the bottom half of the parachute.

☐ Flip the parachute over and roll it up into a cylinder type arrangement.

☐ Wrap the support lines around the rolled parachute. A tight wrap with more turns will lead to a smaller pack job with a slower opening. A loose wrap will lead to a larger pack job with a faster opening. The amount and tightness of the wraps should be determined based on the desired fit in the rocket and opening speed.

☐ Wrap two rubber bands around the parachute cylinder (one rubber band at one end of the parachute, and a rubber band at the opposite end of the parachute). WARNING: Failure to wrap parachute up can result in the parachute coming undone before it is placed in rocket, and you will have to re-wrap the parachute. Do not remove the rubber bands until directed to do so later in the checklist!

I have observed and verified that all the above procedures were followed.

Signature____ Print Name_____________________________ Date_________________

5.2.3.2 Avionics

Must be observed and checked off by either the Safety Officer or the Deputy Safety Officer.

☐ Separate the payload tube completely, removing both bulkheads and the avionics sled, and unclipping both switch connectors.

☐ Pull test all wires on the altimeters (primary: 2 apogee, 2 main, 2 switch. Secondary: 2 drogue, 2 main, 2 switch, 2 battery).

☐ Put 3 fresh 3.7V Lipo batteries on the battery shelves. WARNING: Failure to use fresh batteries can result in insufficient current to the igniters and failure of the recovery system!

☐ Strap in each battery with one Velcro strap each.

- ☐ Ensure that batteries are secure. WARNING: Failure to properly secure the batteries can lead to them coming loose in flight and coming off of their connectors or damaging the altimeters!
- ☐ Make sure the avionics are turned off before plugging switches in. WARNING: Failure to follow this step could result in black powder charges igniting, and can result in injury.
- ☐ Connect the altimeter switch connector.
- ☐ Plug batteries into both altimeters.
- ☐ Lay avionics sled on its side.
- ☐ Turn on primary altimeter.
- ☐ Plug in Micro-USB cable.
- ☐ Make sure primary altimeter is configured correctly (redundant apogee mode).
- ☐ Unplug Micro-USB cable.
- ☐ Turn off primary altimeter.
- ☐ Plug LCD screen into secondary altimeter.
- ☐ Turn on secondary altimeter.
- ☐ Make sure secondary altimeter is configured correctly (ARM ALT: 10; MAIN ALT: 10; DROGUE DELAY: 6; DEPLOY MODE: 2).
- ☐ Turn off secondary altimeter.
- ☐ Unplug LCD screen.
- ☐ Place the avionics sled onto the threaded rods.
- ☐ Secure the avionics sled on the threaded rods with nuts. WARNING: Failure to secure the sled can result in damage to the avionics during flight!
- ☐ Connect primary apogee connector to P1. WARNING: Failure to connect will result in the ejection charge failing.
- ☐ Connect main connector to P2. WARNING: Failure to connect will result in the ejection charge failing.
- ☐ Connect secondary drogue connector to S1. WARNING: Failure to connect will result in the ejection charge failing.
- ☐ Connect secondary main connector to S2. WARNING: Failure to connect will result in the ejection charge failing.
- ☐ Insert aft bulkhead with avionics sled into payload tube.
- ☐ Insert forward bulkhead into payload tube and onto threaded rods, securing with nuts.
- ☐ Turn on primary the altimeter and wait for 3 short bees, a long pause, then 7 or 8 short beeps followed by 1 long beep. If this fails, go to section 5.2.10.1 to troubleshoot

- ☐ Turn off the primary altimeter
- ☐ Turn on the secondary altimeter and wait for 1 long beep followed by 1 long beep, repeated. If this fails, go to section 5.2.10.1 to troubleshoot
- ☐ Turn off the secondary altimeter

I have observed and verified that all the above procedures were followed.

Signature____ Print Name______________________________ Date__________________

5.2.3.3 Ejection Charges

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

PUT ON SAFETY GLASSES BEFORE WORKING WITH THE EJECTION CHARGES. WARNING: Failure to put on safety glasses could lead to injuries when working with black powder.

GROUND YOURSELF BEFORE WORKING WITH THE EJECTION CHARGES. WARNING: Failure to ground yourself could lead to accidental ignition of black powder.

- ☐ Make sure all igniter leads are folded twice.
- ☐ Connect igniter leads to the P1 terminal block.
- ☐ Insert igniter tip into bottom of P1 ejection cup.
- ☐ Pour in pre-measured black powder (1.8g).
- ☐ Insert wadding.
- ☐ Secure with 3 strips of masking tape. WARNING: Failure to secure the charge with tape could result in black powder falling out of the ejection cup.
- ☐ Connect igniter leads to the P2 terminal block.
- ☐ Insert igniter tip into bottom of P2 ejection cup.
- ☐ Pour in pre-measured black powder (2.2 g).
- ☐ Insert wadding.
- ☐ Secure with 3 strips of masking tape. WARNING: Failure to secure the charge with tape could result in black powder falling out of the ejection cup.

- ☐ Connect igniter leads to the S1 terminal block.
- ☐ Insert igniter tip into bottom of S1 ejection cup.
- ☐ Pour in pre-measured black powder (2.2 g).
- ☐ Insert wadding.
- ☐ Secure with 3 strips of masking tape. WARNING: Failure to secure the charge with tape could result in black powder falling out of the ejection cup.
- ☐ Connect igniter leads to S2 terminal block.
- ☐ Insert igniter tip into bottom of S2 ejection cup.
- ☐ Pour in pre-measured black powder (2.2 g).
- ☐ Insert wadding.
- ☐ Secure with 3 strips of masking tape. WARNING: Failure to secure the charge with tape could result in black powder falling out of the ejection cup.
- ☐ Take payload tube outside from preparation area and away from other people. WARNING: Failure to take altimeter away from a populated location can result in multiple serious injuries if the charges ignite.
- ☐ Making sure ejection cups are pointed away from people, turn on secondary altimeter and wait for 1 long beep then 3 short beeps repeated.
- ☐ Turn off secondary altimeter.
- ☐ Making sure ejection cups are pointed away from people, turn on primary altimeter and wait for 3 short beeps, then 7 short beeps, then 3 short beeps repeated. WARNING: Failure to keep charges pointed away from people can result in injury if black powder ignites.
- ☐ Turn off primary 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.

I have observed and verified that all the above procedures were followed.

Signature____ Print Name______________________________ Date__________________

5.2.4 Payload Preparation

Must be observed and checked off by either the Safety Officer or the Deputy Safety Officer.

PUT ON SAFETY GLASSES BEFORE WORKING WITH THE EJECTION CHARGE. WARNING: Failure to put on safety glasses could lead to injuries when working with black powder.

GROUND YOURSELF BEFORE WORKING WITH THE EJECTION CHARGE. WARNING: Failure to ground yourself could lead to accidental ignition of black powder.

- ☐ Inspect nosecone for defects and damage.
- ☐ Inspect rover for defects and damage.
- ☐ Check all wire connections.
- ☐ Ensure all batteries are fresh / charged.
- ☐ Connect power to Arduino.
- ☐ Make sure all body panels are attached and secured.
- ☐ Wait for an established signal between ground station and rover.
- ☐ Place rover in the left side of the nosecone. The axles of the front and back drive motors should be placed into the standoffs.
- ☐ Close the right side of the nosecone towards the left side.
- ☐ Ensure that the nosecone is closed off and the solenoid is locked. WARNING: If the solenoid is not locked the nosecone could open in flight, leading to debris and an unpredictable trajectory.
- ☐ Attach to igniters to the terminal block.
- ☐ Insert both igniter tips into the bottom of the ejection cup.
- ☐ Pour the pre-measured black powder (1 g) into the cup.
- ☐ Insert wadding.
- ☐ Secure with 3 pieces of masking tape.
- ☐ Attach switch leads to the nosecone.
- ☐ Insert the nosecone into the payload tube.
- ☐ Secure with 4 shear pins. WARNING: Failure to secure the nosecone could lead to drag separation and a ballistic return of the nosecone.

I have observed and verified that all the above procedures were followed.

Signature____ Print Name______________________________ Date________________

5.2.5 Final Rocket Assembly

Must be observed and checked off by either the Safety Officer or the Deputy Safety Officer.

- ☐ Attach nosecone to the payload tube, and secure it with 4 shear pins. WARNING: Failure to secure nosecone can lead to nosecone separation during flight.
- ☐ Attach parachute to recovery harness, and ensure the quick links are on tight and secured. WARNING: Failure to secure quick links can result in the parachute separating from the rocket.
- ☐ Attach parachute blast protector to the upper end of the recovery harness by running the recovery harness through the blast protector's pre-cut hole.
- ☐ Attach upper end of recovery harness to both fore-end (payload tube) U-bolts, and secure with quick links. WARNING: Failure to secure quick links can result in the parachute separating from the rocket.
- ☐ Take both Jolly Logics from their container boxes and inspect them to make sure they are powered and not damaged. WARNING: If the Jolly Logics are not fully charged before flight they may stop working during flight.
- ☐ Tie both Jolly Logics to the swivel on the parachute.
- ☐ Attach the locking pin of the first Jolly Logic into the pin hole of the second Jolly Logic. WARNING: Failure to ensure the locking pin is secured could result in the pin coming loose during flight.
- ☐ Attach the locking pin of the second Jolly Logic into the pin hold of the first Jolly Logic. WARNING: Failure to ensure the locking pin is secured could result in the pin coming loose during flight.
- ☐ Inspect the rubber band that will hold both Jolly Logics in place. WARNING: If the rubber band has any holes or tears in it, the rubber band may snap during flight.
- ☐ Take both Jolly Logics and wrap the rubber band around the parachute cylinder locking both Jolly Logics into place.
- ☐ Turn on both Jolly Logics and program them both for 700 feet. WARNING: Programming the Jolly Logics to release at too low of an altitude could result in the parachute not having enough time to deploy before hitting the ground.
- ☐ Remove the 2 rubber bands that were holding the parachute in its cylinder pack. WARNING: Failure to remove these rubber bands could result in the parachute not opening!
- ☐ Place the parachute blast protector around the parachute and slide parachute and recovery harness into parachute tube. Make sure the blast protector is all the way around the parachute, and ensure

no part of the parachute is exposed. WARNING: Failure to completely protect the parachute with the protector could result in the parachute melting from ejection charge heat.

- ☐ Slide the parachute tube into the payload tube and secure with 4 rivets.
- ☐ Attach the lower end of the recovery harness to the 2 U-bolts on the JIM with quick links and ensure the quick links are on tight. WARNING: If the quick links are not on tight the recovery harness may separate from the rocket during flight.
- ☐ Secure the avionics bay to the parachute tube with 4 shear pins.

I have observed and verified that all the above procedures were followed.

Signature____ Print Name______________________________ Date__________________

5.2.6 Motor Preparation

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

PUT ON SAFETY GLASSES BEFORE WORKING WITH THE MOTOR. WARNING: Failure to put on safety glasses could lead to injuries when working with the motor.

GROUND YOURSELF BEFORE WORKING WITH THE MOTOR. WARNING: Failure to ground yourself could lead to accidental ignition of the motor.

- ☐ Assemble motor according to manufacturer's instructions, making sure to check all components for damage. WARNING: Failure to follow the manufacturer's instructions could lead to the motor malfunctioning.
- ☐ Measure igniter against motor. WARNING: Do not insert igniter into motor!
- ☐ Install motor in motor mount and secure with retaining ring. WARNING: Failure to secure motor into the motor mount with retainer ring will lead to motor ejection during flight.
- ☐ Tape igniter to fin for transport to pad. WARNING: Failure to tape igniter to fins can result in losing the igniter during transport.

I have observed and verified that all the above procedures were followed.

Signature____ Print Name______________________________ Date__________________

5.2.7 Launch Rail Setup

Must be observed and checked off by either the Safety Officer or the Deputy Safety Officer.

- ☐ Completely fill out the flight card.
- ☐ Take rocket to the Launch Control Officer for inspection. WARNING: The Launch Control Officer's ruling on the rocket's flight readiness in FINAL, and it will be respected by team members.
- ☐ Take the rocket to the launch pad.
- ☐ Disconnect ignition system power. WARNING: Leaving the ignition system powered could result in the rocket launching while there are still people at the launcher!
- ☐ Unlock launch rail pin.
- ☐ Lower launch rail.
- ☐ Carefully slide rocket onto launch rail. WARNING: If the rocket is not kept straight the rail buttons might break!
- ☐ Raise launch rail to a vertical position.
- ☐ Secure launch rail in vertical position by locking launch rail pin.
- ☐ If possible, spray down launch area with water. WARNING: Launching on dry grass could start a fire.
- ☐ Clear launch area of unnecessary personnel. WARNING: Having unnecessary personnel near the launch area could result in more injuries if the rocket launches unexpectedly.

I have observed and verified that all the above procedures were followed.

Signature____ Print Name______________________________ Date__________________

5.2.8 Igniter Installation

Can be done only by the mentor. Must be observed and checked off by either the Safety Officer or the Deputy Safety Officer. This section will be modified as needed to reflect the launch process of the NAR personnel in Huntsville.

- ☐ Turn on primary altimeter (Easy Mega) and wait for 3 short beeps followed by 7 or 8 short beeps, repeated. If this fails, go to section 5.2.10.1 to troubleshoot

- ☐ Turn on the secondary altimeter (RRC3) and wait for 1 long beep followed by 3 short beeps, repeated. If this fails, go to section 5.2.10.1 to troubleshoot
- ☐ Arm the payload ejection charge.
- ☐ Insert igniter into motor and secure with plug. WARNING: Failure to insert igniter will result in motor not firing.
- ☐ Ensure ignition system leads are not powered (touch them together and look for sparks). WARNING: Attaching live leads to the igniter could lead to unexpected motor ignition!
- ☐ Connect ignition system leads to igniters.
- ☐ Wrap excess igniter wires around the ignition leads. WARNING: Failure to wrap the wires around the leads may result in the leads falling off the wires, and the motor not firing.
- ☐ Clear launch area. WARNING: Failure to clear the launch area could result in injuries if personnel are too close to the launch pad.
- ☐ Inform RSO that the rocket is ready for launch
- ☐ Make sure a team member remains near the Launch Control Officer in case the launch needs to be delayed.
- ☐ All team members will wait until after the rocket has launched, descended to the ground, and given the all-clear from the Launch Control Officer to move to recover the rocket.

I have observed and verified that all the above procedures were followed.

Signature_______________________________________ Print Name____________________________ Date_________________

5.2.9 Reinspection Procedures

After the rocket has been deemed ready to fly no one other than members of the team or necessary NAR personnel should be allowed to handle or make alterations to the rocket for any reason. If this happens, a re-inspection of the rocket will commence with the following procedures:

- ☐ The Launch Control Officer will be notified that the launch needs to be delayed.
- ☐ After the Launch Control Officer has cut the power to the launch pad the team members will wait at least sixty seconds, and after they received the go ahead from the Launch Control Officer to be able to approach the launch pad. WARNING: Failure to adhere to the instructions of the Launch Control Officer can result in the team not being able to launch. If a member approaches the launch pad

before the go ahead from the Launch Control Officer, the rocket may launch prematurely leading to personnel getting seriously injured.

- ☐ Only the team mentor may now approach the launch pad to disengage the rocket's motor igniter. WARNING: Too many personnel at the launch pad could result in multiple injuries if the rocket launches prematurely.
- ☐ Carefully disconnect the ignition system power. WARNING: Leaving the power connected may result in premature ignition of the rocket with personnel at the launch pad.
- ☐ Carefully unwrap the ignition system wires from around the launch pad clamps.
- ☐ Remove the launch pad clamps from the igniter and set the clamps down in the appropriate location.
- ☐ Carefully remove the igniter from the motor. WARNING: If the igniter is left in the motor it may ignite.
- ☐ Personnel needed for the remainder of the Launch Pad Removal procedures may now approach the launch pad
- ☐ Disarm the recovery system (primary and secondary altimeters) and the payload ejection charge. WARNING: Failure to complete this step could result in the recovery system deploying while on the launch pad.
- ☐ Carefully lower the launch rail to its horizontal position.
- ☐ Slowly slide the rocket off the launch rail. WARNING: Failure to use care when removing the rocket could result in the launch rail buttons on the rocket becoming damaged or breaking off.
- ☐ Hand the rocket off to a team member to hold on to while launch pad disassembly procedures finish.
- ☐ Return the launch rail to its vertical position.
- ☐ Team members will now return the rocket to the team prep area.
- ☐ Repeat all steps for launch preparation to ensure that the rocket and all components are functioning as intended.

I have observed and verified that all the above procedures were followed.

Signature____ Print Name______________________________ Date__________________

5.2.10 Troubleshooting

5.2.10.1 Altimeters

Troubleshooting with loaded charges must be overseen by the Safety Officer or Deputy Safety Officer.

WARNING: Always wear safety glasses when troubleshooting with loaded charges. Always be aware of where the charges are pointed.

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 igniters to terminals

If problem persists:

- ☐ Open avionics bay
- ☐ Check quick connector
- ☐ Check terminals on altimeter

5.2.10.2 Ignition

If motor fails to ignite:

- ☐ Wait 60 seconds and for clearance from the RSO before approaching
- ☐ Check firing system power
- ☐ Check firing system lead connection

If neither of those are the issue:

- ☐ Replace the igniter
- ☐ If replacing igniter, follow procedures for installing igniter

I have observed and verified that all the above procedures were followed.

Signature____ Print Name_____________________________ Date_________________

5.2.10.3 Rover Deployment Failure

If rover fails to deploy:

- ☐ Verify that there is a radio connection, moving to get line-of-sight if necessary.
- ☐ Resend deployment signal.
- ☐ If the rover still doesn't deploy, wait 60 seconds and for clearance from the RSO before approaching.
- ☐ Carefully approach rocket, watching for potential fires or explosions.
- ☐ Disarm the payload ejection charge and proceed with the post-flight procedures.

I have observed and verified that all the above procedures were followed.

Signature____ Print Name_____________________________ Date_________________

5.2.11 Post-flight Inspection

5.2.11.1 Successful Flight

These procedures will be modified as needed to reflect competition requirements in Huntsville.

- ☐ Wait for the all-clear from NAR / NASA personnel.
- ☐ Verify radio connection to the payload.
- ☐ Send deployment signal. If the rover does not deploy, go to section 5.2.10.3 to troubleshoot.
- ☐ Wait for the rover to finish its mission, watching it if possible to ensure that it doesn't leave debris or start a fire.
- ☐ Send shutdown signal.
- ☐ Check the path from the rocket to the rover for any debris and cleanup as necessary.
- ☐ Retrieve rover.
- ☐ Retrieve nosecone.
- ☐ Take them back to the prep area.
- ☐ Go back out to the rocket.
- ☐ Keep distance from rocket landing site and do not go up to rocket until it has been verified that there is no threat of fire or explosion. WARNING: Failure to follow this step could result in personnel being injured.
- ☐ Make sure all 4 ejection charges have fired. WARNING: Failure to follow this step could result in personnel being injured.
- ☐ Record apogee altitude.
- ☐ Turn off both altimeters.
- ☐ Check fins for damage.
- ☐ Check body for damage.
- ☐ Make sure motor is still secured.
- ☐ Check parachute for damage.
- ☐ Check blast protector for damage.
- ☐ Check lower recovery harness swivel for damage.
- ☐ Check 4 recovery harness quick links for damage.
- ☐ Check 4 recovery harness U-bolts for damage.
- ☐ Check parachute quick link for damage.

- ☐ Check parachute swivel for damage.
- ☐ Check upper recovery harness swivel for damage.
- ☐ Disconnect recovery harness from avionics bay (2 quick links).
- ☐ Make sure quick links are closed.
- ☐ Disconnect recovery harness from payload tube (2 quick links).
- ☐ Make sure quick links are closed.
- ☐ Return rocket (in 2 pieces) to tent / assembly area.
- ☐ Remove motor retainer.
- ☐ Remove and save spent motor.
- ☐ Check motor mount for damage.
- ☐ Reattach motor retainer.
- ☐ Remove both bulkheads from payload tube, unclipping connectors.
- ☐ Remove sled (do not unclip switch 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.
- ☐ Unclip switch connector.
- ☐ Insert aft bulkhead with avionics sled into payload tube.
- ☐ Insert forward bulkhead into payload tube and onto threaded rods, securing with nuts.
- ☐ Insert parachute, blast protector, and recovery harness into parachute tube.
- ☐ Close the nosecone and insert it into the payload tube.

5.2.11.2 Failed Flight

- ☐ Keep distance from rocket crash site and do not go up to the rocket until it has been verified there is no threat of fire or explosion
- ☐ 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

5.3 Safety and the Environment

5.3.1 Risk Matrix and Definitions

Probability	Severity			
	1 Catastrophic	2 Critical	3 Marginal	4 Negligible
A – Frequent	1A	2A	3A	4A
B – Probable	1B	2B	3B	4B
C – Occasional	1C	2C	3C	4C
D – Remote	1D	2D	3D	4D
E – Improbable	1E	2E	3E	4E

Severity – Probability			
High Risk Unacceptable	Medium Risk Undesirable	Low Risk Acceptable	Minimal Risk Desirable

Figure 5.1 - Severity-Probability Matrix

5.3.2 Definitions of Severity and Probability

<u>Severity</u>

Catastrophic (1): Loss of life or a permanent disabling injury. Loss of facility, systems or associated hardware. Irreversible severe environmental damage that violates law and regulation.

Critical (2): Severe injury or occupational related illness. Major damage to facilities, systems, or equipment. Reversible environmental damage causing a violation of law or regulation.

Marginal (3): Minor injury or occupational related illness. Minor damage to facilities, systems, or equipment. Mitigatable environmental damage without violation of law or regulation where restoration activities can be accomplished.

Negligible (4): First aid injury or occupational related illness. Minimal damage to facility, systems, or equipment. Minimal environmental damage not violating law or regulation.

Probability

Frequent (A): Occurring or done on many occasions, in many cases, or in quick succession. Hazards that happen this often are treated as if they will happen, and require mitigating first before anyone may be allowed to perform a task involving a frequent hazard.

Probable (B): Likely to happen. Hazards happening this often should still be expected and must be mitigated first before anyone may be allowed to perform a task involving a probable hazard.

Occasional (C): Occurring, appearing, or done infrequently and irregularly. Occasional hazards will still be mitigated after more probable hazards are reduced first, and occasional hazards will still be taken just as serious as any hazard.

Remote (D): Expected to occur at some point, but not very often. Hazards happening this often will still be mitigated after more probable hazards are reduced first, and will still be treated as serious as any hazard.

Improbable (E): Very unlikely to occur. Hazards happening this often will be mitigated after other more probable hazards are reduced first, but will be treated as serious as any hazard.

Combined Risk Definitions

High risk / unacceptable: Exceptionally dangerous, and will not be allowed to happen under any circumstances.

Medium risk / undesirable: Harmful and objectionable. Will only be allowed if it is necessary. Will require further mitigation to decrease risk.

Low risk / acceptable: Will be allowed, but can still be mitigated further to decrease harm.

Minimal risk / ideal: Will be allowed, and has been mitigated to present the least amount of harm.

5.3.3 Personnel Hazards

5.3.3.1 Hazards to Personnel at Launch Sites

	Hazard			
	Effect(s)			
Cause(s)	Mitigation(s)	Pre-Mitigation	Verification	Post-Mitigation
	Ballistic / high speed return of the team's rocket			
	Minor to serious injury to personnel. Possible death. Minor to serious damage to property. Destruction of the launch vehicle. Destruction of the payload. Failure of the mission			
Ejection charges not powerful	1. Ejection charges will be tested multiple times before each	1C	1. PSLT launch vehicle operational procedures	1E

	Hazard			
	Effect(s)			
Cause(s)	Mitigation(s)	Pre-Mitigation	Verification	Post-Mitigation
enough to separate the rocket at apogee	flight to ensure energetic separation. 2. There will be a total of 4 ejection charges that can separate the rocket		2. PSLT launch prep checklist; Data gathered from past launches	
Altimeter does not have sufficient charge to fire igniter	1. Each altimeter will be connected to a different battery. 2. The batteries will be replaced each flight with new ones	1C	1. PSLT launch vehicle design procedure 2. Launch vehicle launch preparation checklist	1E
Parachute is not ejected from the rocket when ejection charge fires	1. The recovery system will be designed as a "cannon," such that the gas from the ejection charges firing pushes the parachute out of the rocket. 2. There will be 4 ejection charges, so if one fails to push the parachute out of	1C	1. PSLT launch vehicle design process 2. PSLT launch vehicle design process; data	1E

	Hazard			
	Effect(s)			
Cause(s)	Mitigation(s)	Pre-Mitigation	Verification	Post-Mitigation
	the rocket, there will be backups		gathered from past launches	
Parachute is melted together by the ejection charge and does not open	A parachute protector will be placed on the recovery harness between the parachute and the ejection charges	2B	PSLT launch preparation checklist	2E
Chute release does not have sufficient power and does not open	1. There will be 2 chute releases used, connected in series, so that if one fails, the other can still release the parachute. 2. Both chute releases will be charged before each flight	2C	1. PSLT launch vehicle design process. 2. Launch preparation checklist	2E
Black powder does not ignite because it is wet	Black powder will be stored in sealed containers. Liquids will be kept away from black powder when it is being worked with	1D	MSDS for black powder	1E

	Hazard			
	Effect(s)			
Cause(s)	Mitigation(s)	Pre-Mitigation	Verification	Post-Mitigation
Ejection charge igniter is bad	1. All igniters will be inspected prior to use. 2. There will be a total of 4 ejection charges that can separate the rocket, each of which will have a different igniter	1D	1. Launch preparation checklist 2. Launch vehicle design process	1E
Ejection charge igniter is not properly connected to terminal	1. All electrical connections in the recovery system will be inspected before each flight. 2. There will be a total of 4 ejection charges that can separate the rocket, each of which will be connected to a different terminal. The altimeters will beep out their continuity status	1D	1. Launch preparation checklist. 2. Launch vehicle design process	1E

	Hazard			
	Effect(s)			
Cause(s)	Mitigation(s)	Pre-Mitigation	Verification	Post-Mitigation
Terminal is not properly connected to altimeter	1. All electrical connections will be inspected before each flight. 2. There will be a total of 4 ejection charges that can separate the rocket, each of which will be connected to a different terminal. The altimeters will beep out their continuity status	1D	1. Launch preparation checklist 2. Launch vehicle design process	1E
Chute release is jammed and does not open	1. There will be 2 chute releases used, connected in series, so that if one fails, the other can still release the parachute. 2. Both chute releases will be tested before each flight to ensure proper operation	2D	1. Data gathered from past launches; Launch preparation checklist 2. Launch vehicle design process	2E
	Ballistic / high speed return of other rockets			

	Hazard			
	Effect(s)			
Cause(s)	Mitigation(s)	Pre-Mitigation	Verification	Post-Mitigation
	Minor to serious injury to personnel. Possible death. Minor to serious damage to property			
Some failure of the rocket	Personnel will be alert at all times at a launch. When a rocket is being launched, personnel will stop what they are doing and watch the rocket until it is safe	1C	NAR safety code; PSLT launch site safety rules	3C
	Motor comes free			
	Minor to serious injury to personnel. Damage to the rocket. Minor to serious damage to property			
The motor mount is not properly secured inside the airframe	1. Stress tests will be performed on the motor mount to ensure it is able to withstand flight forces. 2. The motor mount will be inspected before each launch	2C	1. Launch vehicle design process 2. Launch preparation checklist	2E

	Hazard			
	Effect(s)			
Cause(s)	Mitigation(s)	Pre-Mitigation	Verification	Post-Mitigation
The motor retainer is not properly secured around the motor tube	1. Stress tests will be performed on the motor retainer to ensure it is able to withstand flight forces. 2. The motor retainer will be inspected before each launch	2C	1. Launch vehicle design process 2. Launch preparation checklist	2E
The motor casing fails	The motor casing will be inspected before each launch	3C	Launch preparation checklist	3D

Table 5.1 – Assessment of Launch Site Hazards

5.3.3.2 Hazards to Personnel in Facilities

	Hazard			
	Effect(s)			
Cause(s)	Mitigation(s)	Pre-Mitigation	Verification	Post-Mitigation
	Burns			
	Minor to serious injury to personnel. Minor to serious damage to property			
Pressurized gas tank combusts	Gas tank will be stored away from heat sources and personnel will not	1C	Manufacturer's safe handling instructions.	1E

	Hazard			
	Effect(s)			
Cause(s)	Mitigation(s)	Pre-Mitigation	Verification	Post-Mitigation
	work with gas tank near any heat sources		Launch vehicle ACS construction procedures.	
Unintentional motor ignition during motor preparation	1. Motors will be prepared away from all nonessential personnel. The person preparing the motor will ground themselves before handling motor components. Motors will be prepared away from heat sources. Motors will be prepared away from ignition sources. The igniter will not be inserted into the motor until the rocket is on the launch pad. All other NAR guidelines will be	1C	PSLT motor preparation checklist	2E

	Hazard			
	Effect(s)			
Cause(s)	Mitigation(s)	Pre-Mitigation	Verification	Post-Mitigation
	followed regarding motor handling. 2. Safety glasses will be worn when assembling the motor			
Unintentional motor ignition in storage	Motors will be stored away from heat sources. Motors will be stored away from ignition sources. Motors will be stored in sealed containers	2D	MSDS for rocket motor	2E
Unintentional motor ignition during launch pad preparation	All nonessential personnel will vacate the area before the igniter is inserted into the motor. Ensure power is disabled to the launch control system before connecting to the ignition leads. Discharge control system clips before connecting them to the igniter leads	1C	PSLT launch prep checklist	2E
Unintentional black powder	All nonessential personnel will vacate	1C	PSLT launch prep checklist	2E

	Hazard			
	Effect(s)			
Cause(s)	Mitigation(s)	Pre-Mitigation	Verification	Post-Mitigation
ignition during rocket preparation	the area before black powder charges are prepared. The person preparing the black powder charge will ground themselves before handling the black powder. Black powder charges will be prepared away from heat sources. Black powder charges will be prepared away from ignition sources			
Unintentional black powder ignition during launch pad preparation	All black powder charge ignition systems will require a switch to be armed before they will be able to ignite, and those switches will not be armed until the rocket is on the launch pad. All nonessential personnel will clear the area before black powder charges are armed	1C	PSLT pre-launch checklist	3E

	Hazard			
	Effect(s)			
Cause(s)	Mitigation(s)	Pre-Mitigation	Verification	Post-Mitigation
Aerosolized spray paint ignites	Painting with spray paint will be done outside. Painting with spray paint will be done away from ignition sources	2D	MSDS for aerosol spray paints; PSLT shop safety rules	3E
Unintentional black powder ignition in storage	Black powder will be stored away from heat sources. Black powder will be stored away from ignition sources. Black powder will be stored in sealed containers	1D	MSDS for black powder; PSLT safety rules	2E
Acetone / acetone fumes ignite	Acetone will be used away from ignition sources. Acetone will be stored in sealed containers. Acetone will not be left open longer than necessary	2D	MSDS for acetone; PSLT shop safety rules	2E
Denatured alcohol / denatured alcohol fumes ignite	Denatured alcohol will be used away from ignition sources. Denatured alcohol will be stored in sealed containers. Denatured alcohol will not be left	2D	MSDS for denatured alcohol; PSLT shop safety rules	2E

	Hazard			
	Effect(s)			
Cause(s)	Mitigation(s)	Pre-Mitigation	Verification	Post-Mitigation
	open longer than necessary			
Battery ignites	Battery leads will not be crossed. Electrical systems will be analyzed for the appropriate voltage before any batteries are connected	2D	Data gathered during payload design process	2E
Unintentional igniter ignition	Igniters will be kept away from sources of electrical buildup. Personnel handling igniters will ground themselves first	3D	PSLT launch pad prep checklist	3E
	Respiratory illness			
	Long-term health issues			
Inhaling fiberglass dust	All personnel in the vicinity will wear dust masks when fiberglass is being worked with. All dust will be cleaned up after working with fiberglass, and at least 10 minutes will be given for any remaining dust to settle before	2B	MSDS for fiberglass; PSLT shop safety rules.	2E

	Hazard			
	Effect(s)			
Cause(s)	Mitigation(s)	Pre-Mitigation	Verification	Post-Mitigation
	personnel remove their masks			
Inhaling acetone fumes	Personnel will take care when working with acetone. Personnel will not place their heads directly over open acetone	3C	MSDS for acetone; PSLT shop safety rules.	3E
Inhaling denatured alcohol fumes	Personnel will take care when working with Denatured alcohol. Personnel will not place their heads directly over open denatured alcohol	3C	MSDS for acetone; PSLT shop safety rules.	3E
Inhaling aerosolized spray paint	Personnel will wear at least dust masks, preferably respirators while using spray paint	3C	MSDS for aerosol spray paints; PSLT shop safety rules.	3E

Table 5.2 – Assessment of Risks to Personnel from Materials

5.3.3.3 Testing Hazards

	Hazard				
	Effect(s)				
Cause(s)	Mitigation(s)		Cause(s)	Mitigation(s)	
	Burns				
	Personnel are injured; damage to testing facility / area				
Black powder charge goes off while personnel are near rocket during ground fire test	1. All personnel will maintain a safe distance from rocket during ground fire test. 2. Personnel will wear safety glasses before performing a ground fire test	1C	1. PSLT testing procedures 2. PSLT safety rules	1E	
Black powder charge goes off while testing altimeter	1. Any personnel testing altimeters will first take the avionics away from other personnel. 2. Personnel will point avionics away from themselves and others when testing.	1C	1. PSLT pre-launch checklist 2. PSLT pre-launch checklist	1E	
Ground fire test causes a facility fire	All ground fire tests will be conducted outside away from buildings and people	1C	PSLT testing procedures	1E	

Table 5.3 - Assessment of the Testing Hazards

	Hazard				
	Effect(s)				
Cause(s)	Mitigation(s)		Cause(s)	Mitigation(s)	
	Personnel are struck by moving parts				
	Personnel are injured				
Improperly secured test articles come loose during testing (e.g. ACS nozzle and hose whipping back).	1. Ensure all parts of the system being tested are properly secured before testing. 2. Personnel will maintain a safe distance during testing	1C	1. PSLT testing procedures 2. PSLT safety rules	1E	
Fast moving parts of test articles striking personnel (e.g. nosecone separating during ground fire test).	1. Personnel will not stand in nosecone's travel path during testing. 2. Personnel will maintain a safe distance away from any systems being tested	1C	1. PSLT launch vehicle construction and testing operations 2. PSLT safety rules	1E	

Table 5.4 - Assessment of Testing Hazards

5.3.4 Failure Modes

	System			
	Hazard			
	Effect(s)			
Cause(s)	Mitigation(s)	Cause(s)	Mitigation(s)	
	Recovery System			
	Parachute fails to deploy, or slow the rocket down			
	Injury to personnel and the rocket becomes damaged			
Bulkheads aren't sealed tight, and force from the ejection charge blows through into rocket	On frigid days when the bulkheads can shrink, keep them insulated	1C	Data gathered from subscale launch	1E
Ejection charges are packed improperly	1. Ejection charges will be packed according to the pre-launch procedural checklist. 2. Careful inspection of the ejection charges to ensure they are packed properly which will then be verified by the Safety Officer before launch	1C	Recovery system pre-launch preparation checklist	1E
Dead batteries causing electronics in recovery	1. Only use fresh batteries and batteries that can last long enough to keep electronics powered in case there is a launch delay	1C	Recovery system pre-launch preparation checklist	1E

	System			
	Hazard			
	Effect(s)			
Cause(s)	Mitigation(s)	Cause(s)		Mitigation(s)
system to not work	2. Batteries will be carefully inspected and verified by the Safety Officer to ensure they are working before launch			
Altimeter isn't turned on, or programmed incorrectly	Altimeter configuration will be checked before flight. Altimeter activation will be verified before flight	1C	Recovery system pre-launch preparation checklist	1E
Jolly Logic Altimeter is not charged sufficiently and turns off	1. Ensure that the Jolly Logic is fully charged before packing for launch day. 2. Have a backup charging device available to charge up Jolly Logic 3. Careful inspection of the Jolly Logic during pre-launch preparations and verified by the Safety Officer to ensure Jolly Logic is functioning	2C	1. Data gathered from past launches. 2. Data gathered from past launches. 3. Recovery system pre-launch checklist	2E
Jolly Logic altimeter is programmed to have parachute	1. Calculate the correct altitude to deploy parachute so the parachute has enough time to fully deploy and slow down rocket	2C	1. Data gathered from past launches.	2E

	System			
	Hazard			
	Effect(s)			
Cause(s)	Mitigation(s)	Cause(s)	Mitigation(s)	
deploy too late during descent	2. Careful inspection of the Jolly Logic during the pre-launch preparations to ensure the correct altitude is programmed before flight. This will be verified by the Safety Officer before flight		2. Recovery system pre-launch checklist	
Parachute tears during descent	1. Analysis to choose a parachute of the correct size and material that is durable enough to withstand forces during flight. 2. The Parachute will be inspected during pre-launch preparations and verified by the Safety Officer before flight	2D	1. Data gathered during launch vehicle design 2. Recovery system pre-launch checklist	2E
Parachute chords become tangled or tear during flight	1. The chords of the parachute will be carefully inspected during pre-launch preparations and verified by the Safety Officer to ensure they are not torn or frayed 2. The parachute chords will be packed in a safe manner, carefully inspected and verified by the Safety Officer to ensure	2D	Recovery system pre-launch checklist	2E

	System			
	Hazard			
	Effect(s)			
Cause(s)	Mitigation(s)	Cause(s)	Mitigation(s)	
	they do not tangle up during flight.			
Rubber band wrapping Jolly Logic around parachute snaps during flight	Careful inspection of the Jolly Logic during pre-launch preparations to ensure the rubber band has no tears, or that the rubber band is wrapped too tight around the parachute. This will also be verified by the Safety Officer before launch	2D	Recovery system pre-launch checklist	2E
Jolly Logic securing pin is not locked in place and comes undone during flight	1. Make sure the parachute is wrapped tight enough so that the locking pin can lock into place. 2. Careful inspection during pre-launch preparations to ensure that the locking pin is secure and cannot come undone. This will be verified by the Safety Officer before launch	2D	Recovery system pre-launch checklist	2E
Recovery harness breaks	1. The recovery harness used will be made of material strong enough to withstand the forces experienced during flight. 2. The recovery harness will be tested before being used, it will be installed according to the	1D	1. Data gathered during recovery system design 2. Recovery system pre-launch checklist	1E

	System				
	Hazard				
	Effect(s)				
Cause(s)	Mitigation(s)	Cause(s)	Mitigation(s)		
	recovery system prep checklist and verified by the Safety Officer before flight				
Quick links are not secured to recovery harness	Careful inspection of the quick links during pre-launch preparations to ensure the quick links are secured and will not come undone during flight. This will be verified by the Safety Officer before flight	1D	Launch vehicle pre-launch preparation checklist	1E	

Table 5.5 - Recovery System Failure Modes and Effects Analysis

	System				
	Hazard				
	Effect(s)				
Cause(s)	Mitigation(s)	Cause(s)	Mitigation(s)		
	Airframe				
	Parts separate from vehicle during flight				
	Injury to personnel and the rocket becomes damaged				
Fins break off from airframe	1. During construction an adequate amount of epoxy that is of a proper mixture will be applied to all contact points of the fins and airframe. 2. Fins will be secured with epoxy clay fillets.	1D	1. Data gathered from past launches.	1E	

	System			
	Hazard			
	Effect(s)			
Cause(s)	Mitigation(s)	Cause(s)	Mitigation(s)	
	3. Fins will be inspected before any flights by the team, the Safety Officer, and the Range Safety Officer to ensure they are secure		2. Launch vehicle construction procedures. 3. Launch vehicle pre-launch checklist	
Airframe fractures during flight	1. The airframe will be constructed of durable materials. 2. Stress tests will be performed on airframe to ensure that it can withstand flight forces. 3. Airframe will be carefully inspected and then verified by the Safety Officer and the range Safety Officer before launch	1D	1. Launch vehicle construction procedures. 2. Data gathered from past builds. 3. Launch vehicle pre-launch checklist	1E
Nosecone separates during flight	1. During construction the nosecone will be properly attached to airframe and tested before flying. 2. During launch preparations the nosecone will be inspected by the Safety Officer and range	1D	1. Launch vehicle construction procedures.	1E

	System				
	Hazard				
	Effect(s)				
Cause(s)	Mitigation(s)	Cause(s)	Mitigation(s)		
	Safety Officer before flight to ensure flight readiness		2. Launch vehicle pre-launch checklist		
Fins are asymmetrically attached to airframe	1. During construction a fin jig will be used to ensure that the fins are attached symmetrically to the rest of the airframe. 2. The fins will be inspected and then verified by the Safety Officer before launch	2D	1. Launch vehicle construction procedures. 2. Launch vehicle pre-launch checklist	2E	
Heat warping the airframe disturbing laminar flow	1. During storage, transportation, and preparation the airframe will be kept out of direct sunlight or any other heat sources to prevent heat warping 2. The airframe will be inspected during pre-launch preparation and then verified by the Safety Officer to ensure there is no warping of the airframe	2D	1. MSDS for fiberglass body. 2. Launch vehicle pre-launch checklist	2E	

Table 5.6 - Airframe Failure Modes and Effects Analysis

	System				
	Hazard				
	Effect(s)				
Cause(s)	Mitigation(s)		Cause(s)	Mitigation(s)	
	Altitude Control System (ACS)				
	Rocket flies out of control				
	Personnel are injured, and the rocket is damaged				
Pressurized gas tank comes loose during flight	1. Proper design of the gas tank mountings to ensure the security of the gas tank. 2. Perform stress tests on the gas tank mountings to ensure they can withstand force of flight. 3. The gas tank mountings will be carefully inspected during pre-launch preparations and then verified by the Safety Officer before launch	1D	1. Data gathered during the ACS design process. 2. ACS construction procedures 3. ACS pre-launch preparation checklist	1E	
Gas thrusters on launch vehicle are pointing in the wrong direction when expelling gas during flight	1. Calculate where the nozzles should be pointing on the airframe. 2. Perform adequate testing before flying 3. Careful inspection of the nozzles during pre-launch preparations to ensure their facings haven't been changed. This will then be verified by the Safety Officer before launch	1D	1. Data gathered during the ACS design process. 2. ACS construction procedures 3. ACS pre-launch preparation checklist	1E	

	System			
	Hazard			
	Effect(s)			
Cause(s)	Mitigation(s)	Cause(s)	Mitigation(s)	
Obstruction in altitude control system leading to uneven gas distribution	1. Careful inspection of the hoses and nozzles during construction to ensure no obstructions are in them. 2. Test the hoses and nozzles before flying to ensure there are not blockages. 3. Careful inspection during pre-launch preparations to ensure there are no blockages. This will then be verified by the Safety Officer before launch	1D	1. ACS construction procedures. 2. ACS construction procedures 3. ACS pre-launch preparation checklist	1E
Pressurized gas tank becoming extremely cold during use, freezing airframe making it brittle	1. The area surrounding the pressurized gas tank will be insulated to prevent the airframe from freezing. 2. The gas tank area will be carefully inspected during pre-launch preparations and then verified by the Safety Officer to ensure it is properly insulated	1D	1. Data gathered during the ACS design process. 2. ACS pre-launch preparation checklist	1E

Table 5.7 - Altitude Control System Failure Modes and Effects Analysis

	System			
	Hazard			
	Effect(s)			
Cause(s)	Mitigation(s)	Cause(s)	Mitigation(s)	
	Altitude Control System			
	Rocket fails to slow down or speed up			
	Target altitude not reached			
Gas thrusters fire too early or too late	1. Sufficient testing of the altitude control system before using in the rocket. 2. Careful inspection of the system's electronics during pre-launch preparations to ensure it is functioning as intended	2C	1. ACS construction procedures. 2. ACS pre-launch preparation checklist	2E
Gas leaks out before thrusters are supposed to engage	1. Sufficient testing of the altitude control system before using in the rocket. 2. Careful inspection of the hoses, nozzles, and other components to ensure there are no leaks	2D	1. ACS construction procedures. 2. ACS pre-launch preparation checklist	2E
Increased drag from nozzles protruding too far from airframe	1. Calculate maximum appropriate distance that nozzles can protrude, and ensure during building of the rocket that nozzle cannot protrude further than allowed.	2D	1. Data gathered during the ACS design process	2E

	System			
	Hazard			
	Effect(s)			
Cause(s)	Mitigation(s)	Cause(s)	Mitigation(s)	
	2. Careful inspection of the rocket during pre-launch preparations to make sure nozzles are not protruding further than allowed.		2. ACS pre-launch preparation checklist	
Rocket sits out in the sun for a prolonged period. Gas pressure builds up in tank causing tank to rupture or leak	1. Insulate the interior of the airframe with expanding spray foam. 2. Keep the rocket in a shaded area and away from heat sources 3. The tank will only be filled to 47% of its rated pressure (16% of burst pressure)	2D	1. Data gathered during the ACS design process. 2. MSDS for the pressurized gas tank 3. Data gathered during the ACS design process	2E

Table 5.8 - Altitude Control System Failure Modes and Effects Analysis

	System		
	Hazard		
	Effect(s)		
Cause(s)	Mitigation(s)	Cause(s)	Mitigation(s)
	Payload		
	Rover is unable to leave launch vehicle or travel full distance for objective		
	Mission failure		

	System			
	Hazard			
	Effect(s)			
Cause(s)	Mitigation(s)	Cause(s)	Mitigation(s)	
Payload hits a rock / obstruction and gets damaged	1. Design the payload to be made of durable enough materials to endure contact with any rocks and / or obstructions on the ground 2. Run simulations of the payload contacting rocks / obstructions to ensure it can handle them	2C	1. Data gathered during the payload design process. 2. Payload test procedures	2E
Nosecone gets stuck in ground upon landing	1. A rounded nosecone will be used to help mitigate the probability of the payload becoming stuck in the ground 2. Test flights to make sure the rounded nosecone does not get stuck in the ground	2C	1. Data gathered during the payload design process. 2. Payload test procedures	2E
Nosecone does not split at all, or enough to allow rover to leave	1. Tests on the nosecone separation will be performed before flying to ensure the nosecone splits as intended. 2. During pre-launch preparations the nosecone will be carefully inspected, and then verified by the Safety Officer before launch to ensure it is functioning as intended	2C	1. PSLT payload operational procedures. 2. Payload pre-launch preparation checklist	2E

	System				
	Hazard				
	Effect(s)				
Cause(s)	Mitigation(s)	Cause(s)		Mitigation(s)	
Nosecone gets stuck in tree, causing rover to fall when deployed	1. The payload design and materials used in its construction will be durable enough to withstand a fall. 2. The rover will also be tested to simulate falls to ensure it is durable	2D	1. Data gathered during the payload design process. 2. PSLT payload operational procedures	2E	
Batteries for payload electronics are dead	1. Use only fresh batteries with a charge long enough to power rover electronics in case there is a flight delay. 2. Test batteries before flying to make sure they can last long enough to account for a flight delay. 3. Careful inspection of the batteries during pre-launch preparations which will also be verified by the Safety Officer before launch. 4. A relay will be used to separate the motor and camera battery from all sources of current draw until launch	2D	1. Data gathered from past launches. 2. PSLT payload operational procedures. 3. Payload pre-launch preparation checklist. 4. Payload construction procedures	2E	

	System				
	Hazard				
	Effect(s)				
Cause(s)	Mitigation(s)	Cause(s)		Mitigation(s)	
Rover gets stuck in the parachute or debris on the ground	1. Design the rover to have orientation sensors to help it avoid obstructions 2. Adequate testing. Run simulations before flying to make sure the rover can avoid getting stuck in the parachute or other entanglements. 3. Careful inspection of the rover's orientation sensors to ensure they are functioning as intended. This will then be verified by the Safety Officer	2D	1. Data gathered during the payload design process. 2. PSLT payload operational procedures 3. Payload pre-launch preparation checklist	2E	

Table 5.9 - Payload System Failure Modes and Effects and Analysis

	System				
	Hazard				
	Effect(s)				
Cause(s)	Mitigation(s)	Cause(s)		Mitigation(s)	
	Payload Ejection Charges				
	Charge doesn't fire or isn't powerful enough				
	Mission failure				
Ejection charge isn't powerful enough to	1. Perform ground fire tests to ensure the charge is powerful enough to eject rover sled	2C		2E	

	System			
	Hazard			
	Effect(s)			
Cause(s)	Mitigation(s)	Cause(s)	Mitigation(s)	
eject rover sled	2. Careful inspection of the charges during pre-launch preparations to make sure the correct amount of black powder was put in ejection cup. This will also be verified by the Safety Officer before launch		1. PSLT payload operational procedures 2. Payload pre-launch preparations checklist	
Command to fire ejection charge isn't received	1. The team will use equipment strong enough to broadcast a signal to fire the ejection charge. 2. Adequate testing of signal transmission to the rover with nearby interference to ensure the signal is strong enough to reach the rover. 3. Careful inspection of the signal transmission equipment during pre-launch preparations to make sure equipment is working as intended. This will then be verified by the Safety Officer	2C	1. Data from last year's launch where other radio equipment interfered. 2. PSLT payload operational procedures. 3. Payload pre-launch preparations checklist	2E

	System			
	Hazard			
	Effect(s)			
Cause(s)	Mitigation(s)	Cause(s)		Mitigation(s)
Arming switch not armed	Arming switch will be carefully inspected during pre-flight preparation and verified by the Safety Officer to ensure the arming switch is on and in good working order before flight	2C	Payload pre-launch preparation checklist	2E
Damp powder charge fails to ignite	1. Black powder will be stored in dry, sealed containers. 2. The cup will be checked to make sure it is dry before any black powder is placed in it, and it will be carefully inspected by the Safety Officer before flight	2D	1. MSDS for black powder 2. Payload pre-launch preparation checklist	2E
Wires are disconnected	1. During construction wires will be securely attached to all devices. 2. All wires and electronics will be carefully inspected and pull-tested during pre-launch preparations, and will be verified by the Safety Officer to ensure they are secured before flight	2D	1. Payload construction procedures 2. Payload pre-launch preparation checklist	2E

	System				
	Hazard				
	Effect(s)				
Cause(s)	Mitigation(s)	Cause(s)		Mitigation(s)	
Igniters are bad	Redundant igniters will be used	2D	Payload pre-launch preparation checklist	2E	

Table 5.10 - Payload System Failure Modes and Effects and Analysis

	System			
	Hazard			
	Effect(s)			
Cause(s)	Mitigation(s)	Cause(s)	Mitigation(s)	
	Payload Electronics			
	Rover is unable to function as intended			
	Mission failure			
Solar panel does not deploy	1. Perform multiple tests to ensure that the solar panel will deploy as intended 2. During pre-launch preparations thoroughly inspect the solar panel deployment to ensure everything is working as intended. This will then be verified by the Safety Officer before launch	2C	1. Payload operational procedures 2. Payload pre-launch preparation checklist	2E
Righting mechanism motor or linear	1. The solar panel / righting mechanism will be controlled by two high-torque, low speed motors. The righting	2C	1. Solar panel motor design data gathered.	2E

	System			
	Hazard			
	Effect(s)			
Cause(s)	Mitigation(s)	Cause(s)		Mitigation(s)
actuator gets stuck / doesn’t have sufficient torque	mechanism will be actuated by a linear actuator and the solar panel bracket will be actuated by a high-torque motor with a speed of 0.5 revolutions per minute. 2. Run multiple tests before launching to ensure the motor works as intended. 3. Carefully inspect the solar panel motor before launch to ensure it is working as intended. This will be verified by the Safety Officer before launch		2. Payload operations procedures 3. Payload pre-launch preparation checklist	
Water leaks in causing a short	1. Connections will be waterproofed during construction. Any connections or components that cannot be waterproofed will be elevated to help prevent getting wet. 2. Test the rover to ensure the connections are safe from moisture 3. Carefully inspect the connections during pre-launch preparations to make sure the	2C	1. Data gathered during design process 2. Payload operational procedures	2E

	System			
	Hazard			
	Effect(s)			
Cause(s)	Mitigation(s)	Cause(s)	Mitigation(s)	
	connections are dry and safe from moisture		3. Payload pre-launch preparation checklist	
Sensors fail	1. Sensors will be mounted and wired securely. If possible, they will be mounted on shock-absorbable material 2. Multiple tests will be conducted to ensure the sensors are working as intended 3. Careful inspection of the sensors during pre-launch preparations to ensure they are working as intended	2C	1. Data gathered during the design process. 2. Payload operational procedures 3. Payload pre-launch preparation checklist	2E
Incorrect wiring	1. During construction, the wiring will be inspected and attached securely. 2. Adequate testing of the wires to make sure they function and are not loose 3. Careful inspection of all wiring including pull-testing of the wires during pre-launch	2C	1. Data gathered during the design process 2. Payload operational procedures	2E

	System			
	Hazard			
	Effect(s)			
Cause(s)	Mitigation(s)	Cause(s)	Mitigation(s)	
	preparations and then verified by the Safety Officer		3. Payload pre-launch preparation checklist2	
Battery overloads / explodes	Circuit analysis will be performed and tested to ensure the battery functions safely and as intended	2C	Payload design and testing procedures	2E
Electronics overheat	1. Circuit analysis will be performed and tested to ensure the all electronics function safely and as intended. 2. Full duration tests (including a multi-hour wait on the launch pad) will be performed to ensure there are no issues	2C	Payload design and testing procedures	2E
Bad connections	Careful inspection of all the connections during pre-launch preparations to ensure connections are good. This will then be verified by the Safety Officer before flight	2C	Payload pre-launch preparation checklist	2E
Broken electronics	1. Design to have electronics located away from places that may hit the ground or other hazards. 2. Mount electronics on shock absorbing materials	2C	1. Data gathered during design process.	2E

System					
Hazard					
Effect(s)					
Cause(s)	Mitigation(s)		Cause(s)	Mitigation(s)	
	3. Test the design to ensure the location of the electronics is free from danger.		2. Data gathered during design process 3. Payload operational procedures		

Table 5.11 - Payload Electronics System Failure Modes and Effects and Analysis

System					
Hazard					
Effect(s)					
Cause(s)	Mitigation(s)		Cause(s)	Mitigation(s)	
Payload Communications					
Communications Failure					
Rover failing to deploy properly or getting damaged					
The rover's communications are down due to interference from another team's equipment	1. Have radio equipment with a signal strong signal to reach the rover and give it commands. 2. Test the radio equipment by simulating other radio interference to make sure it is strong enough. 3. Carefully inspect all radio equipment before launch to make sure it is functioning as	2C	1. Data gathered from last year's flight where interference was an issue. 2. Payload operational procedures. 3. Payload pre-launch	2E	

	System				
	Hazard				
	Effect(s)				
Cause(s)	Mitigation(s)		Cause(s)	Mitigation(s)	
	intended			preparation checklist	

Table 5.12 - Payload Communication System Failure Modes and Effects and Analysis

	System				
	Hazard				
	Effect(s)				
Cause(s)	Mitigation(s)		Cause(s)	Mitigation(s)	
	Rover's Wheels				
	Damage to the wheels, and / or failure to operate				
	Rover is unable to move				
Wheel gets damaged during deployment or while traversing terrain	1. The wheels will be made from aluminum to withstand contact with obstacles. 2. Design the wheels to return to their stowage positions before the right mechanism actuates. 3. Test the wheels in rough terrain to ensure they will work reliably. 4. Careful inspection of the wheels during pre-launch	2C	1. Data gathered during the design process. 2. Data gathered during the design process. 3. Payload operational procedures. 4. Payload pre-launch checklist	2E	

	System			
	Hazard			
	Effect(s)			
Cause(s)	Mitigation(s)	Cause(s)	Mitigation(s)	
	preparations to ensure they are not damaged.			
No power to the wheels	1. Have a reliable power system in place that can keep the wheels powered even in case of a launch delay. 2. Ensure all connections are soldered securely. 3. Run multiple tests on wheels to ensure they function as intended. 4. Carefully inspect all components of the wheel system during pre-launch preparations	2C	1. Data gathered during the payload design process. 2. Data gathered during the design process. 3. Payload operational procedures. 4. Payload pre-launch checklist	2E
Wheel gets stuck or entangled in debris	1. Program wheels to be able to turn in reverse to free itself from entanglement. 2. Test the rover multiple times in simulations to ensure the rover can back away from an obstacle. 3. Careful inspection of the rover’s wheels during pre-launch preparations to ensure	2C	1. Data gathered during the design process . 2. Payload operational procedures.	2E

	System			
	Hazard			
	Effect(s)			
Cause(s)	Mitigation(s)	Cause(s)	Mitigation(s)	
	the wheels are in good working order.		3. Payload pre-launch checklist.	

Table 5.13 - Rover Wheel Failure Modes and Effects and Analysis

	System			
	Hazard			
	Effect(s)			
Cause(s)	Mitigation(s)	Cause(s)	Mitigation(s)	
	Motor			
	Motor fails to ignite or has defect			
	Injury to personnel and damage to rocket			
Motor mount separates from airframe during launch	1. During construction an adequate amount of epoxy of a proper mixture will be applied to secure the motor mount to the airframe. 2. Epoxy clay fillets will be used to strengthen connections between the motor mount and the airframe. 3. Perform stress tests on the motor mount to ensure the mount is secured to the airframe	1C	1. Data gathered from past builds. 2. Launch vehicle construction procedures. 3. Data gathered from past builds.	1E

	System			
	Hazard			
	Effect(s)			
Cause(s)	Mitigation(s)	Cause(s)		Mitigation(s)
	4. During pre-launch preparations, the motor mount will be carefully inspected and then verified by the Safety Officer before launch		4. Launch Vehicle pre-launch preparation checklist	
Igniters ignite too early	1. Research which igniters are the most reliable and cost efficient. 2. Test several igniters to ensure they are reliable. 3. Follow all launch pad prep procedures including making sure there is no continuity to pad when loading up rocket.	1C	1. Data gathered during design process. 2. PSLT operational procedures. 3. Launch vehicle pre-launch checklist.	1E
Motor heat causes fire inside the rocket	1. The motor section of the rocket will be completely sealed away from the rest of the rocket by secure bulkheads able to resist heat from the motor. The motor will also have a plugged forward closure to prevent motor ejection into the rocket.	2C	1. Launch vehicle building procedures	3E

	System			
	Hazard			
	Effect(s)			
Cause(s)	Mitigation(s)	Cause(s)	Mitigation(s)	
	2. Before launch the entire motor section will be carefully inspected and then verified by the Safety Officer to ensure it is in good condition		2. Launch vehicle pre-launch preparation checklist	
Motor has manufacturer defect	1. Follow all manufacturer instructions for storing, transporting and handling the motor. 2. Careful inspection of the motor fuel grains and other components during pre-launch preparations to ensure there are no problems with the motor	3C	1. Aerotech MSDS 2. Pre-launch preparation checklist	3E
No continuity to launch pad	1. Follow all pre-launch checklist items including plugging the power into the launch pad when finished prepping rocket on pad. WARNING: If there is no continuity, follow all instructions from the Range Safety Officer first before	2C	1. Launch vehicle pre-launch checklist.	2E

	System			
	Hazard			
	Effect(s)			
Cause(s)	Mitigation(s)	Cause(s)	Mitigation(s)	
	attempting to troubleshoot continuity at the launch pad		2. NAR / TRA safety rules for launching.	
Motor under propels, or over propels the rocket.	1. Run simulations to determine what altitude the motor will propel the rocket to. 2. Perform multiple launches to ensure motor will propel rocket to desired altitude. 3. Careful inspection of the motor during pre-launch preparations.	3C	1. Data gathered from launch vehicle design process. 2. Data gathered from past launches. 3. PSLT pre-launch checklist	3E

Table 5.14 - Motor System Failure Modes and Effects and Analysis

5.3.5 Environmental Hazards

Cause(s)	Mitigation(s)	Pre-Mitigation	Verification	Post-Mitigation
	Hazard			
	Effect(s)			
	Environmental Impact on Rocket			
	Damage to or Loss of the Rocket			
Extreme cold temperatures causing parts to shrink, bulkheads no longer sealing off areas.	1. Keep rocket insulated in a tent. 2. Carefully inspect bulkheads and other parts of rocket to make sure all seals are still intact.	1C	1. Data gathered from subscale launch 2. Launch vehicle pre-launch checklist	1E
Cloudy or rainy conditions causing the rocket to be unable to tracked in the sky after launch	As per FAA regulations for high powered rocketry (14 CFR 101 subpart C, §101.25), a high-powered rocket may not be flown into a cloud or at an altitude where the horizontal visibility is less than five miles. If it is cloudy or raining, then the team will reschedule a launch when the weather is clear	1D	CFR 101 subpart C, §101.25	1E
Direct sunlight / high temperatures causing	The rocket will be assembled and stored in shaded area	2D	PSLT launch vehicle construction procedures	2E

	Hazard			
	Effect(s)			
Cause(s)	Mitigation(s)	Pre-Mitigation	Verification	Post-Mitigation
electronics to overheat				
High humidity causing airframe to swell, or electronics to become wet	The rocket will be inspected by the Safety Officer via the pre-flight checklist and then by the Range Safety Officer for flight readiness.	2D	PSLT launch preparation checklist	2E
Windy conditions causing the rocket to fly off of the intended course and drift further away while landing	1. The team will not launch into high winds, and will wait for better conditions. 2. The team will check simulations and flights for stability. Minimize time under main parachute to ensure minimal drift while maintaining safe landing speed.	2D	1. NAR safety code item #9 “Launch Site” 2. Data gathered from past launches	2E
High winds causing prep-area tent to blow over	The prep-area tent will be anchored to the ground with metal stakes.	2D	PSLT launch event operations	2E

Table 5.15 - Assessment of the Impact of the Environment on the Rocket

	Hazard			
	Effect(s)			
Cause(s)	Mitigation(s)	Cause(s)	Mitigation(s)	Cause(s)
	Rocket Impact on the Environment			
	Damage to the Environment			
Rocket causing a grass fire during launch or when landing	The location where the team launches at will be free of any dry grass that may catch on fire as per NAR High Powered Rocket Safety Code part 7 "Launcher". Fire extinguishers will be on hand in case any fires do start	2D	NAR safety code part 7 “Launcher”; PSLT launch site safety rules	1E
Rocket crashing or parts breaking off of the rocket during flight, potentially introducing hazardous materials to the local ecosystem	1. Ground fire test will be conducted to ensure that the recovery system works to avoid crashes. Parts such as fins will be securely attached to airframe and tested to ensure they can withstand force. 2. In case of crash the team will clear the area of debris as much as possible	2D	1. PSLT launch vehicle construction and testing procedures. 2. PSLT failed flight checklist	2E

	Hazard			
	Effect(s)			
Cause(s)	Mitigation(s)	Cause(s)	Mitigation(s)	Cause(s)
Wildlife wandering near launch site potentially harming them	1. The range will first be declared clear by the range Safety Officer before any launch occurs. 2. If any animals get near the launch site, the launch will be postponed, and no one should attempt to move the animal	2D	1. NAR safety code part 5 "Launch Safety" 2. PSLT launch site safety rules	2E
Liquid coming into contact with APCP motor and then getting into the ground, potentially contaminating ground water	APCP motors will be stored in a dry container away from liquids, and will be kept dry when inserting into rocket and prepping for launch	2D	MSDS for rocket motor storage and handling.	2E

Table 5.16 - Assessment of the Impact of the Rocket on the Environment

	Hazard			
	Effect(s)			
Cause(s)	Mitigation(s)	Cause(s)	Mitigation(s)	Cause(s)
	Environmental Impact on Rover			
	Damage to the rover			
Muddy ground, stones, or corn cobbs preventing rover from moving	1. Design the rover's wheels to be able to traverse difficult ground. 2. Test drive the rover on difficult terrain to prove design works 3. Carefully inspect rover before launch to ensure the wheels are working	2C	1. Data gathered during the design process. 2. Payload construction and testing process 3. Payload pre-launch prep checklist.	2E
Water from a pond, creek, etc. damaging internal electronics	1. Seal the internal electronics behind watertight barriers. 2. Carefully inspect the rover during pre-launch preparations	2C	1. Payload design process. 2. Payload pre-launch checklist.	2E

	Hazard			
	Effect(s)			
Cause(s)	Mitigation(s)	Cause(s)	Mitigation(s)	Cause(s)
Rover falling from an elevated position	1. Build the rover from durable materials. 2. Test the rover by simulating falls to prove the rover’s construction is durable. 3. Carefully inspect the rover during pre-launch preparations to ensure rover is not damaged	2C	1. Payload design process. 2. Payload construction and testing process. 3. Payload pre-launch checklist	2E

Table 5.17 - Assessment of the Impact of the Environment on the Rover

	Hazard			
	Effect(s)			
Cause(s)	Mitigation(s)	Cause(s)	Mitigation(s)	Cause(s)
	Rover’s Impact on the Environment			
	Damage to the Environment			
Emissions from the rover polluting the air	The Rover will be designed to be completely battery powered	2C	Rover design process	2E

	Hazard			
	Effect(s)			
Cause(s)	Mitigation(s)	Cause(s)	Mitigation(s)	Cause(s)
Electrical fire in the rover spreading to the grass or other vegetation	1. Test the rover's electronics to ensure the batteries and / or other electronic parts don't overload or catch fire. 2. Careful inspection of the rover's electronics before flight to ensure electronics are in good working order. 3. If possible, the rover will be observed during operation to ensure there are no hazards	2D	1. Payload design and construction process. 2. Payload pre-launch checklist 3. Post-flight checklist	2E
Payload ejection charge starts grass fire	If the rocket lands in a place where fire is a hazard, it will either be moved, the grass will be sprayed with water, or the rover will not be deployed	2D	Post-flight checklist	2E

	Hazard			
	Effect(s)			
Cause(s)	Mitigation(s)	Cause(s)	Mitigation(s)	Cause(s)
Parts of the rover breaking off, getting into the soil or water	1. Design the rover to be durable. 2. Test drive the rover to make sure no parts break off. 3. Careful inspection of the rover during 4. All team member will carefully inspect the rocket landing zone and the path of the rover. All debris will be cleaned up	2D	1. Payload design process 2. Payload construction and testing process 3. Payload pre-launch checklist 4. Post launch checklist	3E

Table 5.18 - Assessment of the Impact of the Rover on the Environment

6 Payload Criteria

6.1 Mission Statement

The payload will be designed to safely deploy a rover that is both robust and versatile; it will utilize unique space-efficient wheel designs, and employ a creative and resilient body and righting mechanism to overcome any landing condition.

6.2 Design

6.2.1 Overview

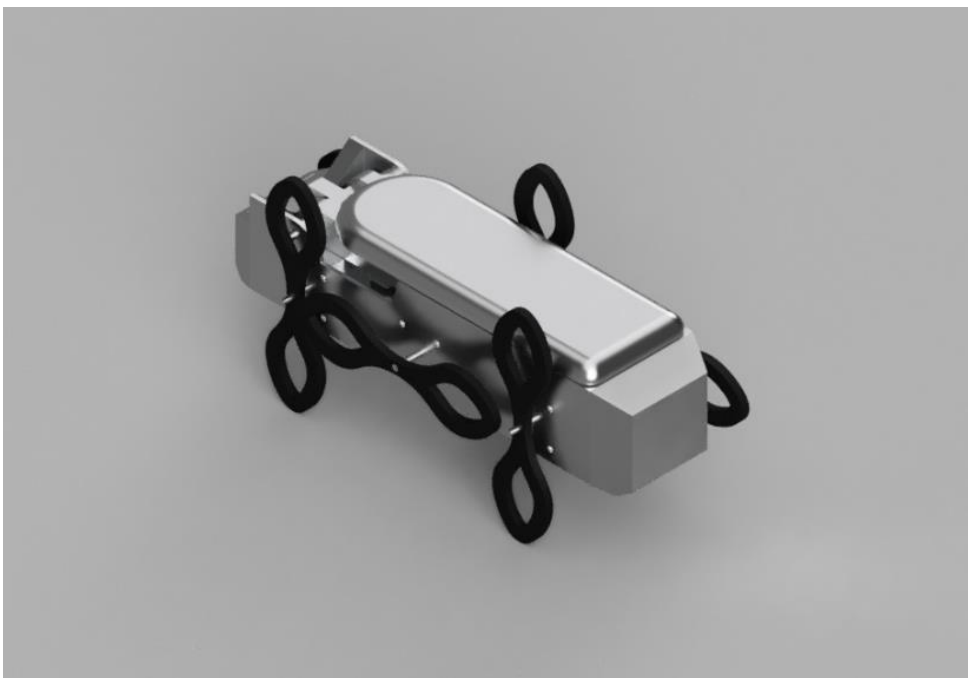

Figure 6.1 - Rover with Wheel in Driving Configuration

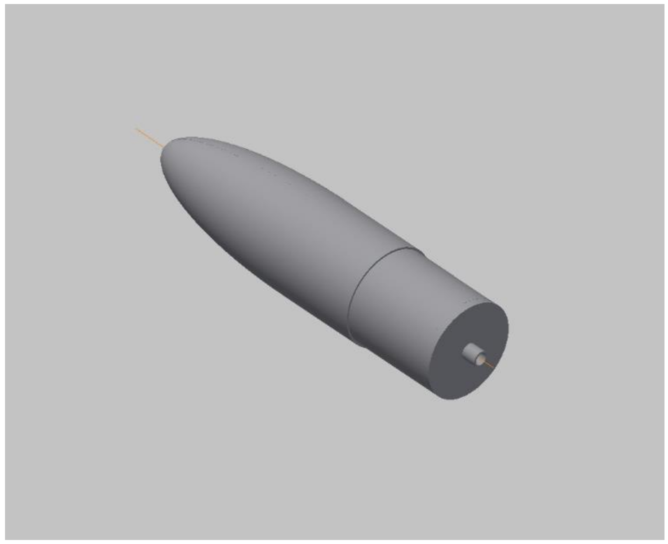

Figure 6.2 - Closed Nosecone

The payload is made up of several key components, the deployment system, the rover body, the drive system, the solar panel & righting mechanism, and the electronics.

6.2.2 Rover Deployment

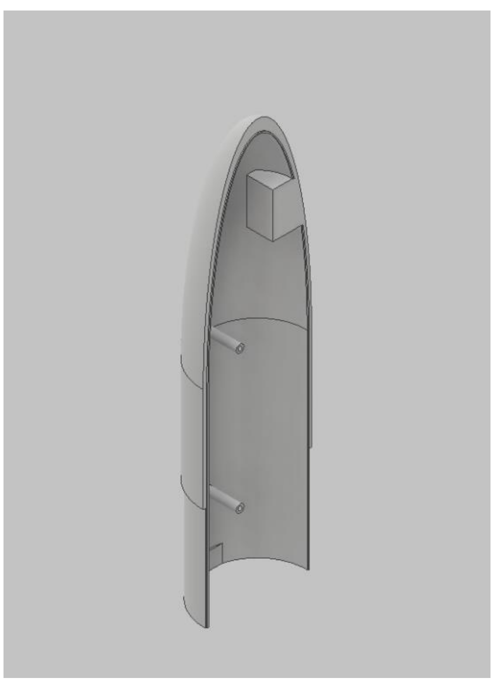

Figure 6.3 - Left Nosecone

Note the shelf for the solenoid lock.

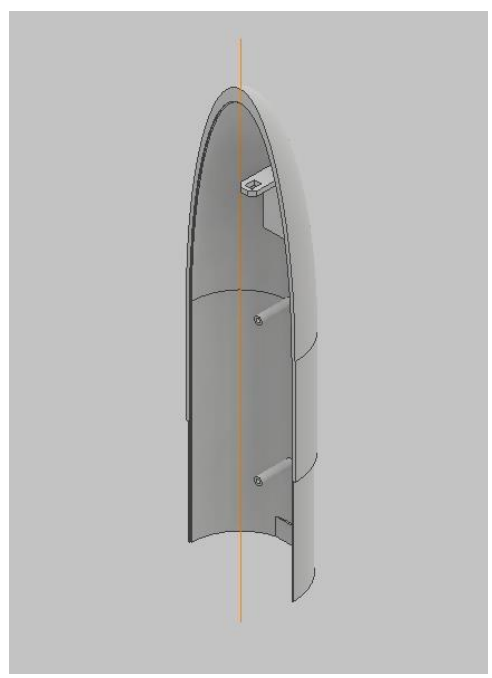

Figure 6.4 - Right Nosecone

This side has the latch that corresponds to the solenoid lock.

The rover will be housed and deployed from the nosecone. The nosecone is an ellipsoid shape, as shown in the overview figure. The nosecone will be 3D printed and be made from dense ABS plastic. This way a custom nosecone that conforms to the rover is made.

The decision to go with this design was previously shown in the matrix in the PDR. This design gave better protection to the rover, was more conducive to a good deployment, and minimized weight.
The nosecone is made up of two parts. At the bottom are hinges that are mounted to a bulkhead and torsion springs to maintain outward force. When the nosecone is closed, the payload tube will help hold the two parts together in addition to a solenoid lock at the top of the nosecone. The lock will be controlled by the rover. Inside there are two standoffs with springs inside that correspond to the outer for motor axles of the rover. The rover will be held in place by those springs.

Overall the nosecone is 18 in. long with a 6 in. shoulder. The internal diameter is 5.75 in. up into the curve of the ellipsoid. The solenoid is positioned such that it is as far up as possible so that it comfortable fits and sits on the center axis of the nosecone. The wiring for the solenoid will run along the side of nosecone and be attached to a terminal on the rover.

To eject the nosecone from the rocket, a 1 g black powder ejection charge will be used. It will use two igniters in case one igniter fails. As shown in the wiring diagram, an external key will be required to arm the ejection charge. Once the rover receives the signal from the ground station, it will set off the igniters.

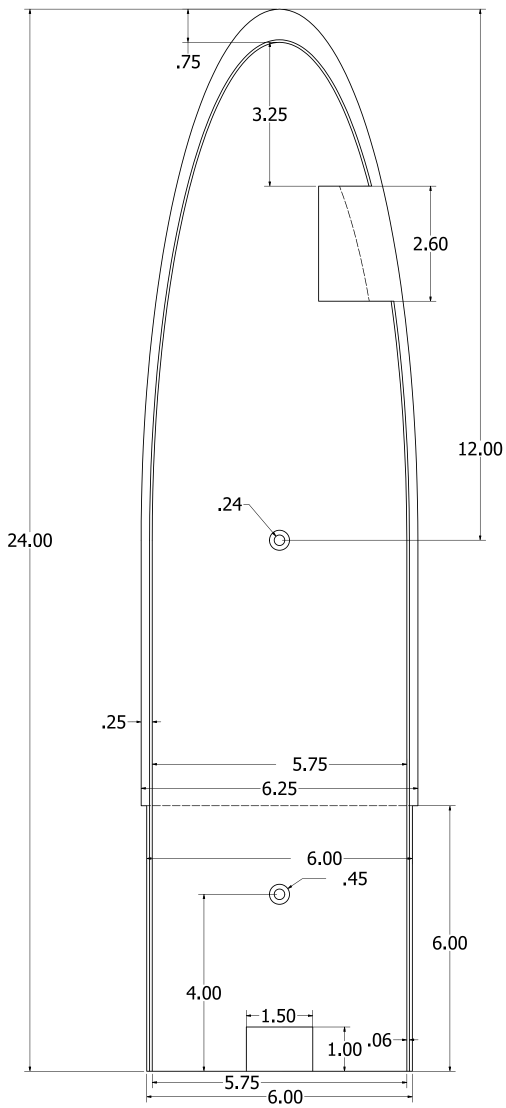

Figure 6.5 - Half the Nosecone

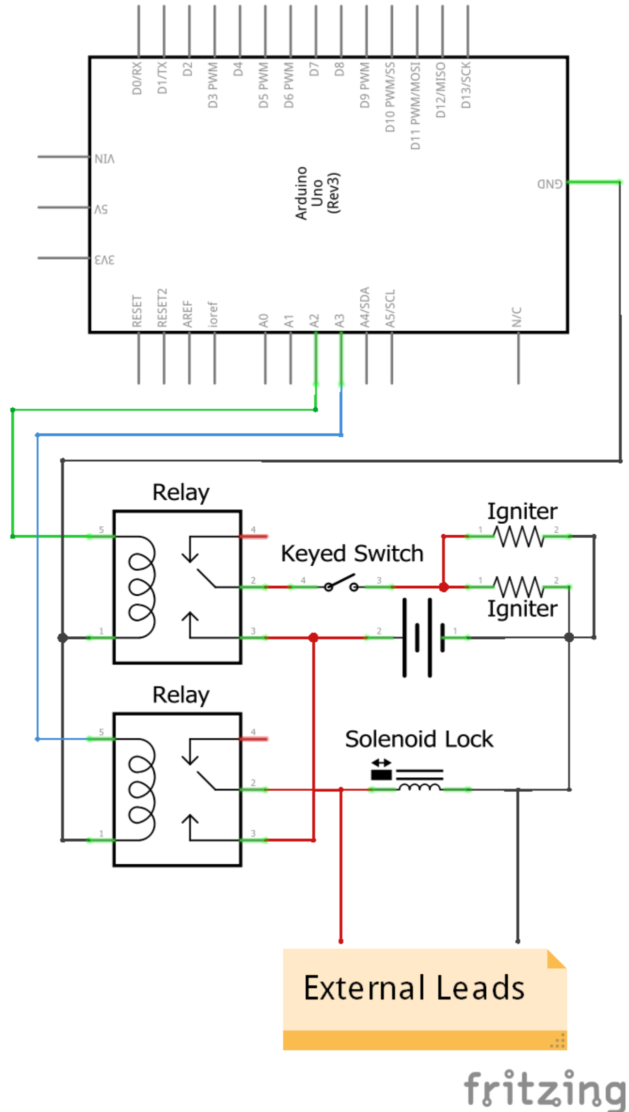

Figure 6.6 - Wiring Diagram of the Deployment Electronics

The right nosecone has almost all the same dimensions.

6.2.3 Rover Body

The rover body has an octagonal shape on the longitudinal axis with the bottom section composed of five sides and the top section composed of the solar panel bracket / righting mechanism, which makes up the three remaining sides. It is 14 in. long and 3.65 in. wide. This shape was chosen to provide room for the three wheels on each side, and to maximize space for the electric components that will be stored inside.

Additionally, the rover body will have tapered fore and aft ends. These tapers provide extra ground clearance for the rover's approach and departure angles, which will increase the rover's ability to traverse obstacles. The six wheels are positioned in the center line of the two vertical sides. The middle wheels are positioned in the center of the rover body (7 in. from the front and 7 in. from the back), and the fore and aft sets of wheels are both positioned 4 in. from the middle set of wheels. Each wheel will have a 3.5 in. radius. Therefore, each fore and aft wheel will extend 1/2 in. past the fore and aft ends, respectively. This will further aid obstacle traversing.

The wheel motors will be bolted onto the frame sides on a rectangular bolt pattern that is in accordance with the threaded bolt holes on the wheel motors. The top piece is composed of a righting mechanism / solar panel bracket that is flat on its top section and beveled on each side. This righting mechanism hinges on the front of the rover bottom section. It hinges on a pin that is placed 1.5 in. aft of the front edge, 0.5 in. below the top, and 1.35 in. above the wheel centerline. This mounting location was chosen to enable the solar panel righting mechanism to be clear of the front wheel motors.

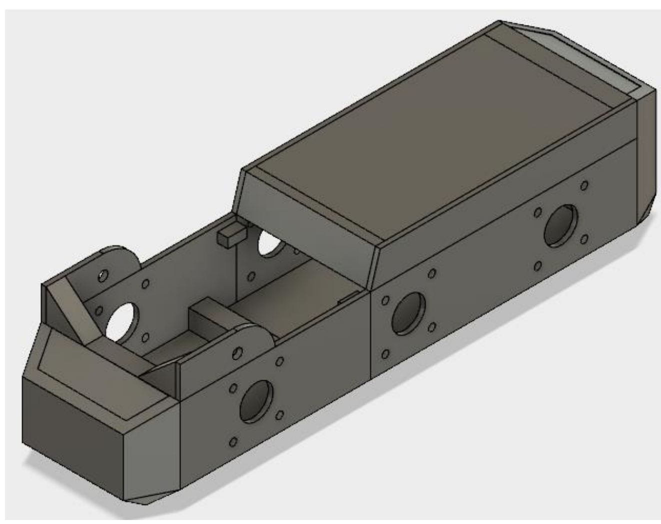

Figure 6.7 - Top View of the Rover Body

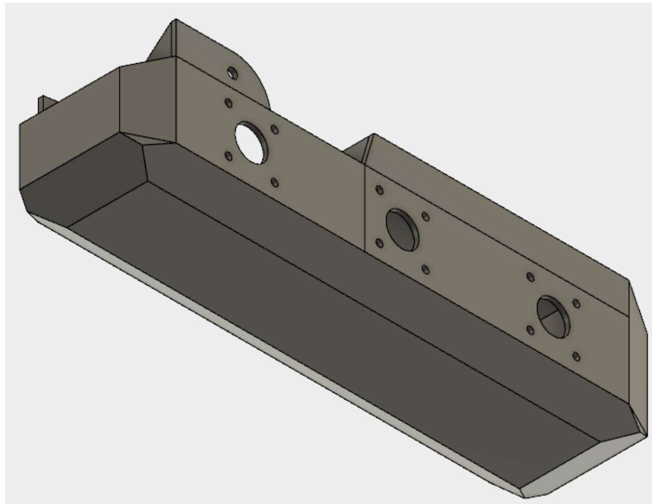

Figure 6.8 - Top View of the Rover Body (with Plastic Panels in Place)

The rover body will be composed of plastic paneling and an aluminum frame. The aluminum frame will be composed of two eighth-inch sheets of aluminum which make up the two vertical sides, and they will be bolted to aluminum horizontal crossbeams that are 3.4 in. long and 1/2 in. thick. This will provide a maximum external body width of 3.65 in. and a max internal body width of 3.4 in..

There will be two main horizontal crossbeams at the fore and aft ends and four supporting crossbeams near the center of the frame. Two of these horizontal supporting crossbeams will be located on the bottom of the rover frame, and the other two crossbeams will be at the top of the rover frame. The two bottom crossbeams will be centered between the fore and middle wheels; and between the middle and aft wheels.

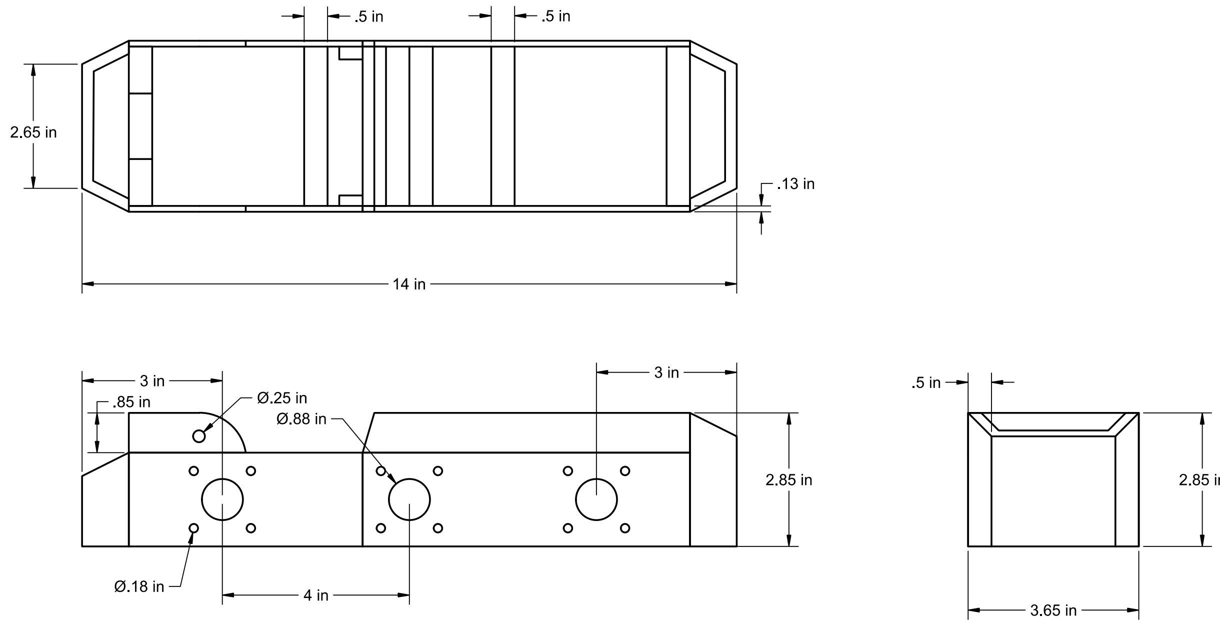

Figure 6.9 - Rover Body

Additionally, the bottom three sides of the rover body will be composed of a 3D printed panels and will be mounted onto the aluminum frame on these two bottom crossbeams. One of the top horizontal crossbeams will be located at the junction of the righting mechanism and the solar panel bracket, and it will have a 1/4 in. chamfer to enable the righting mechanism to function without interference. The other top crossbeam will be located 1 in. aft of the first top crossbeam, and this crossbeam will mount the linear actuator which controls the righting mechanism.

Finally, the tapered fore and aft ends of the rover body will be composed of quarter-inch thick aluminum sections. This extra thickness is to protect sensors and to better withstand any impact forces.

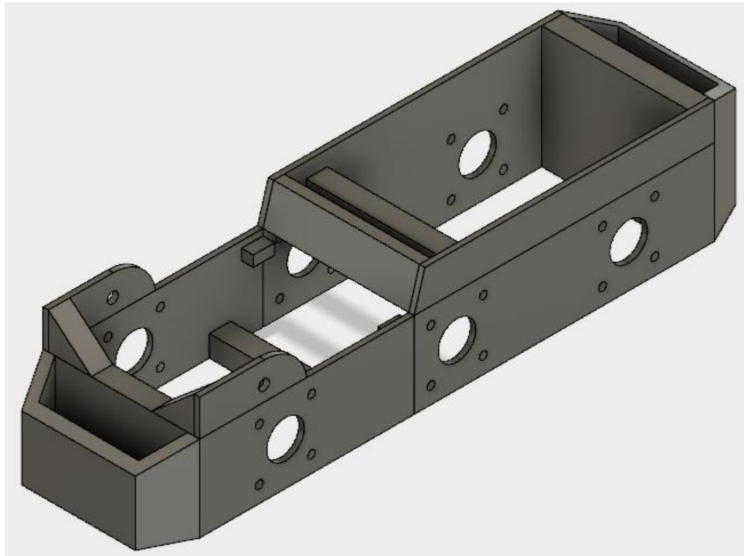

Figure 6.10 - Aluminum Rover Frame Top View

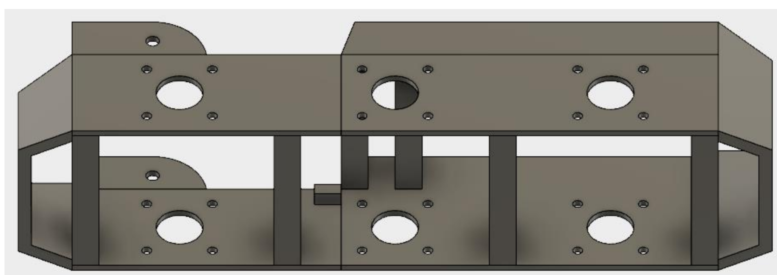

Figure 6.11 - Rover Body with all Cross Beams

6.2.4 Rover Mobility

The rover will be equipped with six infinity wheels, each powered by a stepper motor. The infinity shape of the wheels was chosen so that when stowed in the nosecone the wheels could be put parallel to the rover body to conserve space, while also allowing a generous amount of ground clearance once out of the payload tube and free from the nose cone. Due to the unique shape of the wheels, a lot of care must be taken to keep them in time, for this reason we have chosen to use stepper motors. The stepper motors will allow us to control each wheel on an individual basis to optimize performance and ensure that the they remain synchronized.

The wheels are made from 1/4 in. aluminum and are 7 in. long by 1.9 in. at their widest.

Figure 6.12 - Rover Wheels

The wheels will not all rotate in sync together, the front left, middle right, and rear left will be in sync with each other while the remaining three wheels will be 90 ° out of phase. This arrangement will cause the rover to "wobble" similar to a cockroach walking. The rover will be programmed to keep this configuration throughout its travels, and will automatically correct for wheel misalignment due to turning, motor speed differences, slippage, etc. See the overview image to see the orientation of the wheels.

6.2.5 Solar Panel and Righting Mechanism

The top section of the rover is composed of the righting mechanism and the solar panel bracket, which doubles as the arm for the righting mechanism. Orientation will be determined by sensors on the rover.

The righting mechanism will consist of a mounting bracket and a commercially-available electric motor that is mated to a torque conversion box. The motor will have a speed of 1/2 RPM, and it will be held in place by an aluminum bracket that will be fastened to the torque box portion of the motor. The bracket will be composed of two 1/2 in. thick arms and two 1/4 in. diameter pins that are mounted in two corresponding holes in the sides of the rover body. This bracket will be machined from a solid block of aluminum to ensure strength and rigidity. The bracket will also have a mounting point in its center for a linear actuator, which will deploy and retract the righting mechanism as needed. As the linear actuator pulls forward or back, it uses the solar panel as a lever with the fulcrum being the axles that the right mechanism is on. The joint between the linear actuator and the righting mechanism allows for free movement and thus creates an elbow like movement.

If the rover lands on its back, the righting mechanism will deploy and ideally flip the rover onto its front. If the rover lands on its side, the righting mechanism will deploy and then swing the solar panel bracket to the appropriate side to push the rover back onto its front. Then it will swing the solar panel bracket upright, retract the righting mechanism, and complete its travel. Once it has completed its travel, it will deploy the righting mechanism to expose the solar panels to the sky, and its mission will be complete.

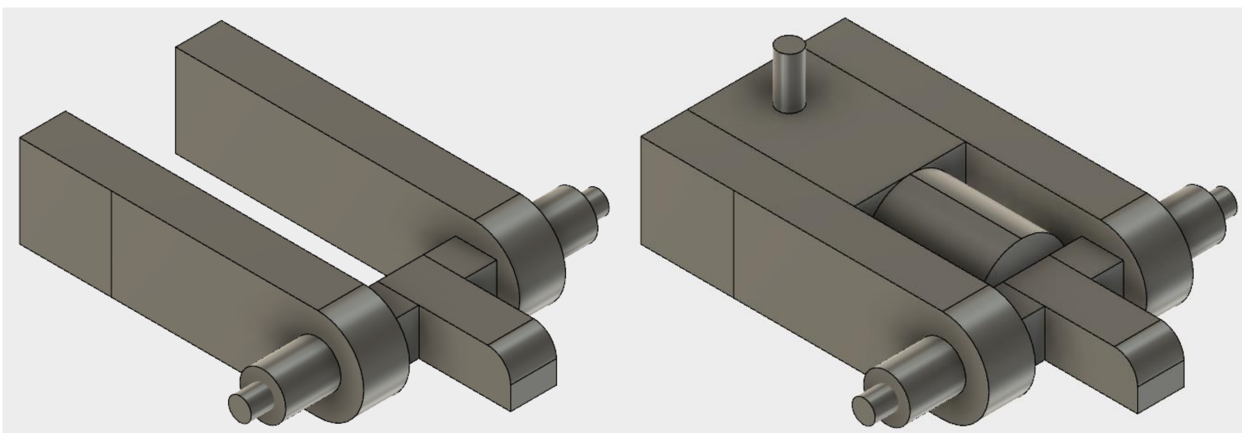

Figure 6.13 - Righting Mechanism with and without Motor

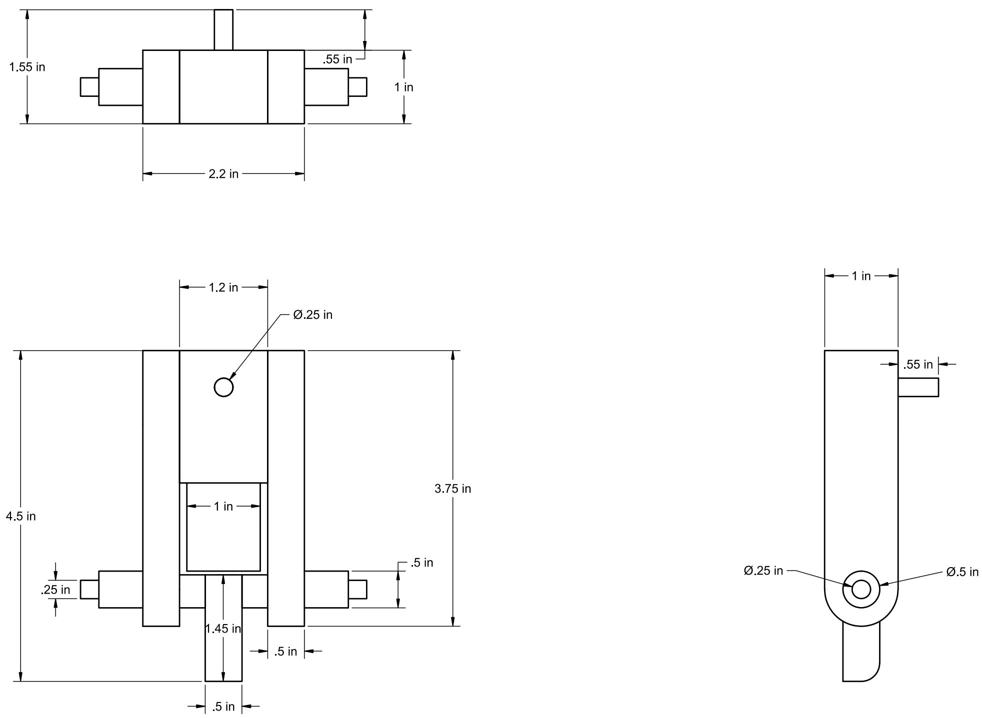

Figure 6.14 - Righting Mechanism

Figure 6.15 - Solar Panel Bracket Bottom View

Figure 6.16 - Solar Panel Bracket Top View

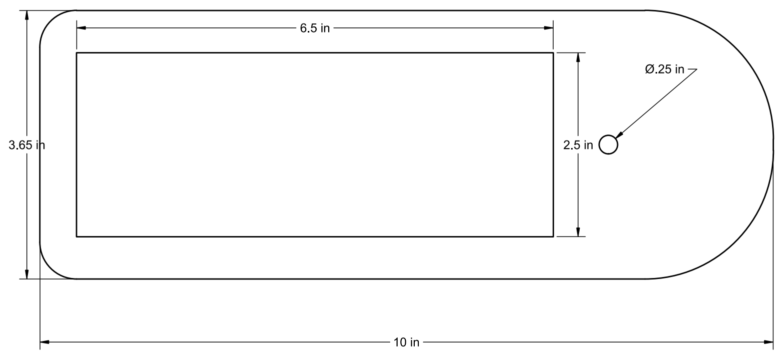

Figure 6.17 - Solar Panel Bracket

6.2.6 Rover Control Electronics

The payload electronics are divided up into five subsystems: sensors, wheel control, righting mechanism, camera system, and deployment.

6.2.5.1 Sensors

This subsystem contains the microcontroller, sensors, and transceiver. The chosen design uses an Arduino microcontroller to control and power the sensors and transceiver.

Name	Model	Manufacturer	Notes
Microcontroller	Arduino Uno Rev3	Arduino	The Arduino was chosen for its small size and compatibility with other components
Barometer	BMP280	Adafruit	An Arduino compatible barometer was chosen instead of a radio-enabled altimeter to reduce the number of independent transmitters in the launch vehicle and payload
Infrared (IR) Distance Sensor	GP2Y0A21YK0F	Sharp	This sensor was chosen because of its simplicity (it uses an analog output, so it only needs one I/O pin on the Arduino) and its protective casing
Inertial Measurement Unit (IMU)	BNO055	Adafruit	This IMU was chosen because of its built-in sensor fusion chip, meaning the Arduino doesn't have to do the calculations to determine the orientation of the IMU
GPS Receiver	Ultimate GPS v3	Adafruit	The required GPS receiver will be in the rover so that it can perform the dual purpose of tracking the launch vehicle in flight and tracking the progress of the rover after deployment
Transceiver	XBee-PRO 900HP	Digi-Key	The transceiver will send data to the ground station, as well as receive the signal to deploy the rover. It has a transmitting power of 250 mW and a 2 dB antenna, giving it a range of 7.3 miles
Battery	1300 mAh 2S 7.4 V 20C LiPo	E-flite	7.4 V lipo, 1300 mAh

Table 6.1 - Rover Sensors

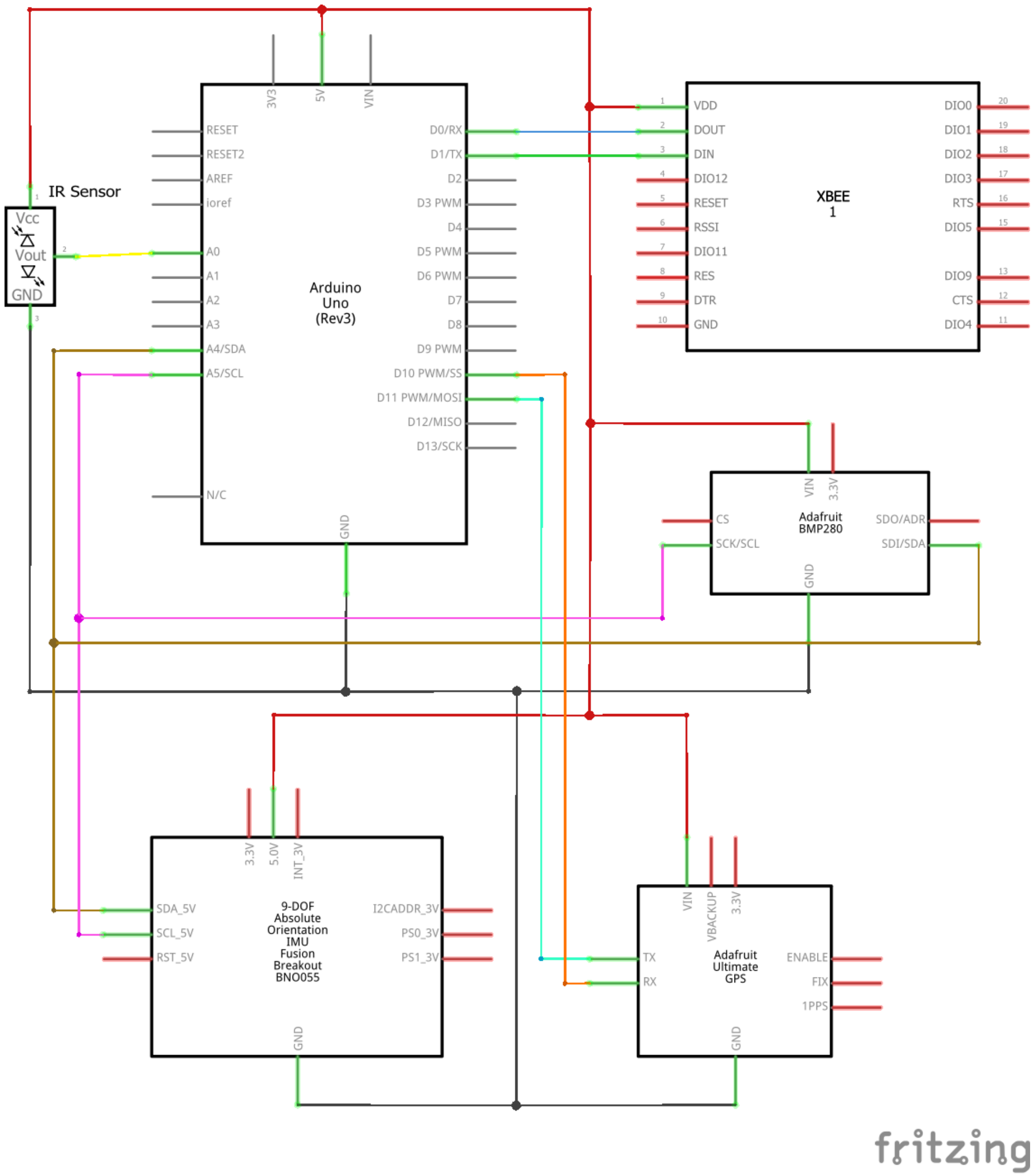

Figure 6.18 - Rover Internal Controls and Sensors

6.2.5.2 Wheel Control

This subsystem contains the motors used to turn the wheels, the controllers for those motors, the batteries to power them, and a relay. Each motor will be driven by its own A4988 motor driver; these drivers will be connected to the Arduino in two sets of three: front-left, back-left, and center-right; and front-right, back-right, and center-left. When the rover is moving, these two sets will one-quarter turn out of sync—see the rover mobility section for further detail. Each set can be rotated forwards or backwards independently, allowing the rover to drive forwards, backwards, or rotate in place.

Name	Model	Manufacturer	Notes
Motor Driver	A4988	Pololu	This driver was chosen for its small size and the fact that it does not require a heat sink
Wheel Motors	ROB-09238	Sparkfun	Stepper motors for controlled movement and precise synchronization.
Batteries	AA	Duracell	8 AAs in series. These batteries will also power the righting mechanism motor, linear actuator, camera, and video transmitter
Relay	SR-05VDC-SL-C	Songle	The purpose of this relay is to keep the batteries from being drained while the rocket is waiting for launch. This is the same relay shown in the camera system and righting mechanism sections

Table 6.2 - Rover Drive Electronics

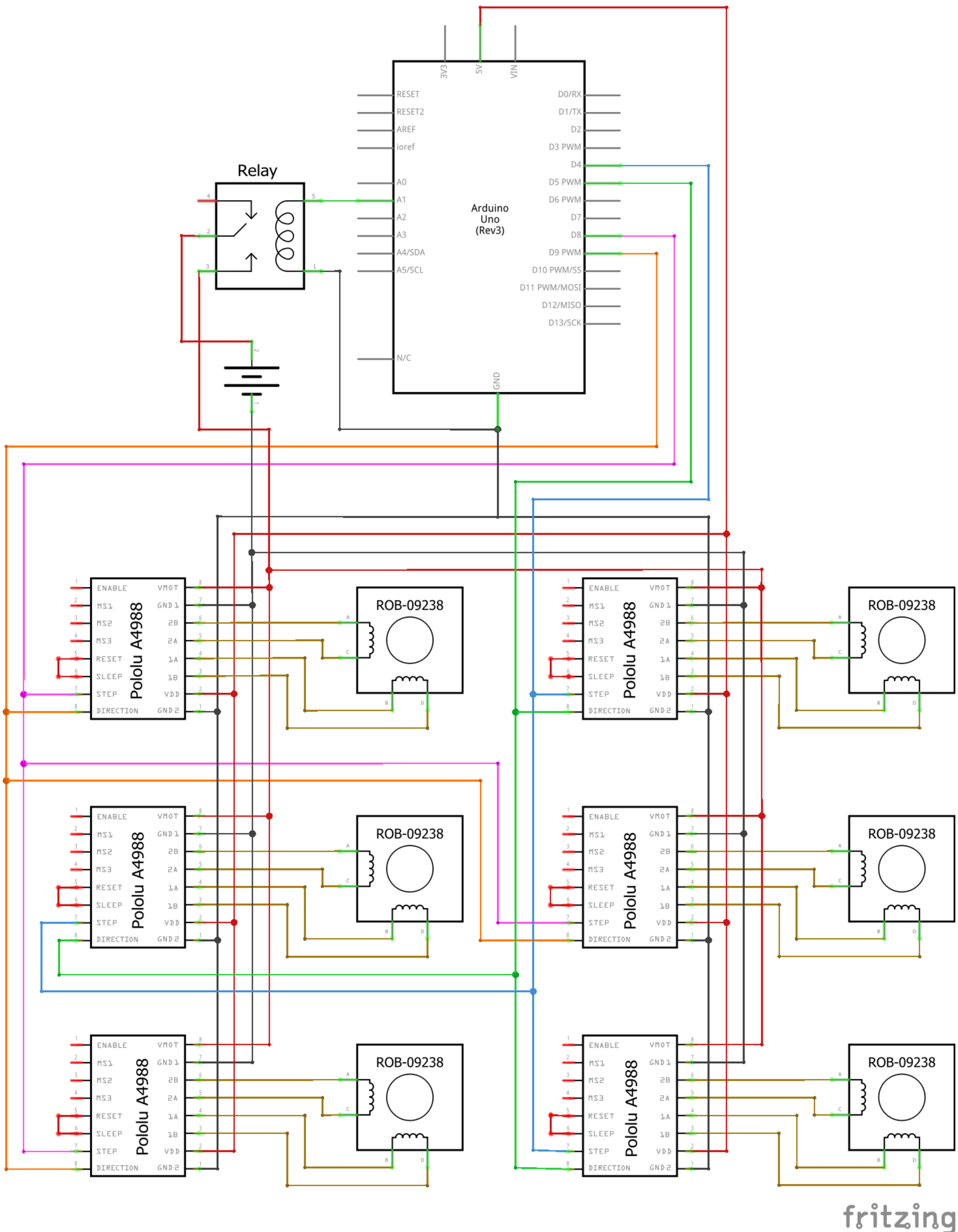

Figure 6.19 - Rover Motors and Motor Controllers

6.2.5.3 Righting Mechanism

This subsystem contains a DC motor, a linear actuator, their respective drivers, and a voltage regulator. It also uses the batteries and relay as the wheel motors and camera system.

Name	Model	Manufacturer	Notes
Motor Driver	DRV8871	Adafruit	This is a very small DC motor driver to allow the Arduino to control the direction of the motor
Linear Actuator Driver	Linear Actuator Control Board	Actuonix	This board allows the Arduino to precisely control the position of the linear actuator
Motor	DC 5 V 0.5 RPM 6 mm Shaft High Torque Turbine Worm Geared Motor	UXCell	This motor is very high torque, allowing it to flip the rover back to vertical if it ends up on its side
Linear Actuator	L12-50-210-P	Actuonix	Stroke: 50 mm Gearing: 210:1 Force: 45 N
Voltage Regulator	UBEC DC/DC Step-Down (Buck) Converter	Adafruit	This is an inline voltage regulator to provide 5 V to the righting mechanism motor

Table 6.3 - Righting Mechanism Electronics

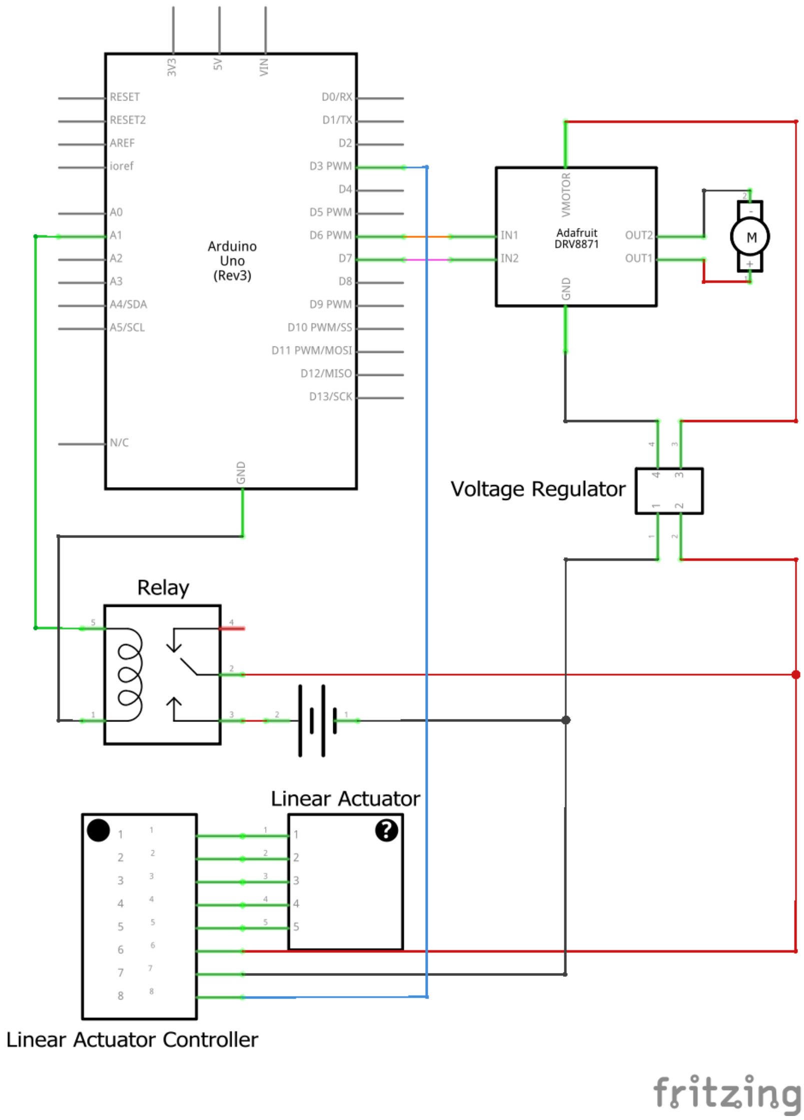

Figure 6.20 -Righting Mechanism Control Units

6.2.5.4 Camera System

This subsystem contains a camera and a video transmitter, along with the same relay and battery used in the Wheel Control and Righting Mechanism subsystems above. When the Arduino detects launch the relay will be closed, turning on the camera and transmitter. Video will then be transmitted back to the ground station and recorded there. Video is transmitted during the flight so that, in the event of a failure, it can be used to help identify the cause.

Name	Model	Manufacturer	Notes
First Person View (FPV) Camera	CM-650 Mini	Lumenier	26mmx26mm
FPV Transmitter	TX5G2R	Lumenier	5.8 GHz 2 dB antenna 200 mW 1 mile range

Table 6.4 - Video Transmission Unit

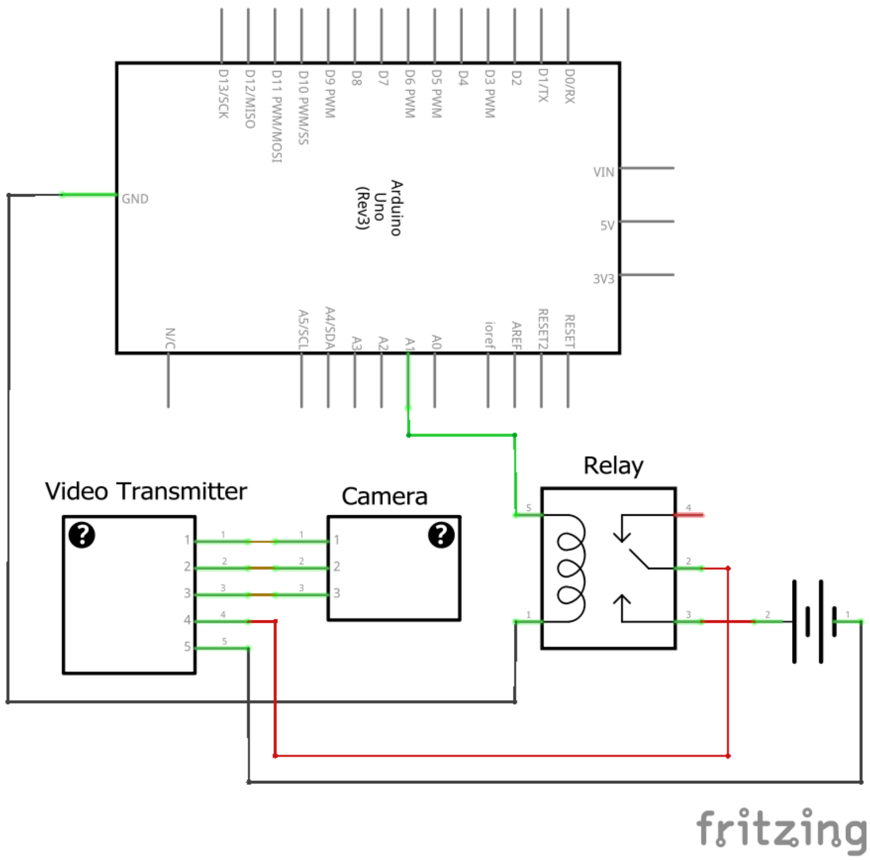

Figure 6.21 - Video Transmission Circuit

6.2.5.5 Deployment System

This subsystem contains two igniters, a switch, a solenoid lock, and two relays. When the rover receives the deployment signal, it will close the first relay, igniting an ejection charge that will propel the nosecone out of the payload tube—see the deployment section for more details. There are two igniters in case one of them fails to ignite. Once the nosecone has come to a stop the second relay will be closed, opening the solenoid lock and allowing the nosecone to spring open on its hinges. The solenoid lock also has external leads; a battery can be applied to these leads to manually open the solenoid. This is to prevent the nosecone from accidentally being locked shut.

Name	Model	Manufacturer	Notes
Relay	SR-05VDC-SL-C	Songle	Single Channel 5 V
Switch	HI - Light & Fan Switches	Unique Bargains	
Battery	9 Volt	Amazon	Generic battery
Solenoid	0837L DC 12 V 8 W	Amico	Door lock solenoid

Table 6.5 - Rover Deployment Electronics

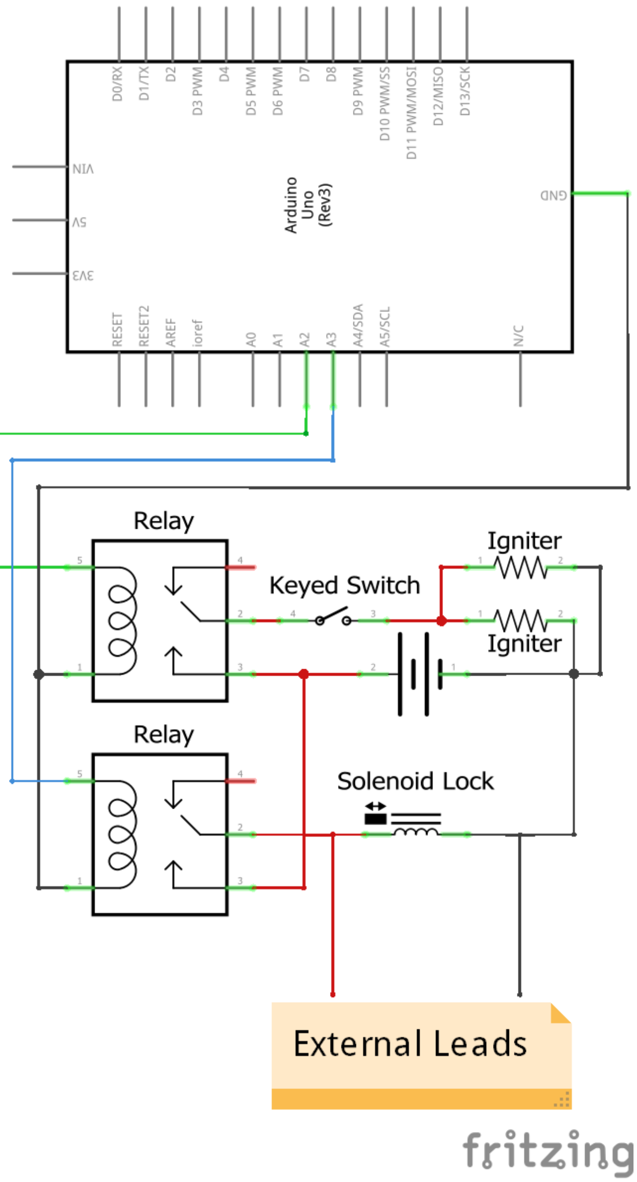

Figure 6.22 - Deployment Circuit

6.2.7 Integration with Launch Vehicle

The payload interfaces with the Launch Vehicle in two ways: it serves as the nosecone for the rocket and is held in place by shear pins. The rover needs to be both internally stored and have an easy deployment thus the ideal position was in the very top housed in the nosecone.

Since the entire nosecone assembly needs to be ejected, shear pins are needed instead of rivets. Four, #4-40 shear pins will join the shoulder of the nosecone to the payload tube of the rocket.

7 Project Plan

7.1 Testing

7.1.1 Launch Vehicle Tests

Test Name	Test Objective(s)
Avionics pressure test	Ensure that the avionics are accurately reading the changes in pressure and therefore altitude
Avionics battery Test	Ensure that the avionics batteries will last through pad time and the flight
Ejection ground fire	Ensure that the ejection charges separate the rocket with enough energy to fully break it apart during flight and push out the parachute
Flight simulation	Ensure that the rocket will fly safely and correctly
Motor mount test	Ensure that the motor mount will retain the motor while it is burning
Parachute unfurling test	Ensure that the parachute will rapidly open
Push / pull test	Test that each mount and junction will withstand a high amount of force
Sectional vibration test	Test each section to ensure that the motions of flight will not break each part

Table 7.1 - Launch Vehicle Tests

7.1.1.1 Avionics Pressure Test

- Success Criteria
  - Altimeter fires igniter at the correct pressure
- Testing Variable
  - Air pressure
- Testing Methodology
  - Program altimeter to fire at a specified altitude
  - Calculate the air pressure at that altitude
  - Connect battery to altimeter
  - Place altimeter in vacuum chamber and connect it to vacuum chamber LEDs

    - Seal vacuum chamber
    - Reduce pressure until the LED comes on (altimeter attempts to fire an igniter)
    - Record pressure
- What can be Learned from Failure
    - If the altimeter attempts to fire the igniter at a significantly incorrect altitude, then it may have been damaged in a previous flight and should not be flown

7.1.1.2 Avionics Battery Test

- Success Criteria
    - Batteries are still capable of firing igniters after 3 hours of simulated pad time.
- Testing Variable
    - Battery types
    - Altimeter models
- Testing Methodology
    - Short drogue (or apogee) and main terminals
    - Charge batteries
    - Connect batteries to altimeters
    - Turn on altimeters
    - Wait for confirmation that they are in idle / pad mode (see launch procedures)
    - Wait at least 3 hours
    - Turn off altimeters
    - Attach two igniters to each altimeter
    - Connect altimeters to a computer with the correct control software
    - Fire igniters
- What can be Learned from Failure
    - If the igniters do not fire, then either lower-power altimeters or higher capacity batteries should be used

7.1.1.3 Ejection Ground Fire

- Success Criteria
    - Rocket separates energetically
    - Parachute is pulled out
    - Recovery harness fully extends
    - Parachute is undamaged
    - Airframe and bulkheads are undamaged
- Testing Variable
    - Ejection charge size
- Testing Methodology
    - Follow launch procedures to pack the parachute and prepare the ejection charges (prepare only the P1 (3.8 g) and P2 (4.7 g) charges)
    - Connect ejection cup wires to test harnesses
    - Run test harness leads out through vents holes
    - Place rocket outside
    - Connect launcher leads to test harness leads connected to the P1 charge
    - Stand as far back as possible
    - Use launcher to trigger ignition of ejection charge
    - Repack the parachute
    - Repeat steps above to fire the P2 charge
- What can be Learned from Failure
    - If one or both charges fail to separate the rocket, then they should be increased and the test repeated
    - If the parachute is damaged, then it should be replaced, and the parachute packing procedures should be altered

7.1.1.4 Flight Simulation

- Success Criteria
    - Projected altitude is close to (ideally above) 5,280 ft.
    - Rocket shows a stability margin between 2 and 4 throughout the ascent

- Rocket exceeds 52 ft/s at rail exit
  - Rocket does not exceed Mach 1
  - Kinetic energy of any section does not exceed 75 ft-lbs at landing
- Testing Variable
  - Rocket diameter
  - Nosecone shape
  - Fin size
  - Motor
  - Ballast mass
- Testing Methodology
  - Create rocket model in RockSim
  - Enter launch day conditions
  - Run simulation
  - Repeat (creating a new model to avoid compatibility issues) in OpenRocket
- What can be Learned from Failure
  - If the rocket is unstable, the fins can be made larger or the center of gravity can be moved forwards
  - If the rocket under- or over-shoots the target altitude the motor choice and ballast mass should be altered
  - If the rocket does not reach 52 ft/s at rail exit then either the mass should be reduced or a motor with a higher initial thrust should be used
  - If the rocket exceeds Mach 1, either the ballast mass should be increased, or a lower thrust motor should be used
  - If the kinetic energy of a section exceeds 75 ft-lbs at landing, either the parachute should be made larger or the mass of that section should be reduced
- Results
  - This test has been repeated numerous times to produce the current launch vehicle design. The primary design changes it has caused are changing the motor choice from an L1150 to an L1420 and changing the parachute from 12 ft to 14 ft

7.1.1.5 Motor Mount Test

- Success Criteria
  - Motor mount remains in place
  - No damage occurs
- Testing Variable
  - Weight
- Testing Methodology
  - Separate the booster section from the rest of the rocket
  - Place it upside down on hard level ground
  - Place a board on top of the motor mount
  - Slowly add weights to the board up to 350 lbs. WARNING: If the weights fall they could cause serious injury or damage the floor or nearby objects
- What can be Learned from Failure
  - If damage occurs, then the connection between the motor mount and the airframe is not strong enough. Reinforce the connection points with new epoxy clay fillets and repeat the test. If it still fails, remove the motor mount and reattach it with more well-filleted centering rings.

7.1.1.6 Parachute Unfurling Test

- Success Criteria
  - Parachute opens in under 4 seconds
- Testing Variable
  - Parachute packing methods
- Testing Methodology
  - Pack the parachute according to the launch procedures
  - Attach a moderately heavy weight to the parachute
  - Go to a high place such as a roof or deck
  - Throw the parachute and weight off of the roof / deck. WARNING: Make sure that no one is underneath the parachute's trajectory and that everyone nearby is aware of the test
  - Record how long it takes the parachute to unfurl

- What can be Learned from Failure
    - If the takes too long to unfurl, try a different packing method. If the unfurling time cannot be reduced, then the chute releases need to be set for a higher altitude

7.1.1.7 Push / Pull Test

- Success Criteria
    - No parts break
    - No parts move
- Testing Variable
    - Force
- Testing Methodology
    - WARNING: Wear safety glasses before conducting stress tests, as objects may fragment or come loose
    - Apply a substantial amount of force to all load-bearing joints and parts, including: fins, centering rings, bulkheads, threaded rods, ejection cups, U-bolts, swivels, quick links, and the nosecone. WARNING: Do not pull objects directly towards yourself, in case they come loose
- What can be Learned from Failure
    - If any parts or joints break, then they need to be redesigned to be stronger and similar parts should be carefully tested to make sure they don't break

7.1.1.7 Sectional Vibration Test

- Success Criteria
    - No damage occurs
- Testing Variable
    - Vibration force
- Testing Methodology

- Assemble each section of the rocket as for flight (without the motor and using sand or some other stand-in for the black powder) but do not connect the sections to each other
    - Vibrate each section
    - Fully disassemble the rocket and check for damage
- What can be Learned from Failure
    - If damage occurs or parts come loose (especially avionics and recovery system parts), find a better way to secure them and repeat the test

7.1.2 Payload Tests

Test Name	Test Objective(s)
Battery test	Ensure that the batteries will last through pad time and the flight
Data Transmission test	Ensure that the data is being received from the XBee and video transmission. Also, to ensure that the Arduino is receiving commands from the ground station
Nosecone ground fire	Ensure that the nosecone will separate with enough energy to clear the rocket as well as any possible debris in front of the nosecone
Nosecone impact test	Ensure that the nosecone can survive an impact from landing or ejection
Nosecone vibration test	Ensure that the nosecone can survive the motions of flight
Rover deployment test	Ensure that the rover will reliably be deployed from the nosecone
Rover impact test	Ensure that the rover can survive a fall onto the ground
Rover mobility test	Ensure that the rover can move over a variety of terrain
Rover position test	Test to make sure that the rover can determine its position to the rocket
Rover reorientation test	Ensure that the rover can reliably right itself from any orientation
Rover solar panel deployment	Ensure that the rover can deploy a foldable solar panel
Rover vibration test	Ensure that the rover can survive the motions of flight

Test Name	Test Objective(s)
Sensor detection	Ensure that the sensors are accurately reading the surrounding and that the program reacts correctly to the data

Table 7.2 - Payload Tests

7.1.2.1 Battery Test

- Success Criteria
    - The batteries last through:
        - 3 hours of idle (open relays, low power configuration of transmitters and sensors)
        - Movement of the righting mechanism to simulate a reorientation
        - 50 ft of driving
- Testing Variable
    - Battery drain
- Testing Methodology
    - Turn on the rover and time until 3 hours
    - Flip the rover upside down and initiate the righting mechanism program
    - Drive the rover 50 ft
- What can be Learned from Failure
    - Batteries do not have enough capacity and should be upgraded
    - A different configuration might be required to conserve power

7.1.2.2 Data Transmission

- Success Criteria
    - No packet loss
- Testing Variable
    - Reliability of connection over distance and flight conditions
- Testing Methodology
    - Establish data connection
    - Ensure data is being received

- Ensure commands are being received
- Repeat but over a distance of up to a mile
- Repeat but at a launch

- What can be Learned from Failure
  - What interferences are possible such as competing radio waves or terrain obstruction and mitigations for them such as changing antennas

7.1.2.3 Nosecone Ground Fire

- Success Criteria
  - Nosecone clears the payload tube with vigor
- Testing Variable
  - Ejection size
- Testing Methodology
  - Attach the nosecone to the rest of the rocket with a packed charge (done through procedures)
  - Attach leads to the igniters
  - Fire and see if enough the nosecone moves away from the rocket with enough energy to clear a path in front
- What can be Learned from Failure
  - The ejection charge is too little and should be increased

7.1.2.4 Nosecone Impact Tests

- Success Criteria
  - Nosecone sustains no damage
- Testing Variable
  - Structural integrity of the nosecone
- Testing Methodology
  - Do a ground fire with some debris obstructing the nosecone WARNING: Wear safety glasses before conducting impact tests, as objects may fragment or come loose

    - Drop test the nosecone WARNING: Make sure that no one is underneath the nosecone's trajectory and that everyone nearby is aware of the test
- What can be Learned from Failure
    - The weak points of the nosecone where supports should be added
    - The density of the nosecone is too light and should be increased

7.1.2.5 Nosecone Vibration Test

- Success Criteria
    - Nosecone sustains no damage
- Testing Variable
    - Structural integrity of the nosecone
- Testing Methodology
    - Vibrate the nosecone
- What can be Learned from Failure
    - Weak points of the nosecone where supports should be added

7.1.2.6 Rover Deployment Test

- Success Criteria
    - Rover deploys from the nosecone with little damage
- Testing Variables
    - Structural integrity of the rover
    - Reliability of deployment design
- Testing Methodology
    - Follow procedures to properly pack the rover and set the nosecone
    - Trigger it on level ground
    - Trigger it with debris or rough terrain in front
    - Trigger deployment from various orientations
- What can be Learned from Failure
    - Points of failure where design changes can be made

7.1.2.7 Rover Impact Test

- Success Criteria
    - The rover survives with no damage that prevents it from continuing
- Testing Variable
    - Rover structural integrity
- Testing Methodology
    - WARNING: Wear safety glasses before conducting stress tests, as objects may fragment or come loose
-
    - Turn on rover
    - Establish data connection
    - Drop test the rover WARNING: Make sure that no one is underneath the rover's trajectory and that everyone nearby is aware of the test
    - Repeat over several heights and terrains
- What can be Learned from Failure
    - What forces are absorbed, where they are absorbed and how they are absorbed and where supports need to be added

7.1.2.8 Rover Mobility Test

- Success Criteria
    - The rover is able to traverse a variety of terrains
- Testing Variable
    - Effectiveness of wheel design and drive system
- Testing Methodology
    - Set up rover per procedures
    - Drive 50 ft over level, soft, hard, wet, and rough terrain as well as small brush
- What can be Learned from Failure
    - What changes are required such that the rover can overcome all these terrains

7.1.2.9 Rover Position Test

- Success Criteria
    - The rover accurately determines its relative positions
- Testing Variable
    - Distance from the rocket
- Testing Methodology
    - Start the rover at a point
    - Instruct it to drive 5 ft, 10 ft, 25 ft, and 50 ft
    - At each milestone, it should send a message that it has reached that milestone
    - Compare declared distances to measured distances
- What can be Learned from Failure
    - Error margin of the rover and what programming compensations must be done
    - How far the rover should go to safely meet the required minimum of 5 ft

7.1.2.10 Rover Reorientation Test

- Success Criteria
    - The rover consistently returns itself to an upright position
- Testing Variable
    - Righting mechanism reliability
- Testing Methodology
    - Set the rover in an incorrect orientation
    - Allow it to determine its orientation and then move to right itself
- What can be Learned from Failure
    - What positions are recoverable and where designs need to be adjusted to account for that position
    - The strength of the solar panel bracket and the righting mechanism

7.1.2.11 Rover Solar Panel Deployment Test

- Success Criteria
  - The rover reliably unfolds the solar panel
- Testing Variable
  - Reliability of solar panel
- Testing Methodology
  - Turn on the rover
  - Initiate the unfolding of the solar panel
- What can be Learned from Failure
  - Under what conditions the rover cannot deploy its solar panel and how to adjust its code to accommodate that situation

7.1.2.12 Rover Vibration Test

- Success Criteria
  - The rover does not sustain any damage
- Testing Variable
  - Structural integrity of the rover
- Testing Methodology
  - Vibrate the rover
- What can be Learned from Failure
  - Weak points of the rover where supports should be added

7.1.2.13 Rover Sensors Test

- Success Criteria
  - The sensors give accurate readouts
- Testing Variable
  - Sensor accuracy
- Testing Methodology

- Change the environment and check to see that the sensor readout is accurate
    - Change the position of an object and see if the infrared sensor accurately detects the change
    - Change the pressure in a vacuum chamber with the rover inside and ensure the altimeter reads out the correct altitude associated with the changes in pressure
    - Change the orientation of the rover and check the IMU readouts are correct

- What can be Learned from Failure
  - The limitations and margins of error of the sensors and if the program needs to compensate in any way

7.1.3 Altitude Control System Tests

Test Name	Test Objective(s)
Battery test	Ensure that the batteries will last through pad time and flight
Exhaust velocity	Determine whether the ACS exhaust velocity is high enough to create a hazard
Mobile test	Test to see, while the rocket is suspended in the air, that the ACS causes movement in the rocket
Sensor detection	Ensure that the sensors are reading correct values and are reacting correctly to the readings
Solenoid reaction time	Test to see if the solenoids can react quickly enough to the commands of the Arduino
Tank drain	Test to see how long it takes to drain the tank of gas

Table 7.3 - ACS Tests

7.1.3.1 Battery Test

- Success Criteria
  - The ACS batteries can last through:
    - 3 hours of idle configuration
    - The solenoids doing 1 minute of continuous operation
    - The solenoids doing 1 minute of pulsed operation

- Testing Variable
    - Battery capacity
- Testing Methodology
    - Set the ACS on idle configuration and then time
    - Activate solenoids for 1 minute continuously
    - Repeat with new batteries but with 1 minute of pulsed operation
- What can be Learned from Failure
    - How long the solenoids and ACS can electronically run and if more battery capacity is required
    - If a more efficient configuration is possible or necessary

7.1.3.2 Exhaust Velocity

- Success Criteria
    - Determine whether the exhaust gas from the ACS poses a hazard
- Testing Variable
    - Tank pressure
- Testing Methodology
    - Pressurize the tank to flight pressure
    - WARNING: Safety glasses should be worn during this test! Keep out of the way of thrusters when they are firing
    - Secure test materials (such as paper and cloth) in front of the forward firing nozzles
    - Fire the forward thrusters
    - Turn off the ACS
    - Inspect the test materials for damage
    - If they are damaged, decide whether to proceed with caution when using the ACS or use a lower pressure
    - If using a lower pressure, update documentation and repeat this test to ensure that the new pressure is safe
- What can be Learned from Failure
    - Nothing (failure of this test means no useful data was collected)

7.1.3.3 Mobile Test

- Success Criteria
  - ACS causes noticeable movement in rocket
- Testing Variable
  - ACS design
- Testing Methodology
  - Assemble rocket as for flight (without energetics, but with the motor casing and payload)
  - Suspend the rocket (e.g. from the ceiling) so that it can swing forwards and backwards somewhat
  - Fire the rear facing thrusters, and note any movement of the rocket WARNING: Safety glasses should be worn during this test! Keep out of the way of thrusters when they are firing
  - Repeat with forward firing thrusters
  - Take rocket down
- What can be Learned from Failure
  - If there is no appreciable movement then the ACS needs to be modified in some way to increase the thrust (e.g. higher-pressure tank, different nozzle shape, etc.)

7.1.3.4 Sensor Detection

- Success Criteria
  - ACS control system can accurately predict apogee
- Testing Variable
  - Altitude prediction algorithm
- Testing Methodology
  - Program the ACS control system to attempt to predict the apogee throughout a flight and record those predictions
  - Fly the rocket
  - Compare the predictions to the actual altitude
- What can be Learned from Failure
  - If the predictions are far off the correct value, the algorithm needs to be changed or the ACS won't be effective

7.1.3.5 Solenoid Reaction Time

- Success Criteria
    - Arduino can toggle the solenoids in 0.1 s
- Testing Variable
    - Delay time
- Testing Methodology
    - Connect all components of ACS control system together (except the barometer)
    - Program the Arduino to open and close the solenoids every 0.1 s
    - Start the program and film the solenoids with a high-speed camera
    - Review the footage to see what the response time is
- What can be Learned from Failure
    - If the response time is slow, that must be taken into consideration when writing the ACS control program

7.1.3.6 Tank Drain

- Success Criteria
    - Thrust results are similar to predictions
- Testing Variable
    - Tank pressure
- Testing Methodology
    - Prepare the ACS as per the launch procedures, filling the tank to half flight pressure
    - Place the booster section of the rocket on a scale and tare it
    - Open the forward thrusters and let the tank drain, recording the peak and average thrust WARNING: Safety glasses should be worn during this test! Keep out of the way of thrusters when they are firing
    - Record the amount of time it took to empty
    - Refill the tank, flip the booster section and repeat, this time opening the rear-facing thrusters
    - If the test data matches up with predictions, repeat the test with full flight pressure
- What can be Learned from Failure

- If the tank drain time or thrust values differ significantly from predictions, either identify the error in the predictions or repeat this and other ACS tests and work off or empirical values

7.2 Requirements Compliance

The following sections identify the verification plans for all the requirements set forth in the USLI handbook as well as those defined by the team. The team defined requirements will discuss not only each requirement and associated verification plan, but also the reason that each requirement was imposed and what team goal it pertains to.

7.2.1 NASA Defined Requirements

ID refers to the requirement's ID in the handbook.

ID	Verification Type	Verification Plan
1.1	Demonstration	The team's mentor has been made aware of his responsibilities and restrictions
1.2	Demonstration	The team's project manager is maintaining a project plan that includes milestones, team activities, and other dates (see section 7.4 Timeline) and a list of personnel assignments; the treasurer is maintaining a current budget and funding plan (see section 7.3 Finance); the director of engagement & outreach is maintaining a plan for the team's engagement & outreach activities, as well as recording progress toward engagement goals (see section 7.5 Engagement and Outreach Plan); and the safety officer is maintaining a list of hazards and mitigations, and is working with the launch vehicle and payload leaders to develop checklists for testing and launch operations (see section 5 Safety)
1.3	Demonstration	The contact information for all foreign nationals has been submitted
1.4	Demonstration	A definitive list of team members going to launch week is included in section 1 General Information and their information has been submitted
1.5	Demonstration	Over 430 participants have been engaged in hands-on, educational activities (see section 7.5 Engagement and Outreach Plan)
1.6	Demonstration	The team has created a website for document hosting and community engagement (piedmontlaunch.org)
1.7	Demonstration	All deliverables will be posted on the team's website, both on the home page and on a documents page which includes historic documents
1.8	Demonstration	All deliverables will be converted to PDF format before submission

ID	Verification Type	Verification Plan
1.9	Demonstration	All reports will include a table of contents with three levels of section headings added during document assembly
1.10	Demonstration	All reports will have page numbers at the bottom of the page added during document assembly
1.11	Demonstration	Tiger Fuel Co., one of PSLT's primary sponsors, has provided the use of their conference room for both teleconference reviews and practice presentations
1.12	Demonstration	The launch vehicle is designed to use 1515 rails
1.13	Demonstration	PSLT's webmaster has implemented these standards and will continue to ensure they are in place on the team's website
1.14	Demonstration	The team's mentor has been identified in section 1.1 Team Contacts and is aware of all of his responsibilities
2.1	Analysis, Testing	The launch vehicle's ability to carry the payload to 5,280 ft has been analyzed using RockSim and OpenRocket, and will be tested during full-scale test flights
2.2	Demonstration	The recovery system includes a commercially available, barometric altimeter to be used as the scoring altimeter on launch day
2.3	Demonstration	The recovery system includes two externally accessible switches, one to arm each altimeter
2.4	Demonstration	The recovery system includes two batteries, one for each altimeter
2.5	Demonstration	The arming switches in the recovery system are keyed to prevent them from being deactivated by flight forces
2.6	Analysis, Testing	The director of testing & analysis will lead analysis of the forces on the launch vehicle to ensure that it is able to withstand them, as well as developing testing plans for both the subscale and full-scale launch vehicles to be implemented prior to their first test flights (see section 7.4 Timeline and section 7.1 Testing)
2.7	Demonstration	The launch vehicle is designed to separate into only two independent sections, which will be tethered together
2.8	Demonstration	The launch vehicle design has only a single stage utilizing only one motor
2.9	Demonstration	The launch vehicle is designed such that the separate sections of it can be prepared for flight in parallel, allowing it to be readied within three hours of the FAA waiver opening (to be demonstrated during full-scale test flight)
2.10	Analysis, Testing	Calculations will be performed on all time sensitive systems on the launch vehicle, particularly the recovery system, to ensure that they are able to remain in launch-ready configuration for at least one hour. Testing to ensure these systems are able to do that will be included in the subscale and full-scale test plans (see section 7.1 Testing)
2.11	Demonstration	The launch vehicle design allows the motor to be directly connected to a standard firing system and requires no other hardware to initiate launch
2.12	Demonstration	The launch vehicle design requires no external circuitry or special ground support equipment to initiate launch
2.13	Demonstration	The launch vehicle design uses a commercially available, Ammonium Perchlorate Composite Propellant (APCP) motor

ID	Verification Type	Verification Plan
2.14.1	Demonstration	The launch vehicle design uses one pressure vessel. The model purchased has a factor of safety of 6.4 at the pressure it will be operated at (see section 4.1.2.5.1 Propellant Tank)
2.14.2	Demonstration, Analysis	The launch vehicle design includes a pressure relief valve which is documented as seeing the full pressure of the included pressure vessel and being capable of withstanding the maximum pressure and flow rate of that vessel (see section 4.1.2.5.1 Propellant Tank)
2.14.3	Demonstration	The Safety Officer will ensure that the full pedigree of the pressure vessel used in the rocket is recorded and included in all following reports
2.15	Demonstration	The launch vehicle design uses a motor that has less than 5,120 N-s of impulse
2.16	Analysis	RockSim and OpenRocket simulations have been done on the launch vehicle design to ensure that the static stability margin at rail exit is above 2.0 (see section 4.4 Mission Performance Predictions)
2.17	Analysis, Testing	RockSim and OpenRocket simulations have been done on the launch vehicle design to ensure that velocity at rail exit is above 52 ft/s (see section 4.4 Mission Performance Predictions). Additionally, the velocity at rail exit will be measured during the full-scale test flight
2.18	Demonstration	A subscale model has been flown (see section 4.2 Subscale Flight Results)
2.18.1	Demonstration	The subscale closely resembled the full-scale rocket with only a few differences (see section 4.2 Subscale Flight Results)
2.18.2	Demonstration	The subscale rocket carried two altimeters to report the apogee as well as other flight data (see section 4.2 Subscale Flight Results)
2.19	Demonstration	Construction of the full-scale rocket has begun and is largely completed, and construction of the payload will begin shortly after the submission of this document (see section 7.4 Timeline)
2.19.2	Demonstration	The full-scale payload will be flown on the full-scale test flight(s)
2.19.3	Demonstration	The altitude control system, the only system that affects the energy of the launch vehicle in flight, will be flown on the full-scale test flight(s)
2.19.4	Demonstration	The full-scale motor will be used for all full-scale test flights to ensure that the data gathered is as accurate as possible
2.19.5	Demonstration	Any ballast used will not be changed after the full-scale test flight; although, there is not currently any expectation that ballast will be required
2.19.6	Demonstration	None of the components of the launch vehicle will be changed after the full-scale test flight unless for safety purposes
2.19.7	Demonstration	The first full-scale test flight is scheduled for well before FRRs are submitted (see section 7.4 Timeline)
2.20	Demonstration	The launch vehicle design does not have any structural protuberances fore of the burnout CG (see section 4.1 Design and Verification of Launch Vehicle)
2.21 - 2.21.8	Analysis, Demonstration	The design of the launch vehicle does not include forward canards, forward firing motors, motors that expel titanium sponges, hybrid motors, motor clusters, or friction fitting of motors, and the total ballast used is less than 10% of the total mass of the launch vehicle. RockSim and OpenRocket

ID	Verification Type	Verification Plan
		simulations have been done to ensure the launch vehicle design does not exceed Mach 1 at any point in flight (see section 4.4 Mission Performance Predictions)
3.1	Demonstration	The launch vehicle design has both apogee separation and main parachute deployment staged by onboard altimeters
3.2	Demonstration	Ground ejection tests are included in the set of tests for prior to both the subscale and full-scale launches (see section 7.1 Testing)
3.3	Analysis, Testing	RockSim and OpenRocket simulations have been done to determine the velocity at landing of the launch vehicle design, which has been used to ensure that the highest kinetic energy of any section is below 75 ft-lbf (see section 4.4 Mission Performance Predictions). Additionally, the velocity at landing will be measured for the full-scale test flight(s)
3.4	Demonstration	The recovery system design does not share any electronics with the payload design (see section 4.3.2 Electronics Design)
3.5	Demonstration	All recovery system electronics are powered by commercially available batteries (see section 4.3.2 Electronics Design)
3.6	Demonstration	The recovery system has not only redundant altimeters, but has redundancy for all components (see section 4.3 Recovery Subsystem)
3.7	Demonstration	The recovery system design does not utilize motor ejection (see section 4.3.1.4 Ejection)
3.8	Demonstration	The recovery system design uses nylon shear pins to secure the parachute compartment (see section 4.1.2.6 Integrated Design)
3.9	Analysis, Testing	RockSim and OpenRocket simulations and hand calculations have been done with the launch vehicle design to ensure that the rocket will not drift more than 2,500 ft from the launch pad (see section 4.4 Mission Performance Predictions). Additionally, the distance that the rockets drift will be measured for both the subscale and full-scale test flights
3.10	Demonstration	The payload includes a GPS module that will be used to track the position of the rover, and thereby the rocket, during flight (see section 6.2.5 Electronics)
3.11.1	Demonstration	The recovery system electronics are in a separate compartment from any other electronics with the exception of a pair of switch wires for the payload
3.11.2	Demonstration	The recovery system electronics will be shielded from the payload, which has the only transmitting device on the rocket
3.11.3	Demonstration	The recovery system electronics will be shielded from the solenoid valves used in the ACS and the solenoid used in the payload
3.11.4	Demonstration	The recovery system electronics will be shielded from all other onboard electronics
4.1	Demonstration	PSLT has selected the deployable rover challenge
4.2	Demonstration	No other challenges have been selected
4.3	Demonstration	See 4.2 above
4.5.1	Demonstration	The rover design remains entirely enclosed within the airframe of the launch vehicle until deployment

ID	Verification Type	Verification Plan
4.5.2	Demonstration	The rover design includes a transceiver so that deployment can be remotely triggered
4.5.3	Inspection	The rover will use an onboard GPS module to detect its distance from the rocket. Additionally, when the rover is recovered, that distance will be measured
4.5.4	Inspection	When the rocket is being recovered, the solar panel on the rover will be inspected to ensure that it has opened
5.1	Demonstration	The Safety Officer will work with the payload and launch vehicle leaders to develop the launch operations procedures that will be used for all launches and that will be included in the FRR and LRR (see section 5.1 Launch Concerns and Procedures)
5.2	Demonstration	PSLT has designated a Safety Officer (see section 1.1 Team Contacts)
5.3 - 5.3.4	Demonstration	The Safety Officer has been made aware of his responsibilities and they are included in the team handbook
5.4	Demonstration	All team members have been made aware of the rules regarding all launches. Additionally, the Safety Officer and deputy Safety Officer will ensure that all team members abide by those safety rules and will brief team members on all such rules before any event
5.5	Demonstration	The Safety Officer's responsibilities include understanding and ensuring compliance with all relevant FAA rules and regulations

Table 7.4 - Verifications for NASA Defined Requirements

7.2.2 Team Defined Requirements

The following tables discuss requirements defined by PSLT beyond those included in the handbook.

7.2.2.1 Launch Vehicle

Requirement	Purpose	Verification Type	Verification Plan
The rocket achieves an altitude within 100 ft of 5280 ft	To demonstrate the capability of the altitude control system	Analysis Demonstration Inspection	The capabilities of the altitude control system have been estimated through calculations (see section 4.4.3 ACS Predictions). This capability will also be demonstrated during the full-scale test flight(s), and the final result will be determined on launch day by an inspection of the altitude reached
Use a 1515 launch rail	To ensure the launch rail used is able to support	Demonstration	The design of the launch vehicle includes 1515 rail buttons for launch support

Requirement	Purpose	Verification Type	Verification Plan
	the weight of the rocket		
Use a 12 ft launch rail	To increase the stability of the rocket off the launch rail	Demonstration	A 12 ft or longer launch rail will be requested at all launches
Have a static stability margin under 4	To prevent the rocket from being over-stable and going off-course or losing excessive altitude due to weather cocking	Analysis	The static stability margin is under 4 (see section 4.4 Mission Performance Predictions)

Table 7.5 - Verifications for Team Defined Launch Vehicle Requirements

7.2.2.2 Payload

Requirement	Purpose	Verification Type	Verification Plan
The rover is able to move even if one wheel motor fails	To ensure the rover is robust and able to move the required 5 ft from the rocket	Testing	The rover's ability to move with any motor disabled will be included in the test set for the payload (see section 7.1 Testing)
The rover is able to traverse different soil types including at a minimum hard packed dirt, loose dirt, and mud	To ensure the rover is versatile and able to move the required 5 ft from the rocket	Testing	The rover's ability to traverse different soil types will be included in the test set for the payload (see section 7.1 Testing)
The rover is able to traverse different terrain types including at a minimum furrowed ground, flat ground, and swampy ground	To ensure the rover is versatile and able to move the required 5 ft from the rocket	Testing	The rover's ability to traverse different terrain types will be included in the test set for the payload (see section 7.1 Testing)
The rover is able to be deployed regardless of how the rocket lands	To ensure the rover is versatile and able to be deployed	Testing	The rover's ability to be deployed in suboptimal landing conditions will be included in the test set for the payload (see section 7.1 Testing)

Requirement	Purpose	Verification Type	Verification Plan
The rover is able to fit within a 6 in. body tube	To prevent the launch vehicle from having so much drag that it cannot reach one mile on an L-class motor	Demonstration	The rover design is capable of fitting within a 6 in. body tube
The rover and deployment system are able to withstand high forces applied to the front or back	To ensure the rover and deployment system are robust and able to withstand the forces of ejection and any following impacts	Analysis Testing	Simulations will be done to ensure the payload design is able to withstand the required forces. Additionally, the payload's ability to withstand the required forces will be included in its test set (see section 7.1 Testing)
The rover is able to detect and avoid obstacles	To ensure the rover does not become stuck and is able to move the required 5 ft from the rocket	Testing	The rover's ability to avoid obstacles will be included in the test set for the payload (see section 7.1 Testing)
The rover is able to detect when it is 5 ft from the launch vehicle	To ensure that the rover is the required 5 ft from the rocket when the solar panel deploys	Testing	The rover's ability to detect its distance from rocket will be included in the test set for the payload (see section 7.1 Testing)
The rover stores enough power to be able to remain in standby mode on the launch pad for at least two hours	To ensure that the rover is still functional even if there is a long wait on the launch pad after it has been activated	Testing	The rover's ability to remain in standby mode for two hours will be included in the test set for the payload (see section 7.1 Testing)

Table 7.6 - Verifications for Team Defined Payload Requirements

7.2.2.3 Recovery System

Requirement	Purpose	Verification Type	Verification Plan
Have a 99.99% or higher confidence that the launch vehicle will recovery safely	To ensure the rocket is able to be safely recovered	Demonstration	A sufficient number of recovery system tests will be performed to ensure a 99.99% or higher confidence of safe recovery (see section 7.1 Testing)
The recovery harness will have redundant attachment points at both ends	To reduce the load on either attachment point to decrease the risk of failure and to prevent unsafe return if one attachment point fails	Demonstration	The recovery system design utilizes two U-bolts at each end of the recovery harness (see section 4.3.1.3 Mounting Points)
The recovery system will utilize four, redundant ejection charges	To ensure separation of the rocket to prevent a ballistic return because of the use of only one point of separation	Demonstration	The recovery system design utilizes four, redundant ejection charges (see section 4.3.1.4 Ejection)
The recovery harness is able to withstand at least twice the amount of force applied to it during main parachute deployment	To ensure an adequate margin of safety	Analysis Testing	Once the force applied at main parachute deployment is determined, the recovery harness material will be tested to ensure that it is able to withstand that force
Utilize a “cannon” design where the parachute is stored between the ejection charges and the end of the body tube that it exits through	To ensure the parachute is properly deployed by having it pushed out of the parachute tube by the ejection charges rather than relying on the inertia of any section	Demonstration	The recovery system utilizes this type of design (see section 4.3 Recovery Subsystem)

Table 7.7 - Verifications for Team Defined Recovery System Requirements

7.2.2.4 Safety

Requirement	Purpose	Verification Type	Verification Plan
Establish an accident reporting system in case anyone is injured	To promote the culture of safety within the team	Demonstration	The safety officer is working with the team leader to develop an accident reporting system
Ensure all team members are trained to use any equipment that is necessary for their job	To prevent injury to team members	Demonstration	A list will be kept of what equipment each team member is trained to use, which the safety officer will have at any time that personnel might need to use that equipment

Table 7.8 - Verifications for Team Defined Safety Requirements

7.2.2.5 General

Requirement	Purpose	Verification Type	Verification Plan
Engage a minimum of 600 participants in hands on STEM related activities	To spread STEM education	Demonstration	PSLT's director of engagement & outreach is responsible for planning all engagement events, keeping track of the number of people engaged at each event, and writing engagement reports
Reach a minimum of 2000 people to inform them of SL and STEM opportunities	To spread STEM education	Demonstration	PSLT's director of engagement & outreach is responsible for planning all engagement events, keeping track of the number of people engaged at each event, and writing engagement reports
Provide the opportunity for team members to become level one or two high-power certified	To allow team members to be able to gain additional experience with high-power rocketry	Demonstration	PSLT's mentor and several team members are level one or two certified, and so are able to certify other team members that are interested

Table 7.9 - Verifications for Team Defined General Requirements

7.3 Finance

7.3.1 Budget

Item	Vendor	Qty	Cost (including tax and shipping)
Airframe Tube	Madcow Rocketry	All	$239.76
5.5 in. x 5.5 in. x 0.125 in. TTW G10 Fins	Giant Leap Rocketry	4	$156.32
J540R Motor Reload	Sirius Rocketry	1	$136.44
Motor Retainer	Aero Pack	1	$65.68
Coupler Bulkhead	Madcow Rocketry	2	$14.31
Tube Bulkhead	Madcow Rocketry	1	$6.73
Jolly Logic Chute Release	AMW ProX	1	$114.52
RRC3 Sport Altimeter	Apogee Components	1	$73.11
Altus Metrum Easy Mega Flight Computer	AMW ProX	1	$312.48
1/4'' Quick Link	Tractor Supply	5	$7.64
7 ft TAC-1 Parachute	Giant Leap Rocketry	1	$151.64
Recovery Harness	Giant Leap Rocketry	6 yd	$18.43
U-Bolt 3/8 in.	Tractor Supply	4	$12.17
6in. Parachute Protector	Apogee Components	1	$9.89
Swivel	Tractor Supply	3	$7.65
GPS	Missileworks	1	$90.19
Assorted Hardware	Various	All	$37.22
Total			$1,454.18

Table 7.10 - Subscale Budget

Item	Vendor	Qty	Cost (including tax and shipping)
Airframe Tube	Madcow Rocketry	All	$465.22
8.5 in. x 8.5 in. x 0.25 in. TTW G10 Fins	Giant Leap Rocketry	4	$156.32
L1420 R-P Motor Reload	Sirius Rocketry	2	$491.22
Motor Retainer	Aero Pack	1	$76.87
Coupler Bulkhead	Madcow Rocketry	2	$19.36
Tube Bulkhead	Madcow Rocketry	1	$10.96
90 deg Brake Line Fittings (Thruster Nozzles)	MSC Industrial Supply	8	$17.55
Ninja Aluminum Compressed Air Tank	Amazon	1	$150.95

Item	Vendor	Qty	Cost (including tax and shipping)
Jolly Logic Chute Release	AMW ProX	1	$114.52
RRC3 Sport Altimeter	Apogee Components	1	$73.11
Altus Metrum Easy Mega Flight Computer	AMW ProX	1	$312.44
1/4’’ Quick Link	Tractor Supply	5	$7.64
14 ft, standard, low-porosity, 1.1 rip-stop Parachute	Rocketman	1	$167.45
Recovery Harness	Giant Leap Rocketry	10 yd	$47.34
U-Bolt 3/8 in.	Tractor Supply	4	$12.17
Sunward 18 in. Parachute Protector	Apogee Components	1	$14.43
Swivel	Tractor Supply	3	$7.65
GPS	Adafruit	1	$40.22
Arduino	Arduino	2	$44.51
IMU	Adafruit	1	$36.77
IR sensor	Adafruit	1	$15.98
Altimeter	Adafruit	1	$10.81
Xbee	Digi-Key	1	$53.11
FPV camera	Lumenier	1	$54.29
FPV transmitter+antenna	Lumenier	1	$40.14
Assorted Parts (jumper wires, resistors, etc.)	Various	All	$22.86
50MM Linear Actuator	Robotshop	1	$90.89
Electrical Motor	Amazon	1	$16.99
Electric Stepper Motor	Sparkfun	8	$119.60
Solar Panel Bracket	Midwest	1	$24.58
Righting Mechanism	Midwest	1	$22.23
Rover Frame	Midwest	1	$13.62
Solar Panel	Amazon	1	$8.43
Springs	Amazon	1	$5.73
Pack of 12 3/8’’-24 Fittings for 3/16’’ tube	Amazon	1	$8.24
LTW Fitting Glass 3000 Stainless Steel 316 Pipe Hex Nipple Fitting 3/8’’ Male NPT Air Fuel Water (Pack of 5)	Amazon	1	$13.49
Ninja Paintball Microbore Remote	Amazon	1	$37.95
Robert Manufacturing R209 Series Bob Brass Adapter, 3/8’’ NPT Male x 1/8’’NPT Female	Amazon	1	$5.73

Item	Vendor	Qty	Cost (including tax and shipping)
Anderson Metals 56110 Brass Pipe Fitting, Hex Bushing, ½ ''NPT Male Pipe x3/8''NPT Female Pipe	Amazon	5	$22.75
Assorted Hardware	Various	All	$37.22
Total			$2,891.34

Table 7.11 - Full-Scale and Payload Budget

The above expenses have already been incurred, and no significant additional development expense is expected.

The team's current budget balance of $6,854 will be sufficient to cover the Launch Week attendees' lodging costs with a $40 per diem for meals and other expenses. Team members are required to cover their own travel costs for the seven hour drive to Huntsville.

7.3.2 Funding Plan

PSLT added two new funding sources since the PDR since the team is now coordinating with two schools for paid educational rocket classes. One is with PVCC summer kids' camp. The other is with the Community Homeschool Enrichment Center (CHEC), a homeschool-based nonprofit organization. Team members are currently running a regular class for ten students from 11:00 AM to 12:30 PM on each Friday through the winter session, receiving $1,100 in tuition payments. This has the potential to be a sustainable educational business, as CHEC would like to continue this partnership in the upcoming spring session.

As noted in the PDR, PSLT has three primary funding sources: PVCC, local corporate sponsors, and individual donors. PSLT has already received $5,000 from PVCC. PVCC is also willing to make further contributions for the success of the project in other areas. Tiger Fuel Company and OFM Computer Systems are the primary local corporate sponsors, and the team will soon be partnering with a new local business, Snowing in Space Coffee, which sells nitro-infused cold-brew coffee. Notably, Tiger Fuel Company has agreed to pick up any shortages in the team's budget. In addition to financial sponsorship, Tiger Fuel Company also provides a conference room, file sharing software, and variety of other services. OFM offers technical support, such as web hosting and a server for the team's project wiki.

7.4 Timeline

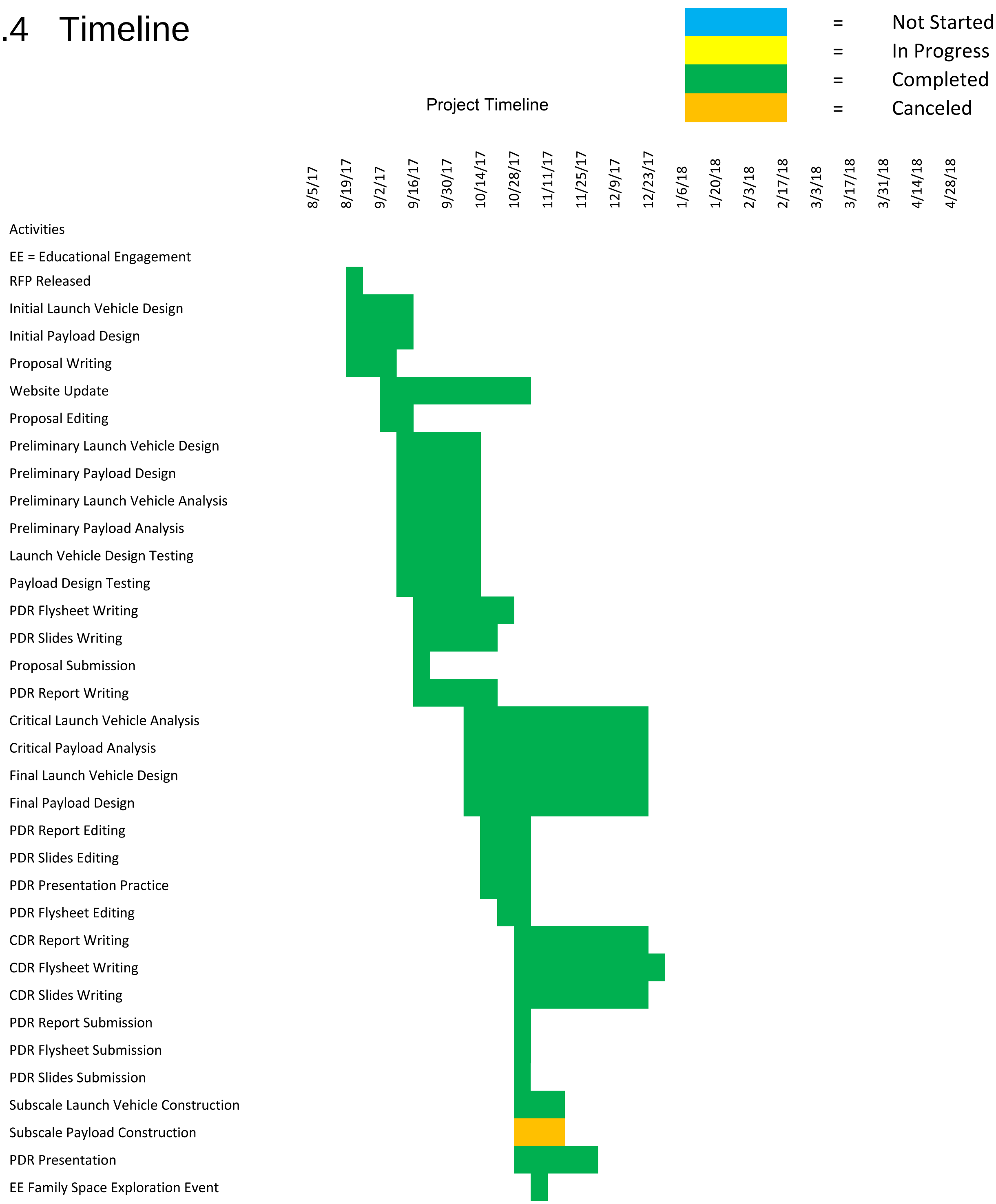

Figure 7.1 - Project Timeline Part 1

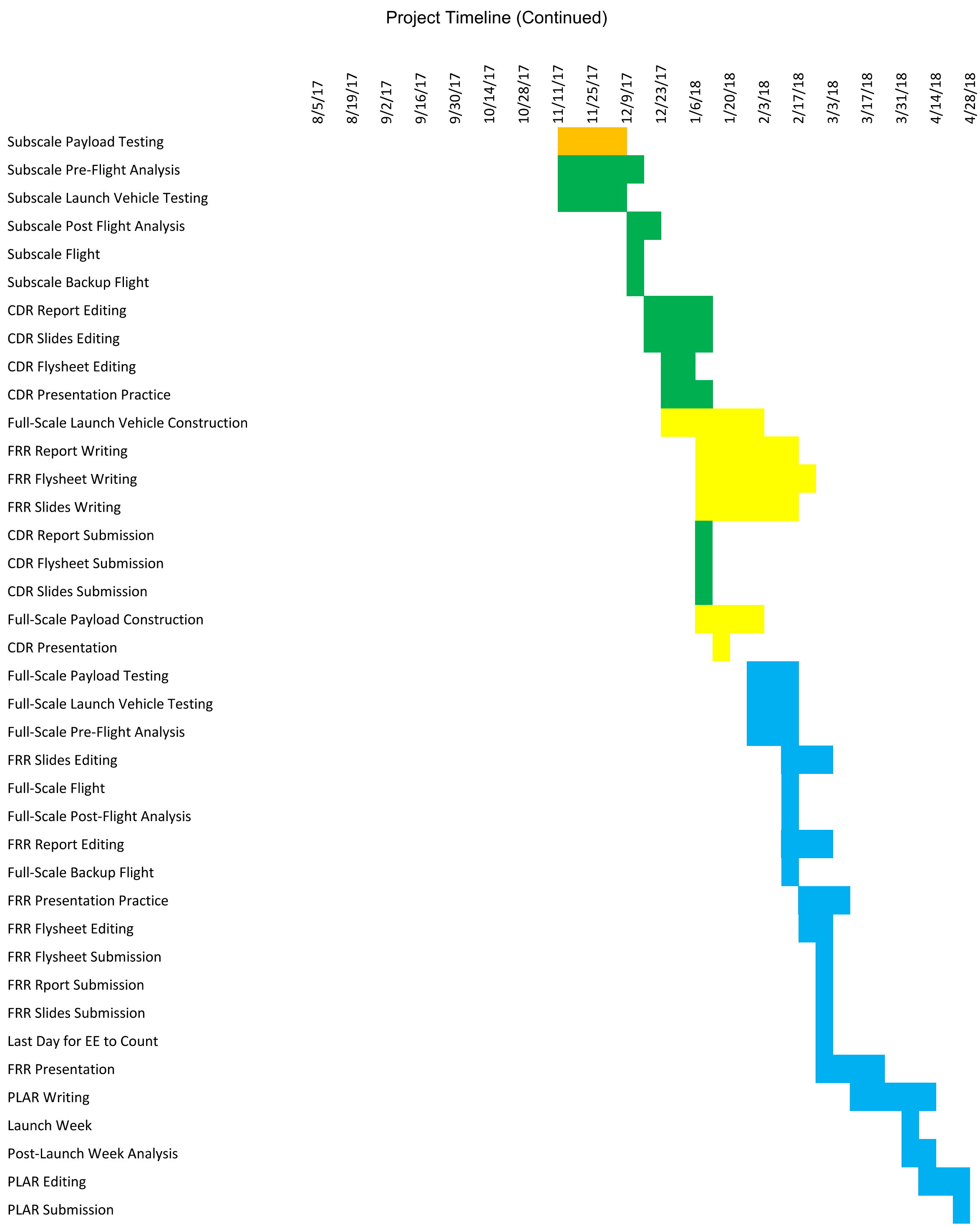

Figure 7.2 - Project Timeline Part 2

The dates provided on the project timeline indicate the date of the left of the two columns that they are above, and that all dates are the Saturday closest to when the beginning or end of an item is.

7.5 Engagement and Outreach

Since the PDR, the Piedmont Student Launch Team educational and outreach sub-team has mostly focused on the FSEE and Girls Geek Day classes. In November, PSLT hosted a 200+ person event featuring former astronaut Dr. Kathryn Thornton and The National Radio Astronomy Observatory's Dr. Matthew Morgan as speakers. Also in November, PSLT taught several 50-minute classes at a monthly women-in-STEM program for elementary school girls. This program, Girls Geek Day, is hosted by a local women-in-STEM organization, Charlottesville Women in Tech.

Currently, the PSLT education and outreach sub-team is reaching out to the local branch of the International Rescue Committee (IRC) and is in the prosses of developing a STEM education program for children of refugees and children who are refugees. Although developing this program will be the primary focus of the PSLT educational team, they will also be teaching at Girls Geek Day and a local cooperative homeschooling center. The PSLT educational sub-team will also be partnering with local public schools and youth programs in single day STEM-related events, demonstrations, workshops, and panels. PSLT is planning on partnering with local chapters of the Boys and Girls Club and Big Brothers Big Sisters.

In July, PSLT will be partnering with Piedmont Virginia Community College to teach a week-long workshop-style class for 6 to 9 year-olds. In this class, as with the homeschool class, PSLT will be teaching children basic principles of physics and rocketry, as well as building rockets.