Piedmont Student Launch Team

2018 NASA Student Launch
Preliminary Design Review

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

November 3, 2017

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Glossary of Acronyms

PSLT	-	Piedmont Student Launch Team
PVCC	-	Piedmont Virginia Community College
TRA	-	Tripoli Rocketry Association
AGL	-	Above Ground Level
VAST	-	Valley AeroSpace Team
NOVAAR	-	Northern Virginia Association of Rocketry
NAR	-	National Rocketry Association
STEM	-	Science, Technology, Engineering, and Mathematics
IRC	-	International Rescue Committee
ABS	-	Acrylonitrile Butadiene Styrene
FMEA	-	Failure Modes and Effects Analysis
APCP	-	Ammonium Perchlorate Composite Propellant
GPS	-	Global Positioning System
LiDAR	-	Light Detection And Ranging
IMU	-	Inertial Measurement Unit
DOF	-	Degrees Of Freedom
IR	-	Infrared
FAA	-	Federal Aviation Administration
FSEE	-	Family Space Exploration Event
CHEC	-	Community Homeschool Enrichment Center
CG	-	Center of Gravity
CP	-	Center of Pressure

1 General Information

1.1 Team Contacts

Name	Title	Email	Telephone
Dr. Yanina Goddard	Professor of Physics	ygoddard@pvcc.edu	434-961-5341
David Oxford	Team Mentor	david@oakhaven.org	434-996-9131
Andrew Oxford	Team Leader	leader@piedmontlaunch.org	434-996-4658
Troy Dodd	Safety Officer	safety@piedmontlaunch.org	434-953-6901

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 21 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
Alex	Deputy Safety Officer Webmaster	Safety Payload Launch Vehicle	Electronics Programming Structural Analysis
Andrew	Team Leader & Project Manger	Administrative	None
Anna	Director of Testing & Analysis	Launch Vehicle Payload	Analysis
D'Ann	Director of Social Media	Engagement & Outreach	Communications
Jesse	Director of Engagement & Outreach	Engagement & Outreach Payload	Outreach Education
Lu	Treasurer	Administrative Engagement & Outreach	Structural Education Outreach Communications
Rodney	Launch Vehicle Leader	Launch Vehicle	Structural Analysis
Michael	Deputy Launch Vehicle Leader	Launch Vehicle	Structural Analysis
Sander	Payload Leader	Payload	Electronics
Troy	Safety Officer Director of Art	Safety Launch Vehicle	Structural Graphic Arts

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
Branson	Launch Vehicle	Structural
Carl	Launch Vehicle Payload	Electronics Structural
Chris	All	Graphic Arts
Daniel	Launch Vehicle Payload	Electronics Structural
James	Launch Vehicle Administrative	Electronics Structural
Nathanael	Launch Vehicle Engagement & Outreach Payload	Electronics Structural Communications
Nelly	Launch Vehicle	Communications
Shane	Launch Vehicle Payload	Electronics Programming Structural
Sophia	Launch Vehicle Payload Engagement & Outreach	Structural Analysis Education Outreach Communications
Victoria	Launch Vehicle Engagement & Outreach Administrative	Structural Analysis Education

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

Statistic	Value
Diameter (in.)	6.17
Length (in.)	90
Mass without motor (lbs)	23.63
Rail exit velocity (ft/s)	77.7
Static stability margin	2.38
Motor selection	Aerotech L1150
Parachute diameter (ft)	12
Recovery harness length (ft)	24
Altitude control system	Cold gas thrusters

Table 2.1 - Launch Vehicle Information

2.3 Payload

PSLT is doing 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 Since Proposal

3.1 Launch Vehicle Criteria

- The altitude control system will utilize cold gas thrusters capable of either accelerating or decelerating the launch vehicle as needed after motor burnout to allow for better precision of altitude control and the ability to compensate for some degree of variability in motor performance (see section 4.1.3.2 Altitude Control System)

3.2 Payload Criteria

- The rover will utilize figure-eight shaped wheels (infinity wheels) to allow it to traverse rugged terrain better, to fit more easily inside the launch vehicle, and to eliminate issues with running the wheels backward
- The rover will have six wheels to even out the rocking induced by the infinity wheel design and to provide more redundancy in case of motor failure

3.3 Project Plan

- PSLT will be partnering with the Charlottesville IRC to encourage STEM in the local refugee community (see section 7.5 Engagement & Outreach Plan)

4 Launch Vehicle Criteria

4.1 Selection, Design, and Rationale

4.1.1 Mission Statement and Success Criteria

4.1.1.1 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 the apogee, while allowing the rocket to safely return to the ground in a way such that the payload may be safely deployed.

4.1.1.2 Success Criteria

- The rocket achieves an altitude within 100 ft of 5,280 ft
- No section of the rocket lands with a kinetic energy greater than 75 ft-lbs
- The launch vehicle is recovered undamaged

4.1.2 System Designs

4.1.2.1 Airframe

The major design alternatives are listed below, grouped by what section of the airframe they are part of.

4.1.2.1.1 Overall

Material	Pros	Cons
G12 Fiberglass	Cheaper than carbon fiber Stronger than phenolic paper	Heaviest Hazardous
Carbon Fiber	Stronger than fiberglass and phenolic paper Lighter than fiberglass	More expensive than fiberglass or phenolic paper Difficult to work with
Phenolic Paper	Lighter than carbon fiber or fiberglass Cheaper than carbon fiber or fiberglass	Significantly less durable than carbon fiber or fiberglass

Table 4.1 - Launch Vehicle Material Options

Criteria (weight)	Fiberglass	Carbon Fiber	Phenolic Paper
Cost (x1)	3	1	4
Complexity (x1)	3	1	4
Durability (x3)	4	4	1
Weight (x2)	2	3	4
Total	22	20	19

Table 4.2 - Launch Vehicle Material Decision

A large diameter launch vehicle was preferred to provide as much space as possible for the payload. There are three main alternatives for launch vehicle diameter / shape that allow a large amount of space for the payload: a 6 in. diameter, a 6 in. diameter lower section with a transition to an 8 in. diameter upper section, or an 8 in. diameter.

Shape	Pros	Cons
6 in.	Least drag Least weight	Least space for payload
6 in. with 8 in. Upper Section	More space for payload Less weight than a fully 8in launch vehicle	Higher weight High drag
8 in.	More space for payload	Highest weight High drag

Table 4.3 - Launch Vehicle Diameter Options

Criteria (weight)	6 in.	6 in. with 8 in. Payload Section	8 in.
Cost (x1)	3	2	1
Weight (x2)	3	2	1
Complexity (x2)	4	3	4
Payload Space (x3)	2	4	4
Drag (x3)	3	1	1
Total	32	27	26

Table 4.4 - Launch Vehicle Diameter Decision

4.1.2.1.1 Booster Section

The booster section houses the motor mount and fins, and is connected to the avionics bay.

Number of Fins	Pros	Cons
3	Lower drag Lower weight Less construction and installation time	Harder to align evenly on the booster section Larger angle between fins creates a greater risk of breaking when setting the rocket down without a stand
4	Increased stability Easier to align evenly on booster section Fins are less likely to break when setting the rocket down without a stand	More drag More weight More construction and installation time
5+	Aesthetics	Even more drag Even more weight Even higher construction and installation time

Table 4.5 - Fin Number Options

Criteria (weight)	3 Fins	4 Fins	5+ Fins
Cost (x1)	4	3	2
Complexity (x2)	3	4	1
Weight(x2)	4	3	2
Aerodynamics (x3)	2	3	2
Total	14	28	12

Table 4.6 - Fin Number Decision

Fin Shape	Pros	Cons
Trapezoidal	Protection from impact damage Easy to design Easy to manufacture Easy to attach	None
Clipped Delta	Easy to design Easy to manufacture Easy to attach	Slightly less protection from impact damage

Fin Shape	Pros	Cons
Tapered Swept	None	Much less protection from impact damage
Elliptical	Low drag	Difficult to design Difficult to manufacture Difficult to attach

Table 4.7 - Fin Shape Options

Criteria (weight)	Trapezoidal	Clipped Delta	Tapered Swept	Elliptical
Cost (x1)	2	2	2	2
Complexity (x2)	4	3	3	1
Aerodynamics (x3)	3	3	3	4
Total	19	17	17	16

Table 4.8 - Fin Shape Decision

Fin Material	Pros	Cons
G12 fiberglass	Cheaper than carbon fiber Very durable	Hazardous
Carbon Fiber	Stronger than fiberglass Lighter than fiberglass Very durable	More expensive than fiberglass. Difficult to work with
Balsawood	Lighter and cheaper than fiberglass or carbon fiber	Significantly weaker than fiberglass and carbon fiber
Plywood	Cheaper than carbon fiber or fiberglass Stronger than balsawood Lighter than fiberglass or carbon fiber Easily assessible	Weaker than carbon fiber and fiberglass More expensive than balsawood
Aluminum	Stronger than fiberglass Cheaper than carbon fiber or fiberglass	Heavier than fiberglass or carbon fiber Will dent if struck by an object Heavier than fiberglass or carbon fiber

Table 4.9 - Fin Material Options

Criteria (weight)	Fiberglass	Carbon Fiber	Balsawood	Plywood	Aluminum
Cost (x2)	3	1	4	4	2
Complexity (x2)	3	2	3	3	2
Weight (x3)	3	4	4	3	2
Durability (x3)	4	4	1	1	3
Total	33	30	27	24	23

Table 4.10 - Fin Material Decision

4.1.2.1.3 Parachute Tube

The parachute tube houses the main parachute. Because the parachute tube is a very simple, but relatively large and heavy, component, alternate materials were considered to reduce the mass of the launch vehicle.

Parachute Tube Material	Pros	Cons
G12 Fiberglass	Cheaper than carbon fiber Stronger than phenolic paper	Heaviest Hazardous
Carbon Fiber	Stronger than fiberglass and phenolic paper Lighter than fiberglass	More expensive than fiberglass or phenolic paper Difficult to work with
Phenolic Paper	Lighter than carbon fiber or fiberglass Cheaper than carbon fiber or fiberglass	Significantly less durable than carbon fiber or fiberglass

Table 4.11 - Parachute Tube Material Options

Criteria (weight)	Fiberglass	Carbon Fiber	Phenolic Paper
Cost (x1)	3	1	4
Complexity (x1)	3	1	4
Durability (x3)	4	4	1
Weight (x2)	2	3	4
Total	22	20	19

Table 4.12 - Parachute Tube Material Decision

4.1.2.1.5 Nosecone

Because the nosecone is an integral part of the rover deployment mechanism, it is only covered here as it directly relates to the launch vehicle.

Nosecone Material	Pros	Cons
ABS Plastic	Easily accessible by 3D printing Payload sled can be made a single piece with the nosecone Flexible design Easily able to recreate in the event of damage	Increased time spent on printing and designing
G12 Fiberglass	No time spent printing or designing	Not commercially available in the correct shape Less design flexibility. More expensive

Table 4.13 - Nosecone Material Options

Criteria (weight)	ABS	Fiberglass
Cost (x1)	3	2
Complexity (x2)	3	3
Adjustability (x2)	4	1
Availability (x3)	4	1
Total	29	13

Table 4.14 - Nosecone Material Decision

Nosecone Shape	Pros	Cons
Ellipsoid	Less likely to embed in soft ground Ensures rocket will be on its side before rover is deployed Lower drag than blunt	Not commercially available for 6 in. diameter launch vehicle tube
Ogive	Lower drag than blunt	Higher risk than ellipsoid of embedding into the ground
Cone	Simple to design Lower drag than blunt	Highest risk of embedding into the ground Less space to hold rover
Blunt	Will not embed into the ground	Very high drag Unnecessary additional weight

Table 4.15 - Nosecone Shape Options

Criteria (weight)	Ellipsoid	Ogive	Cone	Blunt
Payload Accommodation (x3)	4	2	1	1
Aerodynamics (x3)	3	4	2	1
Total	21	18	9	6

Table 4.16 - Nosecone Shape Decision

4.1.2.2 Altitude Control System

The options for precisely controlling the apogee altitude that were considered are listed below.

4.1.2.2.1 Holes in Airframe

Flaps on the side of the airframe would open inward, creating a concave space that would disrupt the laminar flow of air over the launch vehicle, thereby increasing drag.

4.1.2.2.2 Balloons

Many options utilizing one or more inflatable balloons were considered. These include: heating (partially with heat from the motor) of a balloon mechanism to increase the volume of the balloon to create spherical airbrakes; deploying a large balloon just below 5,280 ft to lift the launch vehicle and payload to the appropriate height and popping it, allowing the rocket to begin its decent; and deploying a balloon just below 5,280 ft to carry the altimeter itself directly to the target altitude without the launch vehicle.

4.1.2.2.3 Water Ballast

This design uses water as ballast to add mass to the launch vehicle that could be gradually ejected to reduce mass during flight. Reducing the mass during powered ascent would increase the apogee, as the motor does not have to lift as much mass. Reducing the mass during the coast phase would lower apogee by decreasing the inertia of the launch vehicle, making it more susceptible to drag.

4.1.2.2.4 Airbrakes

A number of airbrake designs of varying sizes, shapes, and deployment mechanisms were considered. These include a design where four flat plates would rotate symmetrically out of the body of the rocket, a design where a rotor would be deployed during flight which could then increase or decrease the velocity of the launch vehicle depending on which way it was spun, and a fin based airbrake where the fins could adjust their angle relative to the direction of airflow for increased drag.

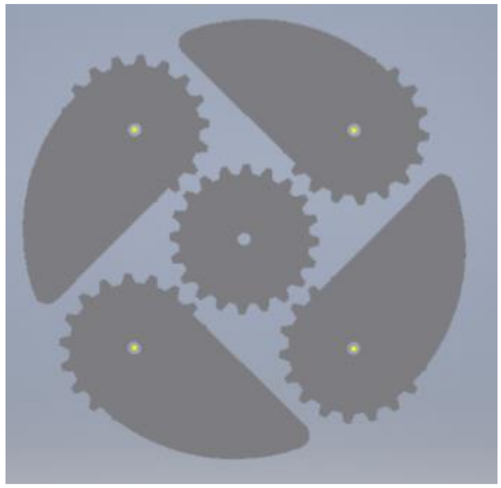

Figure 4.1 - Flat Plate Airbrake Design

4.1.2.2.5 Drag Parachute

This design deploys a parachute from the aft end of the launch vehicle before apogee is reached. The early release of a parachute induces significant drag, while firing it out the back means that the aerodynamic shape of the launch vehicle is not disturbed. This reduces the force on the airframe compared to early deployment of a parachute from the center of the launch vehicle.

4.1.2.2.6 Cold Gas Thrusters

This design uses pressurized gas, stored in a pressure vessel and expelled through forward- or rear-facing nozzles, to increase or decrease the velocity of the launch vehicle after motor burnout, thus changing the apogee altitude. Each set of nozzles (forward- and rear-facing) would be controlled by a single valve. These valves would be opened and closed as needed based on velocity data from a barometric altimeter.

Another consideration to this design was the potential to gather gas from the air that could be used for the thrusters, which would reduce the need to store tanks of gas on the rocket at launch. Nitrogen gas is highly abundant in the atmosphere (~78% of air is N_2 gas) and so could be easily gathered. This air would then be purified to isolate the nitrogen gas for use in the thrusters. This idea was dismissed because the equipment necessary to collect and isolate the N_2 gas would weigh more than the tank that it was replacing.

4.1.2.2.7 Comparison

Altitude Control System	Pros	Cons
Holes in Airframe	No protrusions Minimal chance of damage or rupturing of complex protruding device Minimal moving parts Inexpensive	Difficult to calculate or control full effect of drag increase Difficult to fine tune for individual flights accurately Can only decrease apogee; can't do anything to help if the apogee ends up less than 5,280 ft
Balloons	Easy storage in rocket body when deflated Slow management of height would allow for better fine tuning Inexpensive	There is a chance of the balloon(s) popping Difficult to determine the size or quantity of balloon needed to support the weight of the launch vehicle or increase drag by the proper amount Longer active time compared to other design options means a higher chance of failure Difficult to test and analyze performance
Water Ballast	Water is a dense substance so a minimal quantity of ballast could be stored on the rocket Water is a completely harmless substance and would therefore cause no environmental concerns	Material must be ejected from the rocket that cannot be controlled and will fall from the sky in indeterminable trajectory Storing a liquid makes transporting the rocket and assembling the components more complicated and introduces potential for leaks Apogee can only be increased while the motor is firing, making it difficult to correct for an underperforming motor
Airbrakes	Highly precise control over altitude that could be adjusted in flight by the degree to which the brakes protrude to account for flight day conditions Numerous placement options to experiment with and test multiple similar airbrake design capabilities	Creates turbulent flow around the rocket, which can cause instability Difficult to manufacture Difficult to install Chance for mechanical and programming failures Expensive Can only reduce velocity, not increase it

Altitude Control System	Pros	Cons
Drag Parachute	The parachute can be used for both altitude control and recovery systems Easy to make and implement Inexpensive	The sudden massive increase in drag could create incalculable variations in airflow around the rocket body and parachute, which could interfere with trajectory The drag induced cannot be fine-tuned by means other than timing of deployment Can only lower apogee
Cold Gas Thrusters	Highly precise altitude correction for both undershooting and overshooting the target altitude No major protrusions to create instability	Expensive to construct (when considering the need to buy multiple sections of piping, thruster nozzles, a tank, and spare parts to account for additional testing and prototyping that would need to be conducted prior to final implementation) High pressure storage of gas could be potentially dangerous and extra precautions must be taken when handling and transporting If either of the block valves fail to open, then that entire section of the altitude control system will be completely inoperable during flight (this is as opposed to having each of the eight thrusters individually controlled, which could allow three of four forward facing thrusters to still succeed which, while slightly disturbing trajectory, would still effectively adjust altitude to a degree)

Table 4.17 - Altitude Control System Options

Criteria (weight)	Cold Gas Thrusters	Holes in Airframe	Balloons	Water Ballast	Airbrakes	Drag Parachute
Cost (x1)	1	2	3	2	2	2
Weight (x2)	2	3	3	3	3	4
Complexity (x2)	1	2	2	3	2	4
Precision (x3)	4	2	3	2	3	2
Bi-Directionality (x3)	4	0	3	3	0	0
Safety (x3)	3	3	2	1	3	3
Total	40	27	37	32	30	33

Table 4.18 - Altitude Control System Decision

4.1.3 Current Design

4.1.3.1 Airframe

4.1.3.1.1 Overall

The launch vehicle will have a continuous 6 in. diameter. While this doesn't allow as much room for the payload, the drag and weight induced by an 8 in. nosecone would necessitate a motor larger than L-class to reach the target altitude.

The primary construction for the launch vehicle will be G12 fiberglass. It is very strong, not too expensive, and commercially available in a 6 in. diameter. While it does pose a safety hazard, PSLT has experience mitigating this risk.

Estimated mass of the launch vehicle: 19.6 lbs

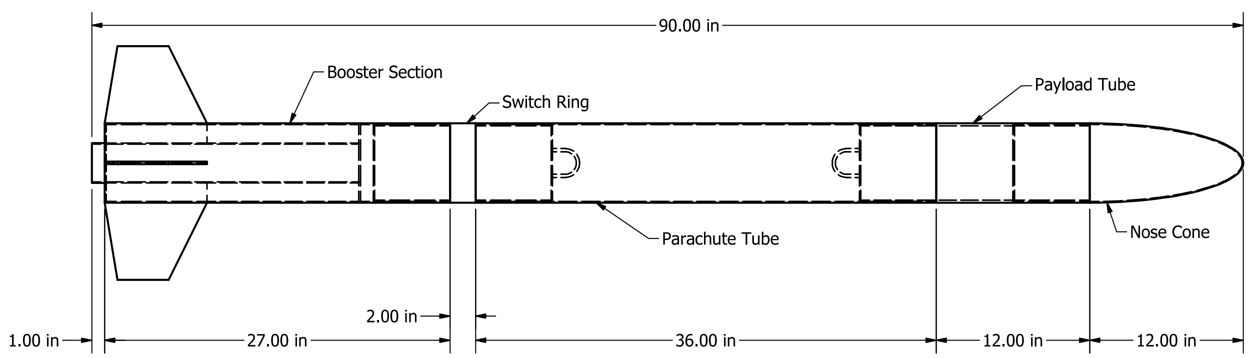

Figure 4.2 - Full Launch Vehicle Side View

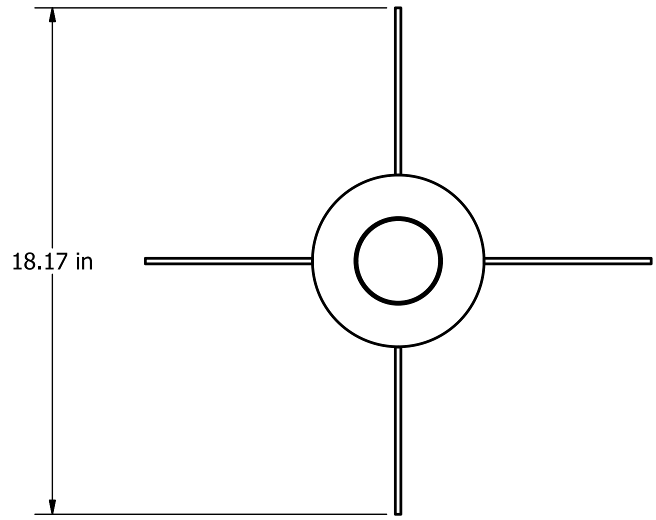

Figure 4.3 - Full Launch Vehicle Rear View

4.1.3.1.2 Booster Section

The booster section will contain four trapezoidal fins which will be mounted though-the-wall to the motor tube. Using four fins allows for easy alignment on the outer tube and less stress on the fins when setting the rocket down without a stand. Trapezoidal fins will be used because they are easy to design, manufacture, and attach while offering protection from impact damage because there are no major sweep angles. The area between the motor mount and outer tube will be filled with two-part expanding foam for added strength and adhesion. The motor mount tube will have a diameter of 75 mm and will be held in place by two fiberglass centering rings, one at the front of the motor mount tube, and the other at the rear. A 75 mm AeroPack retainer will be attached to the aft end of the motor mount tube to secure the motor during flight.

Estimated mass: 5.8 lbs

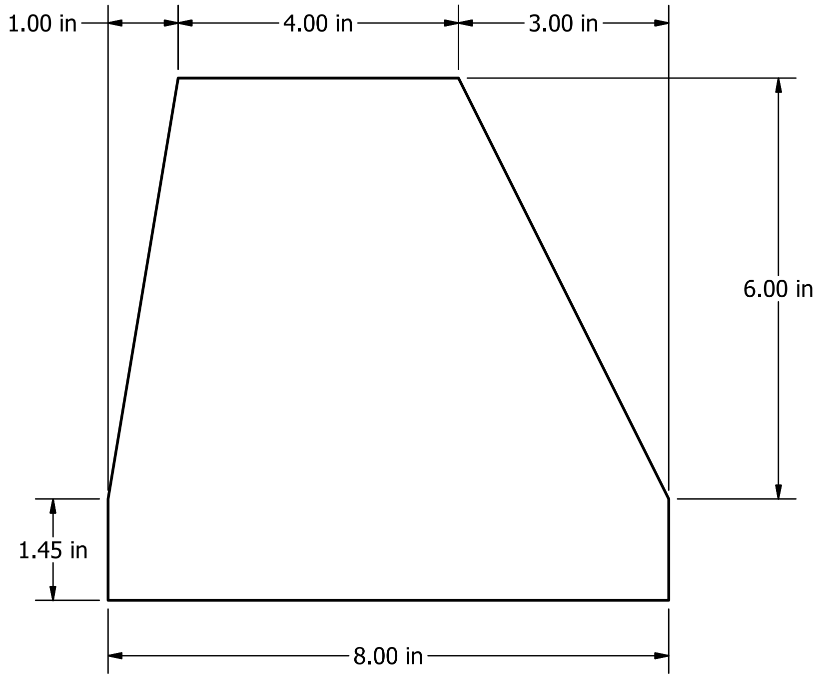

Figure 4.4 - Fin Side View

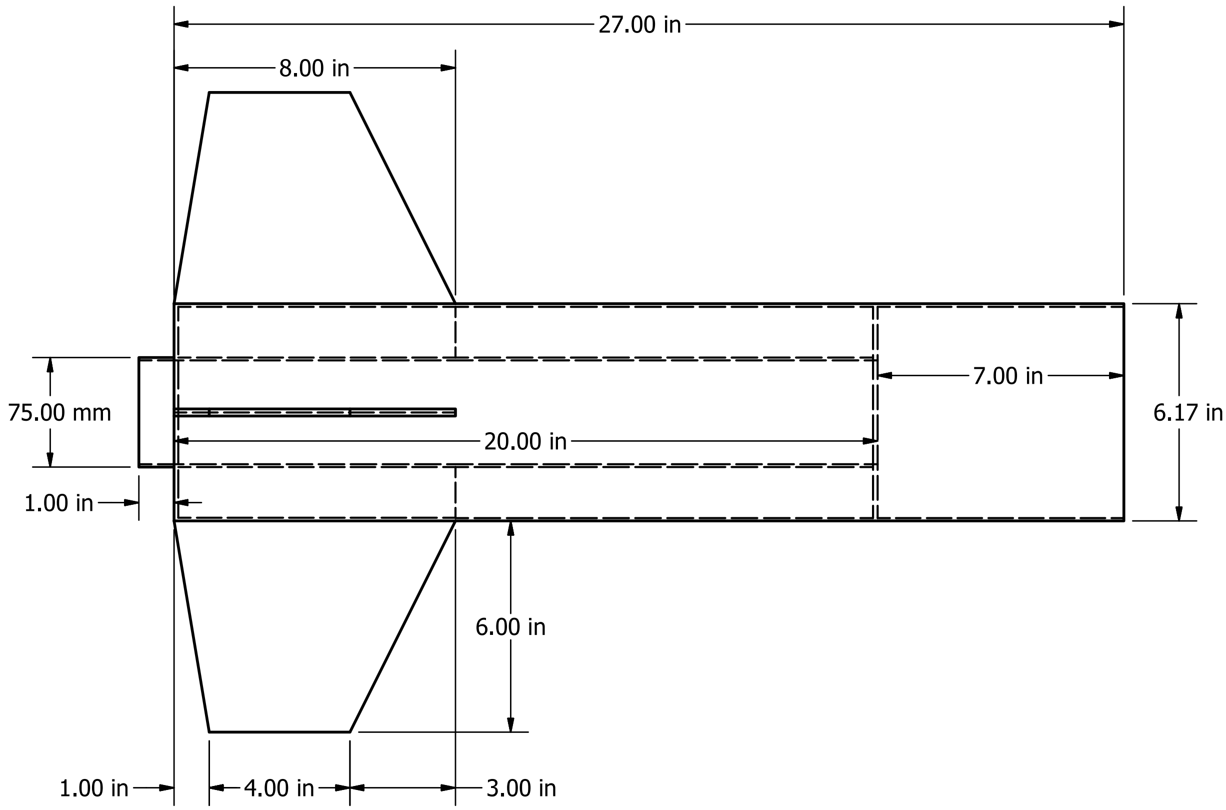

Figure 4.5 - Booster Section Side View

4.1.3.1.3 Avionics Bay

The avionics bay houses the recovery system altimeters, batteries, and switches. It has 1 caliber (6 in.) shoulders on each end and a 2 in. switch ring in the center. Both ends are capped by bulkheads. The forward bulkhead has two U-bolts (for attaching the recovery harness) and four ejection cups attached to it.

Estimated mass: 3.0 lbs

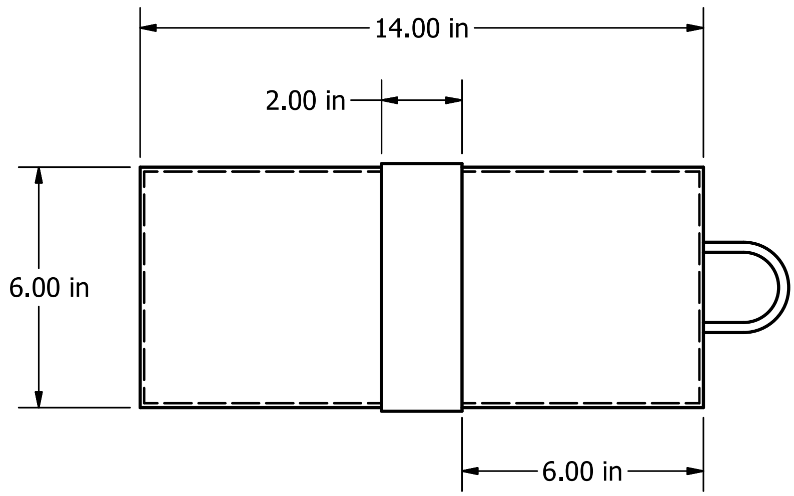

Figure 4.6 - Avionics Bay Side View

4.1.3.1.4 Parachute Tube

The leading design choice for the parachute tube is for it to be constructed of fiberglass. This offers a good trade-off between strength and weight.

Estimated mass: 3.9 lbs

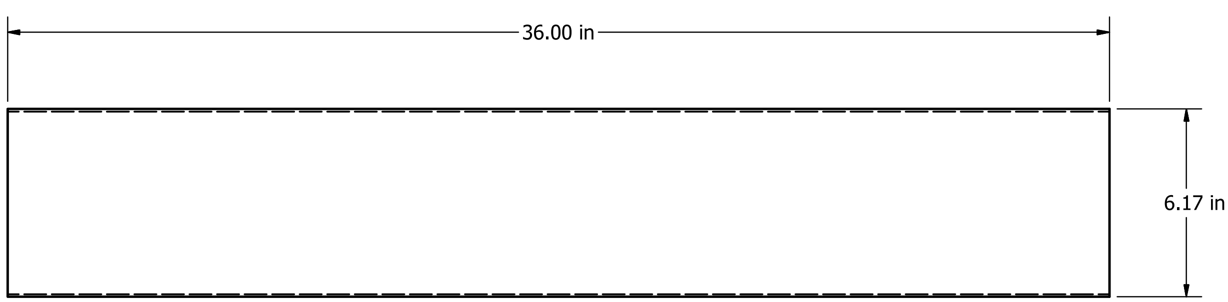

Figure 4.7 - Parachute Tube Side View

4.1.3.1.5 Payload Tube

The payload tube, along with the nose cone, houses the payload. It is a 12 in. tube with a 12 in. coupler in it, offset by 6 in. to create a 6 in. shoulder. The aft end of the coupler is capped with a bulkhead. There are two U-bolts attached to the bulkhead for attaching the recovery harness.

Estimated mass: 3.2 lbs

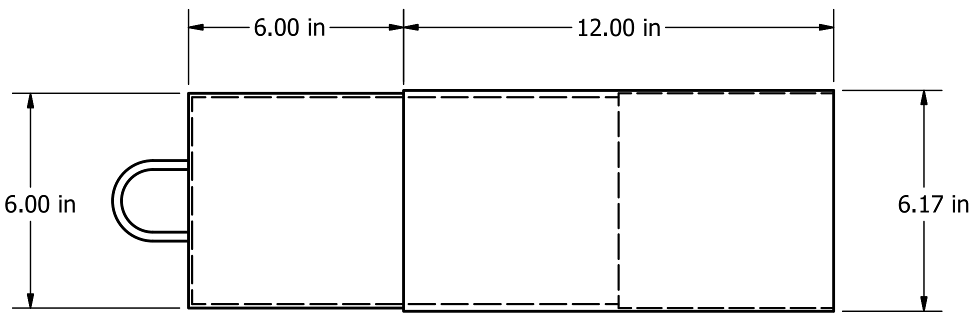

Figure 4.8 - Payload Tube Side View

4.1.3.1.6 Nosecone

The leading design choice for the nosecone is to have it be in the shape of an ellipsoid. This will ensure that if the launch vehicle lands nose first, it will not embed into the ground. Instead, it will fall over and still allow for a successful rover deployment. ABS is the primary choice for nosecone material because it is easily accessible, cheap, and allows for a custom design that can incorporate the payload. Additionally, in the event of damage or change of design, the nosecone can easily be redesigned, and 3D printed again.

Estimated mass: 1.0 lbs

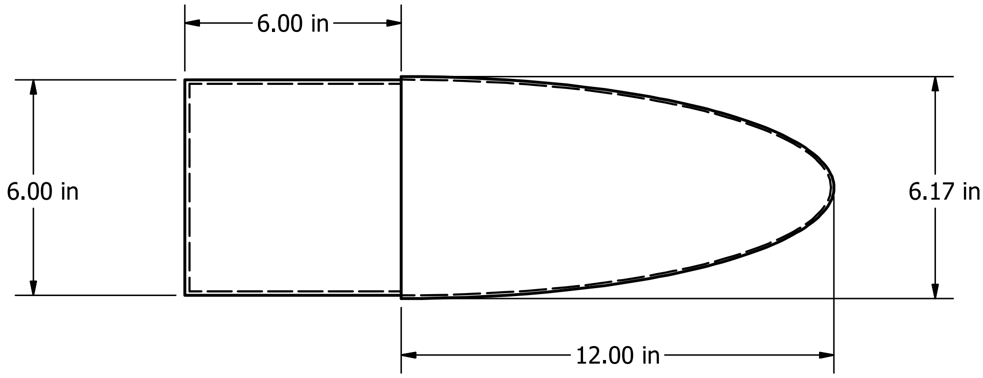

Figure 4.9 - Nosecone Side View

4.1.3.1.7 Connections

The table below lists the connections between airframe segments and how they are secured to avoid drag separation during flight.

Connection	Securing Device	Number of Securing Devices
Fore end of booster section to aft end of avionics bay	5/32 in. plastic rivets	4
Fore end of avionics bay to aft end of parachute tube	5/32 in. plastic rivets	4
Fore end of parachute tube to aft end of payload tube	#4-40 shear pins	4
Fore end of payload tube to aft end of nose cone	#4-40 shear pins	4

Table 4.19 - Launch Vehicle Section Connections

4.1.3.2 Altitude Control System

The leading design for the altitude control system is a combined rear- and forward-facing set of symmetrical thrusters. With four thrusters facing forward and four facing backward, the launch vehicle will be equipped to either increase its altitude or reduce it as necessary to account for launch day conditions. The thrusters will be centered inside of the rocket body and protrude toward the edge of the rocket tube at an angle to avoid large protrusions from the rocket body that would induce drag. The angle of the thruster ejection will slightly decrease the efficiency when compared to a thruster facing exactly in line with the direction of flight; however, it will also allow the sides of the rocket body to remain undisturbed excepting the eight small holes out of which the thrusters will point. This will ensure the laminar flow over the surface of the rocket body is minimally disturbed throughout the flight, while allowing the thrusters to still complete their task of adjusting altitude as the rocket approaches apogee.

Options that were considered for the propellant are N_2 which is non-flammable, and highly inert; CO_2, which has many similar properties, but a slightly lower specific impulse due to its higher molecular mass; He which has a high specific impulse, but is expensive; and H_2, which has a very high specific impulse, but is also very dangerous to work with due to its combustibility and reactivity. The chosen propellant is N_2 gas, and as such the tank size and storage capacity was calculated taking into account the mass of N_2 gas that would be required.

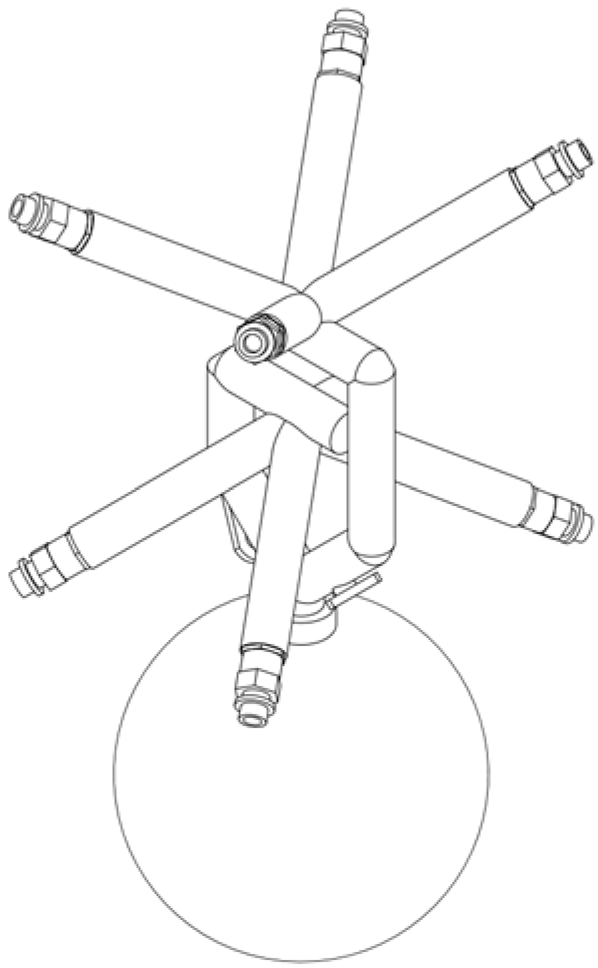

Figure 4.10 - Cold Gas Thruster System Isometric

As the above drawing shows, the rear-facing set of thrusters and forward-facing set will be individually operated by use of a Y-shaped break in the air piping. The thruster nozzles will be commercially available industrial grade pressurized gas nozzles. The current design has one notable difference from the image above, the angle of the nozzles will be increased from the 45° shown in the images to close to 90°. This is to reduce the amount of propellant being expelled horizontally, and thus increase the vertical thrust.

Estimated mass: 1.0 lb

4.2 Recovery System

4.2.1 Parachute

Main Parachute Size	Pros	Cons
144 in. (12 ft)	Allows the mass of the launch vehicle to increase without violating the 75 ft-lbf per section requirement	Heavier More expensive
132 in. (11 ft)	Cheaper Lighter	Doesn’t leave room in the design for the mass to increase

Table 4.20 - Parachute Size Options

Criteria (weight)	144in	132in
Cost (x1)	2	3
Design Flexibility (x2)	2	1
Total	6	5

Table 4.21 - Parachute Size Decision

A 144 in. main parachute was chosen to allow the mass of the launch vehicle or payload to increase without going over the limit of 75 ft-lbf at landing.

Dual Deployment Type	Pros	Cons
Drogue + Main	The launch vehicle separates at two points, increasing the chance that at least one separation will occur, and thus decreasing the chance of a ballistic return of the launch vehicle	Takes up more space, requiring a larger, heavier launch vehicle Requires folding and packing two parachutes, increasing the chances of something being done incorrectly, leading to a recovery system failure
Main + Chute Release	Simpler to prepare before launches Takes up less space in the launch vehicle	Launch vehicle only separates at one point, increasing the risk of a ballistic return

Table 4.22 - Dual Deployment Type Options

Criteria (weight)	Drogue + Main	Main + Chute Release
Space (x2)	1	3
Complexity (x2)	2	3
Total	6	12

Table 4.23 - Dual Deployment Type Decision

The chosen design uses a main parachute contained by two redundant Jolly Logic chute releases, connected in series. The chute releases will allow the parachute to unfold at 800 ft. This removes the need for a drogue parachute compartment, making the launch vehicle smaller and lighter. The weight saved by this can instead be used in the payload, allowing more flexibility in the payload design without requiring a larger motor.

The parachute will be connected to the recovery harness 6 ft from the payload tube. This off-center placement means that the lower section of the launch vehicle will hang below the upper 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.

4.2.2 Recovery Harness

The recovery harness will be the generally recommended length of three times the length of the launch vehicle, which is 24 ft (rounded up from 22.5 ft based on the lengths that can be purchased). The recovery harness will be made of 1/2 in. tubular Kevlar. At each end of the harness, there will be a swivel to lessen the chance of the harness getting twisted during deployment and descent. Each swivel will be connected to two quick links.

Attachment Device	Pros	Cons
U-bolt	Distributes force over a wider area	Larger footprint
Lifting Hook (Forged Eye-bolt)	Smaller footprint	Distributes force over a smaller area

Table 4.24 - Recovery Harness Attachment Options

Criteria (weight)	U-bolt	Lifting Hook
Footprint (x1)	1	3
Probability of Failure (x2)	4	2
Total	9	7

Table 4.25 - Recovery Harness Attachment Decision

The quick links will each be connected to a U-bolt; two on the forward end of the avionics bay and two on the aft end of the payload tube.

4.2.3 Deployment System

There will be two independent deployment systems, each consisting of an altimeter, a battery, an arming switch, and two black powder-filled ejection cups.

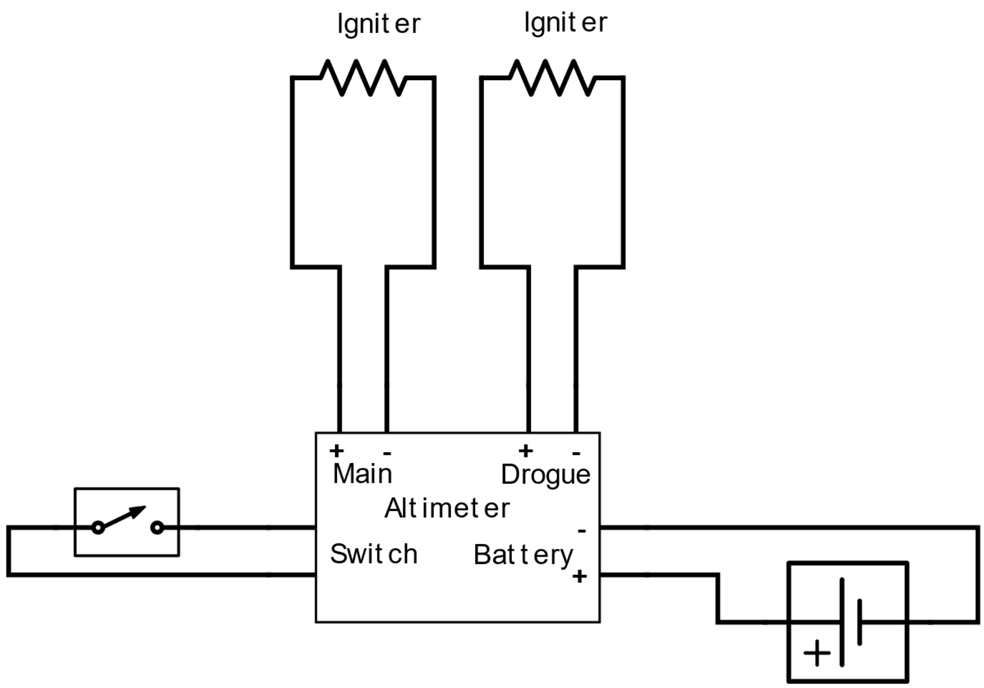

Figure 4.11 - Wiring of a Single Altimeter

The four ejection cups are all attached to the forward avionics bulkhead, as shown below:

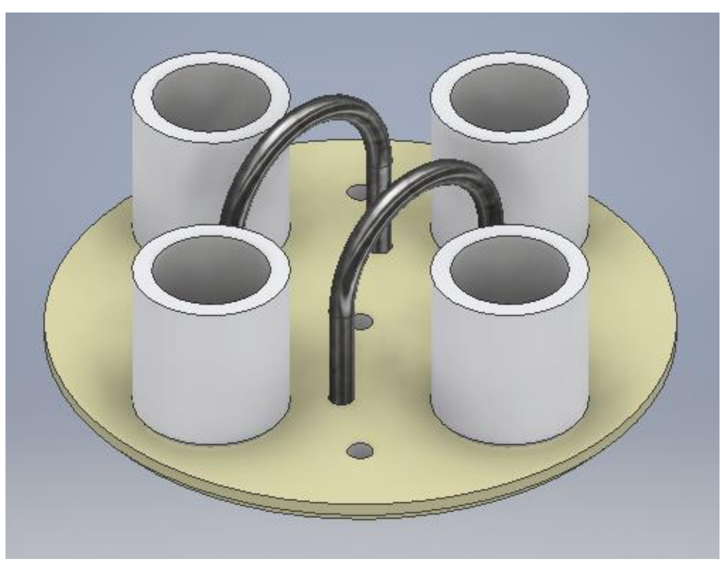

Figure 4.12 - Ejection Cups

The four ejection charges will fire in series as shown below:

Ejection Charge	Firing Condition	Altimeter
1	Altitude == 5,200 ft or apogee, whichever happens first	1
2	Apogee + 2 seconds	2
3	Apogee + 4 seconds	1
4	Altitude == 500 ft on descent	2

Table 4.26 - Ejection Charge Firing Sequence

Note that ejection charge 4 will fire after the chute releases have released. This means that if the first three ejection charges fail to cause separation because the parachute is wedged in place, the fourth one will fire after the geometry of the parachute has changed (because it will no longer be held together by the chute releases).

4.3 Mission Performance Predictions

4.3.1 Simulation Models

The mission performance predictions section is based on the following model of the rocket and launch conditions. The data provided was determined through a combination of RockSim and OpenRocket simulations and manual calculations.

Table 4.27 describes the statistics from the launch vehicle and payload used in the simulations.

Rocket Statistic	Value
Launch vehicle mass (lbs)	19.63
Payload mass (lbs)	4.00
Launch vehicle CG (in.)	52.09
Payload CG (in.)	6.00
Combined launch CG location (in.)	45.48
CP location (in.)	68.63
Cd	0.45

Table 4.27 - Rocket Model

Launch Condition	Value
Altitude Above Sea Level (ft)	600
Latitude (°)	34
Temperature (°F)	70
Wind Speed (mi/h)	0
Humidity (%)	50
Pressure (bar)	1.013
Launch Rail Length (ft)	12
Launch Rail Size	1515

Table 4.28 - Launch Conditions Model

Based on the above model and simulations performed, an Aerotech L1150 motor was selected for use. Figure 4.13 shows the thrust curve of that motor.

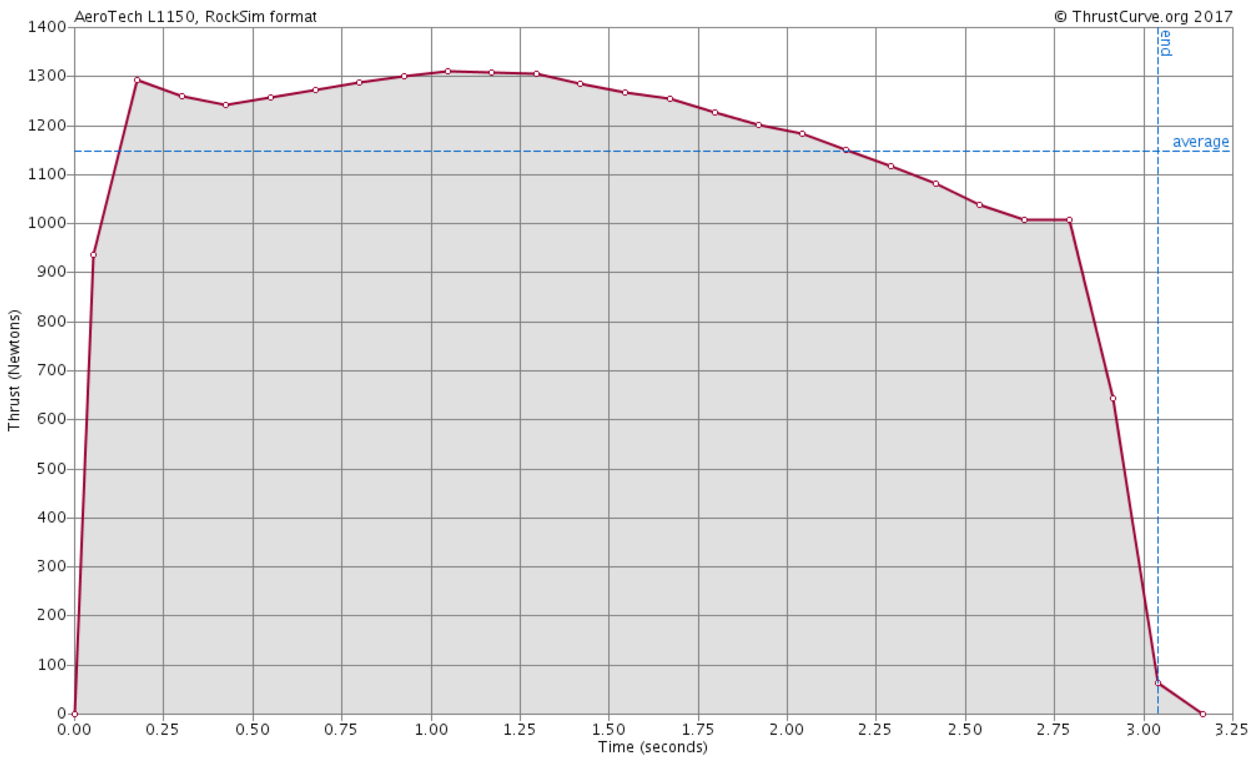

Figure 4.13 - L1150 Thrust Curve

For the purpose of this section, it is assumed that the altitude control system is not active. This is to provide the performance of the rocket design itself as well as a baseline from which to determine the requirements of the altitude control system.

4.3.2 Flight Profile Simulations

This section describes the flight of the rocket based on the simulations done in both RockSim and OpenRocket and manual calculations.

Table 4.29 gives the values from each simulation as well as the average value for each statistic.

Simulated Statistic	RockSim Value	OpenRocket Value	Average Value
Apogee (ft)	6,009	5,184	5,596.5
Static Stability Margin at Rail Exit	2.38	2.06	2.22
Rail Exit Velocity (ft/s)	77.7	79.4	78.5
Maximum Velocity (ft/s)	686.5	682	684.3
Velocity at Main Deployment (ft/s)	93.4	97.3	95.4
Velocity at Landing (ft/s)	15.35	15.8	15.6
Maximum Acceleration (ft/s^2)	751.8	273.2	512.5
Time to Burnout (s)	3.11	3.2	3.16
Time to Apogee (s)	18.98	17.8	18.4
Descent Time (s)	97.81	76.2	87.0
Total Flight Time (s)	116.80	94	105.4

Table 4.29 - Flight Statistics

Figure 4.14 indicates the CP and CG locations throughout the flight.

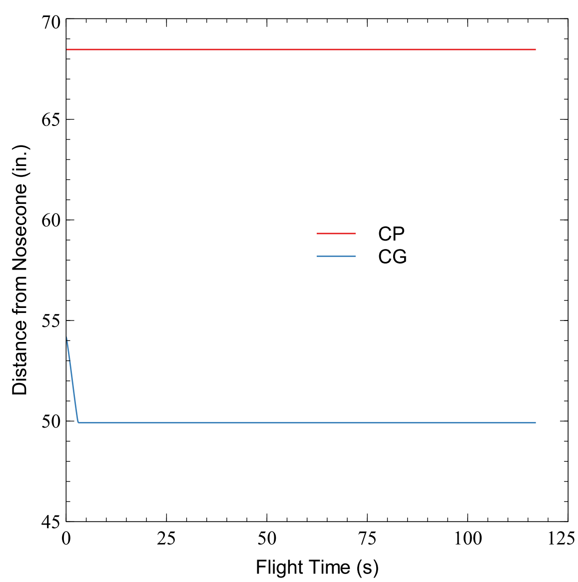

Figure 4.14 - CG and CP Throughout Flight

4.3.3 Landing Predictions

Table 4.30 shows the kinetic energy of each section of the rocket at landing.

Section	Mass (oz)	Velocity (ft/s)	Kinetic Energy (ft-lbs)
Upper	131.51	15.35	30.10
Lower	246.49	15.35	56.41

Table 4.30 - Kinetic Energy at Landing

Table 4.31 shows various drift predictions for the rocket. The RockSim and OpenRocket simulations provide drift predictions that take into account weather-cocking which results in a shorter drift distance. The calculated values were determined by multiplying the descent time by the wind speed, which provides a worst-case estimation of drift. Together, these values provide a range which the actual drift is expected to fall within. The values from the simulations use the same model as the rest of the mission performance predictions section with the exception of the different values of wind speed.

Wind Speed (mi/h)	RockSim (ft)	OpenRocket (ft)	Calculated (ft)
0	0	7.5	0
5	338	72.2	558.8
10	705	192.1	1117.6
15	947	387.8	1676.4
20	1430	575.6	2235.2

Table 4.31 - Drift Predictions

5 Safety

The Piedmont Student Launch Team is fully committed to working within 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. The Safety Officer will, in conjunction with the launch vehicle and payload leads, create safe procedures for building, testing, and launching / deploying high-power rockets and the rover, and will work with the Director of Engagement & Outreach to develop safe procedures for all outreach events. Team members will follow all safety rules, 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.

The Safety Officer, as well as other team members, will use the Hierarchy of Hazard Control system in order to identify and prevent potential hazards. This system is designed to prevent hazards starting with methods that are proven as the most effective at preventing hazards and moves through different controls if the controls before it will not work. The controls, in order, are: eliminating the risk entirely by removing the hazardous material or potentially dangerous task from the team's procedures; substituting a hazardous material or task with one that is safer; engineering controls that create separations between the team members and the hazard; administrative controls that warn team members about hazards and train members to avoid them; and personal protective equipment that functions as a final barrier between team members and hazards.

In case of emergencies, it will be necessary to have plans and procedures in place to prevent catastrophe. The Safety Officer will work with the team mentor, team leader, and area leads to establish emergency plans and training for all team members in how to respond in emergency situations such as how to safely evacuate a dangerous area, proper use of a fire extinguisher, CPR, and other training.

As the team learns about new potential hazards, the Safety Officer will research those hazards, establish safe controls to mitigate them, and implement those safe controls. The new data will then be added to a risk assessment database for future knowledge. The safety section provides preliminary hazard information involved with the project in order to identify potential danger and mitigate it. A risk severity-probability matrix is used to rank hazards by their impact and likelihood. Preliminary assessments are categorized by risks to personnel, a Failure Modes and Effects Analysis (FMEA) that identifies where systems could potentially fail on the launch vehicle or payload as well as proposed mitigations, environmental risks, and project risks in that order. Hazards that pose the greatest threat are listed first in their categories and will be analyzed, researched and mitigated first. The following Figure 5.1 describes the severity-probability matrix used in this document.

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

5.1 Personnel Hazard Analysis

Personnel are the team's most important asset, and cannot be replaced if something happens to them. Injuries to personnel can result in delays to components being built, deliverables not being completed on schedule, the project failing, serious bodily harm to a team member, or even death. Identifying potential risks before they become an accident and preventing them from happening at all is paramount to keeping the team safe and keeping the project moving.

As the project moves forward, modifications or additions to processes may become necessary. Any modifications or additions to the processes will need to be safely controlled before implementation, and will first undergo analysis and testing for safety. The Safety Officer will work with area leads to analyze and test any modifications or additions, and will make sure they are implemented if needed. Any hazard which PSLT identifies that is not Low or Minimal Risk will have a mitigation applied as shown in the following sections. The risk level both before and after the applied mitigation is shown in Tables 5.1 – 5.3.

5.1.1 Hazards to Personnel from Materials

Hazard			
Effect(s)			
Cause(s)	Mitigation(s)	Pre-Mitigation	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 work with gas tank near any heat sources	1C	1E
Unintentional motor ignition during motor preparation	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 ignitor will not be inserted into the motor until the rocket is on the launch pad. All other NAR guidelines will be followed regarding motor handling	1C	2E
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	2E
Unintentional motor ignition during launch pad preparation	All nonessential personnel will vacate the area before the ignitor 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 ignitor leads	1C	2E

Hazard			
Effect(s)			
Cause(s)	Mitigation(s)	Pre-Mitigation	Post-Mitigation
Unintentional black powder ignition during rocket preparation	All nonessential personnel will vacate 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	1C	2E
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	3E
Aerosolized spray paint ignites	Painting with spray paint will be done outside. Painting with spray paint will be done away from ignition sources	2D	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	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	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 open longer than necessary	2D	2E
Battery ignites	Battery leads will not be crossed. Electrical systems will be analyzed for the appropriate voltage before any batteries are connected	2D	2E
Unintentional ignitor ignition	Ignitors will be kept away from sources of electrical buildup. Personnel handling ignitors will ground themselves first	3D	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 personnel remove their masks	2B	2E

Hazard			
Effect(s)			
Cause(s)	Mitigation(s)	Pre-Mitigation	Post-Mitigation
Inhaling acetone fumes	Personnel will take care when working with acetone. Personnel will not place their heads directly over open acetone	3C	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	3E
Inhaling aerosolized spray paint	Personnel will wear at least dust masks, preferably respirators while using spray paint	3C	3E

Table 5.1 – Preliminary Assessment of Risks to Personnel from Materials

5.1.2 Hazards to Personnel from Facilities

Hazard			
Effect(s)			
Cause(s)	Mitigation(s)	Pre-Mitigation	Post-Mitigation
Burns			
Minor to serious injury to personnel. Minor to serious damage to property			
Touching recently cut metal	Personnel will be trained not to touch metal unprotected for at least 5 minutes after it has been cut. Personnel will wear heavy gloves when cutting metal	3B	4C
Splashing solder	Personnel will wear heavy, long-sleeved clothing when working with the soldering iron. Personnel will wear safety glasses when working with the soldering iron	2C	4C
Touching soldering iron	Personnel will be trained not to touch the element on the soldering iron without being sure that it is cool	3C	4D
Touching output of hot-air gun	Personnel will be trained not to touch the output of the hot-air gun unprotected for at least 5 minutes after use	3C	4D
Cuts / Punctures			
Minor to serious injury to personnel			
Saw blade comes into contact with personnel	Personnel will be trained to not touch moving equipment. Personnel will maintain a distraction free environment when working	1C	1E

Hazard			
Effect(s)			
Cause(s)	Mitigation(s)	Pre-Mitigation	Post-Mitigation
Drill comes into contact with personnel	Personnel will be trained to not touch moving equipment. Personnel will maintain a distraction free environment when working	3C	3D
Personnel slips	Personnel will wear high traction shoes when working. The floor of the work space will be kept clean	3C	3E
Personnel trips on cord	Cords will be secured and out of major walkways	3C	3E
Sharp tool slips	Personnel will maintain a distraction free work environment	3C	3D
Impacts			
Minor to serious injury to personnel			
Personnel trips on cord	Cords will be secured and out of major walkways	3C	3E
Personnel slips	Personnel will wear high traction shoes when working. The floor of the work space will be kept clean	3C	3E
Respiratory illness			
Long-term health issues			
Inhaling lead fumes from solder	Non-lead-based solder will be used	2C	4E
Inhaling fumes from the laser cutter	The filter and suction system will be in use when the laser cutter is being used	3C	4E

Table 5.2 – Preliminary Assessment of Risks to Personnel from Facilities

5.1.3 Hazards to Personnel at Launch Sites

Hazard			
Effect(s)			
Cause(s)	Mitigation(s)	Pre-Mitigation	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 enough to separate the rocket at apogee	Ejection charges will be tested multiple times before each flight to ensure energetic separation. There will be a total of 4 ejection charges that can separate the rocket	1C	1E

Hazard			
Effect(s)			
Cause(s)	Mitigation(s)	Pre-Mitigation	Post-Mitigation
Altimeter does not have sufficient charge to fire ignitor	Each altimeter will be connected to a different battery. The batteries will be replaced before each flight with new ones	1C	1E
Parachute is not ejected from the rocket when ejection charge fires	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. There will be 4 ejection charges, so if one fails to push the parachute out of the rocket, there will be backups	1C	1E
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	2E
Chute release does not have sufficient power and does not open	There will be 2 chute releases used, connected in series, so that if one fails, the other can still release the parachute. Both chute releases will be charged before each flight	2C	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	1E
Ejection charge ignitor is bad	All ignitors will be inspected prior to use. There will be a total of 4 ejection charges that can separate the rocket, each of which will have a different ignitor	1D	1E
Ejection charge ignitor is not properly connected to bridge	All electrical connections in the recovery system will be inspected before each flight. There will be a total of 4 ejection charges that can separate the rocket, each of which will be connected to a different bridge. The altimeters will beep out their continuity status	1D	1E
Bridge is not properly connected to altimeter	All electrical connections will be inspected before each flight. There will be a total of 4 ejection charges that can separate the rocket, each of which will be connected to a different bridge. The altimeters will beep out their continuity status	1D	1E
Chute release is jammed and does not open	There will be 2 chute releases used, connected in series, so that if one fails, the other can still release the parachute. Both chute releases will be tested before each flight to ensure proper operation	2D	2E
Ballistic / high speed return of other rockets			

Hazard			
Effect(s)			
Cause(s)	Mitigation(s)	Pre-Mitigation	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	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 to the airframe	Stress tests will be performed on the motor mount to ensure it is able to withstand flight forces. The motor mount will be inspected before each launch	2C	2E
The motor retainer is not properly secured to the motor tube	Stress tests will be performed on the motor retainer to ensure it is able to withstand flight forces. The motor retainer will be inspected before each launch	2C	2E
The motor casing fails	The motor casing will be inspected before each launch	3C	3D

Table 5.3 – Preliminary Assessment of Risks to Personnel at Launch Sites

5.2 Failure Modes and Effects Analysis

As the team begins to build and test the systems that will comprise the launch vehicle and payload, it is important to identify key failures and prevent them before they happen. A system of Failure Modes and Effects Analysis (FMEA) will be utilized by the Safety Officer and other team members to identify these potential failures. The function of the team's FMEA will be to study each system and identify any possible risks of failure that can happen, and to prioritize those risks in descending order starting with the most hazardous risks first. The risks will by identified with: what the system is; what can fail; what could cause the failure and why; the impact of the failure; and how to prevent or mitigate the failure. The team understands that not every failure can be predicted and the FMEA system will also be used for any failure that does happen. Below is a table of preliminary potential failures, their likelihood, and impacts as well as mitigations.

System			
Hazard			
Effect(s)			
Cause(s)	Mitigation(s)	Pre-Mitigation	Post-Mitigation
Rover			
Communications Failure			
Rover failing to deploy properly or getting damaged			
The rover's communications are down due to interference from other team's equipment, bad wiring, or power failure	More powerful radio equipment may be necessary to get a strong signal to the rover and ensure the rover's receiver will take commands. Any new equipment purchased will increase the team's spending, and will need to be factored in when planning the budget	2C	2D
The rover misinterprets commands	Accurately analyze the rover's sensor inputs and conduct adequate testing before launching. Design the rover to be durable enough to withstand potential damage it may encounter	2C	2E
The rover has a power failure, or the ejection charge doesn't fire	Perform adequate testing prior to launching, and ensure that all electronics are thoroughly checked over to be in good working order	2C	2E
Rover			
Difficult Terrain			
Rover getting stuck			
The rover's wheels cannot negotiate the terrain	Design the rover to have wheels suitable for difficult terrain types, and test the rover several times before launching	2C	2E

Table 5.4 - Preliminary Rover FMEA

System			
Hazard			
Effect(s)			
Cause(s)	Mitigation(s)	Pre-Mitigation	Post-Mitigation
Cold Gas Thrusters			
Explosion			
Personnel are injured and the rocket is damaged			
Gas Leaks inside airframe and ignites from a spark emitted from electrical components	The team will use a non-combustible gas for the thrusters, and will inspect the thruster system to ensure there are no leaks before launching. The team will implement an engineering control to put a separation between any electronics and the pressurized gas tank	1D	1E

System			
Hazard			
Effect(s)			
Cause(s)	Mitigation(s)	Pre-Mitigation	Post-Mitigation
Cold Gas Thrusters			
Rocket flying out of control			
Personnel are injured and the rocket is damaged			
Pressurized gas tank becomes loose during flight inside airframe	All parts of the pressurized gas tank system will be securely mounted inside the airframe and inspected before launching.	1D	1E
Cold gas thrusters on launch vehicle are pointing in the wrong direction when expelling gas during flight	Perform adequate testing and calculate where nozzles should point to ensure gas expels in the correct direction	1D	1E
Cold Gas Thrusters			
Loss of Pressure			
Rocket fails to slow down			
Pressurized gas tank leaks inside airframe	All components of the cold gas thrusters will be tested and systematically inspected before launch to ensure all connections are tight and that there are no leaks	2D	2E
Recovery System			
Drogue chute / main chute failing to deploy			
Injury to personnel and the rocket is damaged			
Altimeter isn't turned on, or programmed incorrectly	Before launching all components of the rocket will be inspected by the team via the pre-launch checklist, and the range Safety Officer will inspect the rocket for flight readiness.	1D	1E
Black powder charge fails to ignite	The team will conduct ground fire tests to ensure that the ejection charge will ignite, and the rocket will be inspected by the team's Safety Officer and then by the range safety office prior to flight	1D	1E
The drogue chute fails to slow the rocket down enough for the main chute to safely deploy	The team will run simulations to determine the proper size of drogue chute for the rocket.	1D	1E
Parachute melts to side of airframe	Before launch the parachute will be checked as per the pre-launch checklist to ensure that recovery wadding is adequate to withstand high temperatures from motor igniting	1D	1E

System			
Hazard			
Effect(s)			
Cause(s)	Mitigation(s)	Pre-Mitigation	Post-Mitigation
Shock chord breaks during parachute deployment	Before launch the shock chord will be inspected as per the pre-launch checklist, and only a chord of strong enough material will be selected	1D	1E

Table 5.5 - Preliminary Launch Vehicle FMEA

5.3 Environmental Hazard Analysis

PSLT will be responsible for having as minimal of an impact on the environment as possible while building, testing, and launching high-power rockets. The team will work to use only the necessary amount of materials to complete the project, will safely dispose of any waste materials, and will recycle whenever possible. Local wildlife will be considered when testing and launching rockets and the payload, and similarly the local environment will be considered when testing and launching to avoid causing a fire. The following table provides a preliminary assessment of environmental risks with mitigations.

Hazard			
Effect(s)			
Cause(s)	Mitigation(s)	Pre-Mitigation	Post-Mitigation
Environmental Impact on Rocket			
Damage to or Loss of the Rocket			
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	1E
Direct sunlight / high temperatures causing electronics to overheat	The rocket will be assembled and stored in shaded area	2D	2E

Hazard			
Effect(s)			
Cause(s)	Mitigation(s)	Pre-Mitigation	Post-Mitigation
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	2E
Windy conditions causing the rocket to fly off of intended course and drift further away while landing	The team will not launch into high winds, and will wait for better conditions. The team will check simulations and flights for stability. Minimize time under main parachute to ensure minimal drift while maintaining safe landing speed.	2D	2E

Table 5.6 - Preliminary Assessment of the Impact of the Environment on the Rocket

Hazard			
Effect(s)			
Cause(s)	Mitigation(s)	Pre-Mitigation	Post-Mitigation
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	1E
Rocket crashing or parts breaking off of the rocket during flight, potentially introducing hazardous materials to the local ecosystem	Ground fire test will be conducted to ensure that the recovery system works to avoid crashes. Parts as rocket fins will be securely attached to airframe and tested to ensure they can withstand force. In case of crash the team will clear the area of debris as much as possible	2D	2E
Wildlife wandering near launch site potentially harming them	The range will first be declared clear by the range Safety Officer before any launch occurs. If any animals get near the launch site, the launch will be postponed, and no one should attempt to move the animal	2D	2E

Hazard			
Effect(s)			
Cause(s)	Mitigation(s)	Pre-Mitigation	Post-Mitigation
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	2E

Table 5.7 - Preliminary Assessment of the Impact of the Rocket on the Environment

5.4 Project Hazard Analysis

During the duration of the project, unforeseen circumstances may arise causing work to slow down or even come to a halt. Any setback, no matter how insignificant, can have a domino effect triggering future setbacks and potentially causing a project failure. To help prevent this from happening, PSLT will work to preemptively identify risks to the project and prevent them from causing issues. If a setback does happen, then the team will have a strategy in place to keep the project moving forward and mitigate any impacts from the setback. Below is a preliminary assessment of risks to the project.

Hazard					
Effect(s)					
Cause(s)	Pre-Mitigation Severity	Pre-Mitigation Probability	Mitigation	Post Mitigation Severity	Post Mitigation Probability
Lack of personnel					
Deliverables and presentations not being completed on time					
Team members dropping out	Medium	High	Ensuring all team members are able to commit time to the project. Making sure all roles can be filled by someone else if needed	Low	Medium

Cause(s)	Pre-Mitigation Severity	Pre-Mitigation Probability	Mitigation	Post Mitigation Severity	Post Mitigation Probability
		Hazard			
		Effect(s)			
Late completion of reports and presentations	High	Low	Set early deadlines and have multiple people working on sections in order to ensure completion	High	Low
Team members becoming overburdened with work and quality of work suffering	Medium	Low	Ensure that work is distributed evenly among team members, and that members have resources necessary to complete tasks	Low	Low
Not Meeting Project Requirements					
Project Failing					
Missing a subscale or full-scale launch due to inclement weather	High	Medium	Have backup launch schedules planned at alternate NAR locations in case of launch cancellation	Medium	Low
Failure to complete rover	High	Low	Rover designs should be within scope of team's ability to complete. Establish project timeline so team members will know how much time will be available to create rover	Low	Negligible
Failure to complete educational engagement requirement	Medium	Low	Plan for numerous outreach events and advertise as much as possible to draw in the most amount of people	Medium	Negligible

Hazard					
Effect(s)					
Cause(s)	Pre-Mitigation Severity	Pre-Mitigation Probability	Mitigation	Post Mitigation Severity	Post Mitigation Probability
Team not having resources for project					
Projects halts					
Unable to purchase necessary rocket motor due to unforeseen manufacturing circumstance e.g. Aerotech warehouse fire	Medium	Medium	Be able to purchase motor from alternate manufacturer or purchase backup motors ahead of time. Any extra motors will increase the cost of project, and should be planned for in budget	Medium	Low
Funding shortages	High	Low	Ensure that budget is spent wisely and find numerous sponsors and individual donors to help cover expenses	Medium	Low

Table 5.8 – Preliminary Project Risk Assessment

6 Payload Criteria

6.1 Mission Statement and Success Criteria

6.1.1 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.

6.1.2 Success Criteria and Challenges

The rover shall have designs that:

- Provide an external means of power cycling to the rover
- Have status LEDs to allow easy diagnosis of problems from the spectator area
- Transmit diagnostic information to the ground station, e.g. battery levels, errors, etc.
- Allow for the transmission of live video
- Self-right the rover by identifying its current orientation and return to the normal orientation from any position
- Are versatile in any expected environment such as mud or water
- Allow the solar panel to provide power to the rover
- Allow for the rover to continue moving if a drive motor fails
- Can identify the rover's position relative to the rocket
- Can withstand impacts due to flight, landing, deployment, falling, etc. without losing functionality
- Can measure and transmit altitude during the flight

The rover is required to:

- Deploy from inside of the rocket
- Be remotely triggered for deployment
- Move under its own power and autonomy 5 ft away from any part of the rocket
- Deploy foldable solar panels after having moved away from the rocket

6.2 System Designs

6.2.1 Rover Deployment

The design of the deployment system is required to:

- Orient the rover relatively correctly once the rover has landed
- Protect the rover
- Minimize points of failure
- Be feasible
- Minimize weight
- Versatile on deployment scenarios
- Be efficient with space

6.2.1.1 Options

Option 1 Guiding Rails:

This system relies on having two rails within the upper section of the rocket that the rover, with corresponding rail guides, could be slotted into and secured on for flight. Once the rocket had landed and the remote signal been received, the rover would ignite an ejection charge from behind itself and be launched out of the payload tube, pushing the nosecone out of the way. The rover itself would have four rail guides, two on each side, that would keep it on the tracks until it exited the rocket.

Pros:

- Simple
- Reliable
- Lower weight

Cons:

- Provides little protection to the rover
- No method of self-righting

Option 2 Nosecone Delivery:

This design uses the nosecone as a faring from which the rover can be released. The nosecone would be held together by compressed springs that are held in place by the body tube itself. Once the nosecone has been ejected by an ejection charge, the nosecone would shoot out and land and then release the rover once it has stopped moving. This allows for the rover to be protected and launched away from the rocket to reduce the chance of becoming entangled.

Pros:

- Protective
- Can survive almost all landing conditions
- Efficient on space
- Can self-right due to the CM moving down in flight

Cons:

- Relatively more complex, i.e. more points of failure
- More weight needed

Criteria (weight)	Option 1	Option 2
Self-righting (x2)	0	2
Protective (x3)	1	4
Points of Failure (x3)	3	1
Feasibility (x1)	4	3
Weight (x2)	4	2
Deployment Conditions (x3)	3	4
Space Efficiency (x1)	3	4
Total	36	42

Table 6.1 - Payload Deployment Decision

6.2.2 Rover Body

6.2.2.1 Rover Body Shape Options

Requirements:

- The rover body will contain all the mechanical and electronic components

Option 1 Rectangular:

Pros: Simplicity
Cons: Reduced storage volume, higher center of gravity

Option 2 Octagonal:

Pros: Increased storage volume, lower center of gravity
Cons: Increased complexity

Criteria (weight)	Option 1	Option 2
Simplicity (x1)	4	2
Low CG (x2)	2	3
Internal Volume (x3)	2	3
Total	14	17

Table 6.2 - Rover Body Shape Decision

6.2.2.2 Rover Body Ends Shape Options

Requirements:

- The fore and aft ends of the rover body need to be enclosed

Option 1 Tapered:

Pros: Increase mobility by increasing approach and departure angles
Cons: Increase complexity of structure

Option 2 Non-tapered:

Pros: Decrease complexity
Cons: Decrease mobility

Criteria (weight)	Option 1	Option 2
Simplicity (x1)	2	4
Improved Mobility (x3)	3	1
Total	11	7

Table 6.3 - Rover Body Ends Shape Decision

6.2.2.3 Rover Frame Options:

Requirements:

- The rover frame will be made of aluminum
- The rover frame needs to be able to withstand all the forces of flight including launch, rocket separation at apogee and subsequent parachute deployment, and landing
- It must be able to withstand the payload tube ejection after landing
- In addition to withstanding all the aforementioned forces, it must be able to keep all inside mechanical and electronic components securely fastened
- The frame must be as light as possible.

Option 1 Full Frame (Unibody):

This option is to make the whole body out of aluminum.

Pros: Strongest design, components can be mounted at any point inside the body
Cons: Heaviest design

Option 2 Skeleton Frame:

This option is to make a skeleton frame out of aluminum and clad the body with plastic paneling.

Pros: Lightest design
Cons: Weakest design, limited component mounting points, most complicated to manufacture

Option 3 Hybrid Frame

This option is to make a frame with aluminum on the two vertical sides, but with plastic paneling on the bottom three sides.

Pros: Provides strong mounting points for most components (especially the wheel motors), stronger than the skeleton frame, some reduction in weight from the full frame
Cons: heavier than the skeleton frame

Criteria (weight)	Option 1	Option 2	Option 3
Component Mounting Points (x1)	4	1	3
Simplicity (x1)	3	1	3
Weight (x3)	1	4	3
Strength (x3)	4	1	3
Total	22	17	24

Table 6.4 - Rover Frame Decision

6.2.3 Electronics

6.2.2.1 Video

The purpose of this subsystem is to record video from the rover's point of view and transmit it to a ground station.

Requirements:

- Be able to transmit to a ground station

Option 1 Separate System:

This option consists of a camera, transmitter, and battery that are not connected to any of the other electronics in the rover.

Pros: allows a dedicated high-bandwidth transmitter

Cons: requires a separate transmitter; requires a separate battery; requires a separate receiver on the ground station

Option 2 Integrated System:

This option consists of a camera connected to the microcontroller. The video would be transmitted using the same transmitter as the other data.

Pros: only requires a camera, no extra transmitter or battery; could use the video to detect obstacles (if using a sufficiently powerful microcontroller)

Cons: requires the general transmitter to have higher bandwidth

Criteria (weight)	Option 1	Option 2
Cost (x1)	2	3
Complexity (x2)	3	2
Space in rover (x2)	2	3
Ease of transmission (x3)	4	2
Total	24	19

Table 6.5 - Video System Decision

6.2.2.2 Rocket Detection / Distance

The purpose of this subsystem is to determine when the rover has met the competition requirement of moving 5 ft from the rocket.

Requirements:

- Be able to determine when the rover is more than 5 feet from the rocket

Option 1 Transponders in Launch Vehicle:

This option consists of radio transponders placed in each section of the launch vehicle.

Pros: the rover can determine its distance from each section of the rocket

Cons: requires multiple transponders in the launch vehicle and a receiver in the rover; makes shielding the recovery avionics more difficult (more transmitters in the launch vehicle)

Option 2 GPS in Rover:

This option consists of putting the required GPS receiver in the rover instead of in the launch vehicle. Because the rover is inside the launch vehicle for the duration of the flight, transmitting the position of the rover is equivalent to transmitting the location of the launch vehicle.

Pros: may require no extra hardware if there is already a GPS receiver in the rover (see GPS receiver subsystem below)

Cons: the rover can only determine its distance from the upper section (by comparing its current position to its position at landing)

Criteria (weight)	Option 1	Option 2
Cost (x1)	2	4
Complexity (x2)	2	4
Space in rover (x2)	3	3
Precision (x3)	3	1
Total	17	21

Table 6.6 - Rocket Detection / Distance System Decision

6.2.2.3 Obstacle Detection

The purpose of this subsystem is to detect obstacles (most likely the sections of the launch vehicle) so that the rover can navigate around them.

Requirements:

- Be able to detect obstacles

Option 1 Ultrasonic Sensor:

This option consists of mounting an ultrasonic sensor to the front of the rover to detect when obstacles are within a certain range.

Pros: none

Cons: wouldn’t work somewhere with no atmosphere

Option 2 Infrared (IR) Sensor:

This option consists of mounting an analog IR sensor to the front of the rover to detect when obstacles are within a certain range.

Pros: there commercially available options with a protective cover; less complex than an ultrasonic sensors or LiDAR (analog vs. digital)

Cons: less accurate than LiDAR

Option 3 Time of Flight Sensor (LiDAR):

This option consists of mounting a laser-based time-of-flight sensor (also known as LiDAR) to the front of the rover to detect when obstacles are within a certain range.

Pros: more accurate than IR

Cons: commercially available options usually have exposed circuitry, requiring a custom-made cover that could interfere with the sensor

Option 4 Touch Sensor:

This option consists of mounting touch-based sensor inside the rover, with a rod protruding through the front.

Pros: doesn't require external circuitry

Cons: shorter range than other options

Criteria (weight)	Option 1	Option 2	Option 3	Option 4
Cost (x1)	3	3	3	3
Complexity (x2)	3	3	3	2
Space in rover (x2)	3	3	3	2
Accuracy (x2)	2	2	3	4
Range (x2)	3	3	3	1
Durability (x3)	2	3	1	3
Total	31	34	28	31

Table 6.7 - Obstacle Detection System Decision

6.2.2.4 GPS Receiver

The purpose of this subsystem is to record and transmit the position of the launch vehicle through the duration of the flight.

Requirements:

- Be able to determine the location of the launch vehicle during flight and after landing
- Be capable of transmitting the location of the launch vehicle during flight

Option 1 GPS in Launch Vehicle:

This option consists of using an altimeter with a built-in GPS receiver as either the primary or secondary recovery system altimeter.

Pros: doesn't require extra hardware in the rover

Cons: the rover doesn't know its location

Option 2 GPS Integrated in Rover:

For this option, a GPS receiver will be put in the rover and connected to the microcontroller.

Pros: the rover knows its location

Cons: requires a GPS receiver in the rover

Criteria (weight)	Option 1	Option 2
Cost (x1)	2	3
Complexity (x2)	4	3
Space in rover (x2)	4	2
Usefulness to rover (x3)	0	3
Total	18	22

Table 6.8 - GPS Receiver Decision

6.2.2.5 Microcontroller

The microcontroller will collect data from the sensors and control the motors (and, by extension, the wheels and solar panel deployment) and communicate with the ground station through a transceiver.

Requirements:

- Be able to integrate with the batteries, sensors, motor driver, and transceiver
- Be capable of controlling the rover autonomously

Option 1 Arduino Uno:

Pros: smaller than a Raspberry Pi

Cons: less processing power than a Raspberry Pi

Option 2 Raspberry Pi 3:

Pros: more processing power

Cons: larger

Option 3 Custom Controller:

A custom microcontroller, specifically designed for use in the rover.

Pros: doesn't have to be as universally compatible as the other options, so could potentially be made smaller than the Arduino and as powerful as the Raspberry Pi

Cons: designing and manufacturing it would slow down testing of the rover; if it is designed for a specific set of sensors, motors, etc., then the rover design can't be easily changed

Criteria (weight)	Option 1	Option 2	Option 3
Cost (x1)	3	2	1
Complexity (x2)	3	3	1
Space in rover (x2)	2	1	3
Processing power (x2)	2	3	3

Criteria (weight)	Option 1	Option 2	Option 3
Total	17	16	15

Table 6.9 - Microcontroller Decision

6.2.2.6 Remote Communication

The purpose of this subsystem is to receive the deployment signal from the ground station after landing.

Requirements:

- Be able to receive the deployment command after landing

Option 1 Receiver in Rocket:

A remotely controlled electronic switch that would complete a circuit, triggering the deployment of the rover.

Pros: doesn't require a connection between the rover and the deployment system

Cons: the rover has to detect deployment itself, as it won't be receiving the deployment signal

Option 2 Transceiver in Rover:

The deployment signal will be sent to the rover's transceiver. The rover will then trigger the deployment mechanism.

Pros: rover knows when deployment occurs; does not require a separate receiver

Cons: rover must be connected to the deployment system

Criteria (weight)	Option 1	Option 2
Cost (x1)	3	3
Complexity (x2)	3	2
Space in rover (x2)	4	3
Usefulness to rover (x3)	0	2
Total	17	19

Table 6.10 - Remote Communication Decision

6.2.2.7 Orientation Detection

The purpose of the subsystem is to determine the orientation of the rover after deployment so that it can right itself if necessary.

Requirements:

- Be able to determine if the rover is upside-down or on its side

Option 1 Inertial Measurement Unit (IMU):

A 9 Degrees Of Freedom (DOF) IMU connected to the microcontroller.

Pros: allows the rover to determine its heading

Cons: more expensive

Option 2 Accelerometer:

A 3 DOF accelerometer connected to the microcontroller.

Pros: cheaper

Cons: the rover cannot determine its heading

Option 3 External Sensor (LiDAR, IR, ultrasonic, touch):

One of the sensor options listed above would be mounted on the underside of the rover. If it detects the ground, then the rover is right-side-up, otherwise it is not.

Pros: none

Cons: requires external sensors, reducing durability; can't determine exact orientation, only correct vs. incorrect

Criteria (weight)	Option 1	Option 2	Option 3
Cost (x1)	2	3	3
Complexity (x2)	3	3	2
Space in rover (x2)	3	3	3
Durability (x2)	3	3	2
Accuracy (x2)	3	2	1
Total	26	25	19

Table 6.11 - Orientation Detection Decision

6.2.2.8 Transmitting Altimeter

The purpose of this subsystem is to record the altitude of the launch vehicle during flight and transmit it to a ground station to determine whether the launch vehicle is following a safe trajectory, especially near apogee, where it may be difficult to see.

Requirements:

- Be capable of reading the altitude in flight
- Be capable of transmitting the altitude back to the ground

Option 1 Commercial Transmitting Altimeter in Rocket:
Either the primary or secondary recovery system altimeter will be a model that is capable of transmitting to a ground station.

Pros: the altimeter could also incorporate a GPS, reducing the number of separate sensors needed
Cons: more expensive; requires a separate receiver

Option 2 Altimeter Integrated in Rover:
An altimeter will be connected to the microcontroller and the altitude data will be sent through the transceiver.

Pros: cheaper
Cons: takes up space in rover

Criteria (weight)	Option 1	Option 2
Cost (x1)	2	3
Complexity (x2)	2	3
Space in rover (x2)	4	3
Total	14	15

Table 6.12 - Transmitting Altimeter Decision

6.2.2.9 Motor Driver

The motor driver is the interface between the microcontroller and the numerous motors in the rover. The primary challenge in selecting a motor driver is the number of motors that need to be independently driven.

Requirements:

- Be capable of driving as many motors as are needed
- Be capable of interfacing with microcontroller and battery

Option 1 Single Commercial Driver:
A single multichannel motor driver.

Pros: simpler
Cons: large; may not be able to find one capable of driving different types of motors

Option 2 Multiple Commercial Drivers:
Multiple single channel motor drivers.

Pros: can be used with any combination of motor types
Cons: takes up a lot of space; expensive, requires many connections to the microcontroller

Option 3 Single, Custom-Made Driver:
A custom designed multichannel motor driver.

Pros: can be designed for any combination of motor types; small; requires fewer connections to the microcontroller
Cons: design and manufacturing could slow down rover testing

Criteria (weight)	Option 1	Option 2	Option 3
Cost (x1)	2	1	3
Complexity (x2)	3	2	1
Space in rover (x2)	2	1	3

Criteria (weight)	Option 1	Option 2	Option 3
Extensibility (x3)	2	4	3
Total	18	19	20

Table 6.13 - Motor Driver Decision

6.2.2.10 Power

This subsystem consists of the battery or batteries to power the rover, along with any necessary voltage regulators.

Requirements:

- Be capable of interfacing with microcontroller and sensors
- be capable of interfacing with motor driver
- be capable of powering microcontroller, sensors, transmitter(s), and motor driver for 3+ hours
- be capable of powering motors for 15 minutes

6.2.2.10.1 Number

Option 1 One Battery:

One battery connected to the motor driver(s) directly and to the microcontroller through a voltage regulator.

Pros: requires less space

Cons: requires at least one voltage regulator

Option 2 Two Batteries:

Two batteries, one for the microcontroller and one for the motor driver(s), each with different voltages.

Pros: may not require voltage regulators (the voltage to the microcontroller will still have to be regulated if using conventional batteries)

Cons: takes up more space

Criteria (weight)	Option 1	Option 2
Cost (x1)	3	2
Complexity (x2)	1	3
Space in rover (x2)	3	2
Total	11	12

Table 6.14 - Number of Batteries Decision

6.2.2.10.2 Type

Option 1 Conventional:

Pros: easier to attach voltage regulators.

Cons: voltage is more variable.

Option 2 Lithium Ion (LiPo):

Pros: more consistent voltage

Cons: hard to attach voltage regulators

Criteria (weight)	Option 1	Option 2
Cost (x1)	2	1
Complexity (x2)	2	3
Total	6	7

Table 6.15 Battery Type Decision

6.2.4 Rover Mobility

Requirements:

- Be able to traverse a wide variety of terrains
- Be able to fit within a 6 in. body tube
- Be able to drive either upright or inverted

Option 1 Screw Drive:

A screw driven design was considered, in which the rover would sit on two horizontal screws that when spun would propel the rover. The screws excel at traversing soft surfaces such as sand and loose dirt, but do not do well on hard pack surfaces. This was ultimately not chosen due to the inability to traverse hard surfaces that may be encountered. Other limitations would be the parachute or recovery harness getting entangled in the screws and preventing the rover from getting the required 5 ft from the launch vehicle.

Option 2 Standard Round Wheels:

Using standard round wheels were considered. Because of the decision to design the rover in such a way that it can upright or inverted, using round wheels large enough to allow adequate ground clearance would not fit in the 6 in. round payload tube.

Option 3 Folding Wheels:

The folding wheels would help resolve the issue of the wheels not fitting in the payload tube but were considered too fragile to be viable.

Option 4 Treads:

Treads were considered but like the standard round wheels would be difficult to fit in the tube while still allowing the vehicle to drive upright or upside-down.

Option 5 S-Curve Wheels:

The S-curve wheel is what inspired the figure-eight wheel. We initially wanted to use the S-curve wheel but had concerns about the wheels going in reverse. We ultimately decided on a double S-curve or a figure-eight.

Option 6 Round Wheels on Rotating Arms:

The idea here is to have the six wheels each attached to a rotating arm, the rotating arms would rotate in pairs; the front, middle and rear. This would allow the use of smaller wheels and still allow the rover to be drive in both the upright and upside-down orientation. The use of the rotating arms would also allow the rover to "climb" over obstacles, by driving close to the obstacle then rotating the arm the front wheels are attached to backwards until the wheels are on top of the obstacle. This design was determined to be too complex and potentially not robust enough to survive the launch, landing, and subsequent ejection from the payload tube.

6.3 Current Design

6.3.1 Rover Deployment

The rover will deploy using the nosecone as a faring and container. It will be stored in the nosecone and held in place by pins. When the signal from the ground station has been received, the rover will ignite the ejection charge behind the bulkhead of the nosecone, and thus be ejected out of the rocket. Once the nosecone-rover package has landed and come to a relative slow motion, the rover will release the sides of the nosecone. This allows the sides to come apart like a clamshell and thus release the rover.

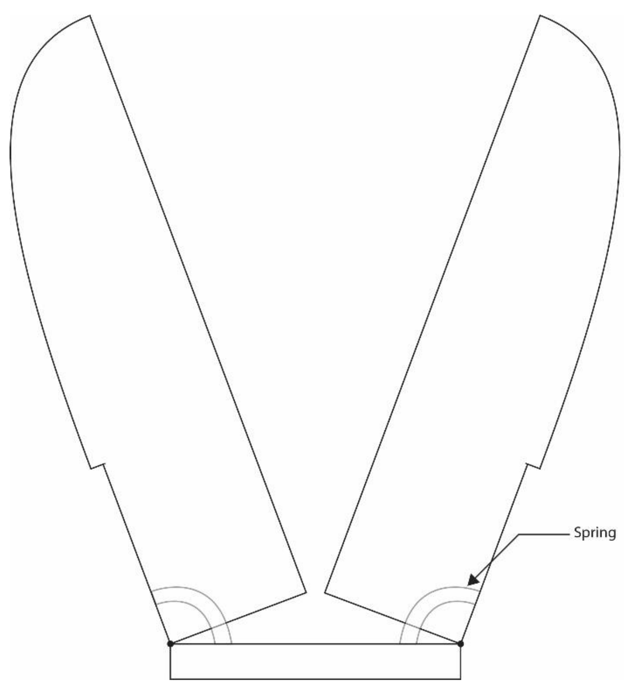

Figure 6.1 - Nosecone Opening

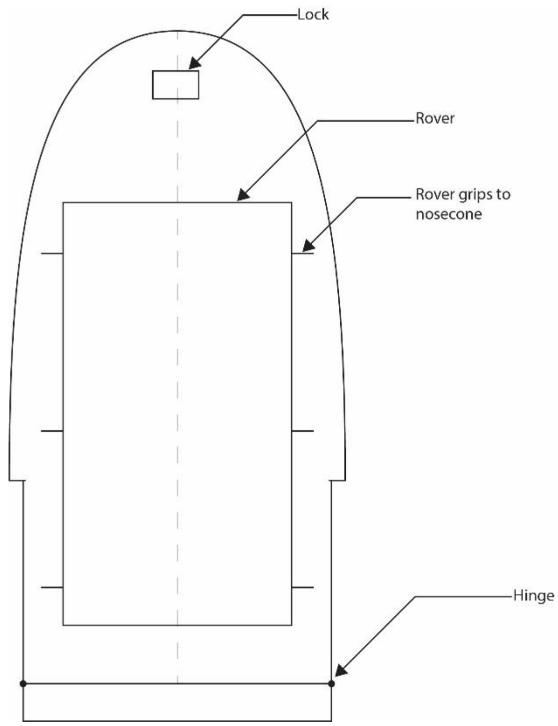

Figure 6.2 - Nosecone with Rover

6.3.2 Rover Body

The rover body has an octagonal shape on the longitudinal axis with the bottom section composed of five sides and the top piece composed of the remaining three sides. 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 are on the top and bottom sides, but not the two vertical sides. 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 top piece is composed of a righting mechanism / solar panel bracket.

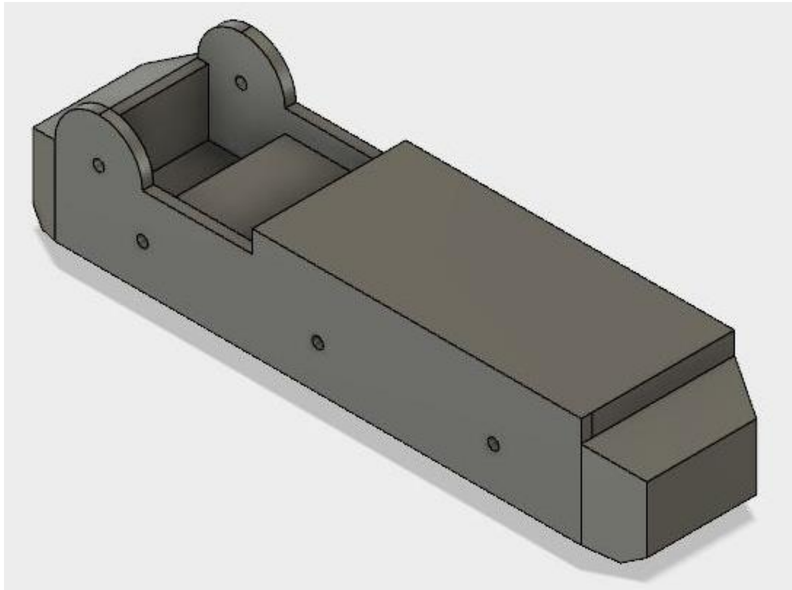

Figure 6.3 - Rover Body with Paneling

The rover frame will utilize a hybrid design with aluminum vertical sides and plastic paneling on the bottom three sides. It will be made in accordance with the above description of the rover body.

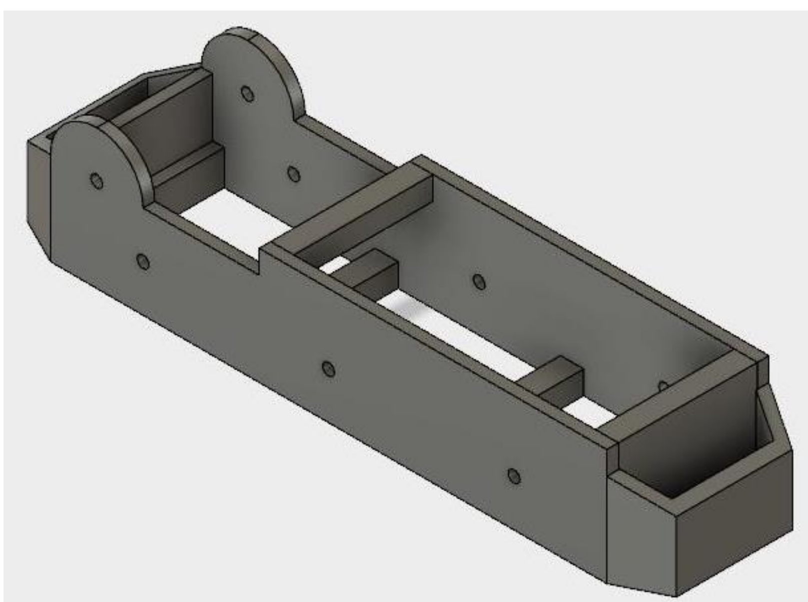

Figure 6.4 - Rover Frame

6.3.3 Electronics

6.3.3.1 Video

The separate system option was chosen. The main reason for this is to prevent the non-critical video from interfering with the transmission of the important data.

6.3.3.2 Rocket Detection / Distance

The GPS in rover option was chosen. There are two main reasons for this: first, it avoids the complexity of having to triangulate the signals from multiple transponders; second, it reduces the number of transmitters near the recovery system avionics.

6.3.3.3 Obstacle Detection

The infrared sensor option was chosen. The primary reason for this is the increased durability compared to ultrasonic or time of flight sensors. The improved range compared to the touch sensor was also a factor.

6.3.3.4 GPS Receiver

The GPS integrated in rover option was chosen. There are two reasons for this: first, unlike the “GPS in launch vehicle” option, it doesn’t require a transmitter in the avionics bay; second, the rover will already have a GPS receiver to compute its distance from the landing point.

6.3.3.5 Microcontroller

The Arduino Uno was chosen as the microcontroller. The reason it was chosen over the Raspberry Pi is its small size, and the fact that the rover is not expected to need to do CPU-intensive calculations. The custom-made microcontroller option was rejected because of the bottleneck it would create on rover construction and testing.

6.3.3.6 Remote communication

The transceiver in rover option was chosen. This option adds the complexity of needing to connect the rover to the deployment system. However, allowing the rover to control its own deployment (after it receives the go-ahead signal) means that other actions done by the rover (such as powering on sensors) can be synchronized with deployment.

6.3.3.7 Orientation Detection

The Inertial Measurement Unit (IMU) option was chosen. The extra sensors in an IMU compared to an accelerometer means that the rover can collect more kinds of data during the flight to help analyze the performance of the launch vehicle. In addition, the ability to determine the rover’s heading may help with navigation.

6.3.3.8 Transmitting altimeter

The altimeter integrated in rover option was chosen. The main reason for this is that, unlike the other option, it doesn’t require putting a transmitter in the avionics bay.

6.3.3.9 Motor Driver

The single custom-made driver option was chosen. The main reason for this is the small amount of space it takes up in the rover. Due to the relative simplicity of a motor driver, the design and manufacture of a custom one shouldn’t create much of a bottleneck.

6.3.3.10 Power

2 Lithium-ion Polymer (LiPo) batteries were chosen. This allows the one to power the motors and camera, and another, lower voltage, one to power the microcontroller (and by extension the sensors and transceiver). In addition, neither battery requires an external voltage regulator.

6.3.4 Rover Mobility

The rover will feature six infinity wheels, each will be a figure-eight shape. The front wheels and back wheels will be on the same plane while the inner wheels will be further out from the body of the rover, this is to allow the wheels clearance from each other while rotating. The shape of the wheels will allow the rover to climb over obstacles better than traditional round wheels due to their ability to grab the top of obstacles and pull the vehicle up. Each of the six wheels will be driven by its own electric motor.
The figure-eight shape of the wheels will allow the wheels to better fit in the payload tube of the launch vehicle by being able to line up horizontally along the side of the rover.

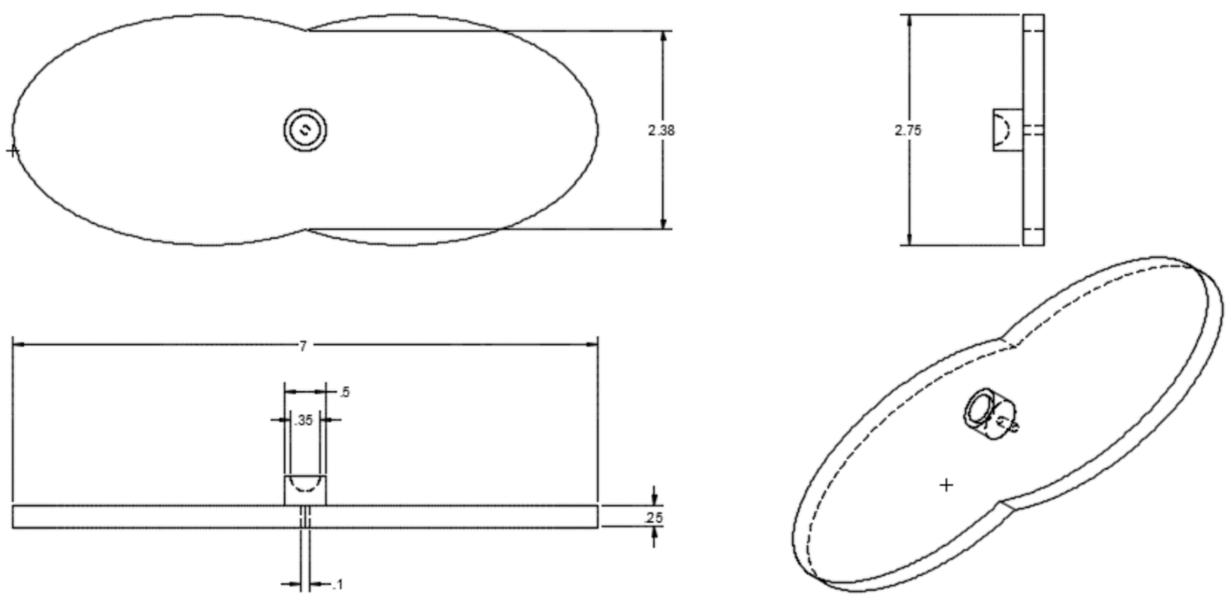

Figure 6.5 - Rover Wheels

6.3.5 Righting Mechanism and Solar Panel

The top section of the rover is composed of the righting mechanism and the solar panel bracket, which acts as the arm for the righting mechanism. Orientation will be determined by sensors on the rover. The righting mechanism will consist of a commercially-available electric motor that is mated to a torque conversion box. This assembly will be held in place by two aluminum brackets that will be fastened to the torque box. These brackets will be fastened to a pin that will be turned by a separate motor within the bottom section of the rover. This will deploy and retract the righting mechanism as needed. 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.

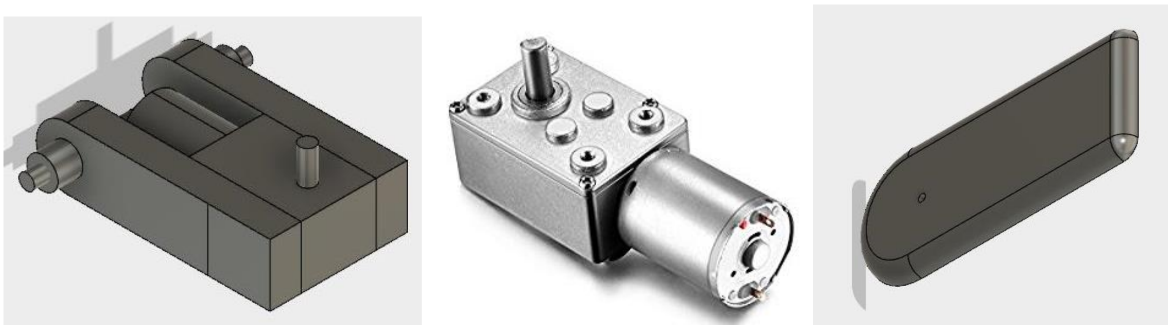

Figure 6.6 - Rover Righting Mechanism

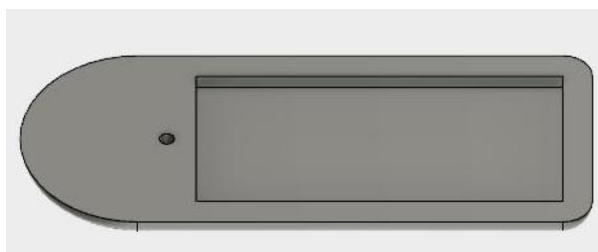

Figure 6.7 - Solar Panel Bracket

6.3.6 Software

The state diagram below shows the states of the rover throughout its operation and the transitions between states. It also shows the nominal algorithm for moving away from the launch vehicle.

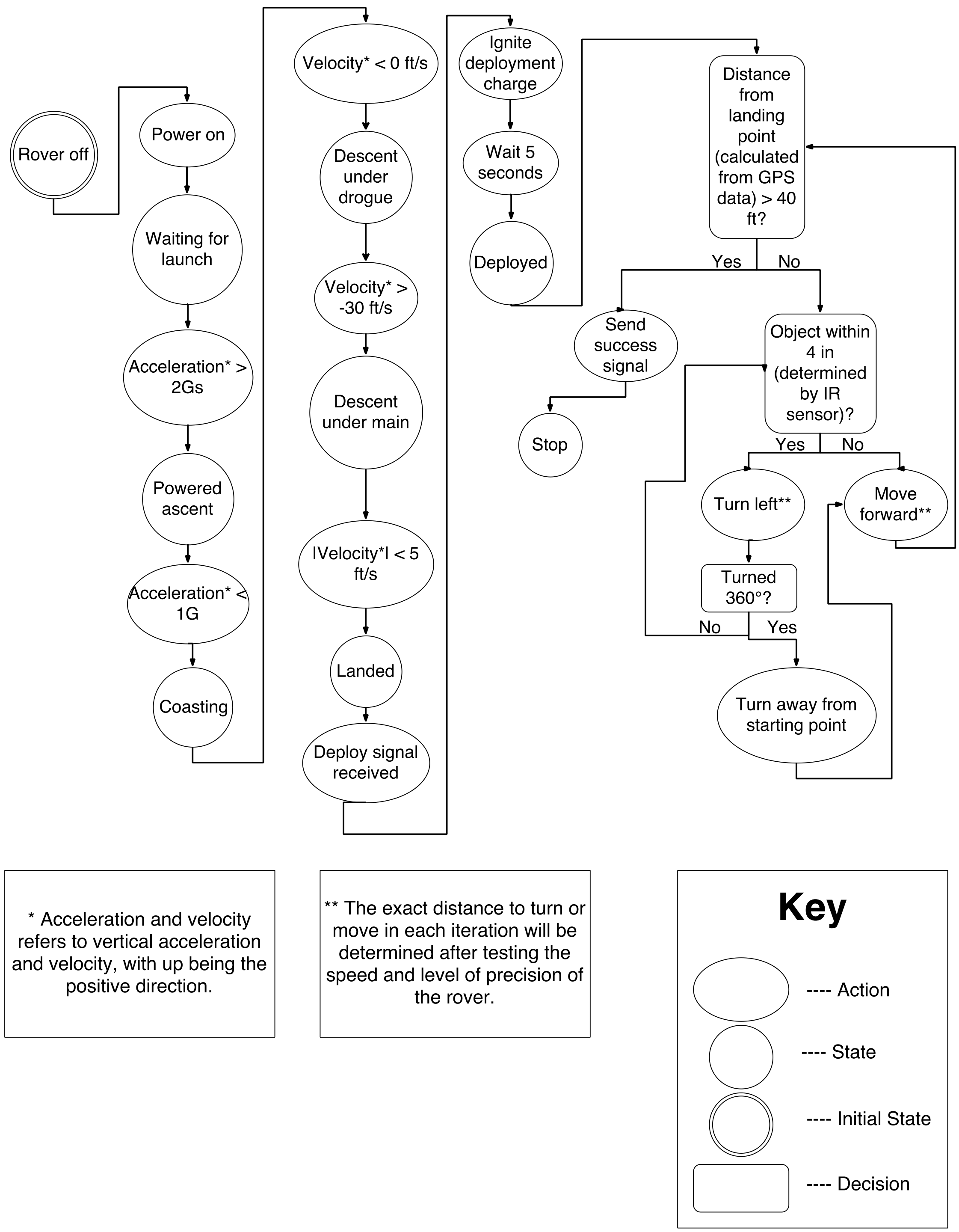

Figure 6.8 - Rover Software

The table below shows what data the rover will be transmitting in each state. It also lists the parameters that will be used to determine if the launch vehicle is following a safe trajectory. If these parameters are violated, a warning signal will be sent to the ground station.

State	Data	Safe Trajectory Parameters
Rover off	None	N/A
Waiting for launch	IMU, altimeter, GPS, video.	N/A
Powered ascent	Same as above, plus an indicator of whether the launch vehicle is following a safe trajectory.	Velocity > 0 ft/s (launch vehicle is not falling). Tilt < 20°.
Coasting	Same as above.	Velocity > 0 ft/s.
Descent under drogue	Same as above.	Velocity > -150 ft/s.
Descent under main	Same as above.	Velocity > -50 ft/s.
Landed	Same as above, but no longer transmitting the safe trajectory indicator.	N/A
Deployed	Same as above, plus IR sensor.	N/A
Stop	Continues transmitting data until it runs out of power or a shutdown command is received.	N/A

Table 6.16 - Data Transmitted

6.3.6.1 Righting mechanism control

The algorithm to control the righting mechanism will be determined after a preliminary version of the rover has been built and tested.

6.3.6.2 Sensor failure

The table below lists the backup plan if any of the sensors fail.

Sensor	Issue	Backup
GPS receiver	Rover cannot determine its distance from the landing point	Move in the same direction for a minimum amount of time. That minimum will be determined after testing the speed of the

Sensor	Issue	Backup
		rover
IMU	Rover can’t determine if it needs to right itself	It will attempt to right itself; this will either right it or do nothing if it is already righted
Altimeter	Rover can’t determine if the launch vehicle is following a safe trajectory	Safe trajectory indicator will be replaced with sensor failure warning
Camera	Rover can’t transmit video	The camera is a non-critical system, so there is no backup
IR sensor	Rover can’t determine if there is an obstacle in front of it	The rover will attempt to move forwards; if its position doesn’t change, then there is an obstacle
Transceiver	Rover can’t transmit data or receive deployment signal	Rover will store critical data. If the deployment signal is not received, the rover will not trigger deployment

Table 6.17 - Sensor Failure Contingencies

7 Project Plan

7.1 Requirements Verification

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.

7.1.1 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 7.2 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 & 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
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 will be provided in the General Information section of the CDR
1.5	Demonstration	PSLT has already engaged with over 100 participants in hands-on educational activities, and has plans for a significant amount of further education (see section 7.5 Engagement & 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
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

ID	Verification Type	Verification Plan
		document assembly
1.11	Demonstration	Tiger Fuel Co., one of PSLT’s sponsors, has provided the use of their conference room for both teleconference reviews and practice presentations
1.12	Demonstration	The launch vehicle design is intended to use 1515 rails
1.13	Demonstration	PSLT’s webmaster has implemented these standards and will continue to ensure they are in place
1.14	Demonstration	The team’s mentor has been identified in section 1.1 Team Contacts
2.1	Analysis, Testing	The launch vehicle’s ability to carry the payload to 5280 ft will be analyzed using RockSim, OpenRocket, and hand calculations, and will be tested during full-scale test flights
2.2	Demonstration	The recovery system design includes a commercially available, barometric altimeter to be used as the scoring altimeter on launch day
2.3	Demonstration	The recovery system design includes two externally accessible switches, one to arm each altimeter
2.4	Demonstration	The recovery system design includes two batteries, one for each altimeter
2.5	Demonstration	The arming switches in the recovery system design have keys 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 7.2 Timeline)
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 with only one motor
2.9	Demonstration	The launch vehicle is designed such that most of the 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 the subscale and full-scale test flights)
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
2.11	Demonstration	The launch vehicle design allows the motor to be directly connected to a standard firing system and requires nothing else to initiate flight
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 motor
2.14.1	Demonstration	The launch vehicle design uses one pressure vessel. The model purchased will have a sufficiently high factor of safety
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

ID	Verification Type	Verification Plan
		being capable of withstanding the maximum pressure and flow rate of that vessel. Testing will be done to ensure the valves used on the subscale and full-scale launch vehicles meet all requirements before their test flights
2.14.3	Demonstration	When the pressure vessels to be used for the subscale and full-scale flights are purchased, the Safety Officer will ensure that their full pedigrees are 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 and hand calculations have been done on the launch vehicle design to ensure that the static stability margin at rail exit is above 2.0
2.17	Analysis, Testing	RockSim and OpenRocket simulations and hand calculations have been done on the launch vehicle design to ensure that velocity at rail exit is above 52 ft/s. Additionally, the velocity at rail exit will be measured during both subscale and full-scale test flights
2.18	Demonstration	Construction of the subscale launch vehicle and payload will begin shortly after this report is submitted with its first test flight planned for December 6th and a backup of December 7th (see section 7.2 Timeline)
2.19	Demonstration	Construction of the full-scale launch vehicle and payload will begin shortly after the CDR report is submitted with its first test flight planned for February 17th and a backup of February 18th (see section 7.2 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
2.19.6	Demonstration	None of the components of the launch vehicle will be changed after the full-scale test flight unless for safety reasons
2.19.7	Demonstration	The first full-scale test flight is scheduled for well before FRRs are submitted (see section 7.2 Timeline)
2.20	Demonstration	The launch vehicle design does not have any structural protuberances fore of the burnout CG
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, and the total ballast used is less than 10% of the total mass of the launch vehicle. RockSim and OpenRocket simulations and hand calculations have been done to ensure the launch vehicle design does not exceed Mach 1 at any point in flight
3.1	Demonstration	The launch vehicle design has apogee separation and main parachute deployment both staged by onboard altimeters
3.2	Demonstration	Ground ejection tests will be included in the set of tests being planned for prior to both the subscale and full-scale launches (see section 7.2 Timeline)
3.3	Analysis, Testing	RockSim and OpenRocket simulations and hand calculations have been done to determine the velocity at landing of the launch vehicle design,

ID	Verification Type	Verification Plan
		which has been used to ensure that the highest kinetic energy of any section is below 75 ft-lbf. Additionally, the velocity at landing will be measured for both the subscale and full-scale test flights
3.4	Demonstration	The recovery system design does not share any electronics with the payload design
3.5	Demonstration	The recovery system design has all electronics powered by commercially available altimeters
3.6	Demonstration	The recovery system design has not only redundant altimeters, but has redundancy for all components
3.7	Demonstration	The recovery system design does not utilize motor ejection at all
3.8	Demonstration	The recovery system design uses nylon shear pins to secure the parachute compartment
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 2500 ft from the launch pad. Additionally, the distance that the rockets drift will be measured for both the subscale and full-scale test flights
3.10	Demonstration	The recovery system design includes a tracker that will transmit the location of the launch vehicle to a ground station
3.11.1	Demonstration	The recovery system design has the recovery system electronics in a separate compartment from any other electronics
3.11.2	Demonstration	The recovery system electronics will be shielded from the payload, which has the only other transmitting device on the rocket
3.11.3	Demonstration	The recovery system electronics will be shielded from the solenoid valves used in the altitude control system
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
4.5.2	Demonstration	The rover design includes a transceiver so that deployment can be remotely triggered
4.5.3	Inspection	The rover design has sensors that it will use to determine when it is at least 5 ft from the rest of the rocket. Additionally, when the rocket is being recovered, the distance between the rover and the rest of the rocket 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
5.2	Demonstration	PSLT has designated a Safety Officer (see section 1.1 Team Contacts)
5.3 -	Demonstration	The Safety Officer has been made aware of his responsibilities and they are

ID	Verification Type	Verification Plan
5.3.4		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
5.5	Demonstration	The Safety Officer's responsibilities include understanding and ensuring compliance with all FAA rules and regulations

Table 7.1 - Verifications for NASA Defined Requirements

7.1.2 Team Defined Requirements

The requirements listed here for the launch vehicle, recovery system, and payload are only preliminary and will be made more specific as the designs of those systems develop. For the time being, they are largely requirements that drive the selection of the types of systems to be used.

7.1.2.1 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 will be estimated through calculations. This capability will also be demonstrated during the subscale and full-scale test flights, 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 the weight of the rocket	Demonstration	The design of the launch vehicle will include 1515 rail buttons for launch support
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 for all launches
Use an Aerotech	To reduce the	Demonstration	The launch vehicle design uses an

Requirement	Purpose	Verification Type	Verification Plan
L1150 motor	cost of the project because PSLT has several spare L1150 motors		Aerotech L1150 motor
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

Table 7.2 - Verifications for Team Defined Launch Vehicle Requirements

7.1.2.2 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
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
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
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

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
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
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
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

Table 7.3 - Verifications for Team Defined Payload Requirements

7.1.2.3 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
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
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
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

Table 7.4 - Verifications for Team Defined Recovery System Requirements

7.1.2.4 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 7.5 - Verifications for Team Defined Safety Requirements

7.1.2.5 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 7.6 - Verifications for Team Defined General Requirements

7.2 Timeline

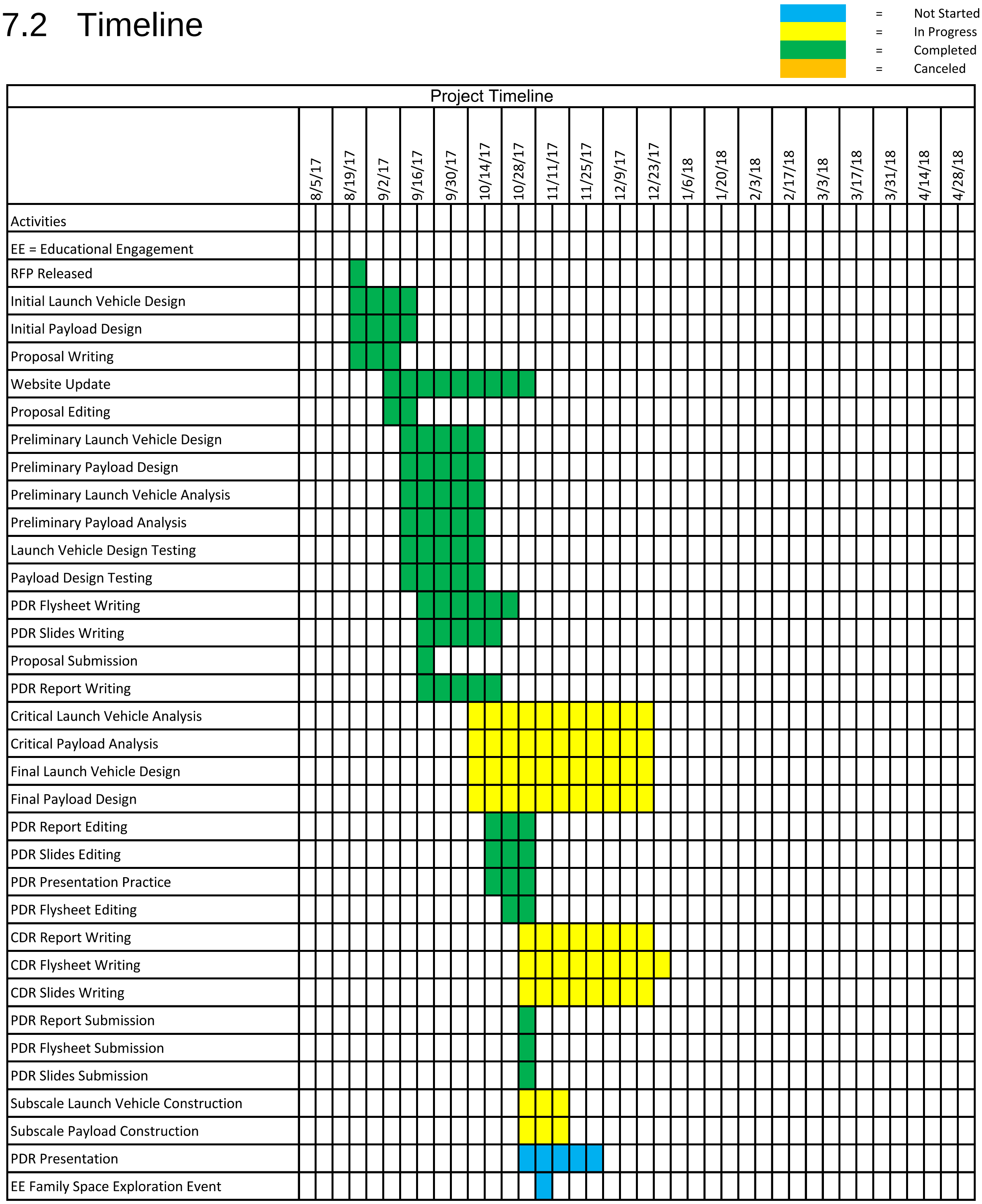

Figure 7.1 - Project Timeline Part 1

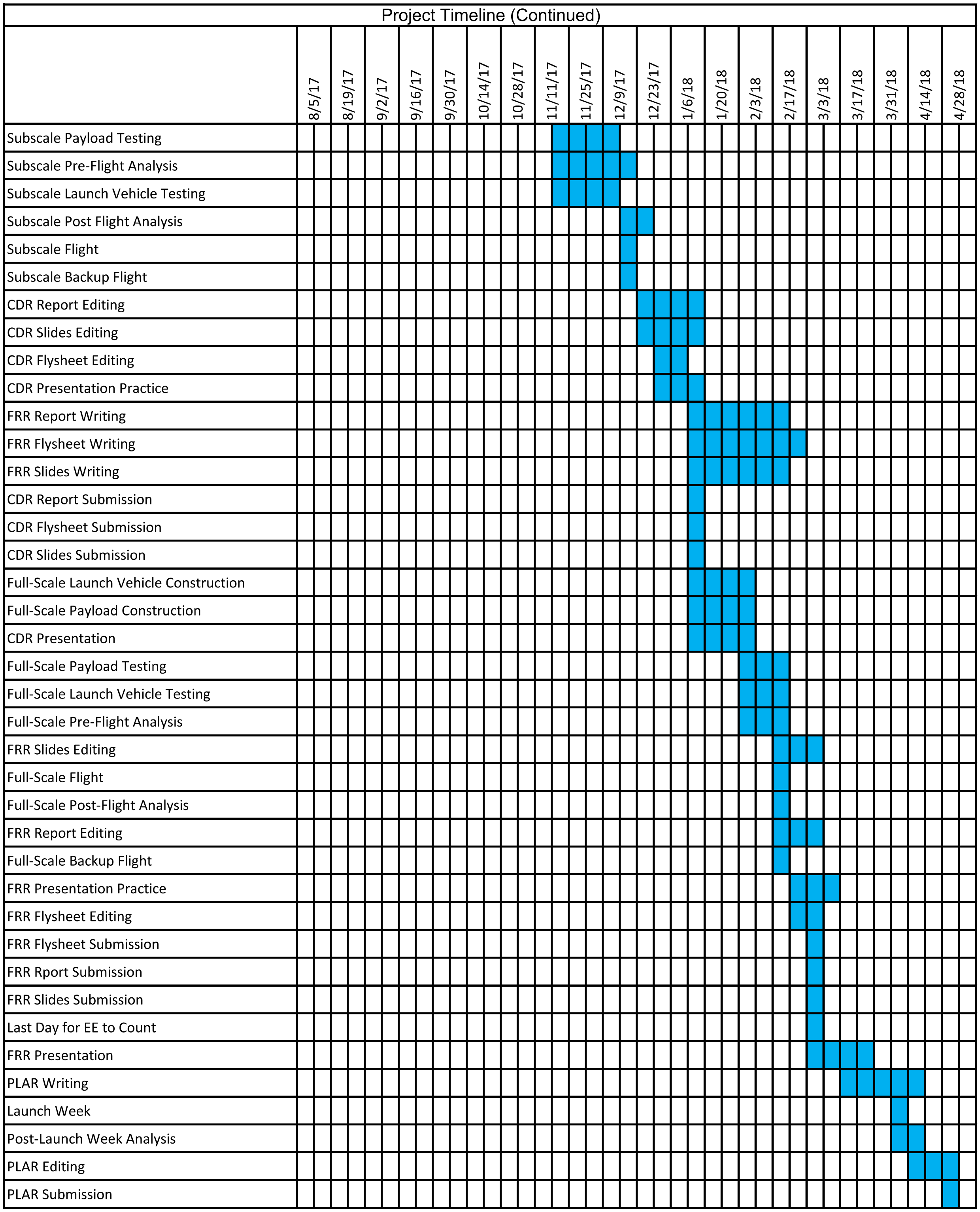

Figure 7.2 - Project Timeline Part 2

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.

7.3 Finance

7.3.1 Budget

Item	Manufacturer	Qty	Unit Price	Tax	Shipping / Handling	Total Cost
Airframe tube	Madcow Rocketry	3	$114	N/A	$5.99	$347.99
G10 Fiberglass sheet	Madcow Rocketry	4	$21	N/A	$41.40 (Shipping & Tax)	$125.40
ABS Plastic	Push Plastic	2	$79.50	N/A	Free	$159
12 in Coupler Bulkhead (x3)	Proline Composites	1	$69.13	N/A	$18.12	$87.25
L1150 R-P motor reload	Sirius Rocketry	1	$169.99	$11.9	$32	$213.89
Motor Retainer	Aero Pack	1	$44	N/A	$5.99	$49.99
Coupler Bulkhead (x3)	Madcow Rocketry	3	$9	N/A	$5.99	$32.99
Tube Bulkhead (x3)	Proline Composites	3	$9.8	N/A	$10.96	$40.36
Paint	Any		$50			$50
Thruster nozzle	MSC industrial supply	10	$2.84	$0.76	$11.6	$40.72
Tube-Aluminum	Karlsson Robotics	4	$3.89	N/A	$9.37	$24.93
Ninja Aluminum Compressed Air Tank	Dr.Paintbal	1	$49.95	N/A	Free	$49.95
Chute Release	Apogee Components	2	$130.95	N/A	$10.99	$272.89
RRC3 "Sport" Altimeters	Apogee Components	2	$71.95	N/A	$4.11	$148.01
1/4'' Quick Link	Apogee Components	5	$3.94	N/A	$4.53	$24.53
12 ft, standard, low-porosity, 1.1 rip-stop Parachute	The Rocketman Parachute	1	$145	N/A	$9.20	$154.20
Recovery Harness	Giant Leap Rocketry		$4.34	N/A	$6.99	$34.72
U-Bolt 3/8 in.	Apogee Components	4	$5.99	N/A	$13.56	$37.52
Sunward 18 in. Parachute Protector	Apogee Components	1	$10.49	N/A	$4.46	$14.95
Swivel	The Home Depot	3	$5.47	$0.87	$5.99	$23.27
GPS	Adafruit	1	$39.95	N/A	$9.15	$49.10

Item	Manufacturer	Qty	Unit Price	Tax	Shipping / Handling	Total Cost
Arduino	Arduino	1	$22.00	N/A	$3.64	$25.64
IMU	Adafruit	1	$34.95	N/A	$9.15	$44.10
IR sensor	Adafruit	1	$14.95	N/A	$9.15	$24.10
Altimeter	Adafruit	1	$9.95	N/A	$9.15	$19.10
Xbee	Digi-Key	1	$51.11	N/A	$9.15	$51.11
FPV camera	Lumenier	1	$49.99	N/A	Free	$49.99
FPV transmitter +antenna	Lumenier	1	$38.99	N/A	Free	$38.99
Misc. parts (jumper wires, resistors, etc.)	Various	N/A	$50	N/A	N	$50
Power system	Various	N/A	$50	N/A	N	$50
Ground Station	Various	N/A	$250	N/A	N	$250
L12 Linear Actuator	Robotshop	1	$80	N/A	Free	$80
Electrical Motor	Amazon	1	$16.99	N/A	Free	$16.99
Electrical Motor 1*	Amazon	6	$16.99	N/A	Free	$101.94
Electrical Motor 2*	Amazon	6	$15.83	N/A	Free	$94.98
Solar Panel Bracket	Midwest	1	$16.89	N/A	Free	$16.89
Righting Mechanism & Rover Frame	Midwest	1	$81.19	N/A	Free	$81.19
Shipping		1	$25.92	N/A	Free	$25.92
Screws		1	$15	N/A	Free	$15
Springs (x2)	Grainger	2	$9.25	N/A	$10.98	$29.48
Springs	Amazon	1	$20.24	$1.07	FREE	$21.31
Hotel Rooms		11	$500			$5,500
Meals		22	$125			$2,750
Transport		2	$50			$100
Total						$11,421

Table 7.7 - Preliminary Budget

7.3.2 Funding Plan

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 system are primary local corporate sponsors. In particular, 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 a variety of other services. OFM offers technical support, such as web hosting and a server for the team's project wiki.

Amount	Allocated To
$1,500	Educational Engagement
$1,932.56	Full-Scale Launch Vehicle
$1,138.83	Full-Scale Payload
$200	Miscellaneous
$1,000	Motors
$200	Safety Equipment
$500	Subscale Launch Vehicle
$500	Testing Equipment
$300	Tools & Construction Materials
$8,350	Launch Week Travel, Food, and Lodging
$15,621.39	Total

Table 7.8 - Allocation of Funds

7.4 Engagement & Outreach Plan

This year, for educational engagement, The Piedmont Student Launch Team has decided to primarily focus on the local community of refugees. Charlottesville VA is a refugee city. The team has recognized this fact as an opportunity, and is working on creating a sustainable program of STEM education specifically for the refugee community. PSLT is working with The International Rescue Committee (IRC), to reach the refugee community. PSLT's top educational engagement goal for this year is to help refugees engage in the local community and get jobs by giving them basic knowledge of STEM overall and providing access to more specific STEM education, such as programing classes. By forging partnerships with organizations like the IRC, the Community Homeschool Enrichment Center (CHEC), PVCC, and many more, PSLT is building programs and groups to support refugees and help them live safe, productive lives. Many of the refugees in Charlottesville came from war-torn nations or were victims of human trafficking. After going through unimaginably terrifying experiences, a high percentage of refugees will never get to live safe stable lives. PSLT hopes to make a positive difference in as many of their lives as possible. Helping refugees learn about things that excite them and learn new job skills can make a massive impact on their lives.

PSLT is not only working to educate the refugee community about STEM, but is also reaching out to anyone who is willing to learn in the local community. This year, the team will be aiming for a much higher numerical goal than last year. Last year PSLT only had a goal of about two hundred people engaged, but this year PLST's numerical goal is to engage with a minimum of 600 people, and the team expects to reach around 800 to 1000. The goals mentioned are specifically for educational engagement. PSLT's outreach goal is 2000, with the combined total of educational engagement and outreach hopefully being 3000 or more. By the one-week mark after being accepted into SL, PSLT had already surpassed one hundred people engaged. This year, the Piedmont Student Launch Team has dozens of events planned. Some of the major events include the following:

- The Family Space Exploration Event (FSEE)
- Organizing museum trips and tours for students and refugees
- Teaching a rocketry class at CHEC
- Girls' Geek Day
- Creating a once weekly STEM school

The following Figure 7.3 shows the current status of PSLT's educational engagement and will be updated as the project progresses.

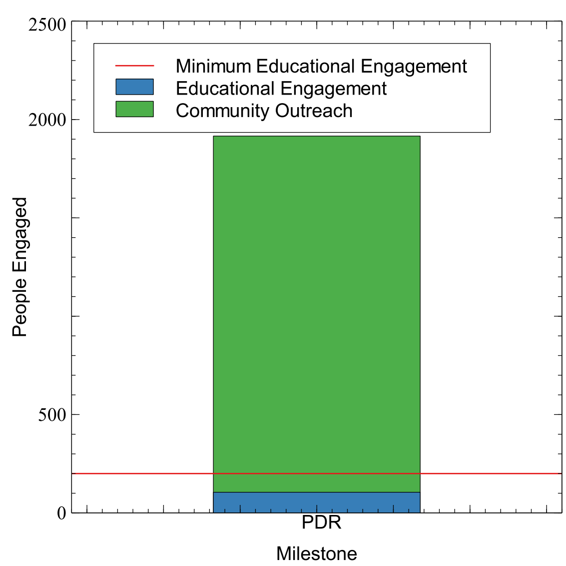

Figure 7.3 - Engagement & Outreach Progress