Piedmont Student Launch Team

2017 NASA Student Launch
Preliminary Design Review

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

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1 General Information

1.1 Team Contacts

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

Table 1.1 - Team Contacts

1.2 Team Organization and Members

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

Table 1.2 - Key Team Members

Name	Project Teams	Functional Teams
Nathan	Launch Vehicle, Experiment	Electrical
Collins	Launch Vehicle, Admin	Programming, Electrical
Rodney	Experiment	Programming
Mykaela	Launch Vehicle, Experiment, Admin	Structural
Cayla	Launch Vehicle	Structural
Daniel	Launch Vehicle	Electrical, Structural

Table 1.3 - Other Team Members

1.3 NAR Section Assistance

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

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

2 PDR Summary

2.1 Team Summary

The name of the team is Piedmont Student Launch Team (PSLT). The team represents Piedmont Virginia Community College (PVCC).

501 College Drive, Charlottesville, Virginia 22902.

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

2.2 Launch Vehicle Summary

Launch Vehicle Information	Details
Weight without motor	22.00 lbs
Weight with motor	27.51 lbs
Motor choice	Kosdon by AeroTech L1400F
Recovery system	The recovery system will use a 30 in drogue parachute and an 84 in main parachute.

Table 2.1 - Launch Vehicle Summary

Launch Vehicle Size	Details
Length	98 in
Body diameter	5.5 in
Fin span	20.4 in

Table 2.2 - Launch Vehicle Size

2.3 Payload Summary

PSLT has chosen to attempt the roll induction and counter-roll challenge. The method chosen to complete this challenge is a reaction wheel. This system uses the law of conservation of angular momentum to induce a rotation in the rocket by spinning a wheel in the direction opposite the direction that the rocket will spin. This method will allow accurate accomplishment of the required 2 rotations and the counter-rotation, as well as being able to control the spin all the way up until apogee. Additionally, the payload will aim a camera at the ground targets from the target identification challenge.

3 Changes Made Since the Proposal

Because many of the designs in the proposal were simply a list of options, the below tables include options that have been chosen, as well as any actual changes.

3.1 Changes to Vehicle Criteria

Change/Selection	Reason
The dimensions of the rocket.	To accommodate the internal components, particularly the recovery system.
The altitude control system will use ballasting.	This allows for reasonable accuracy, without adding significant cost or complexity to the vehicle.
Motor	Because the weight of the rocket has changed, a different motor is needed to reach the target altitude.

Table 3.1 - Changes and Selections for the Launch Vehicle

3.2 Changes to Experiment Criteria

Change	Reason
The rocket will roll to aim a camera at one or more of the targets from the target identification challenge.	To test the ability of the experiment to roll the rocket to a specific position.
The experiment will transmit video back to a ground station.	So that the experiment can be viewed in real-time, rather than having to wait until the data is downloaded from the rocket after landing.

Table 3.2 - Changes to Experiment Criteria

3.3 Changes to Project Plan

Change	Reason
Added a specific goal for the number of women and girls reached through educational engagement.	All members of PSLT believe that there is a fixable disparity in the number of women in STEM fields.
Improved the plan for team sustainability.	It is important that the team is able to continue in future years.
Added plan for spreading Student Launch to other schools.	PSLT believes that the Student Launch provides an opportunity that more schools should take advantage of.

Table 3.3 - Changes to the Project Plan

4 Vehicle Criteria

4.1 Selection, Design, and Rational of Launch Vehicle

4.1.1 Mission Statement

PSLT will build a launch vehicle capable of being launched to an altitude of 5280 ft while carrying an experimental payload. The launch vehicle will be recovered using a dual deployment recovery system. It will also transmit its position to a ground station during and after the flight.

The number one goal of PSLT is to achieve a safe launch, flight, and recovery of the launch vehicle.

A secondary goal of the PSLT is to design a launch vehicle that looks good. However, all other considerations, and safety in particular, come first.

4.1.2 Mission Success Criteria

The mission will be considered successful if the launch vehicle reaches an altitude of approximately 5280 ft, the payload experiment works successfully (as defined under section 6.2), the launch vehicle returns and is recovered safely, and the vehicle successfully transmits its position during and after the flight.

4.1.3 Systems and Alternatives

4.1.3.1 Air Frame

The considerations for the air frame of the launch vehicle are the profile, the number of sections of the body, and the nose cone.

A standard profile is where the entire body of the rocket is the same diameter. A nonstandard profile is one with one or more section of the body that is a different diameter than the rest.

Profile	Pros	Cons
Standard	Easy to design.	None.

Profile	Pros	Cons
	Easy to model. Easy to build. No unusual aerodynamics.	
Nonstandard	Unique look. Potentially, more interior space.	Unusual aerodynamic effects. Harder to design. Harder to model. Harder to build.

Table 4.1 - Launch Vehicle Profile

Body sections are the parts of the launch vehicle that are indented to be separable.

Body Sections	Pros	Cons
Fewer than 3	Fewer places for the rocket to separate accidentally.	Not enough sections to be able to use a drogue and a main parachute without a more complex recovery system.
3	No more parts than needed for the recovery system.	More time and effort spent manufacturing the body.
More than 3	None.	Even more time and effort spent manufacturing the body.

Table 4.2 - Body Sections

Nose Cone Shape	Pros	Cons
Ogive	Commercially available in the same size as the body tubes being used.	Somewhat higher drag.
Parabolic	Somewhat lower drag.	Not commercially available for the size body tube being used.
Cone	Lower drag at high speeds.	Not commercially available for the size body tube being used.

Nose Cone Shape	Pros	Cons
Elliptical	Somewhat lower drag.	Not commercially available for the size body tube being used.

Table 4.3 - Nose Cone Shape

4.1.3.2 Altitude Challenge

Altitude Control	Pros	Cons
Air brakes	Precise control of the altitude of the launch vehicle. Ability to account for variance in launch day conditions.	Need control electronics. Additional points of mechanical and programming failure. More expensive. Creates turbulent flow around the rocket, which can cause instability. Difficult to manufacture. Difficult to install.
Ballasting	Easy to manufacture. Few additional points of failure. No parts exterior to the rocket. Possibility to adjust the CG to make the rocket more stable.	Less precise altitude control. Cannot account for variance in launch day conditions. Possibility to cause the CG to be off-center.

Table 4.4 - Altitude Control

4.1.3.3 Compartmentalization

Because the recovery system will utilize black powder charges to separate the launch vehicle, there is a need to have bulkheads to protect the more sensitive components such as the recovery electronics and the experimental payload. Additionally, several of the bulkheads will be used as mounting points for the recovery harnesses.

Bulkhead Material	Pros	Cons
Plywood	Lighter weight than fiberglass or aluminum. Easier to work with than aluminum.	Not as strong as fiberglass or aluminum.
Fiberglass	Easier to work with than aluminum. Stronger than plywood. Lighter weight than aluminum.	Not as strong as aluminum. More expensive than plywood.
Aluminum	Stronger than plywood or fiberglass.	Much more difficult to work with than fiberglass or plywood. More expensive than fiberglass or plywood.

Table 4.5 - Bulkhead Material

4.1.3.4 Flight Stability

The two main considerations for flight stability are the locations of the center of gravity (CG) and the center of pressure (CP) of the launch vehicle. The location of the CG is determined by the placement of all of the components of the launch vehicle, and the CP is determined primarily by the design of the fins. To be stable, the CG must be ahead of the CP, and to conform with the requirements in the handbook, the CG must be at least 2 body tube diameters ahead of the CP.

Design options that were considered for the fins are the shape, the number, the mounting, the size, and the material. Because size is based on the other considerations, it is only included in the leading fin design (see page 16).

Fins

Fin Shape	Pros	Cons
Trapezoidal	Easy to design. Easy to manufacture. Easier to attach than tube.	Higher drag than elliptical.
Elliptical	Produce less drag than trapezoidal.	More difficult to manufacture.

Fin Shape	Pros	Cons
	Easier to attach than tube.	More difficult to design.
Tube	Unique look.	Not much information was found to base decisions on.

Table 4.6 - Fin Shape

Number of Fins	Pros	Cons
3	Lower weight. Lower drag. Less time, effort, and resources spent on manufacturing and attachment than more fins. Less likely to be made unstable by high wind speeds.	None.
4	None.	More weight. More drag. More time, effort, and resources spent on manufacturing and attachment.
More than 4	None.	Even more weight. Even more drag. Possibility of making the rocket unstable because of turbulent air flow around the fins. Even more time, effort, and resources spent on manufacturing and attachment.

Table 4.7 - Number of Fins

Mounting of Fins	Pros	Cons
Through wall	Stronger attachment. Provides additional points of contact between the motor and air frame.	More difficult to attach. Requires additional work on the body of the rocket.
Exterior	Easier to attach. Does not require additional work on the body of the rocket.	Attachment is not as strong.

Table 4.8 - Mounting of Fins

Fin Material	Pros	Cons
Fiberglass	Stronger than plywood and balsa wood. Cheaper than carbon fiber.	More expensive than plywood or balsa wood. More difficult and more dangerous to work with than plywood or balsa wood.
Balsa wood	Cheaper than others. Lighter than others.	Very weak.
Plywood	Cheaper than fiberglass or carbon fiber. Stronger than balsa wood. Lighter than fiberglass carbon fiber.	Not as strong as fiberglass or carbon fiber. More expensive than balsa wood.
Carbon fiber	Stronger than plywood or balsa wood.	Significantly more expensive than plywood, fiberglass, or balsa wood. More difficult and more dangerous to work with than plywood or balsa wood. More brittle than plywood or fiberglass.

Table 4.9 - Fin Material

4.1.3.5 Launch Stability

The launch stability of the rocket is determined by the rail attachment system, and whether or not the rocket can achieve sufficient speed at rail exit to remain stable. Rail exit velocity is discussed under section 4.3.

Rail Attachment	Pros	Cons
Rail buttons	More strongly attached than launch guides. More aerodynamic than launch guides.	Harder to attach than launch guides.
Launch guides	Easier to attach than rail buttons.	More weakly attached than rail buttons. Less aerodynamic than rail buttons.

Table 4.10 - Rail Attachment

4.1.3.6 Motor Retention

Motor retention is separated into two systems, one for keeping the motor in the motor mount, and one for keeping the motor mount in the launch vehicle.

Motor Retention	Pros	Cons
Engine hook	None.	Not commercially available in the sizes necessary for the engines being considered. Require additional work on the motor mount.
Plate retainer	None.	Not commercially available in the sizes necessary for the engines being considered.
Screw-on retainer	Commercially available in the sizes necessary for the engines being considered.	None.

Table 4.11 - Motor Retention

Motor Mount Retention	Pros	Cons
Thrust plate	Transfers thrust directly from the motor to the body of the rocket.	More difficult to manufacture. More expensive.
Centering rings	Potentially lighter weight. Easier to manufacture.	Relies on attachment method for strength.

Table 4.12 - Motor Mount Retention

The options for materials to use for the construction of centering rings are the same as those used for the construction of bulkheads.

4.1.3.7 Tracking

The most important decision for the tracking system for the launch vehicle is whether to use a commercially available tracker or create a custom tracking system.

Commercial or Custom Tracking	Pros	Cons
Commercial tracking	Very little work involved. Reliable.	Can only send the data that it is designed to send. Likely to be more expensive.
Custom designed tracking	Can transmit data other than just the position of the rocket. Likely to be less expensive.	More likely to fail. Higher chance of causing interference with its own components. More work involved in designing and manufacturing. Additional weight.

Table 4.13 - Commercial or Custom Tracking

Position Detection	Pros	Cons
GPS	More likely to be accurate.	Requires an external input. Requires an additional sensor.
Inertial guidance	Not dependent on external input.	More likely to lose accuracy over the flight. More difficult to program.

Table 4.14 - Position Detection

4.1.4 Leading Design

System	Subsystem	Choice	Reason(s)
Air frame	Profile	Standard	There is substantially more material available for the design and construction of standard profile rockets than nonstandard, and all of the members of PSLT that have worked with model and high power rockets before are familiar with the standard profile. Additionally, there is no significant benefit to using a nonstandard profile.
	Body sections	3	Having 3 body sections allows for the use of a standard dual deployment recovery system, and while using an alternative recovery system is possible, it would introduce significant additional complexity to the design as well as likely adding more possible points of failure. Having more than 3 body sections does not add any benefit, and there is a limit of 4 body sections.

System	Subsystem	Choice	Reason(s)
	Nose cone	Ogive	An ogive nosecone is commercially available for the size body tube being used, so there is no need to custom manufacture one.
Altitude challenge	Altitude Control	Ballasting	This solution is much simpler than an air braking system, and, with adequate testing and simulations, it should still be able to achieve a fairly accurate altitude without the additional complexity and possibility of failure.
Compartmentalization	Bulkhead material	Fiberglass	Because several of the bulkheads will be used as mounting points for the recovery harnesses, the additional strength over plywood was needed, and the strength of aluminum was not considered worth the significant added difficulty in manufacturing. Additionally, PSLT will be making several other parts out of fiberglass, so it is likely that there will be enough spare material from those parts to make all of the bulkheads, eliminating the need to purchase additional material.
Flight stability	Fin shape	Trapezoidal	Trapezoidal fins will be used because they are easier to work with than elliptical fins, and, based on simulations, they work as needed.

System	Subsystem	Choice	Reason(s)
	Number of fins	3	There is no significant benefit to having more than 3 fins. Additionally, there would be a moderate amount of additional time and effort involved in adding more fins.
	Mounting of fins	Through wall	The extra work in attaching the fins will be worthwhile for the additional strength, especially if the rocket lands at an angle.
	Fin material	Fiberglass	Given the possibility for the rocket to land at an angle, fiberglass will be used to ensure the fins are strong enough not to break. Additionally, because several other parts will be made from fiberglass, there is the possibility to reduce the number of sheets of fiberglass needed for the overall construction.
	Fin size	Max. length 10 in, max. extension 7.5 in	Based on the design of the rest of the launch vehicle in simulations, this size allows for stable flight.
Launch stability	Rail attachment	Rail buttons	Rail buttons were chosen for the additional strength that they provide over rail guides because they are mounted through the body of the rocket. Additionally, they have a smaller profile, so they are less likely to cause issues with the aerodynamics of the launch vehicle.
Motor retention	Motor retention	Screw-on retainer	The decision to use screw-on retainers was made because they are the only method of

System	Subsystem	Choice	Reason(s)
			motor retention that is commercially available for the size engines that are being considered.
	Motor mount retention	Centering rings	Centering rings will be used because they are simpler than using a thrust plate, and are much less expensive.
	Centering ring material	Fiberglass	Fiberglass will be used because it offers adequate strength to hold in an L-class engine, while still being fairly easy to work with. Additionally, because they will be made from the same sheets of fiberglass as the bulkheads and fins, there is the possibility of reducing the number of sheets needed.
Tracking	Commercial or custom tracking	Custom tracking	A custom tracking system will be used because it will allow the transmission of more data than just the position of the launch vehicle with a single transmitter.
	Position detection	GPS	A GPS will be easier to use and is likely to be more accurate.

Table 4.15 - Launch Vehicle Leading Design

Drawings of each system are shown in Appendix A.

4.1.5 Motor Alternatives

The motor selection was made based on two criteria. First, the motor must have enough thrust to lift the rocket higher than the required altitude. Second, the motor must not provide so much thrust that the rocket requires a ballast which weighs more than 10% of the rocket's total weight. Several motors meeting these criteria were found and simulations were run to determine the best motor to choose. Table 4.16 shows the predicted altitude for each motor with no ballast.

Motor	Altitude (ft)
Kosdon-by-AeroTech L1400F	5822.2
Cesaroni L1030RL	6379.9
Kosdon-by-AeroTech K750W	5363.7

Table 4.16 - Motor Alternatives

The decision was made to choose the Kosdon by AeroTech L1400F motor. Its thrust curve is shown below.

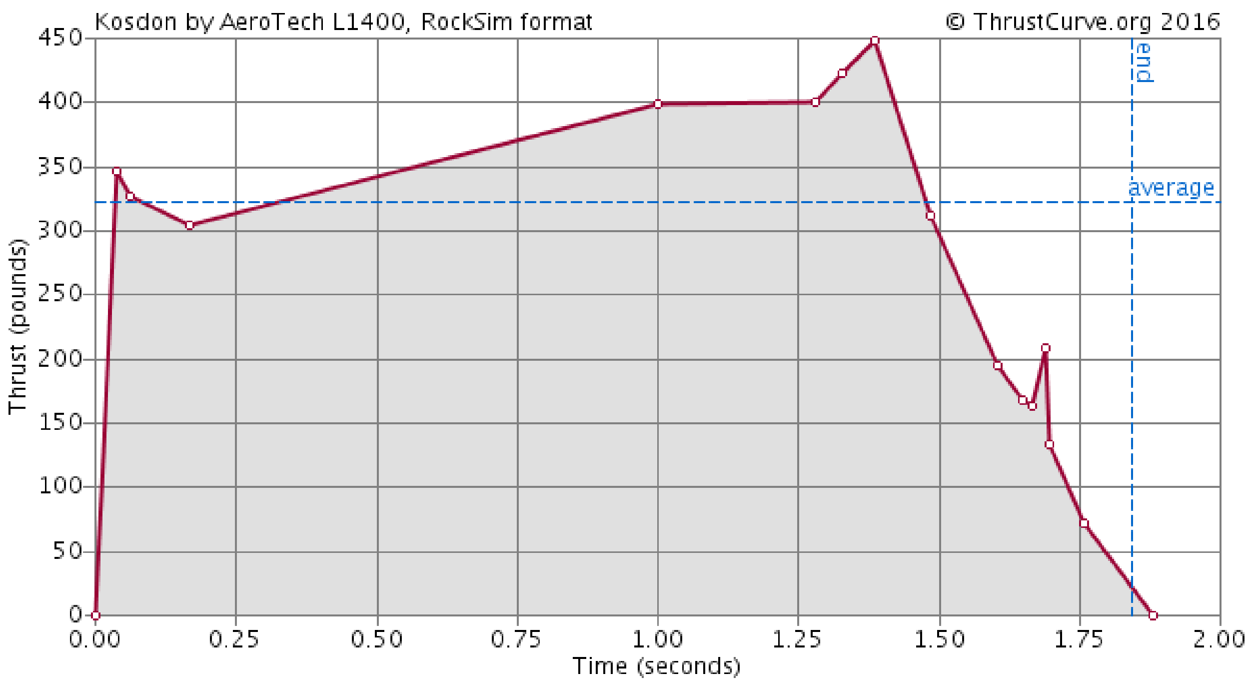

Figure 4.1 - Kosdon by AeroTech L1400F Thrust curve

4.2 Recovery Subsystem

4.2.1 Components and Alternatives

The primary components to the recovery system are the main and drogue parachutes, the recovery harnesses, and the avionics.

Parachute Material	Pros	Cons
Nylon	High heat tolerance. High strength. Commonly available for purchase.	Sensitive to ultraviolet light.
Kevlar	Significantly higher strength than Nylon. Does not melt or burn. Abrasion resistant.	Sensitive to UV light. Abrasive material to handle.

Table 4.17 - Parachute Material

Recovery Harness Material	Pros	Cons
Nylon	High heat tolerance. High strength. Commonly available for purchase.	Sensitive to ultraviolet light.
Kevlar	Significantly higher strength than Nylon. Does not melt or burn. Abrasion resistant.	Sensitive to UV light. Abrasive material to handle.

Table 4.18 - Recovery Harness Material

Mounting Points	Pros	Cons
Eyebolts	Only require one hole in centering rings or bulkheads.	Weaker attachment.
U-bolts	Stronger attachment.	Require two holes in centering rings or bulkheads.

Table 4.19 - Mounting Points

Recovery Harness Attachment	Pros	Cons
Permanent	Less likely to be forgotten. Fewer possible points of failure.	Does not allow the rocket to be separated into its sections.
Quick links	Allows the rocket to be separated into its sections.	More possible points of failure. More likely to be forgotten.
Swivels	Help prevent the recovery harness from tangling. Less likely to be forgotten.	Does not allow the rocket to be separated into its sections.

Table 4.20 - Recovery Harness Attachment

Avionics	Pros	Cons
Barometric altimeter	Required for at least one altimeter. Less expensive.	Requires holes in the rocket body.
Flight computer	Does not require holes in the rocket body.	More expensive.

Table 4.21 - Avionics

Ejection Method	Pros	Cons
Black powder	Simple. Less expensive. Smaller. Lighter weight. Fewer points of failure.	Potentially dangerous.
CO2	Less dangerous.	More expensive. Higher weight. Larger. More points of failure.

Table 4.22 - Ejection Method

4.2.2 Parachutes

Based on the current design of the launch vehicle, it is estimated that a 30 in drogue parachute and a 84 in main parachute will allow for a safe descent. Given parachutes of those sizes, the highest kinetic energy of any section of the launch vehicle at landing is under 50 ft-lbs (see Table 4.3.4.1).

4.2.3 Leading Design

System	Choice(s)	Reason(s)
Parachute material	Nylon	Nylon parachutes are readily available.
Recovery harness material	Kevlar	Kevlar should be strong enough to endure the forces involved in with the recovery system with enough of a safety margin.
Mounting points	U-bolts	The additional point of attachment that each U-bolt provides makes them less likely to break, which makes the recovery system safer.
Recovery harness attachment	Quick links and swivels	Quick links will be used to attach the recovery harnesses to the launch vehicle so that the sections of the launch vehicle can be separated for transport. Swivels will be used to attach the recovery harnesses to the parachutes to prevent tangling the shroud lines.
Avionics	Barometric altimeter	At least one of the altimeters in the rocket is required to be barometric, and it will be simpler to use a barometric altimeter as the secondary one as well.
Ejection method	Black powder	Black powder will be simpler to use than CO2.

Table 4.23 - Recovery System Leading Design

The recovery system will have an avionics bay in the central section of the rocket which will house the altimeters and ejection system and will have attachment points for the recovery harnesses. The recovery harnesses will each be made from 25 ft flat Kevlar. The recovery harnesses will attach the upper and lower sections of the rocket to the central section, and the parachutes will be attached to the recovery harnesses.

Drawings of the recovery system are shown in Appendix A.

4.2.4 Plan for Redundancy

The avionics bay will contain two completely independent altimeters, each of which will have its own battery and be connected to its own pair of ejection canisters, so each altimeter will be able to fire the drogue and main parachute if the other fails.

The recovery harnesses will both have a split at each end so that they can be connected to each of the sections of the rocket that they are meant to attach to in two places. This will both reduce the forces on either attachment point and allow the recovery harness to remain attached even if one of the connections should fail.

4.3 Mission Performance Predictions

The mission performance predictions were made by creating a model of the current design of the rocket in RockSim and running a number of simulations.

Component	Weight (lbs)
Nosecone	1.06
Ballast	2.10
Upper body tube	3.50
Upper Recovery Harness	0.10
Main parachute	1.17
Experiment	3.49
Center body tube	0.19
Tube coupler	1.35
Avionics	2.33
Ejection canisters	0.03
Lower Body tube	1.75
Lower Recovery Harness	0.10

Component	Weight (lbs)
Drogue parachute	0.27
Engine Mount	1.12
L1400F motor	5.51
Fins	1.38
Tailcone	0.02
8 U-bolts	1.14
3 centering rings	0.01
3 bulkheads	1.17
Total	27.86

Table 4.24 - Launch Vehicle Weight

4.3.1 Flight Profile Simulations and Altitude Predictions

Conditions were chosen to reflect the likely conditions of the launch site at Huntsville.

Condition	Value
Altitude above sea level	600 feet
Latitude	34 degrees
Temperature	70 degrees Fahrenheit
Wind Speed	3.0-7.9 mph
Humidity	50%
Pressure	1.013 bar

Table 4.25 - Simulation Conditions

Figures 4.2, 4.3, and 4.4 show the flight profile using the conditions shown in Table 4.25. The rocket exits the launch rail with a velocity of 89.9160 ft/sec. The predicted apogee is 5282.6 feet and occurs 18 seconds into the flight. At apogee, the ejection charge for the drogue chute is fired. The rocket descends at a rate of 56.9 ft/s until it reaches an altitude of 500 ft. When the rocket reaches 500 ft, the ejection charge for the main chute fires and the rocket descends at a rate of 16.6 ft/s until it reaches the ground. The entire flight takes 131 seconds.

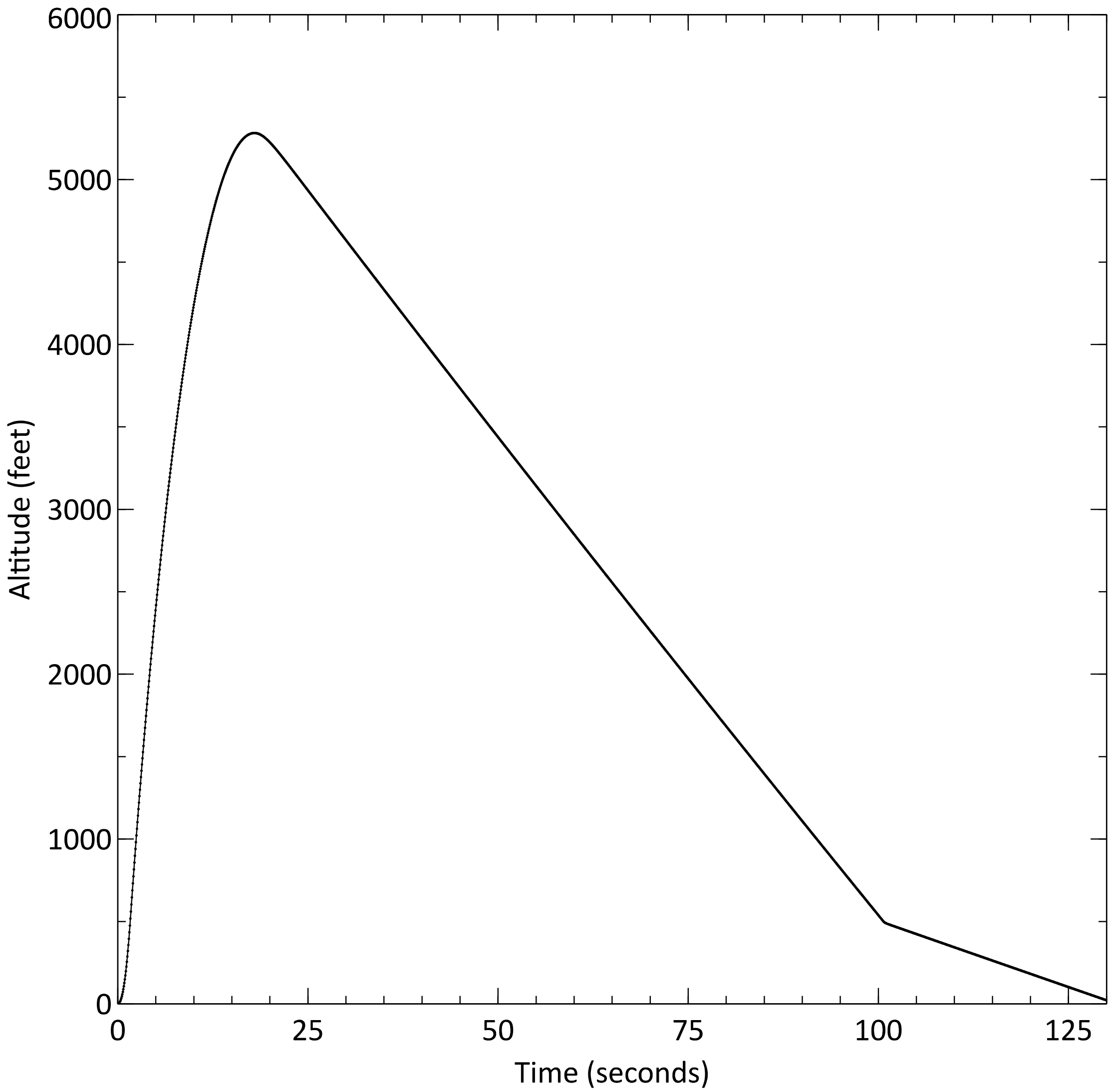

Figure 4.2 - Altitude vs Time

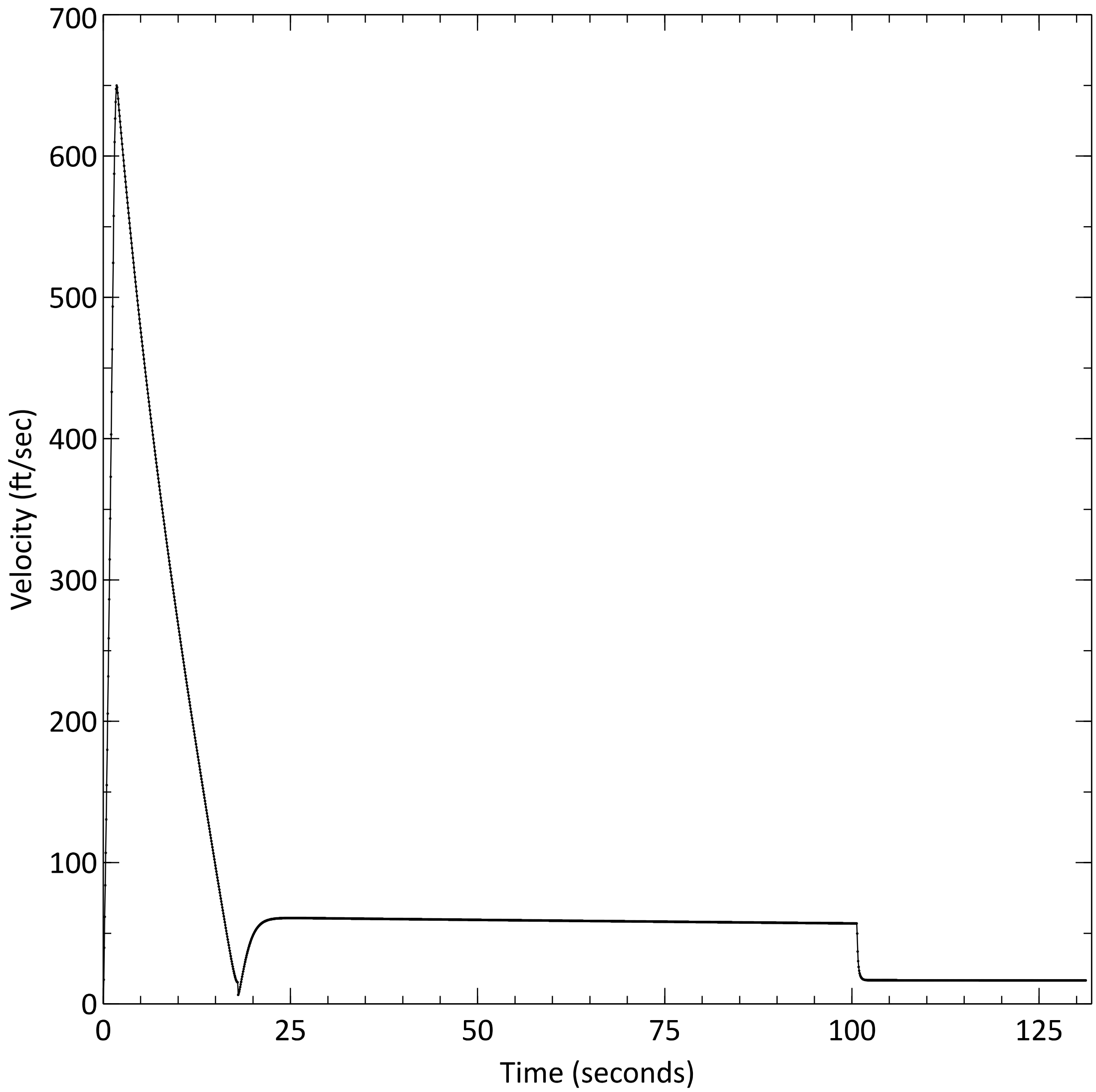

Figure 4.3 - Velocity vs Time

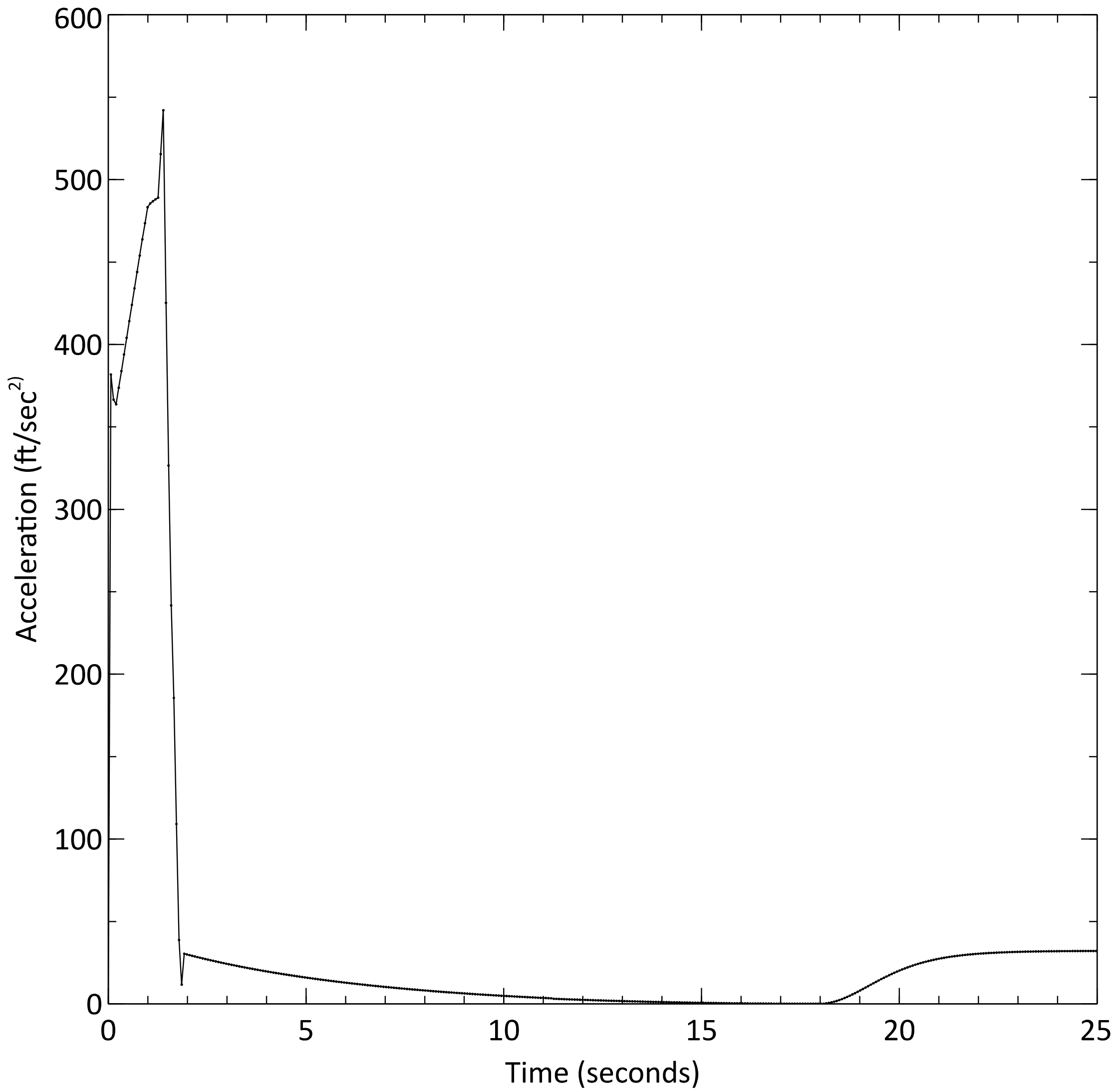

Figure 4.4 - Acceleration vs Time

4.3.2 Center of Pressure and Center of Gravity

The CP and CG for the rocket was found using RockSim. The CG is 54.3944 in from the tip of the nosecone. The CP is 72.5714 in from the tip of the nosecone. The static stability margin is defined as the distance between the CG and the CP, divided by the diameter of the rocket. The static stability margin for the model is 3.27 calibers. As the rocket burns propellant during the flight, the CG moves forward and the stability increases. Figure 4.5 shows the static stability margin.

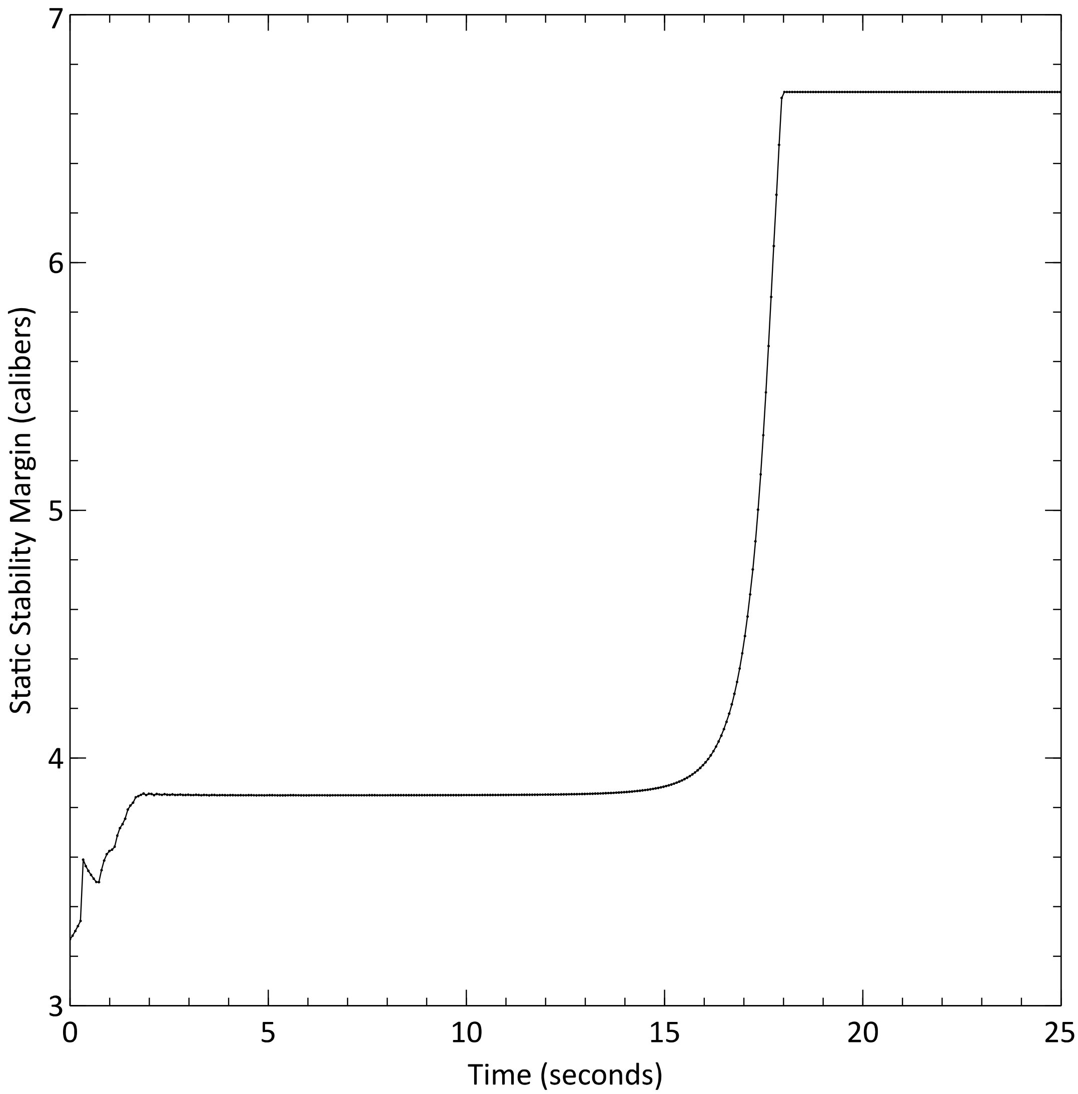

Figure 4.5 - Static Stability Margin vs Time

4.3.3 Landing Predictions

The kinetic energy was calculated using Equation 4.1 where m is the mass of the rocket and v is its velocity.

$$KE = \frac{1}{2}mv^2 \tag{4.1}$$

Section	Velocity (ft/s)	Weight (lbs)	Kinetic Energy (ft-lbs)
Upper	16.6	11.3	48.8

Section	Velocity (ft/s)	Weight (lbs)	Kinetic Energy (ft-lbs)
Center	16.6	5.2	22.6
Lower	16.6	7.4	31.8

Table 4.26 - Energy at Landing

4.3.4 Drift Predictions

Wind Speed	Lateral Drift (ft)
0	0.0
5	542.0
10	1063.0
15	1617.4
20	2226.2

Table 4.27 - Drift Predictions

5 Safety

5.1 Project Components and Risks

On an administrative level there are deadlines to meet for reports, as well as ensuring the design of the rocket is on track. In addition, there are budget concerns. Funding shortages could prevent completion of the rocket or inhibit any required travelling. There are also risks associated with the physical rocket. During fabrication there could be injuries from improper use of power tools. During launch there are quite a few risks.

5.2 Preliminary Check Lists

5.2.1 Final Assembly

- ☐ Check airframe for damage
- ☐ Check payload
    - ☐ Wiring properly in place
    - ☐ No damage
    - ☐ Motor and flywheel secured
- ☐ Check motor casing for damage
- ☐ Check motor mount
- ☐ Check recovery system
    - ☐ Recovery harness connected to drogue chute
    - ☐ Recovery harness connected to main parachute
    - ☐ Recovery harness between lower section and central section
    - ☐ Recovery harness between upper section and central section
    - ☐ Avionics bay
        - ☐ Altimeters in place and secured
        - ☐ Batteries in place, plugged in, and secured
        - ☐ Ejection charges in place
        - ☐ Electric matches threaded to ejection charges
    - ☐ Parachute protectors between ejection charges and parachutes in place
    - ☐ Main parachute checked for damage/imperfections

- ☐ Drogue parachute checked for damage/imperfections
- ☐ Main parachute properly folded and in place
- ☐ Drogue parachute properly folded in place

☐ Attach rocket components with proper fasteners (bolts or shear pins)

☐ Check all connections again

☐ Insert motor into motor casing

___________________________ ___________________________

Safety Officer Range Safety Officer

5.2.2 Launch Procedures

☐ Ensure all unnecessary personnel are in a safe location for launch

☐ Place rocket on launch rails

☐ Have qualified personnel place electronic igniter

☐ Have all personnel move to launch positions

☐ Check with range safety officer to ensure range is all clear and ready for launch

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Safety Officer Range Safety Officer

5.3 Risk Definitions

The severities and likelihoods of the various risks are given in the Risk Assessment Code (RAC) format from pages 58 and 59 of the Student Launch Handbook. The possible values for severity are: 1 – Catastrophic, 2 – Critical, 3 – Marginal, and 4 – Negligible. The possible values for likelihood are: A – Frequent, B – Probable, C – Occasional, D – Remote, and E – Improbable. Appendix C shows the detailed definitions of those values, taken from page 59 of the Handbook.

The risks below have both a Pre-RAC value and a Post-RAC value. Pre-RAC refers to the combined severity and likelihood before mitigations are put in place, and Post-RAC is after the mitigations have been put in place.

5.4 Preliminary Personnel Hazard Analysis

Hazard	Effect	Cause	Mitigation	Pre-RAC	Post-RAC
Accidental black powder ignition	Moderate injury (burns, concussion).	Improper handling or storage of black powder.	Black powder will be properly stored and handled only by those that have been briefed on proper handling.	3D	3E
Power tools	Minor to severe injury.	Improper use. Distractions	All team members involved in the fabrication of the rocket will be briefed on how to safely use all power tools. The safety officer or deputy safety officer will supervise the use of power tools.	2D	2E
Fiberglass	Minor to moderate injury.	Fiberglass dust on skin, in	Gloves and masks will be worn when	3C	3E

Hazard	Effect	Cause	Mitigation	Pre-RAC	Post-RAC
		eyes, or in lungs	working with fiberglass. Any fiberglass dust will be cleaned up as it is produced.		
Rocket or motor flies into launch personnel	Death or severe injury.	Rocket goes off course. Motor comes out of rocket while firing.	See Preliminary Failure Modes and Effects Analysis below.	1E	1E
Falling Debris	Death or sever injury.	Rocket breaks during flight. Recovery system fails.	See Preliminary Failure Modes and Effects Analysis below.	1D	1E

Table 5.1 - Personnel Hazard Analysis

5.5 Preliminary Failure Modes and Effects Analysis

5.5.1 Ignition

Failure	Potential Effects	Causes	Mitigations	Pre-RAC	Post-RAC
Engine fails to ignite	Recycle/delay of launch.	Bad igniter.	None.	4C	4C

Table 5.2 - Ignition Failure

5.5.2 Stable Powered Flight

Failure	Potential Effects	Causes	Mitigations	Pre-RAC	Post-RAC
Rocket goes off course	Failure to reach desired altitude.	Launch rail is not vertical.	Check launch rail direction before launch.	1C	1E
	Vehicle flies into crowd.	Incorrectly aligned fins.	Use ground based and in-flight test to ensure the fins are aligned.		
	Rocket lands in the wrong place.	Offset CG.	Use ballast to ensure the CG is centered.		
	Failure to reach sufficient altitude for recovery system. Not enough time for experiment to run.	Misaligned engine/engine mount.	Use laser cutter to cut pieces for the engine mount.		

Failure	Potential Effects	Causes	Mitigations	Pre-RAC	Post-RAC
Internal damage	Damage to rocket. Experiment failure. Recovery system failure.	High acceleration.	Ensure all points of failure are strong enough to withstand the maximum expected acceleration with a margin of safety.	2D	2E
Engine ejects from rocket while burning	Falling debris.	Top of engine not capped.	Ensure the engine is capped with something that can withstand the exhaust.	1D	1E
	Damage to rocket. Engine flies into crowd.	Engine mount fails.	Ensure the engine mount is strong enough to withstand the force from the engine.		

Table 5.3 - Stable Powered Flight Failure

5.5.3 Rotation Start

Failure	Potential Effects	Causes	Mitigations	Pre-RAC	Post-RAC
Reaction wheel doesn't start	Experiment failure.	Payload electronics failure. Reaction wheel is jammed.	See below. Make sure there are no loose wires or other obstructions near the reaction wheel.	3D	3E
Reaction wheel breaks off of motor	Rocket goes off course. Experiment failure.	Too much angular acceleration.	Test starting and stopping the experiment on the ground; if the acceleration causes damage, the reaction wheel can spin up and spin down slower.	2E	2E
Vibrations damage electronics	Damage to electronics.	Reaction wheel is off center.	Make sure the reaction wheel is centered; run the experiment on the ground many times to ensure	2C	2E

Failure	Potential Effects	Causes	Mitigations	Pre-RAC	Post-RAC
			vibrations are at safe levels.		

Table 5.4 - Rotation Start Failure

5.5.4 Stable Flight While Rotating

Failure	Potential Effects	Causes	Mitigations	Pre-RAC	Post-RAC
Rotation while flying at high velocity breaks fins	Rocket goes off course. Falling debris.	Rotational forces.	Ensure the rocket will not spin fast enough to cause damage.	2D	2E

Table 5.5 - Stable Flight While Rotating Failure

5.5.5 Return to Burnout Rotation

Failure	Potential Effects	Causes	Mitigations	Pre-RAC	Post-RAC
Reaction wheel spins at wrong speed	Experiment fails.	Electronic subsystem failure.	See below.	3C	3D

Table 5.6 - Return to Burnout Rotation Failure

5.5.6 Drogue Deployment

Failure	Potential Effects	Causes	Mitigations	Pre-RAC	Post-RAC
Recovery harness breaks	Falling debris.	Too much black powder.	Repeated tests of the ejection system on the ground.	1D	1E
	Destruction of rocket.	Damaged recovery harness. Rocket is moving too fast.	Inspect the recovery harness before launch. Choose the engine and ballast such that the rocket is moving at a safe velocity when the parachute deploys.		

Failure	Potential Effects	Causes	Mitigations	Pre-RAC	Post-RAC
Ejection charge doesn't ignite	Drogue chute doesn't deploy - see below.	Bad igniter. Altimeters not turned on. Altimeters not programmed correctly. Batteries not charged. Wires come loose. Batteries come loose. Black powder not properly secured before launch.	Redundant igniters and ejection cups. Follow pre-launch checklist. Have the mentor, RSO, and safety officer inspect the ejection system before launch.	1C	1E
Ejection charge fires but drogue chute doesn't deploy	Rocket is moving too fast for main chute to deploy.	Not enough black powder.	Repeated tests of the ejection system on the ground.	1D	1E
	Falling debris.	Too much friction.	Repeated tests of the ejection system on the ground.		

Table 5.7 - Drogue Deployment Failure

5.5.7 Main Deployment

Failure	Potential Effects	Causes	Mitigations	Pre-RAC	Post-RAC
Recovery harness breaks	Falling debris.	Too much black powder.	Repeated tests of the ejection system on the ground.	1D	1E
	Destruction of rocket.	Damaged recovery harness.	Inspect the recovery harness before launch.		
		Rocket is moving too fast.	Choose the size of the drogue chute such that the rocket is moving at a safe velocity when the parachute deploys.		
Ejection charge doesn't ignite	Parachute doesn't deploy - see below.	Bad igniter. Altimeters not turned on. Altimeters not programmed correctly. Batteries not charged. Wires come loose.	Redundant igniters and ejection cups. Follow pre-launch checklist.	1C	1E

Failure	Potential Effects	Causes	Mitigations	Pre-RAC	Post-RAC
		Batteries come loose. Black powder not properly secured before launch.	Have the mentor, RSO, and safety officer inspect the ejection system before launch.		
Ejection charge fires but parachute doesn't deploy	Destruction of rocket.	Not enough black powder.	Repeated tests of the ejection system on the ground.	1D	1E
	Falling debris.	Too much friction.	Repeated tests of the ejection system on the ground.		

Table 5.8 - Main Deployment Failure

5.5.8 Landing

Failure	Potential Effects	Causes	Mitigations	Pre-RAC	Post-RAC
Rocket hits the ground too hard	Damage to rocket.	Parachute is too small.	Run simulations to ensure the parachute is the correct size for the rocket.	2D	2E
Rocket lands in undesirable	Rocket falls on people.	Wind.	Don't launch when there is	2C	2D

Failure	Potential Effects	Causes	Mitigations	Pre-RAC	Post-RAC
place (e.g. on people, on a car, on a road, in a pond, etc.)			too much wind; angle the launch rail to account for wind.		
	Damage to cars, etc.	Bad launch angle.	Check launch rail angle before launch.		
	Damage to rocket.	Drogue chute too big.	Use the smallest possible drogue that will allow safe deployment of the main chute.		
	Electronics destroyed and data lost (rocket lands in pond)	Hazards at launch site.	Choose suitable launch sites for rocket size.		

Table 5.9 - Landing Failure

5.5.9 Payload Electronics

Failure	Potential Effects	Causes	Mitigations	Pre-RAC	Post-RAC
Reaction wheel control failure	Payload fails to meet	Physical failure.	See below.	2C	2E

Failure	Potential Effects	Causes	Mitigations	Pre-RAC	Post-RAC
	experiment criteria.				
	Rocket rotates too fast and causes damage.	Programming error.	The payload control program will be tested on the ground and in test flights; every part of the program will be reviewed by multiple people.		
Data collection failure (GPS, accelerometer/gyroscope, camera)	Data transmission failure (no data to transmit) - see below.	Physical failure.	See below.	3C	3E
	Payload fails to meet experiment criteria.	Programming error.	The payload control program will be tested on the ground and in test flights; every part of the program will be reviewed by multiple people.		

Failure	Potential Effects	Causes	Mitigations	Pre-RAC	Post-RAC
	Data lost. Loss of data for veracity of experiment, design improvements, and PLAR.	Sensor failure.	There will be redundant accelerometers/gyroscopes.		
Data transmission failure	No ground based data backup.	Physical failure.	See below.	3C	3D

Failure	Potential Effects	Causes	Mitigations	Pre-RAC	Post-RAC
	Tracking system failure.	Programming failure. Rocket too far from receiver. Interference.	The payload control program will be tested on the ground and in test flights; every part of the program will be reviewed by multiple people. Ground and in flight tests will ensure the transmitter and receiver have sufficient range. The transceivers will use the 900 MHz frequency to avoid interference from most common radio devices (e.g. Wi-Fi, Bluetooth, etc.).		

Failure	Potential Effects	Causes	Mitigations	Pre-RAC	Post-RAC
Physical failure	All other payload electronics failures.	Batteries come loose. Wires come loose. Batteries not charged	Do ground tests to find out how long the batteries will last; keep track of how long each battery has been used	2D	2E

Table 5.10 - Payload Electronics Failure

5.6 Environmental Risks

5.6.1 Environmental Impacts on Rocket

Hazard	Effect	Mitigation	Pre-RAC	Post-RAC
Direct sunlight/high temperatures	Overheating of electronic components, affecting efficiency. Possible distortion of airframe.	Assemble and store rocket in shaded area.	3D	3E
Humidity	Swelling of airframe components. Wet rocket and electrical components	Inspect rocket before launch for airframe swelling. Electronics should be sealed to	3D	3E

Hazard	Effect	Mitigation	Pre-RAC	Post-RAC
		protect from water.		
Wind	Rocket potentially flies off trajectory. Drifts farther after parachute deployment.	Check simulations and flights for stability. Minimize time on main parachute to ensure minimal drift while maintaining safe landing speed.	2C	2E

Table 5.11 - Environmental Impacts on Rocket Risks

5.6.2 Rocket's Impacts on Environment

Risk	Cause	Effect	Mitigation	Pre-RAC	Post-RAC
Grass fire	Rocket crashes while motor is still burning.	Burnt vegetation. Potential injury.	Fire extinguishers shall be ready during launch.	3D	3E
Scattered rocket components	Rocket breaks during flight. Recovery system fails.	Harmful chemicals and materials released into environment. Negative impacts to wildlife and vegetation.	See Preliminary Failure Modes and Effects Analysis above.	2D	2E

Risk	Cause	Effect	Mitigation	Pre-RAC	Post-RAC
Harming wildlife	Animals wander onto launch field.	Potential injury.	Inspect launch field for potential wildlife.	2D	2E

Table 5.12 - Rocket's Impact on Environment Risks

5.7 Project Risks

Risk	Likelihood	Impact	Mitigation
Late completion of reports and presentations	Low	High	Set early deadlines and have multiple people working on sections in order to ensure completion.
Team members dropping out	Medium	High	Ensuring all members are able to commit time to the team. Making sure all roles can be filled by someone else if needed.
Funding shortages	Low	Medium	Ensure that budget is spent wisely and find sponsors and individual donors to help close gaps.
Rocket destroyed during transport, fabrication, or launch.	Low	High	Take proper precautions to reduce risk, including proper storage. Follow all checklists for inspection of rocket and launch procedure.

Risk	Likelihood	Impact	Mitigation
Failure to complete experiment requirement	Low	High	Experimental flights with proof-of-concept rocket as well as scaling of experiment to subscale and final rockets to ensure design works.

Table 5.13 - Project Risks

6 Experiment Criteria

6.1 Experiment Objective

The experiment will, after motor burnout, rotate the rocket at least twice around its long axis. While doing so, it will use its cameras to locate the ground targets from the target identification challenge. After the rocket has rotated at least twice, it will rotate to aim one of its cameras at one or more of the ground targets. After doing that, the rocket will return to whatever rotation it had at motor burnout.

Additionally, the rocket will stream video from at least one of its cameras during the entire flight.

6.2 Criteria for Success

The experiment will be considered successful if it does the following items in order:

- The rocket rolls around its long axis at least twice,
- The rocket aims one of its cameras at one or more of the ground targets,
- The rocket returns to the same rotation that it had at motor burnout,
- The rocket stream video from at least one camera during the entire flight.

6.3 Systems and Alternatives

6.3.1 Roll Induction

Fin Ailerons

Ailerons could replace part of the edge of the fins to control the rotation of the rocket.

Pros	Cons
Small.	Require external manipulation.
Light.	

Table 6.1 - Aileron Pros and Cons

Fin Manipulation

A system to rotate the entirety of each fin.

Pros	Cons
Very effective for inducing rotation.	Needs high torque to control.
	Large increase in drag.
	Not allowed.

Table 6.2 - Fin Manipulation Pros and Cons

Retractable Fins

This idea uses two sets of small angled fins. One set would deploy to rotate the rocket in one direction and the other set would deploy after restricting the first to rotate the rocket in the opposite direction.

Pros	Cons
Fast deployment.	Lots of moving parts.
	No fine control.
	Slow reaction.

Table 6.3 - Retractable Fins Pros and Cons

Ram-Scoop Air Thruster

This idea entails having four holes near the nose with a valve control on each. One of the openings of each hole would point toward the side such that when they are open, air is redirected sideways and produces a rotation. Two would open in one direction and the other two in the opposite direction.

Pros	Cons
Fast rotation.	Increase drag on the rocket.
Little power needed.	Not very precise control.

Table 6.4 - Ram-Scoop Air Thruster Pros and Cons

Reaction Wheel

Uses a mass on a motor to induce a spin on the rocket through conservation of angular momentum (i.e. by spinning the motor in one direction, the rocket will spin the other way).

Pros	Cons
Variable control. Completely internal. Fast response.	Moderate weight. Moderate power requirement. More complex calculations required by the computer.

Table 6.5 - Reaction Wheel Pros and Cons

6.3.2 Sensors

Sensors will be necessary both to control the experiment and to provide proof of success.

Accelerometer

Pros	Cons
Can be used to gather flight data. Can detect motor burnout.	Not intended to detect rotation.

Table 6.6 - Accelerometer Pros and Cons

Gyroscope

Pros	Cons
Intended to detect rotation.	Cannot detect motor burnout.

Table 6.7 - Gyroscope Pros and Cons

Camera

Pros	Cons
Can be used to identify ground targets. Provides visual evidence of success.	Would be very difficult to detect rotation with. Would be very difficult to detect motor burnout with.

Table 6.8 - Camera Pros and Cons

6.3.3 Electronics

Controller	Pros	Cons
Arduino	Smaller. Cheaper. Less complicated.	Less powerful. No USB ports.
Raspberry Pi	More powerful. USB ports.	Larger. More expensive. More complex.

Table 6.9 - Controller

6.4 Leading Systems

System	Choice(s)	Reason(s)
Roll induction	Reaction wheel	A reaction wheel will be a fairly mechanically simple solution to the challenge that will also provide the required precision of control for the additional team derived requirement.
Electronics	Raspberry Pi	The Raspberry Pi has USB ports which will be used to communicate with the transceiver. It also has more processing power, which will be necessary for the video processing part of the experiment.
Sensors	Accelerometer Gyroscope Camera	None of the sensors can provide all of the data necessary for the completion of the experiment. Additionally, it is possible to buy accelerometers and gyroscopes as a single unit, so there is little added cost or complexity.

Table 6.10 - Leading Experiment Design

There will be two cameras on the experiment, one for use in the target identification and one only for recording data.

Drawings of the experiment design are shown in Appendix B.

6.5 Interfaces

The reaction wheel motor assembly will be attached to the body of the rocket using two centering rings made from fiberglass. The control electronics and sensors for the experiment, except for the cameras, will be housed on an electronics sled that will be attached to the rocket body using two bulkheads that will be made from fiberglass. The cameras will protrude through and be attached to the wall of the rocket.

6.6 Veracity of Experiment

6.6.1 Precision of Instrumentation

Sensor	Precision
3-Axis Accelerometer	0.005 m/s^2
3-Axis Gyroscope	0.07 °/s
Camera	5 megapixels
GPS Position	3 m
GPS Velocity	0.1 m/s

Table 6.11 - Precision of Instrumentation

6.6.2 Data Recovery System

The Raspberry Pi will have a 128 GB micro SD card which will store the data from all sensors for later collection and analysis. Additionally, the GPS position, GPS velocity, acceleration, rotation, and low resolution video will be transmitted to a computer on the ground in real-time.

7 Project Plan

7.1 Requirements Compliance

7.1.1 Minimum Verification Plans

Requirement	Verification Plan	Test(s) If Needed
1.1. The vehicle shall deliver the science or engineering payload to an apogee altitude of 5,280 feet above ground level (AGL).	The vehicle will use at least two altimeters to record the altitude that it reaches during test flight(s) and the final launch. One of the altimeters used during testing will also be used as the final scoring altimeter.	Simulations will be done to ensure that the launch vehicle can theoretically reach the required altitude. Real world testing will be done with, at a minimum, the required test flight.
1.2. The vehicle shall carry one commercially available, barometric altimeter for recording the official altitude used in determining the altitude award winner.	See above. Additionally, the final launch check list will include checking to ensure that the altimeter is turned on.	N/A
1.2.1. The official scoring altimeter shall report the official competition altitude via a series of beeps to be checked after the competition flight.	PSLT will purchase an altimeter capable of reporting the altitude via a series of beeps, and will test that altimeter prior to the final launch to ensure that it works as expected.	The method of reporting the altitude will be tested during the test flight(s).
1.2.3. At the LRR, a NASA official will mark the altimeter that will be used for the official scoring.	The avionics bay will be easily accessible so that the scoring altimeter can be marked easily.	N/A
1.2.5. At the launch field, to aid in determination of the vehicle’s apogee, all audible electronics, except for the official altitude-	The design of the rocket will allow for easy access of any electronics that produce sound,	N/A

Requirement	Verification Plan	Test(s) If Needed
determining altimeter shall be capable of being turned off.	and they will include dedicated switches to turn them off.	
1.3. All recovery electronics shall be powered by commercially available batteries.	The design of the recovery system will use commercially available batteries.	N/A
1.4. The launch vehicle shall be designed to be recoverable and reusable. Reusable is defined as being able to launch again on the same day without repairs or modifications.	The launch vehicle will be designed to withstand any forces that it is likely to experience without taking damage.	The entire launch vehicle will be examined thoroughly after the test flight(s).
1.5. The launch vehicle shall have a maximum of four (4) independent sections. An independent section is defined as a section that is either tethered to the main vehicle or is recovered separately from the main vehicle using its own parachute.	The launch vehicle design has 3 independent sections. All of the sections will be tethered together. To ensure that the sections stay tethered, the recovery harnesses used to connect them will have two attachment points on each section.	N/A
1.6. The launch vehicle shall be limited to a single stage.	The launch vehicle will be designed to use only one stage.	N/A
1.7. The launch vehicle shall be capable of being prepared for flight at the launch site within 4 hours, from the time the Federal Aviation Administration flight waiver opens.	The launch vehicle will be designed so that it can be prepared for launch in less than 4 hours. Additionally, the vehicle will be prepared for launch as much as possible beforehand.	The time required to prepare the launch vehicle during the test flight(s) will be recorded to ensure that the vehicle can be prepared in less than 4 hours.
1.8. The launch vehicle shall be capable of remaining in launch-	The launch vehicle will be designed such that it can remain	The launch vehicle will be put into the launch ready

Requirement	Verification Plan	Test(s) If Needed
ready configuration at the pad for a minimum of 1 hour without losing the functionality of any critical on-board component.	in the launch ready configuration for at least 1 hour plus any additionally time needed for the flight and recovery. Additionally, any components, such as batteries, that can be drained in some way will be replaced/refilled before the launch.	configuration for at least 1 hour and then tested for loss of functionality.
1.9. The launch vehicle shall be capable of being launched by a standard 12 volt direct current firing system. The firing system will be provided by the NASA-designated Range Services Provider.	Because the launch vehicle will use a standard, commercially available engine, there will be no need to use a nonstandard firing system.	N/A
1.10. The launch vehicle shall require no external circuitry or special ground support equipment to initiate launch (other than what is provided by Range Services).	See above.	N/A
1.11. The launch vehicle shall use a commercially available solid motor propulsion system using ammonium perchlorate composite propellant (APCP) which is approved and certified by the National Association of Rocketry (NAR), Tripoli Rocketry Association (TRA), and/or the Canadian Association of Rocketry (CAR).	The launch vehicle will be designed to use a commercially available solid motor.	N/A

Requirement	Verification Plan	Test(s) If Needed
1.12. Pressure vessels on the vehicle shall be approved by the RSO and shall meet the following criteria: 1.12.1. The minimum factor of safety (Burst or Ultimate pressure versus Max Expected Operating Pressure) shall be 4:1 with supporting design documentation included in all milestone reviews. 1.12.2. The low-cycle fatigue life shall be a minimum of 4:1. 1.12.3. Each pressure vessel shall include a solenoid pressure relief valve that sees the full pressure of the tank. 1.12.4. Full pedigree of the tank shall be described, including the application for which the tank was designed, and the history of the tank, including the number of pressure cycles put on the tank, by whom, and when.	PSLT will not use pressure vessels on the launch vehicle.	N/A
1.13. The total impulse provided by a College and/or University launch vehicle shall not exceed 5,120 Newton-seconds (L-class).	The launch vehicle will be designed to a motor of no higher than L-class.	N/A

Requirement	Verification Plan	Test(s) If Needed
1.14. The launch vehicle shall have a minimum static stability margin of 2.0 at the point of rail exit.	The launch vehicle will be designed to achieve a static stability margin of at least 2 at rail exit.	The static stability margin at rail exit will be calculated using both simulations and hand calculations.
1.15. The launch vehicle shall accelerate to a minimum velocity of 52 fps at rail exit.	A motor powerful enough to accelerate the launch vehicle to a rail exit velocity of at least 52 fps will be used.	Simulations and hand calculations will be done to confirm the velocity at rail exit. Additionally, the velocity at rail exit will be recorded during the test flight(s).
1.16. All teams shall successfully launch and recover a subscale model of their rocket prior to CDR. 1.16.1. The subscale model should resemble and perform as similarly as possible to the full-scale model, however, the full-scale shall not be used as the subscale model. 1.16.2. The subscale model shall carry an altimeter capable of reporting the model's apogee altitude.	A subscale rocket will be designed and built as shown in the timeline. The subscale rocket will be designed to be as close as possible to the full scale rocket. The subscale rocket will include the same recovery system design as the full scale rocket, so it will have two altimeters capable of reporting its altitude.	N/A

Requirement	Verification Plan	Test(s) If Needed
1.17. All teams shall successfully launch and recover their full-scale rocket prior to FRR in its final flight configuration. The rocket flown at FRR must be the same rocket to be flown on launch day. The purpose of the full-scale demonstration flight is to demonstrate the launch vehicle's stability, structural integrity, recovery systems, and the team's ability to prepare the launch vehicle for flight. A successful flight is defined as a launch in which all hardware is functioning properly (i.e. drogue chute at apogee, main chute at a lower altitude, functioning tracking devices, etc.). The following criteria must be met during the full scale demonstration flight: 1.17.1. The vehicle and recovery system shall have functioned as designed. 1.17.2. The payload does not have to be flown during the full-scale test flight. The following requirements still apply:	The full scale rocket will be built and flown at least once as shown on the timeline. The recovery system will be prepared in the same manner that it will be for the final launch. The final payload will be flown during the test flight(s) with the only change being the size of the reaction wheel. The final ballast that will be used will be flown on the test flight(s).	N/A

Requirement	Verification Plan	Test(s) If Needed
1.17.2.1. If the payload is not flown, mass simulators shall be used to simulate the payload mass. 1.17.2.1.1. The mass simulators shall be located in the same approximate location on the rocket as the missing payload mass. 1.17.3. If the payload changes the external surfaces of the rocket (such as with camera housings or external probes) or manages the total energy of the vehicle, those systems shall be active during the full-scale demonstration flight. 1.17.4. The full-scale motor does not have to be flown during the full-scale test flight. However, it is recommended that the full-scale motor be used to demonstrate full flight readiness and altitude verification. If the full-scale motor is not flown during the full-scale flight, it is desired that the motor simulate, as closely as possible, the predicted maximum velocity		

Requirement	Verification Plan	Test(s) If Needed
and maximum acceleration of the launch day flight. 1.17.5. The vehicle shall be flown in its fully ballasted configuration during the full-scale test flight. Fully ballasted refers to the same amount of ballast that will be flown during the launch day flight. 1.17.6. After successfully completing the full-scale demonstration flight, the launch vehicle or any of its components shall not be modified without the concurrence of the NASA Range Safety Officer (RSO). 1.17.7. Full scale flights must be completed by the start of FRRs (March 6th, 2016). If the Student Launch office determines that a re-flight is necessary, then an extension to March 24th, 2016 will be granted. This extension is only valid for re-flights; not first time flights.		
1.18. Any structural protuberance on the rocket shall be located aft of the burnout center of gravity.	The only structural protuberances on the launch vehicle will be the fins and cameras, both of which	N/A

Requirement	Verification Plan	Test(s) If Needed
	will be located aft of the post burnout CG.	
1.19.1. The launch vehicle shall not utilize forward canards.	The launch vehicle will be design without forward canards.	N/A
1.19.2. The launch vehicle shall not utilize forward firing motors.	The only motor on the launch vehicle will fire backward.	N/A
1.19.3. The launch vehicle shall not utilize motors that expel titanium sponges (Sparky, Skidmark, MetalStorm, etc.)	PSLT will only use motors without titanium sponges.	N/A
1.19.4. The launch vehicle shall not utilize hybrid motors.	The launch vehicle will be designed to use only solid motors.	N/A
1.19.5. The launch vehicle shall not utilize a cluster of motors.	The launch vehicle will be designed to use only one motor.	N/A
1.19.6. The launch vehicle shall not utilize friction fitting for motors.	The motor retention system on the launch vehicle will utilize a screw-on retainer.	N/A
1.19.7. The launch vehicle shall not exceed Mach 1 at any point during flight.	The motor used for the launch vehicle will be chosen to avoid exceeding Mach 1.	Simulations and hand calculations will be done to confirm that the rocket does not exceed Mach 1.
1.19.8. Vehicle ballast shall not exceed 10% of the total weight of the rocket.	The launch vehicle will be designed to function with ballast that is less than 10% of its weight.	The rocket and the ballast will be weighted.
2.1. The launch vehicle shall stage the deployment of its recovery devices, where a drogue parachute is deployed at apogee	The launch vehicle will be designed to include electronic altimeters that will stage the	See below.

Requirement	Verification Plan	Test(s) If Needed
and a main parachute is deployed at a much lower altitude.	deployment of the recovery system. The recovery system will be designed to use a drogue parachute and a main parachute.	
2.2. Each team must perform a successful ground ejection test for both the drogue and main parachutes. This must be done prior to the initial subscale and full scale launches.	A ground fire test will be performed as shown in the timeline.	N/A
2.3. At landing, each independent sections of the launch vehicle shall have a maximum kinetic energy of 75 ft-lbf.	The recovery system will be designed to keep the kinetic energy of each section of the rocket bellow 75 ft-lbs.	Calculations will be done using data from simulations and hand calculations. Additionally, an analysis will be done of the test flight(s) to verify the energy of the rocket.
2.4. The recovery system electrical circuits shall be completely independent of any payload electrical circuits.	The recovery system will be designed to be independent of the payload electronics. Additionally, the payload and recovery system electronics will be in different sections of the rocket.	N/A
2.5. The recovery system shall contain redundant, commercially available altimeters. The term "altimeters" includes both simple	The recovery system will be designed to include 2 altimeters.	N/A

Requirement	Verification Plan	Test(s) If Needed
altimeters and more sophisticated flight computers.		
2.6. Motor ejection is not a permissible form of primary or secondary deployment.	Primary and secondary deployment will be controlled by the altimeters.	N/A
2.7. Each altimeter shall be armed by a dedicated arming switch that is accessible from the exterior of the rocket airframe when the rocket is in the launch configuration on the launch pad.	The avionics bay will be designed to make the altimeters accessible from the exterior of the rocket.	N/A
2.8. Each altimeter shall have a dedicated power supply.	The recovery system will be designed to have a separate battery for each altimeter.	N/A
2.9. Each arming switch shall be capable of being locked in the ON position for launch.	The switches chosen for the recovery system will be capable of being locked on.	N/A
2.10. Removable shear pins shall be used for both the main parachute compartment and the drogue parachute compartment.	The parachute compartments will be designed to use removable shear pins.	N/A
2.11. An electronic tracking device shall be installed in the launch vehicle and shall transmit the position of the tethered vehicle or any independent section to a ground receiver. 2.11.1. Any rocket section, or payload component, which lands	An electronic tracking system will be designed to transmit the position of the launch vehicle. There will be no untethered sections of the launch vehicle.	The tracking system will be tested on the ground, as well as on both the subscale rocket and on the test flight(s) of the full scale launch vehicle.

Requirement	Verification Plan	Test(s) If Needed
untethered to the launch vehicle, shall also carry an active electronic tracking device. 2.11.2. The electronic tracking device shall be fully functional during the official flight on launch day.		
2.12. The recovery system electronics shall not be adversely affected by any other on-board electronic devices during flight (from launch until landing). 2.12.1. The recovery system altimeters shall be physically located in a separate compartment within the vehicle from any other radio frequency transmitting device and/or magnetic wave producing device. 2.12.2. The recovery system electronics shall be shielded from all onboard transmitting devices, to avoid inadvertent excitation of the recovery system electronics. 2.12.3. The recovery system electronics shall be shielded from all onboard devices which may	The recovery system electronics will be shielded from any other onboard electronics. The recovery system electronics will be the only electronics in the avionics bay, which is an entire section of the launch vehicle.	N/A

Requirement	Verification Plan	Test(s) If Needed
generate magnetic waves (such as generators, solenoid valves, and Tesla coils) to avoid inadvertent excitation of the recovery system. 2.12.4. The recovery system electronics shall be shielded from any other onboard devices which may adversely affect the proper operation of the recovery system electronics.		
The roll maneuvers must follow this sequence of events: 1) Motor burns out. 2) On board instrumentation shall account for any natural rotation of the rocket (can be measured at burnout). 3) The roll system shall induce a moment capable of generating at least 2 full rotations. 4) After 2 full rotations, the roll system shall induce a moment to counter rotation. 5) The system shall return the rocket to its initial rotation measured at motor burnout.	The experimental payload will contain accelerometers and gyroscopes to detect the roll of the launch vehicle at motor burnout. A reaction wheel will be used to induce the roll. The accelerometers and gyroscopes will detect when the vehicle has completed 2 rolls. The reaction wheel will return the vehicle to its initial rotation.	The experiment will be tested during the test flight(s). The experiment will use accelerometers, gyroscopes, and cameras to detect whether the vehicle has rolled as intended.

Requirement	Verification Plan	Test(s) If Needed
3.3.2. Teams shall not intentionally design a launch vehicle with a fixed geometry that can create a passive roll effect.	The launch vehicle will not be designed with a fixed geometry to induce roll.	N/A
3.3.3. Teams shall only use mechanical devices for rolling procedures.	The experimental payload will use mechanical components to induce the roll.	N/A
4.1. Each team shall use a launch and safety checklist. The final checklists shall be included in the FRR report and used during the Launch Readiness Review (LRR) and any launch day operations.	The safety officer will create launch and safety checklists.	N/A
4.2. Each team must identify a student safety officer who shall be responsible for all items in section 4.3.	See section 1.1.	N/A
4.3. The role and responsibilities of each safety officer shall include, but not limited to: 4.3.1. Monitor team activities with an emphasis on Safety during: 4.3.1.1. Design of vehicle and launcher 4.3.1.2. Construction of vehicle and launcher 4.3.1.3. Assembly of vehicle and launcher	The safety officer has been made aware of his responsibilities.	N/A

Requirement	Verification Plan	Test(s) If Needed
4.3.1.4. Ground testing of vehicle and launcher 4.3.1.5. Sub-scale launch test(s) 4.3.1.6. Full-scale launch test(s) 4.3.1.7. Launch day 4.3.1.8. Recovery activities 4.3.1.9. Educational Engagement Activities 4.3.2. Implement procedures developed by the team for construction, assembly, launch, and recovery activities 4.3.3. Manage and maintain current revisions of the team's hazard analyses, failure modes analyses, procedures, and MSDS/chemical inventory data 4.3.4. Assist in the writing and development of the team's hazard analyses, failure modes analyses, and procedures.		
4.4. Each team shall identify a "mentor." A mentor is defined as an adult who is included as a team member, who will be supporting the team (or multiple teams) throughout the project year, and may or may not be affiliated with	See section 2.1.	N/A

Requirement	Verification Plan	Test(s) If Needed
the school, institution, or organization. The mentor shall maintain a current certification, and be in good standing, through the National Association of Rocketry (NAR) or Tripoli Rocketry Association (TRA) for the motor impulse of the launch vehicle, and the rocketeer shall have flown and successfully recovered (using electronic, staged recovery) a minimum of 2 flights in this or a higher impulse class, prior to PDR. The mentor is designated as the individual owner of the rocket for liability purposes and must travel with the team to launch week. One travel stipend will be provided per mentor regardless of the number of teams he or she supports. The stipend will only be provided if the team passes FRR and the team and mentor attends launch week in April.		
4.5. During test flights, teams shall abide by the rules and guidance of the local rocketry club's RSO. The allowance of certain vehicle configurations and/or payloads at the NASA Student Launch Initiative does not	The safety officer will ensure that all team members are aware of the rules of and relating to the local club at any launch.	N/A

Requirement	Verification Plan	Test(s) If Needed
give explicit or implicit authority for teams to fly those certain vehicle configurations and/or payloads at other club launches. Teams should communicate their intentions to the local club's President or Prefect and RSO before attending any NAR or TRA launch.		
4.6. Teams shall abide by all rules set forth by the FAA.	The safety officer will ensure all team members are made aware of the rules set forth be the FAA.	N/A
5.1. Students on the team shall do 100% of the project, including design, construction, written reports, presentations, and flight preparation with the exception of assembling the motors and handling black powder or any variant of ejection charges, or preparing and installing electric matches (to be done by the team's mentor).	The students will do all of the work.	N/A
5.2. The team shall provide and maintain a project plan to include, but not limited to the following items: project milestones, budget and community support, checklists, personnel assigned, educational engagement events, and risks and mitigations.	The team's project manager will maintain a project plan.	N/A

Requirement	Verification Plan	Test(s) If Needed
5.3. Foreign National (FN) team members shall be identified by the Preliminary Design Review (PDR) and may or may not have access to certain activities during launch week due to security restrictions. In addition, FN's may be separated from their team during these activities.	There are no foreign nationals on the team.	N/A
5.4. The team shall identify all team members attending launch week activities by the Critical Design Review (CDR). Team members shall include: 5.4.1. Students actively engaged in the project throughout the entire year. 5.4.2. One mentor (see requirement 4.4). 5.4.3. No more than two adult educators.	The list of team members on the CDR will state which team members will attend launch week.	N/A
5.5. The team shall engage a minimum of 200 participants in educational, hands-on science, technology, engineering, and mathematics (STEM) activities, as defined in the Educational Engagement Activity Report, by	PSLT has already planned several educational engagement activities, and has plans for more.	N/A

Requirement	Verification Plan	Test(s) If Needed
FRR. An educational engagement activity report shall be completed and submitted within two weeks after completion of an event. A sample of the educational engagement activity report can be found on page 28 of the handbook.		
5.6. The team shall develop and host a Web site for project documentation.	The team has created and hosted a website.	N/A
5.7. Teams shall post, and make available for download, the required deliverables to the team Web site by the due dates specified in the project timeline.	There is a section on the team website for deliverables.	N/A
5.8. All deliverables must be in PDF format.	All deliverables will be posted as PDFs.	N/A
5.9. In every report, teams shall provide a table of contents including major sections and their respective sub-sections.	Whoever compiles each report will add a table of contents.	N/A
5.10. In every report, the team shall include the page number at the bottom of the page.	Whoever compiles each report will add page numbers.	N/A
5.11. The team shall provide any computer equipment necessary to perform a video teleconference with the review board. This includes, but not limited to, a	PSLT has acquired access to the equipment necessary for all teleconferences.	N/A

Requirement	Verification Plan	Test(s) If Needed
computer system, video camera, speaker telephone, and a broadband Internet connection. If possible, the team shall refrain from use of cellular phones as a means of speakerphone capability.		
5.12. All teams will be required to use the launch pads provided by Student Launch's launch service provider. No custom pads will be permitted on the launch field. Launch services will have 8 ft. 1010 rails, and 8 and 12 ft. 1515 rails available for use.	The launch vehicle will be designed to use the available launch pads.	N/A
5.13. Teams must implement the Architectural and Transportation Barriers Compliance Board Electronic and Information Technology (EIT) Accessibility Standards (36 CFR Part 1194) Subpart B-Technical Standards (http://www.section508.gov): 1194.21 Software applications and operating systems. 1194.22 Web-based intranet and Internet information and applications.	The webmaster will ensure that the website complies with the requirements.	N/A

Table 7.1 - Minimum Requirement Verification Plans

7.1.2 Team Requirements and Verification Plans

Requirement	Verification Plan	Test(s) If Needed
Engage a minimum of 200 girls and women in educational engagement activities.	Make a special effort to engage women and girls in STEM related activities when doing educational engagement.	Keep track of the number of women and girls engaged during educational engagement activities.
Ensure PSLT is set up to continue into future years.	Set up partnerships, procedures, and community support that can be used to help teams in future years get started. Pass on knowledge and keep track of lessons learned over the course of the project.	N/A
Spread Student Launch to other schools.	Several members of PSLT will transfer to other schools at the end of the year, so they may start teams at other schools.	N/A

Table 7.2 - Team Requirements and Verification Plans

7.2 Budget and Timeline

7.2.1 Budget

Item	Quantity	Unit Cost	Extended Cost
Main Launch Vehicle			
5.5 in fiberglass ogive nose cone	1	$85	$85
5.5 in fiberglass body tube	2	$176	$352

Item	Quantity	Unit Cost	Extended Cost
5.5 in fiberglass body tube coupler	1	$65	$65
54 mm fiberglass body tube	1	$65	$65
¼ in fiberglass sheet	6	$54	$324
U-bolt assembly	8	$5	$40
Quick link	10	$4	$40
1 in X 25 ft Kevlar recovery harness	2	$36	$72
18 in parachute protector	2	$11	$22
84 in main parachute	1	$296	$296
30 in drogue parachute	1	$15	$15
Large rail buttons	1	$5	$5
54 mm motor retainer	1	$32	$32
Nylon shear pins	1	$4	$4
Tracking powder	1	$7	$7
Altimeter	2	$72	$144
Batteries	1	$10	$10
Ejection canisters	2	$4	$8
Tracking system	1	$250	$250
Electronics sled	1	$30	$30
5.5 in fiberglass tail cone	1	$59	$59
Other hardware	1	$5	$5
Subtotal			$1930
Experiment			
Raspberry Pi	1	$40	$40
Accelerometer / Gyroscope	2	$12	$24

Item	Quantity	Unit Cost	Extended Cost
GPS	1	$40	$40
Transmitter electronics	2	$75	$150
Antenna	2	$10	$20
Electric motor	1	$20	$20
Motor controller	1	$20	$20
Mounting hub	1	$8	$8
Steel cylinder (reaction wheel)	1	$50	$50
Camera	2	$40	$80
Electronics sled	1	$20	$20
SD card	1	$60	$60
Other hardware	1	$20	$20
Subtotal			$552
Travel			
Hotel	1	$3000	$3000
Meals	1	$1700	$1700
Transport	1	$100	$100
Subtotal			$4800
Total			$7282

Table 7.3 - Budget

7.2.2 Funding Plan

Funding for PSLT comes from two primary sources: PVCC and corporate sponsors. Other funds and resources have come from individual donations.

Amount	Allocated To
$950	Air frame
$500	Educational engagement
$600	Experiment

Amount	Allocated To
$600	Motors
$1500	Subscale rocket
$500	Other expenses
$600	Other launch vehicle components
$700	Recovery system
$5000	Travel

Table 7.4 - Allocation of Funds

7.2.3 Timeline

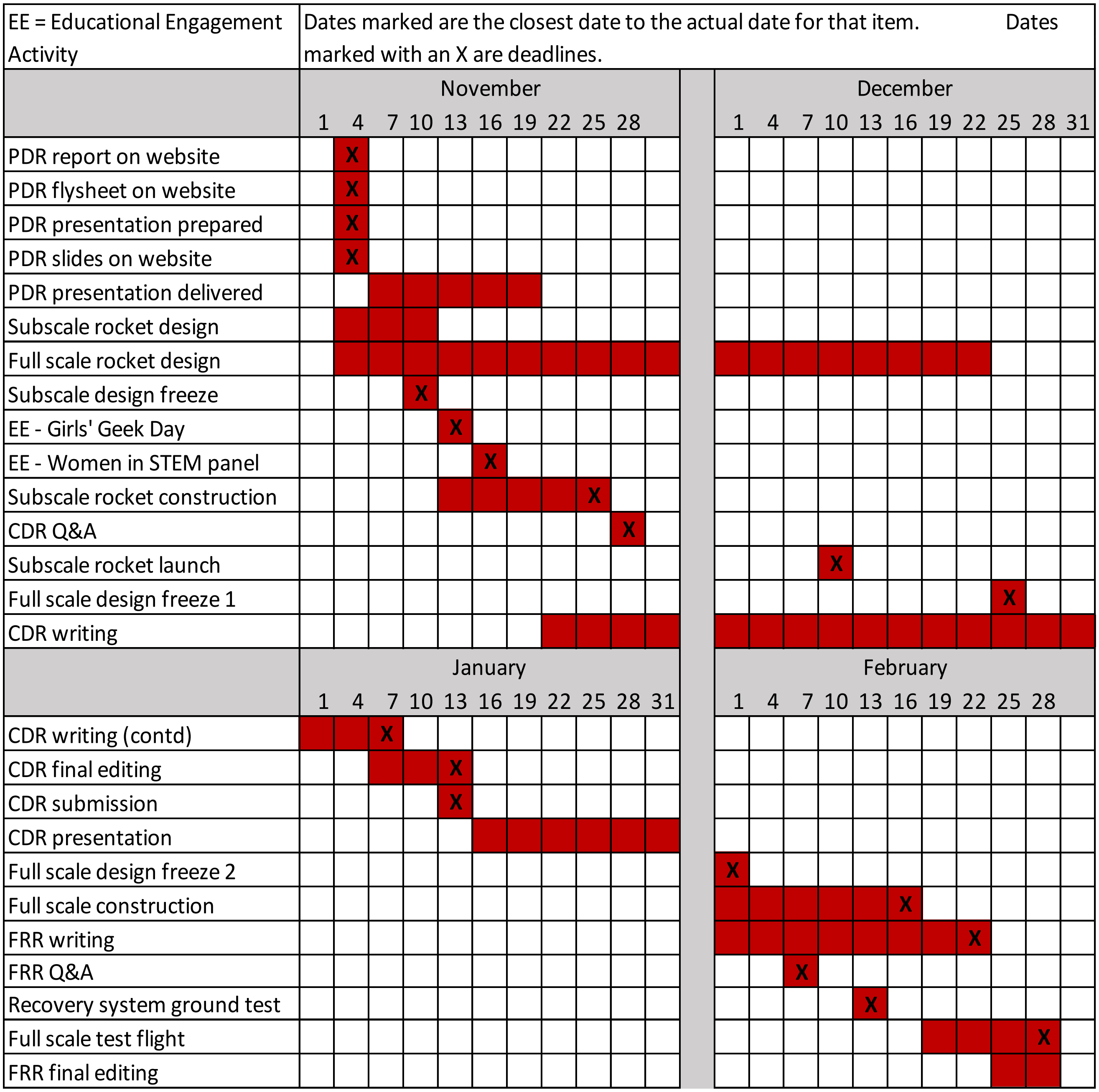

Figure 7.1 - Timeline from November through February

	March											April										
	1	4	7	10	13	16	19	22	25	28		1	4	7	10	13	16	19	22	25	28	31
FRR final editing (contd)		X																				
FRR submission			X																			
FRR presentation																						
LRR preparation												X										
Travel to Alabama													X									
LRR													X									
Launch week safety briefing														X								
Rocket fair														X								
Tours														X								
Launch day															X							
Backup launch day															X							
PLAR writing																	X					
PLAR final editing																			X			
PLAR submission																				X		

Figure 7.2 - Timeline from March through April

Appendix A - Launch Vehicle System Drawings

All dimensions are given in inches.

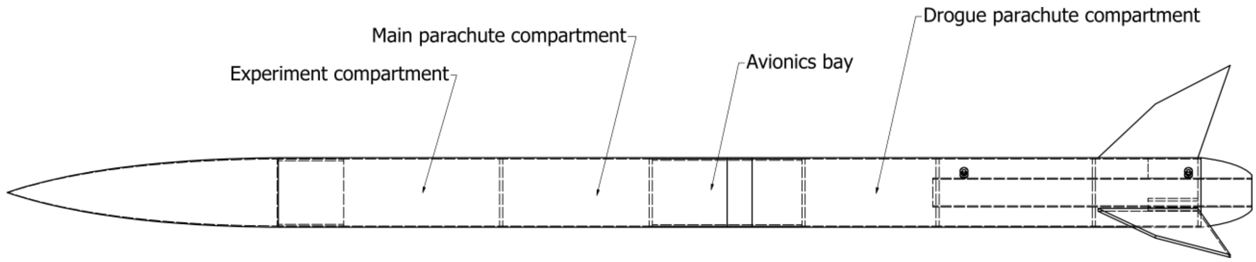

Figure A.1 - Overall Launch Vehicle

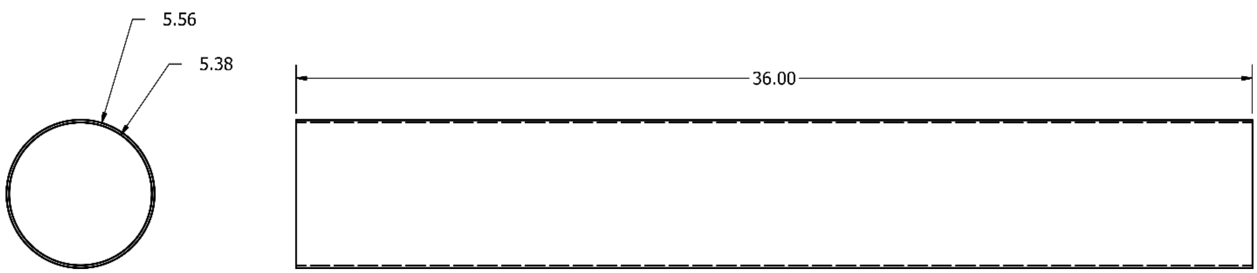

Figure A.2 - Upper Body Section

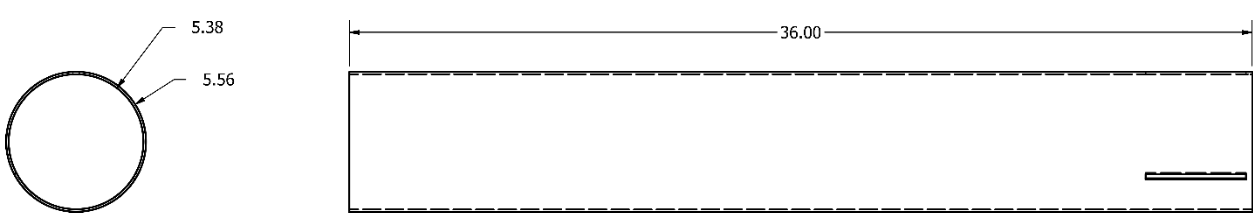

Figure A.3 - Lower Body Section

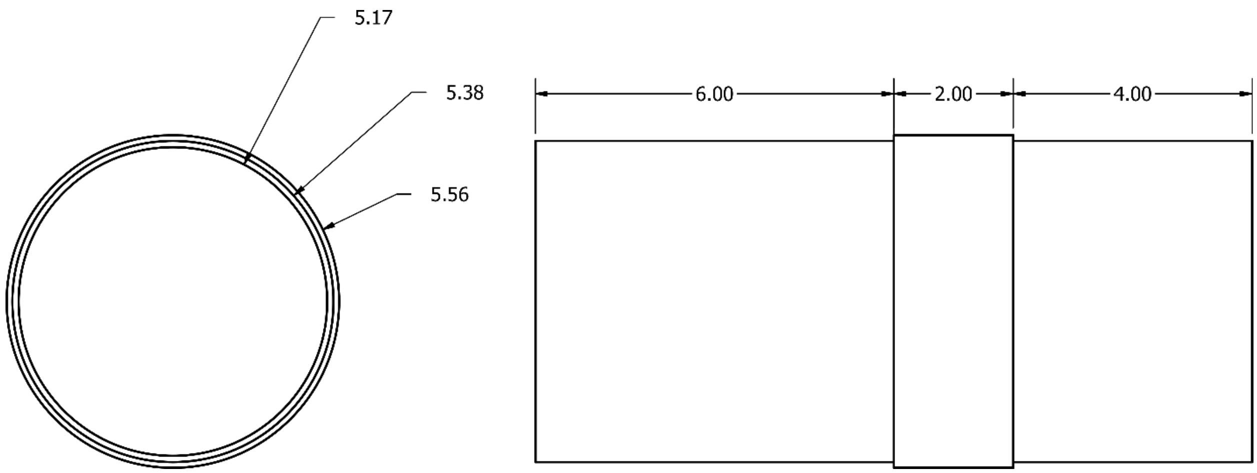

Figure A.4 - Avionics Bay

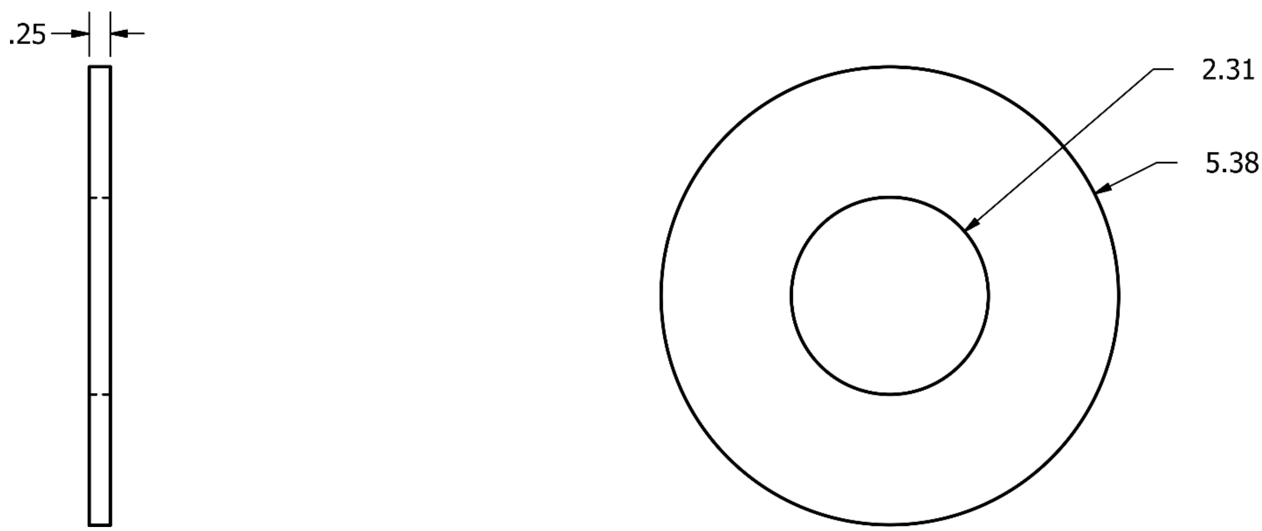

Figure A.5 - Centering Ring

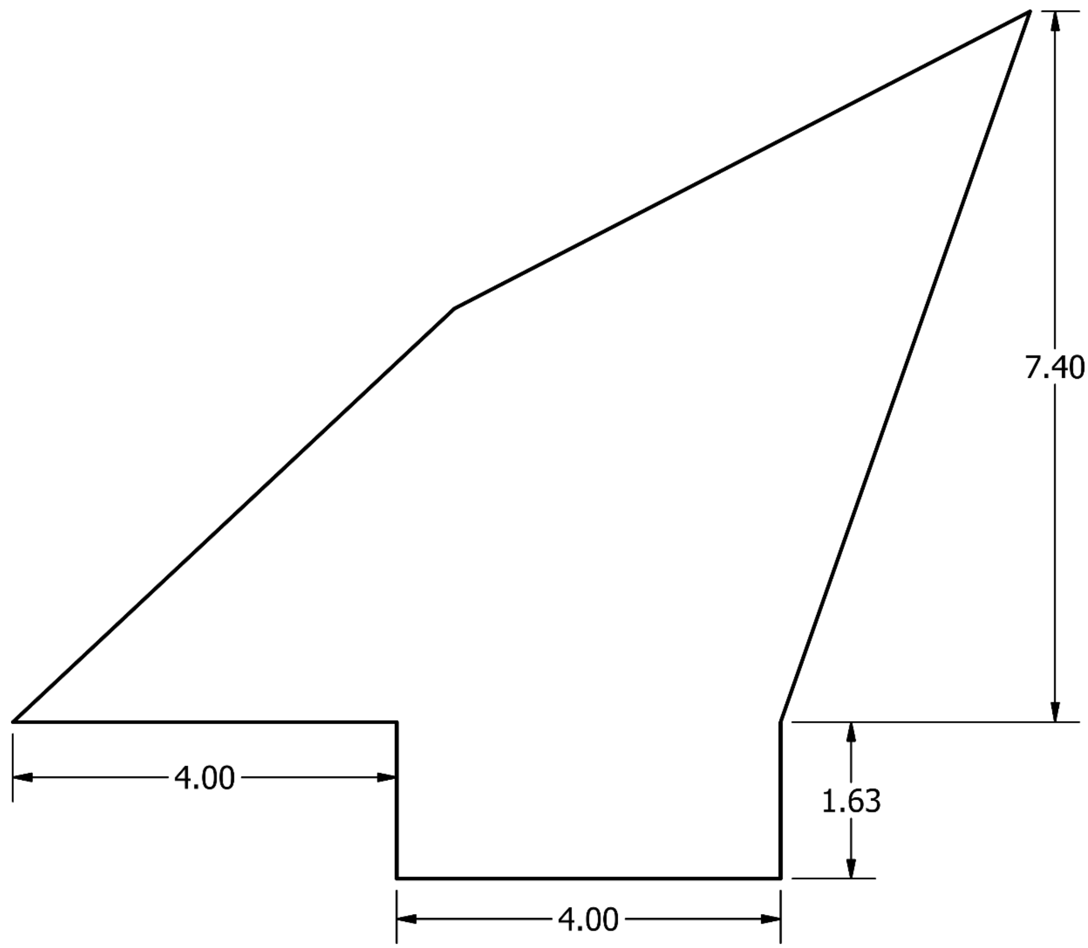

Figure A.6 - Fin

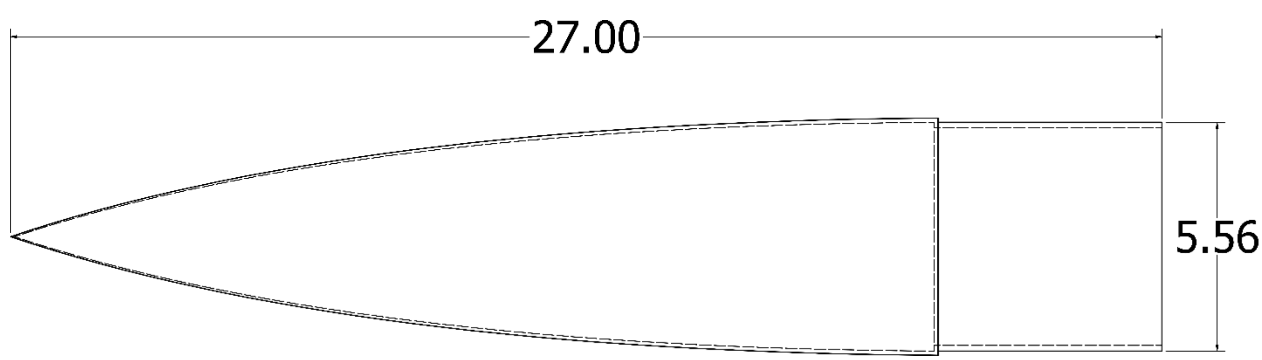

Figure A.7 - Nose Cone

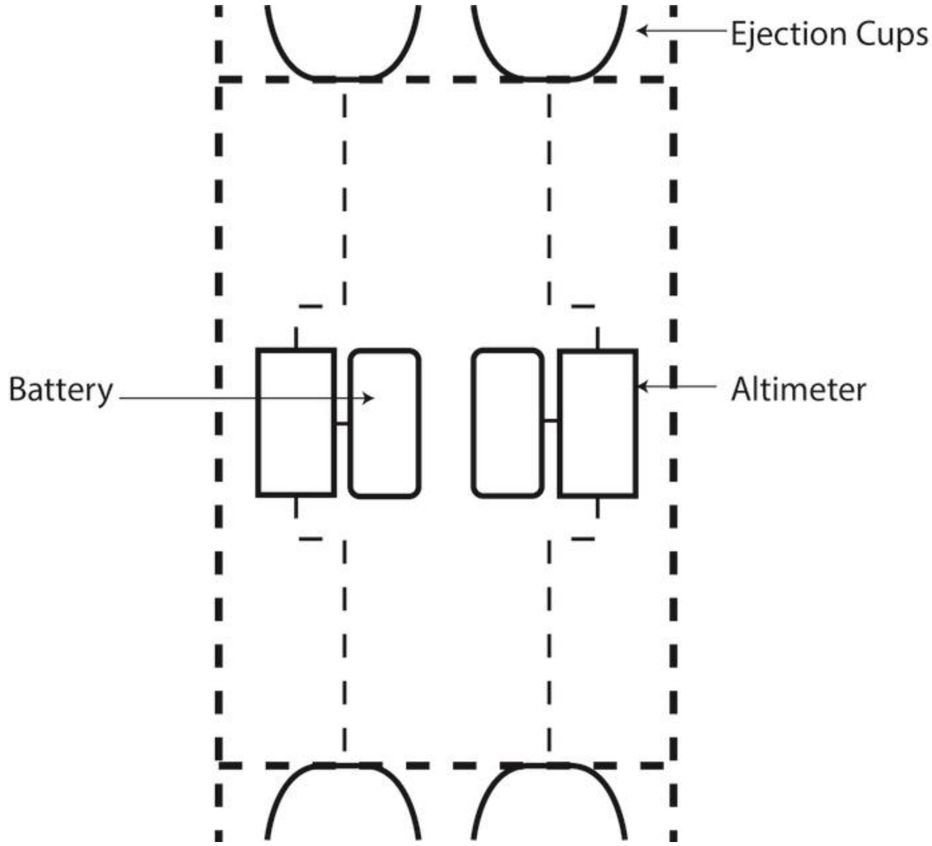

Figure A.8 - Avionics Bay

Appendix B - Experiment Drawings

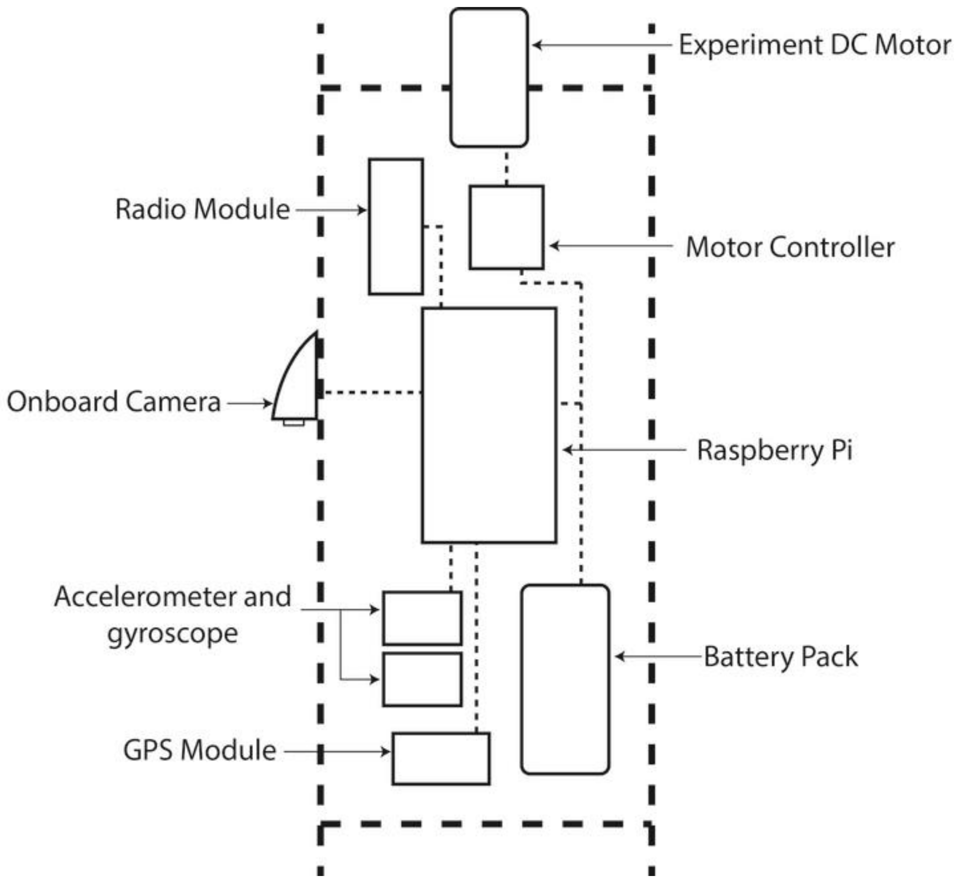

Figure B.1 - Experiment Electronics

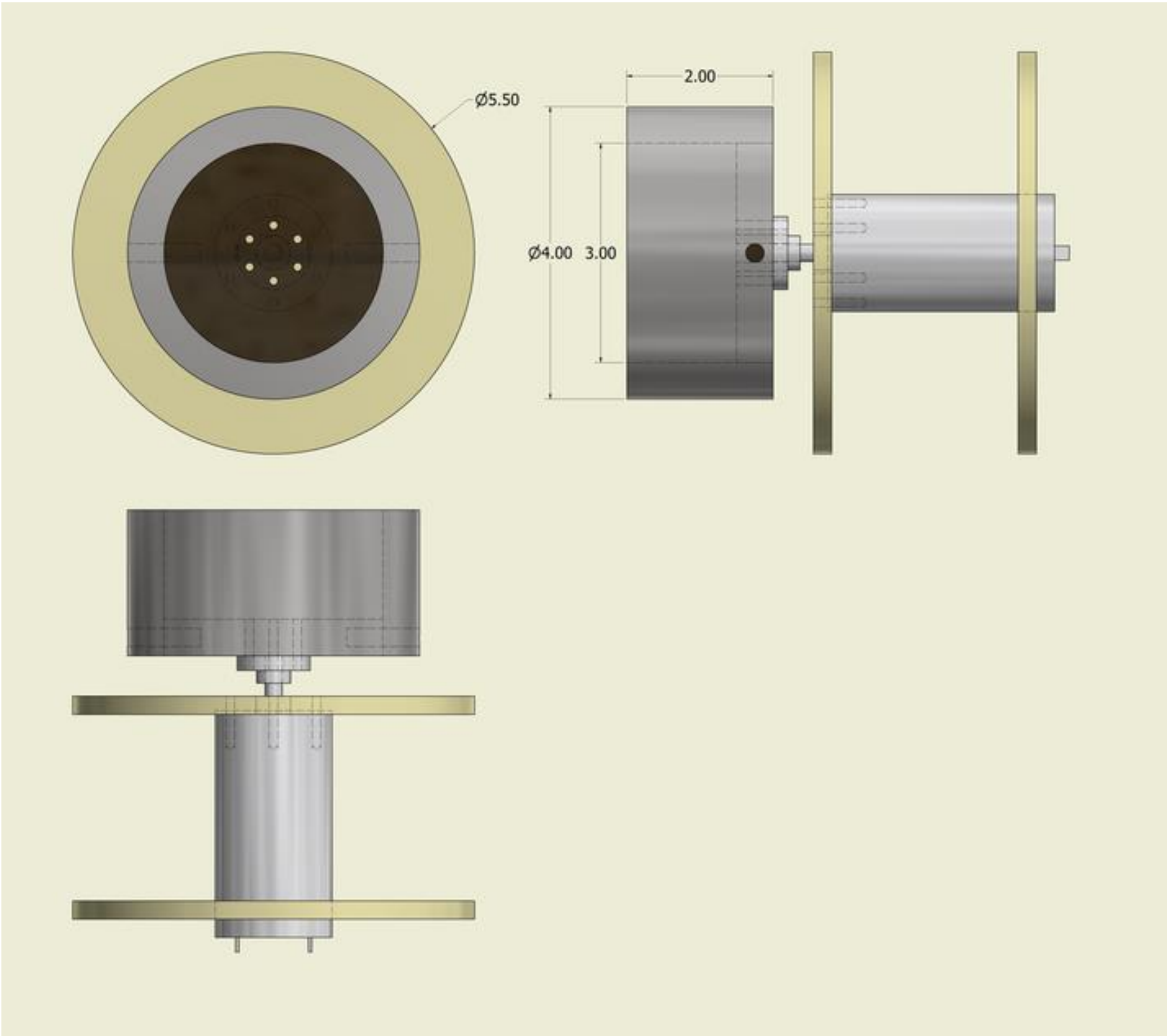

Figure B.2 - Reaction Wheel

Appendix C - Risk Definitions

Description	Personnel Safety and Health	Facility/Equipment	Environmental
1 – Catastrophic	Loss of life or a permanent-disabling injury.	Loss of facility, systems or associated hardware.	Irreversible severe environmental damage that violates law and regulation.
2 - Critical	Severe injury or occupational-related illness.	Major damage to facilities, systems, or equipment.	Reversible environmental damage causing a violation of law or regulation.
3 - Marginal	Minor injury or occupational-related illness.	Minor damage to facilities, systems, or equipment.	Mitigatable environmental damage without violation of law or regulation where restoration activities can be accomplished.
4 - Negligible	First aid injury or occupational-related illness.	Minimal damage to facility, systems, or equipment.	Minimal environmental damage not violating law or regulation.

Table C.1 - Severity Definitions

Description	Qualitative Definition	Quantitative Definition
A - Frequent	High likely hood to occur immediately or expected to be continuously experienced.	Probability is > 0.1
B - Probable	Likely to occur or expected to occur frequently within time.	0.1 ≥ Probability > 0.01
C - Occasional	Expected to occur several times or occasionally within time.	0.01 ≥ Probability > 0.001

Description	Qualitative Definition	Quantitative Definition
D - Remote	Unlikely to occur, but can be reasonably expected to occur at some point within time.	0.001 ≥ Probability > 0.000001
E - Improbable	Very unlikely to occur and an occurrence is not expected to be experienced within time.	0.000001 ≥ Probability

Table C.2 - Probability Definitions

Appendix D - Dictionary of Acronyms

CG	- Center of Gravity
CP	- Center of Pressure
GPS	- Global Positioning System
NAR	- National Association of Rocketry
NOVAAR	- Northern Virginia Association of Rocketry
PSLT	- Piedmont Student Launch Team
PVCC	- Piedmont Virginia Community College
RAC	- Risk Assessment Code
VAST	- Valley AeroSpace Team