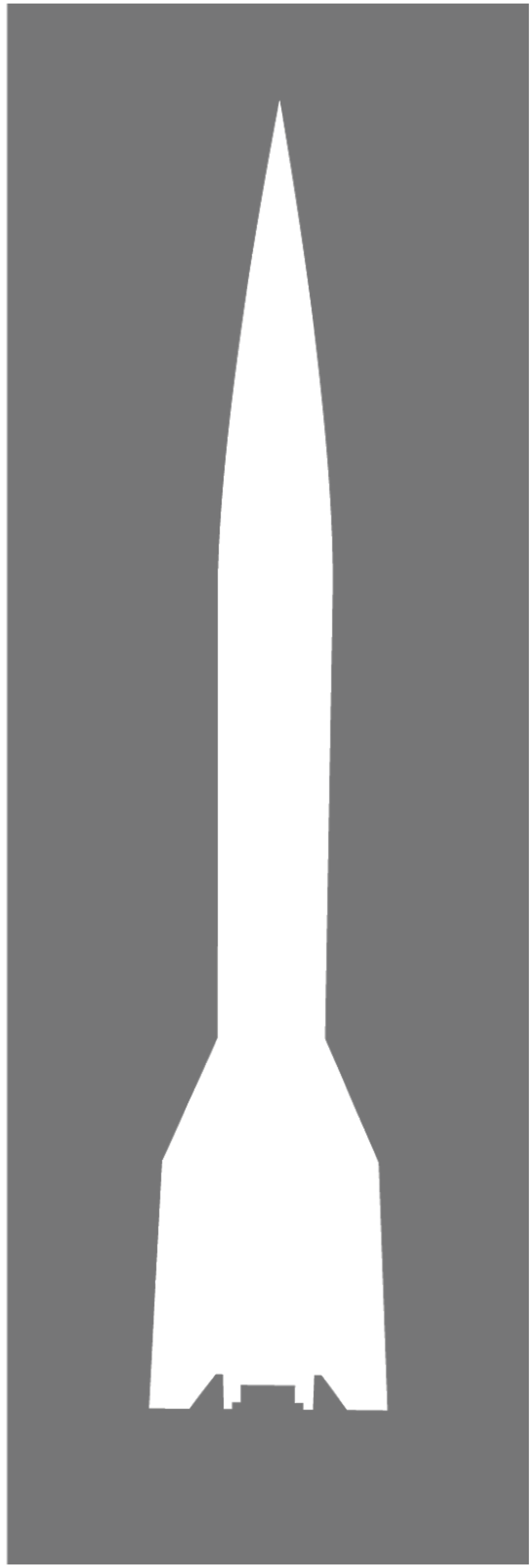
Purdue University

Project Walker



500 Allison Road
West Lafayette, IN 47906

November 2nd, 2018

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1. General Information

1.1. Adult Educator(s)

Name	Barlow, Victor M.
Title	Faculty Mentor
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1.2. Safety Officer

Name	Lyons Jr., Jory C.
Title	Safety Officer
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1.3. Team Leader

Name	Repella III, Michael V.
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1.4. Student Participants

The Purdue Space Program Student Launch (PSP-SL) team competing in NASA's 2019 student launch competition will have 40 participants. Some key personnel other than the ones listed above include Luke Perrin (Assistant Project Manager), Wes O'Dell (Payload Officer), Sean Heapy (Funding Officer), Zach Carroll (Construction Officer), Harith Kolaganti (Social Officer), and Reni Patel (Avionics Officer).

1.5. NAR/TRA Section Affiliations

Name	Indiana Rocketry
Registration	Prefecture #132 (TRA), Section #711 (NAR)

Website	http://www.indianarocketry.org/

1.6. Project Dedication

This project is named after Charles D. Walker, who received a Bachelors of Science in Aeronautical and Astronautical Engineering at Purdue University in 1971. While an employee of the McDonnell Douglas Corp., Charles Walker was confirmed by NASA in 1983 as the first industrial payload specialist. He accompanied the McDonnell Douglas continuous-flow electrophoresis (CFES) equipment as a crew member on space shuttle missions 41D, 51D and 61B, accumulating 20 days of experience in space and traveling 8.2 million miles. This information was retrieved from https://www.purdue.edu/space/astronauts.php#charlesWalker.

2. Summary of PDR

2.1. Team Summary

Team Name: Purdue Space Program Student Launch
Mailing Address: 500 Allison Road, West Lafayette, Indiana 47906
Name of Mentor: Victor Barlow
Mentor's NAR/TRA Number: NAR 88988 L3CC, TRA 6839 TAP
Mentor's Certification Level: Level 3 Certified
Mentor's Contact Information: vmbarlow@purdue.edu, 765-414-2848 (Cell)

2.2. Launch Vehicle Summary

Size and Mass: Our launch vehicle will be 122" tall when assembled and weigh an estimated 39.31 lb when the motor is mounted and 31.27 lb when the motor is not. The vehicle will have an outer diameter of 5.15" and will be constructed using filament wound composite fiberglass.
Motor Choice: We are currently planning on using an Aerotech Rocketry L1520 Blue Thunder as our means for propulsion. It is a 75mm diameter, 3 grain motor that produces a total impulse of 3,715 newton seconds over the course of a 2.4 second burn time.
Recovery System: The rocket will utilize standard dual deployment recovery methods, including redundant electronics and ejection charges using a Telemetrum and RRC3+ Sport. A 24" drogue parachute will deploy at apogee, followed by a 100" main parachute at an altitude of 700' above the ground. The shock cord will consist of 1/2" tubular Kevlar with a 7,200 pound rating.
Milestone Review Flysheet: See attached flysheet.

2.3. Payload Summary

Payload Title: The experimental payload that will be flown in this launch vehicle will be known as the "Walker Texas Rover".

Payload Experiment Summary: The PSP-SL team will launch an autonomous rover and soil sampling system as a payload. The rover will be deployed from the payload bay upon landing and must drive at least 10 feet away from any part of the rocket. This motion will employ a system of sensory data collection and execution of obstacle avoidance maneuvers. Once it has travelled at least the decided upon distance from the closest located rocket part, it will begin soil sampling.

3. Changes Made Since Proposal

3.1. Changes Made to Vehicle

The payload was moved from approximately 22 cm above the motor to the base of the nose cone. In response to this change the team also had to move the main and drogue parachutes to accommodate the payload. This includes the shock cord that each parachute will be connected to. The main parachute is now 33 inches from the nose. The drogue parachute is now 70 inches from the nose cone. The shock cord for the drogue parachute is also now directly above the drogue parachute and directly below the avionics bay. These changes were made so that when the parachutes are deployed the weight of each dangling section of the vehicle is more evenly spread out to reduce overall stress on recovery system components.

The centers of pressure and gravity have also changed position due to the change in payload position. The center of gravity is now located 71.345 inches from the vehicle's nose and the center of pressure is now 89.782 inches from the nose. There is now an 18.437 inch distance between the two locations.

The fins were also changed to accomodate for the change in stability caused by the change in payload location. The fins are now swept backwards. They have a 16 inch root chord length, which is an inch more than the fins from the proposal. The tip chord length was also decreased by an inch. The sweep length is now 12 inches and the angle of sweep was increased from 59° to 66.8°.

The launch vehicle mass decreased to a total of 39.31 lb with the motors due to the removal of some ballast added for stability when the payload was near the motor. This allowed the max acceleration to increase to 287 ft/s^2, the max velocity to increase to 620 ft/s, and the predicted apogee to increase to 5023 ft.

3.2. Changes Made to the Payload

The overall design and functionality of the rocket's payload has stayed mostly unchanged since the initial project proposal, though there have been numerous design decisions made to further flesh out details of the system. For our drivetrain, we decided that the mode of transportation shall be powered by two motors on board a structural chassis platform. This system shall fit snugly inside of a pill shaped container. We decided to use FFFF black powder to detach the nose cone and propel our payload out of the rocket. Based on our systems evaluations, our design yields a framework that can be easily adapted to the needs of this project. Its reliability is easily verifiable via testing given our small stockpile of black powder.

3.3. Changes Made to Project Plan

Generally speaking, there have been no major changes to the project plan as a whole. The changes which have been made have been mostly to solidify exactly when specific events such as the subscale launch are happening and what needs done in the future. The subscale vehicle is almost fully constructed, so the plan has been updated to include a planned launch for the subscale on November 11th. Soliciting donations via the team’s GoFundMe platform has been very beneficial to the progression of the project, so occasional meetings have been scheduled between project management and the communications and marketing director for Purdue University’s School of Aeronautics and Astronautics to further increase publicity.

4. Vehicle Criteria

4.1. Selection, Design, And Rationale Of Launch Vehicle

4.1.1. Mission Statement And Mission Success Criteria

Our mission is to design, build, and fly a fully-reusable, student-built launch vehicle capable of carrying a scientific payload to an altitude of 5,023 feet. For us to consider the flight a success, the vehicle must:

1. Make a stable ascent.
2. Fully deploy both the drogue and main recovery systems at the proper altitudes.
3. Stay completely tethered and have no free-falling sections.
4. Be flyable again without any repairs or alterations.
5. Fully deploy the payload after landing.

4.1.2. Current Vehicle Design - Lower Airframe

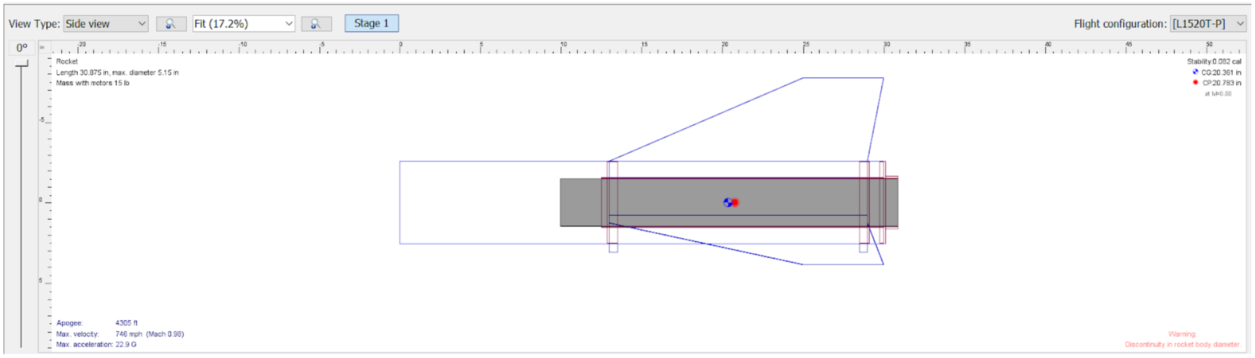
4.1.2.1. Design Alternatives With Pros And Cons

While designing the lower airframe, the team initially faced two options: to make no alterations to the lower airframe that was presented in the proposal, or to use a vehicle with four fins instead of three. Assuming all material choices are constant, an airframe with four fins provides more stability at launch and during flight but also increased drag. Adding a fourth fin would increase the angle between fins from 120 degrees to 90 degrees. The three finned vehicle is projected to have a stability of 3.58 at launch and 2.52 whenever the rocket leaves the launch rail, which is over the minimum value of 2.00 specified in the project handbook.

4.1.2.2. Leading Choice

After considering all of the drawbacks and benefits of a four finned airframe or a three finned airframe, the team elected the latter. The team found that a three finned rocket would be the superior choice. Although four fins provides more stability, it also increases drag and weight. Using the three finned design will allow for less drag while also keeping the stability over 2 as per required by the NASA SL rules, both on the track and coming off of it.

4.1.2.3. Dimensional Drawing



Our lower airframe section will have a 5.15” outer diameter and 5.00” inner diameter, will be 30.86” long, and will have a fin span of 6.00”. The top 5.00” of the tube will interface with the payload coupler.

4.1.2.4. Estimated Mass

As can be seen from the figure above, the estimated weight of the lower airframe of the rocket with the motor mount assembly, thrust plate, rail guides, and fins, is 14.7 pounds. This does not take into account the weight of paint, epoxy adhesive, or metal hardware. We still need to incorporate these objects into the weight figure. Once the section is built, we can obtain a more accurate weight measurement to incorporate into our simulation to better predict altitude and flight parameters.

4.1.3. Current Vehicle Design - Payload Bay

4.1.3.1. Design Alternatives With Pros And Cons

The general design of the payload bay will ultimately rely on two variables: the payload bay length and the payload bay gross weight. The length of the payload bay would determine the size and envelope of the payload, the space occupied in the airframe, as well as contribute to the gross weight of the payload. A shorter length would reduce the size of the payload bay but would also reduce material cost and weight. A longer payload bay would increase the size of the payload at the cost of an increased material weight and material cost. For the payload gross weight, a greater allocated weight for the payload would increase the payload’s influence on the center of gravity resulting in a change to stability, however, this would allow more weight to go into the design of the payload vehicle. A lower payload bay gross weight would limit the impact of the payload on stability and would limit material costs.

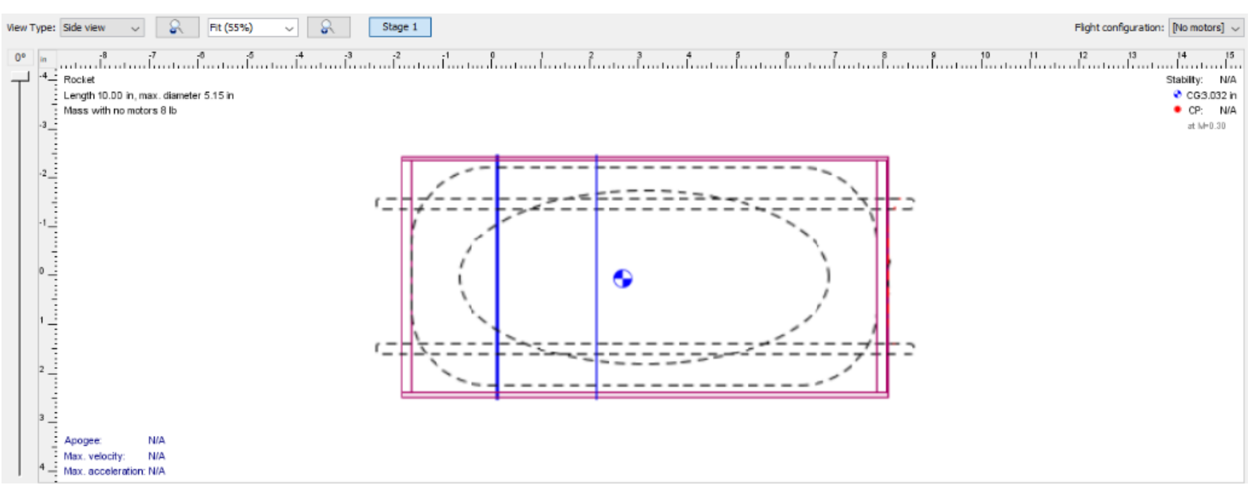
In order to meet the mission success criteria, the payload bay also requires a point of exit that allows the payload to exit the vehicle. The payload bay could either permit an axial exit through either of the bulk plates or an exit normal to the axis going through the coupler. An exit through either end of the payload bay along the rocket axis would limit points of payload bay placement on the rocket body but would allow deployment of the payload regardless or rocket orientation. Exiting the vehicle normal to the rocket axis would allow the payload bay to be placed anywhere along the upper or middle airframes but would require a doorway that interfaces with both the payload bay and rocket body that would be complex in design and limit the allowable orientations for payload deployment.

4.1.3.2. Leading Choice

The payload bay will consist of a single coupler tube with a single bulk plate on one side and a single centering ring on the other. The centering ring will have a concentric plate placed inside of it, sealing the payload bay and providing an exit for the payload vehicle. A band will also be placed on the outside of the payload bay that will have the same inner and outer diameter of the rocket body. This band will be placed 2'' from the end with the centering ring and will allow the payload to interface with the rocket body and nose cone. The length of the payload bay will be 10” with a diameter of a 5”. Threaded rods will run through the bulkheads and the centering ring and will be secured with nuts and washers. This design was chosen to avoid an excess of complexity and to ensure the payload is deployable for any landing orientation of the launch vehicle.

4.1.3.3. Dimensional Drawing

The payload bay will have an encompassing outer diameter of 5.15'' with a coupler of an outer diameter of 5” matching the inner diameter of the rocket body. The inner diameter of the coupler will be 4.815” and will be 10” long. The top of the band will be placed 2” from the top of the payload bay and will be 2” long. The shorter end will interface with the nose cone with the longer end interfacing with the upper air frame.



4.1.3.4. Estimated Mass

The estimated gross payload weight is 8 pounds. This includes the payload bay, the vehicle payload, and all the structural and linkage components. This does not include the weight of paint, epoxies and other adhesives, and interfacing fasteners. The payload mass may increase or decrease based on the requirements of the payload and will also depend on any adhesives and other fasteners that may be needed to secure the payload or payload bay.

4.1.4. Current Vehicle Design - Mid Airframe

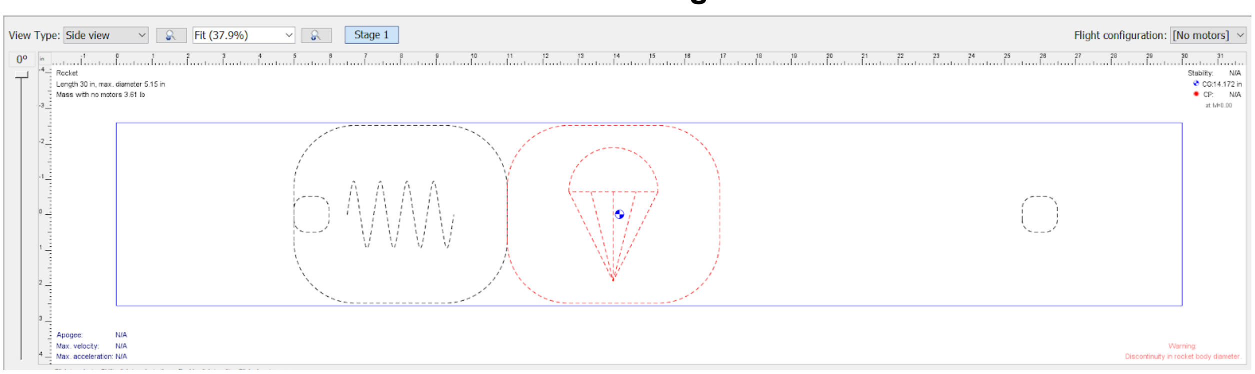
4.1.4.1. Design Alternatives With Pros And Cons

The choice our group faced when designing the mid airframe was to determine the length of the tube necessary for our vehicle. The shorter our airframe was, the lighter our vehicle would be, the less volume we would need to pressurize for ejection, and the less expensive our vehicle would become. A shortened tube, though, also moves the center of gravity closer to the end of the rocket and thus reduces stability margins.

4.1.4.2. Leading Choice

The team elected to use a standard 30” length of tubing. As a result, we do not need to pay an extra fee to have the tube recut to a custom length and the center of gravity remains as far from the aft of the rocket as possible. This also provides us with ample room to pack our drogue recovery gear in, allowing us to use more of the space for coupler shoulders and to allow for longer couplers in the future if needed.

4.1.4.3. Dimensional Drawing



The mid airframe will have an outer diameter of 5.15”, and inner diameter of 5.00”, and will be 30” long. 5.00” of both ends of the tube will be used to interface with coupler tubes, leaving 20.00” of usable room for drogue recovery gear.

4.1.4.4. Estimated Mass

As can be seen from the figure above, the estimated weight of the mid airframe section of the rocket, including the drogue parachute and shock cord, is 57.8 ounces, or 3.61 pounds. This does not take into account the weight of paint or fasteners needed to secure the lower end of the tube to the payload bay coupler. We still need to incorporate these objects into the weight figure. Once the section is built, we can obtain a more accurate weight measurement to incorporate into our simulation to better predict altitude and flight parameters.

4.1.5. Current Vehicle Design - Avionics Bay

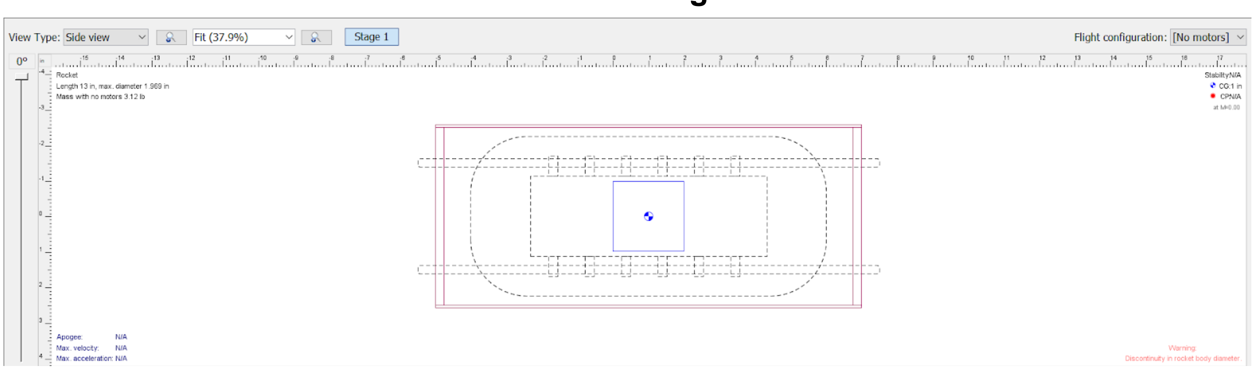
4.1.5.1. Design Alternatives With Pros And Cons

Our avionics bay was subject to the same two main variables the payload bay faced - the length and weight of the coupler tube. The pros and cons were all identical to payload bay design.

4.1.5.2. Leading Choice

We decided to design the avionics bay in an identical manner to the payload bay. The team decided to use a coupler with one caliber of tube interfacing with an airframe on either side. The team believes the switch band on the avionics bay will make arming the altimeters easy enough to be worth including. As a result, our avionics bay is 12.00” long: 5.00” on either end and has a 2.00” long switch band. Threaded rods will run through the bulkheads and be secured with nuts and washers, clamping the bulkheads over the ends of the tube and sealing the avionics inside from any hot gasses produced during ejection charges.

4.1.5.3. Dimensional Drawing



Our avionics bay will have an outer diameter of 5.15” at the switch band and 5.00” at the coupler. The inner diameter of the coupler will be 4.85” and the coupler will be 12.00” long. The 2.00” switch band will be located at the center of the coupler. 5.00” of both ends of the coupler will interface with airframe sections.

4.1.5.4. Estimated Mass

As can be seen from the figure above, the estimated weight of the payload bay of the rocket with the coupler, switch band, bulk plates, and avionics itself, is 3.91 lbs. Once the section is built, we can obtain a more accurate weight measurement to incorporate into our simulation to better predict altitude and flight parameters.

4.1.6. Current Vehicle Design - Upper Airframe

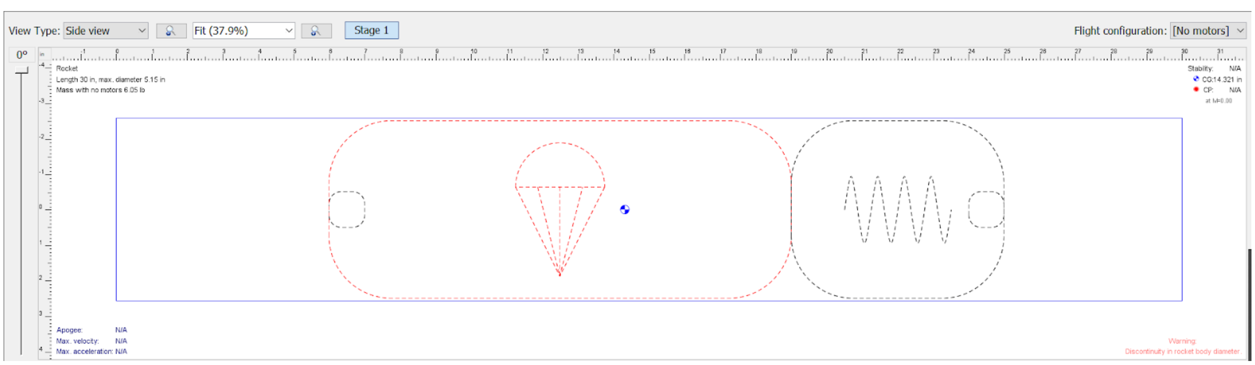
4.1.6.1. Design Alternatives With Pros And Cons

The upper airframe faced the same design alternatives as the mid airframe, and thus the same pros and cons. Factors such as weight, cost, volume, and stability were all taken into consideration when choosing the length of the airframe.

4.1.6.2. Leading Choice

The team elected to use a standard 30” length of tubing for the same reasons as previously stated for the mid airframe. This length of tube is a standard size and is thus cost efficient and prevents a negative shift of the center of gravity. It also provides us with a tight fit for the main recovery gear, resulting in less volume needing to be pressurized by the main ejection charge for deployment.

4.1.6.3. Dimensional Drawing



The upper airframe will have an outer diameter of 5.15”, and inner diameter of 5.00”, and will be 30” long. 5.00” of both ends of the tube will be used to interface with coupler tubes, leaving 20.00” of usable room for main recovery gear.

4.1.6.4. Estimated Mass

As can be seen from the figure above, the estimated weight of the upper airframe section of the rocket with the main parachute and shock cord is 6.05 pounds. This does not take into account the weight of paint, or fasteners needed to secure the lower end of the tube to the avionics bay coupler. We still need to incorporate these objects into the weight figure. Once the section is built, we can obtain a more accurate weight measurement to incorporate into our simulation to better predict altitude and flight parameters.

4.1.7. Current Vehicle Design - Nose Cone

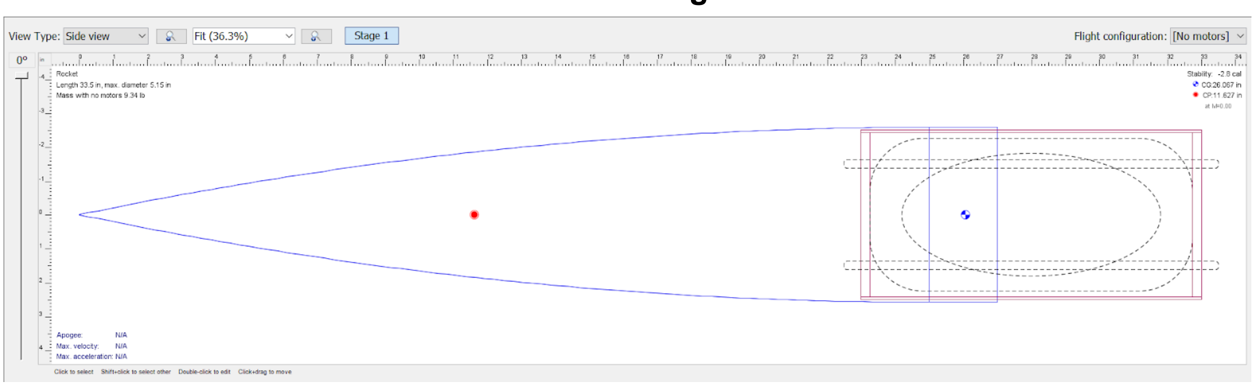
4.1.7.1. Design Alternatives With Pros And Cons

The primary concerns facing our team with regards to nose cone design were nose cone length and overall shape. Shorter nose cones would weigh less, but cost the same as a longer nose cone and induces more drag force. Longer nose cones, while heavier, would allow more room for electronics internally, not cause any notable price increase, and create less drag.

4.1.7.2. Leading Choice

Our team decided to use a nose cone with about a 5:1 length to diameter ratio with an ogive shape and metal tip. This nose cone reduces drag over those with a lower aspect ratio, and increases the amount of internal space that can be used. The metal tip will be secured using a standard bolt and washer, while the coupler will be riveted into place in the base. The coupler will be compressed between two bulkheads held in place by two sections of threaded rod.

4.1.7.3. Dimensional Drawing

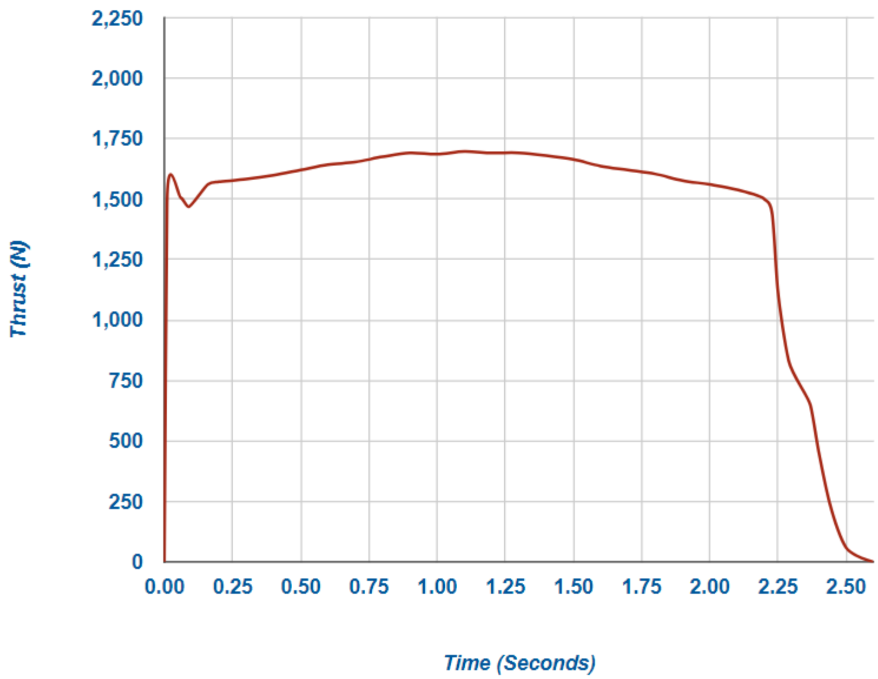


The nose cone section will be a total of 32.00” long and have a maximum outer diameter of 5.15” at the base of the cone and switch band, and a 5.15” outer diameter at the coupler tube. The nose cone alone is 25.00” long, and the bottom 2.00” will interface with the nose cone coupler. The switch band is 2.00” long and will be located 2.00” from the top of the coupler tube, leaving 5.00” of coupling exposed to interface with the upper airframe.

4.1.7.4. Estimated Mass

As can be seen from the figure above, the estimated weight of the nose cone section of the rocket with the cone, coupler, bulk plates, and switch band is about 2.84 pounds. This does not take into account the weight of paint, epoxy adhesive, or metal hardware. We still need to incorporate these objects into the weight figure. Once the section is built, we can obtain a more accurate weight measurement to incorporate into our simulation to better predict altitude and flight parameters.

4.1.8. Current Motor Choice



We are currently planning on using an Aerotech Rocketry L1520 Blue Thunder as our means for propulsion. It is a 2.95 inch diameter, 3 grain, 46% L reloadable composite motor that produces a total impulse of 3743.39 Newton-seconds over the course of a 2.6 second burn time. It has a peak thrust of 1,696.63 N (381.42 lb), an average thrust of 1,439.77 N (323.67 lb), and a liftoff thrust of 1580 N (355.2 lb). When fully loaded, the motor will weigh 8.04 lb, of which 4.08 lb is propellant - meaning after the motor fully burns, there will be 3.96 lb. of leftover hardware.

At liftoff, the rocket will be propelled to a vertical velocity of 79.4 ft/s before clearing the twelve foot long one and a half inch launch rail, thus meeting the minimum requirement of 52 feet per second. During the boost phase of the ascent, our vehicle will experience a maximum acceleration of 287 ft/s^2. After motor burnout, our rocket will continue to ascend for another 15.46 seconds before reaching apogee.

4.2. Recovery Subsystem

4.2.1. Shock Cord

4.2.1.1. Design Alternatives With Pros And Cons

There are several options for us to choose from when determining which shock cord material to utilize in the rocket. For rockets of this size, it is common practice to use either 1” tubular nylon or ½” tubular kevlar. The nylon is cost effective and more elastic in the event of a premature separation, but it is also bulkier and heavier due to the larger width when compared to the kevlar. Furthermore, it is not fire resistant and does not have as high of a tensile strength as kevlar does. Kevlar is comparatively expensive, but is also fireproof, lighter, and occupies less packing volume within the vehicle. It is also stronger than tubular nylon, but will not stretch to dissipate energy when pulled taunt.

4.2.1.2. Leading Choice

We have decided to use a 40’ long section of ½” tubular kevlar as the material for our shock cords in our rocket. As stated previously, they are lightweight, fire resistant, volumetrically efficient, and have a high tensile strength. The tethers we have chosen are rated for 7,200 lbs lifting force, which we believe will be more than adequate for the purpose of this project based on the weight of our rocket. Each end will have a loop sewn into the fabric through which we can pass a quick link for easy attachment to the rocket. In addition, each individual tether, drogue and main, will have a loop sewn ⅓ of the length from the top. This will provide us with an attachment point for the parachute we will be using for recovery.

4.2.1.3. Estimated Mass

The estimated mass of the tether, not including the mass of quick links that attach the shock cord to the rocket and parachute, is 0.5 lbs. Once we have obtained the physical component, we will have a more accurate weight measurement that can be updated in our simulation model.

4.2.2. Drogue Parachute

4.2.2.1. Design Alternatives With Pros And Cons

Several options for drogue recovery were presented with varying methods, sizes, and brands. The team immediately determined that it was not safe to fly without a drogue parachute due to the size and weight of the rocket. It was deemed possible to use a streamer, but streamers provide very little drag and the amount of fabric needed to safely slow and stabilize the rocket during descent would prove too much of a hassle to manage and be too heavy. Ultimately, the team decided to use a traditional parachute that is 24” in diameter. Our group speculates that this will be sufficiently large to slow the rocket to a safe velocity during descent, as well as minimize the risk of individual sections colliding with each other. Furthermore, the team believe that it will provide enough drag to point the camera in such a way that the field of view is still able to recognize the targets we need to identify while free falling.

Once a 24” drogue parachute had been deemed a viable option, the choice had to be made with what brand to use. Our group looked at the Skyangle Cert 3 drogue parachute and the Fruity Chutes Classic Elliptical parachute. The Skyangle parachute has a lower drag coefficient and will result in a faster descent speed and minimal drift distance, but is heavier and bulkier than the Fruity Chute alternative. It was, though, the more economical option. The Fruity Chute could potentially result in an increased drift distance due to the lower descent speed, but would be more stable and have a higher probability of stabilizing the camera to view the targets. It is also lighter and takes less internal volume.

4.2.2.2. Leading Choice

Our team ultimately decided to go with the Skyangle Cert 3 Drogue Parachute as a means of drogue recovery. We chose this because although it weighs more, occupies more volume, and has a lower drag coefficient, it is cheaper and more robust. After comparing simulation results using both options, the difference in drogue descent speed was minimal and therefore would not have made a substantial impact. The alternative our team opted for is constructed of zero porosity, 1.9 oz/yd^2, silicone coated balloon cloth. Four shroud lines, each made of ⅝” military spec tubular nylon with a tensile strength of 2,250 lbs. These shroud lines all attach at the bottom to a 1,500 pound rated heavy duty, nickel plated swivel. The parachute has a tested drag coefficient of 1.26 and a surface area of 6.3 ft^2. It will be attached to the tether via a ¼” stainless steel quick link that connects through the swivel and a loop in the shock cord.

4.2.2.3. Estimated Mass

The estimated mass of the drogue parachute, not including the mass of quick links that attach the parachute to the shock cord or fireproofing, is 0.375 lbs. Once we have obtained the physical component, we will have a more accurate weight measurement that can be updated in our simulation model.

4.2.3. Main Parachute

4.2.3.1. Design Alternatives With Pros And Cons

Our team decided to examine the Skyangle Cert 3 XL Parachute and the Fruity Chutes 84” Iris Ultra Compact Parachute. As in the case with the drogue parachute options, the Fruity Chute weighed substantially less and maintained a tighter packing volume than the Skyangle. It was also significantly more expensive than the Skyangle, and had a lower drag coefficient. Both parachutes offered a similar landing velocity and touchdown energy. The primary benefit of using the Skyangle is not the cost savings or landing speed, but because it weighs more and will be located above the center of gravity of the vehicle, it adds positive stability during flight. The Fruity Chute does not have this advantage and while we would still be within stability limits if we chose to use this option, we would have less of a safety factor due to the decreased distance between the center of gravity and center of pressure as a result of the weight difference.

4.2.3.2. Leading Choice

Our team ultimately decided to go with the Skyangle Cert 3 XL Parachute as a means of main recovery. We chose this because although it weighs more and occupies more volume, it has a higher drag coefficient and is also cheaper and more robust than the Fruity Chute alternative. It is still sized to provide a slow enough landing that no section of the rocket touches down with more than 75 foot pounds of energy, as listed in the requirements. Furthermore, it adds more weight above the center of gravity than the Fruity Chute, increasing our margin of stability. The option our team opted for is constructed of zero porosity, 1.9 ounce per square yard, silicone coated balloon cloth. Four shroud lines, each made of ⅝” military spec tubular nylon with a tensile strength of 2,250 pounds. These shroud lines all attach at the bottom to a 1,500 pound rated heavy duty, nickel plated swivel. The parachute has a tested drag coefficient of 2.59 and a surface area of 89.0 square feet. It will be attached to the tether via a ¼” stainless steel quick link that connects through the swivel and a loop in the shock cord.

4.2.3.3. Estimated Mass

The estimated mass of the main parachute, not including the mass of quick links that attach the parachute to the shock cord or fireproofing, is 3.81 pounds. Once we have obtained the physical component, we will have a more accurate weight measurement that can be updated in our simulation model.

4.2.4. Fireproofing

4.2.4.1. Design Alternatives With Pros And Cons

Fireproofing recovery components such as parachutes in high power rockets is typically done in one of two ways. One option is to use an phenolic insulating material commonly known as “dog barf” that can conform to whatever space it is pressed into. This material is extremely lightweight, inexpensive, and can be added into vacant spaces within the airframe around the recovery components due to its small particle size. The alternative to this is typical a typical nomex blanket that wraps around the recovery gear and acts as a barrier between the nylon and the hot gases produced from the ejection charge. Unlike the phenolic insulation, this option is reusable while still remaining lightweight and inexpensive, and can be attached directly to the parachutes.

4.2.4.2. Leading Choice

Our team decided to use the Nomex blankets as a means of fireproofing our parachutes from the ejection charge gases. They are relatively inexpensive and lightweight, but the main advantage is that it can be passed over the shock cord and attached directly to the parachute. As a result, we can tightly wrap the parachute inside of the material, as opposed to simply packing insulation around it and risk a gap in the fireproofing. Both the drogue and main parachute will be protected using this method, and both Nomex blankets will be 18x18” squares.

4.2.4.3. Estimated Mass

We estimate that the total mass of both the drogue and main Nomex blankets is approximately 0.25 pounds. Once we have obtained the physical component, we will have a more accurate weight measurement that can be updated in our simulation model.

4.2.5. Ejection Charges

4.2.5.1. Design Alternatives With Pros And Cons

For the ejection charges, we created a weighted decision matrix to determine whether we wanted to use FFFFg (4Fg) black powder or a CO_2 ejection device. We used several different criteria to compare the two options. Some of the more important criteria that we were looking at consist of volume, simplicity, reliability, and weight. Beyond this, cleanliness and style (coolness) had medium and little importance ratings, respectively.

Next, we then took the estimated values and calculated values and applied them to the WDM and achieved the finals results with black powder scoring a total of 245 points, whereas the CO2 received a score of 195. Comparing the two total point values, black powder was the clear choice for our type of ejection charge.

		METRIC HOW WILL MEASURE IF THE CRITERION WAS ADDRESSED?					
CRITERIA	Weight/Importance	Overall Estimated Volume	Time to Develop	Reviews	Residue Remaining	Total Weight	Team ranking
Volume	15	X					
Simplicity	15		X				
Reliability	15			X			
Cleanliness	10				X		
Weight	15					X	
Coolness	5						X
	Units	cm^3	hours	1-5	1-5	g	1-5

BENCHMARKING PROCESS (5=Best, 1=Worst)

Overall Estimated Volume	DATA	Score
	>30	1
	>20&<30	2
	15<x<20	3
	>10&<15	4
	<10	5

Residue Remaining	DATA	Score
A lot of Residue	1	1
	2	2
	3	3
	4	4
No Residue	5	5

Time to Develop	DATA	Score
	15	1
	12	2
	9	3
	6	4
	3	5

Total Weight	DATA	Score
	>30	1
	>20&<30	2
	15<x<20	3
	>10&<15	4
	<10	5

Reviews	DATA	Score
	1	1
	2	2
	3	3
	4	4
	5	5

Team ranking	DATA	Score
	1	1
	2	2
	3	3
	4	4
	5	5

BENCHMARKING (Unweighted)		BENCHMARKING (Weighted)	
Black Powder	CO2	Black Powder	CO2
2	1	30	15
4	2	60	30
4	4	60	60
3	5	30	50
3	1	45	15
4	5	20	25
	WEIGHTED TOTAL -->	245	195

4.2.5.2. Leading Choice

From the weighted decision matrix used in the previous section, we determined that we were going to use black powder as our method of ejection. We will use ejection canister caps in combination with masking tape to contain the black powder.

4.2.5.3. Estimated Mass

	Overall Estimated Volume	Time to Develop	Reviews	Residue Remaining	Total Weight	Team ranking
Black Powder	20.88	5 hours	4	3	3	4
CO2	83.9	12 hours	4	5	1	5

In order to figure out the overall estimated mass, we first figured out how many grams of black powder that we will need for the ejection to go smoothly. We used the equation C*D^2*L = grams of BP, where D is the diameter of the airframe, L is the length of the recovery section, and C is a constant conversion from PSI. From there we need 10 PSI which corresponds to a value of 0.00399, the diameter is 5.15 in, and the length is 30 in. Once we plug these values into our formula, we get ~3.22± 0.15 grams of 4Fg black powder per capsule (including backup capsules). Since there will be two capsules on either side, there will be a total of ~12.88 grams of 4Fg black powder used per flight. If we were to use CO2, we would need about 5 times as much CO2 than black powder, ~16 grams, and there would one on either side of the avionics bay, so a total of ~32 grams of CO2.

4.2.6. Altimeter/GPS System

4.2.6.1. Design Alternatives With Pros And Cons

	Price	GPS Price	Total Price	Mininmum Voltage	Maximum Voltage	Maximum height	Ratio of Max. height to Cost	Area	Barometer or accelerometer	Computer Type	Reviews	Weight	GPS / Telemetry
RRC2	45	150	45	3.5	10	40,000	444.44	1.0545	Barometer	Wind pnly	4	10g	0
RRC3+ Sport	90	150	90	3.5	10	40,000	242.497	1.813	Barometer	Wind only	5	17g	1
Eggtimer TRS	140	0	140	4.5	30	30,000	400	1.95	Barometer	Only Wind	4	25g	2
TeleMetrum	300	0	300	3.7	5	100,000	333.33	0.555	Barometric	Wind, Mac, Linux	4	18.4g	2

Weight/Importance: 15: Must have 10: Good to have 5: Nice to have		METRIC HOW WILL MEASURE IF THE CRITERION WAS ADDRESSED?									
CRITERIA	Weight/Importance	Price	Voltage	Maximum height	Ratio of Max. height to Cost	Area	Computer Type	Reviews	Weight	GPS / Telemetry
Cost	15	X								
Battery / Voltage	10		X							
Altitude	15			X						
Efficiency	15				X					
Size	10					X				
Operating System	5						X			
Reliability	15							X		
Extras	15								X	X
	Units	Dollars	Volt	ft	ratio	in^3	Type	Stars	g	yes/no

Our top four choices for altimeters for our launch vehicle were the Missile Works RRC2, Missile Works RRC3+ Sport, Eggtimer TRS, and the Altus Metrum TeleMetrum. To decide which two altimeters we will use for the launch vehicle, we created a weighted decision matrix. In this matrix, we listed the following categories: price, GPS price, total price, minimum and maximum voltage, maximum height, ratio of maximum height to cost, area, barometer or accelerometer, computer type, reviews, weight, and whether or not it has GPS/Telemetry. Once we had these categories, we then conducted research on each altimeter to find the data relevant to each category. Next, we made rankings for each category to see which altimeter was better in each category. Weights were then created for each category: a 15 was a must have, 10 was good to have and 5 was nice to have. The categories of price, altitude, efficiency, reliability and extras were weighted with a 15. Battery/voltage and size were weighted with a 10. Operating system was weighted with a 5. After we ranked each altimeter, we multiplied them by the weight and totaled the score for each one. In the end, the order from most points to least was:

TeleMetrum, RRC3+ Sport, TRS, RRC2, with their following point values respectively: 362.5, 360, 345, 342.5.

BENCHMARKING PROCESS (5=Best, 1=Worst)

Price	DATA	Score
	201-250	1
	151-200	2
	101-150	3
	51-100	4
	0-50	5

Reviews	DATA	Score
1 star'	1	1
	2	2
3 stars'	3	3
	4	4
5 stars'	5	5

Voltage	DATA	Score
Doesnt comply with 9V		1
		2
		3
		4
Uses 9V	9V	5

Weight	DATA	Score
Lighter the better	20-25	1
	15-20	2
	10-15.0	3
	5-10.0	4
	0-5	5

Maximum height	DATA	Score
Dosn't meet req.	<5,000ft	1
		2
Around Req.	<7,000ft	3
		4
over req.	>10,000ft	5

GPS / Telemetry	DATA	Score
doesnt have GPS o	0	1
		2
has either GPS or t	1	3
		4
has both GPS and	2	5

Ratio of Max. height to Cost	DATA	Score
Higher the Better	<300	1
		2
	<450	3
		4
	>450	5

Area	DATA	Score
smaller better	<2	1
		2
	<1.5	3
		4
	<1	5

Computer Type	DATA	Score
0 systems		1
		2
1 - 2 systems		3
		4
3 systems		5

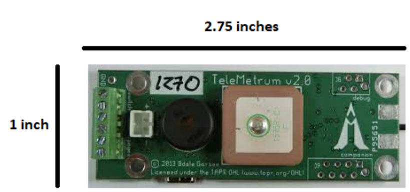
BENCHMARKING (Unweighted)				BENCHMARKING (Weighted)			
RRC3+ Sport System	RRC2 System	Eggtimer TRS	TeleMetrum	RRC3+ Sport System	RRC2 System	Eggtimer TRS	TeleMetrum
5	2	3	1	75	30	45	15
5	5	5	1	50	50	50	10
5	5	5	5	75	75	75	75
1	3	3	5	15	45	45	75
1	3	1	5	10	30	10	50
3	3	3	5	15	15	15	25
5	4	4	4	75	60	60	60
3	2.5	3	3.5	45	37.5	45	52.5
		WEIGHTED TOTAL -->		360	342.5	345	362.5

4.2.6.2. Leading Choice

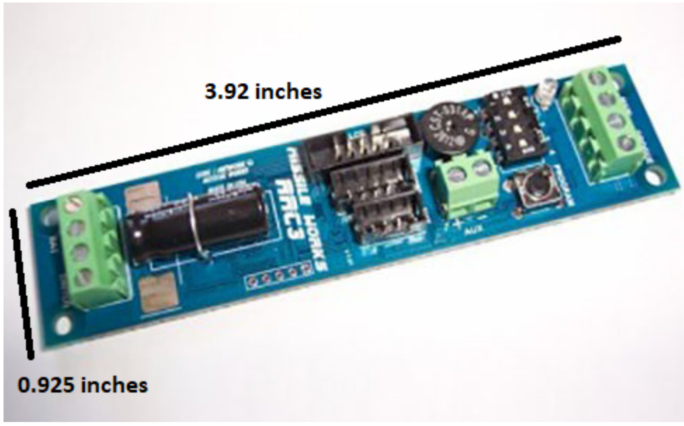
The avionics team decided on using the Telemetrum as our primary altimeter and GPS and the RRC3+ Sport as our secondary, redundant altimeter. We decided to choose the RRC3+ Sport as the secondary altimeter due to the fact that we only need one GPS system for the launch vehicle. To ensure the most redundant system, the two different altimeters operate using separate batteries, the Telemetrum uses a 3.7V LiPo battery while the RRC3+ Sport uses a 9V battery. To facilitate the separation of the launch vehicle in order to deploy the drogue and main parachutes, we decided on using black powder charges, as stated in section 4.2.5.1.

4.2.6.3. Dimensional Drawing

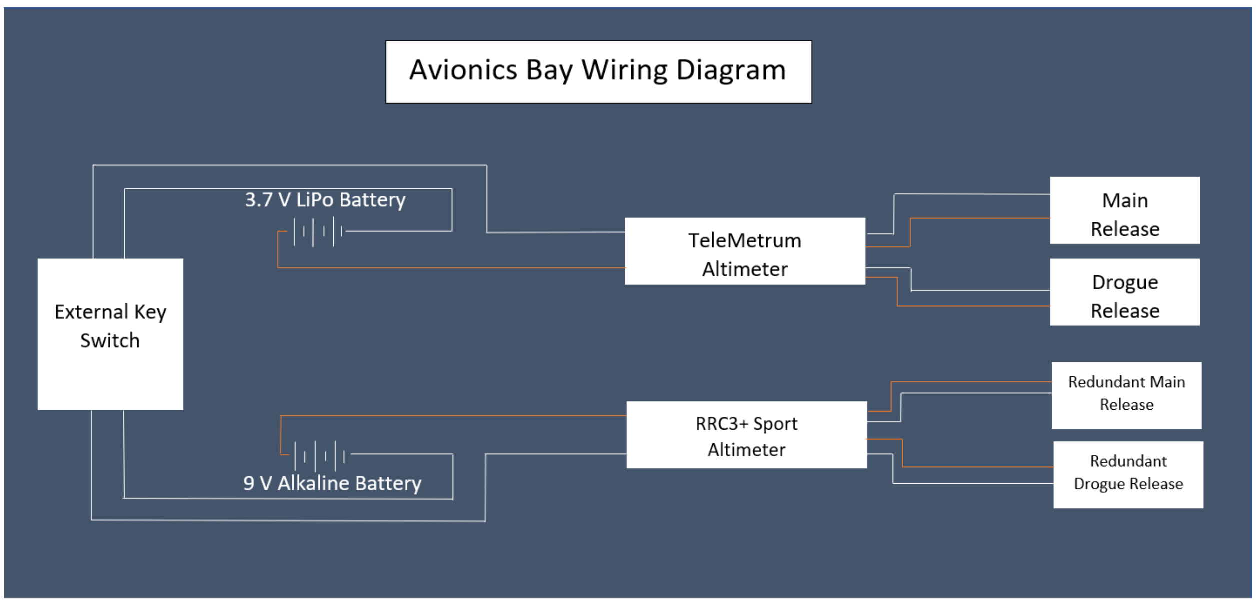
Telemetrum:



RRC3+ Sport:



4.2.6.4. Wiring Diagram



4.2.6.5. Estimated Mass

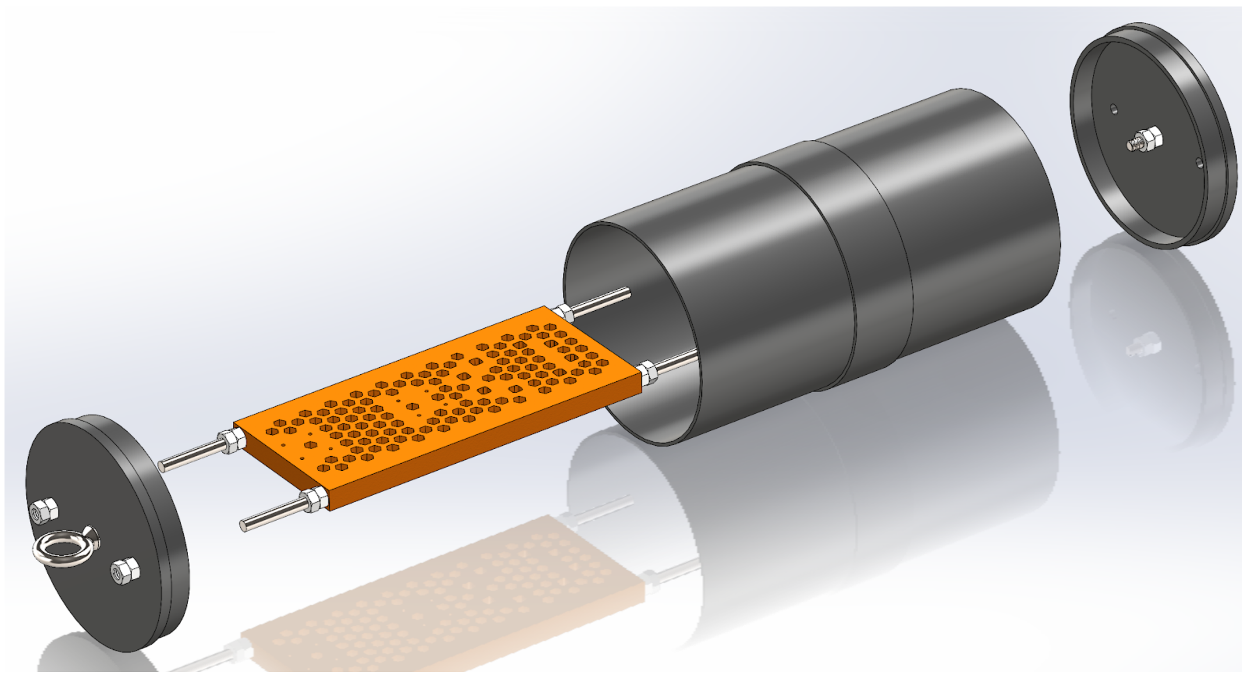
The avionics bay contains the Telemetrum (18.4g), RRC3+ Sport (17g), a 9V Battery (45g), a 3.7V LiPo Battery (75g), and a key switch (~90g). This does not include the added weight of the metal hardware, epoxy adhesive, or body of the avionics bay itself. This gives us an estimated weight of 245.4g or roughly ~0.54 pounds. Outside of the launch vehicle we have the TeleDongle (227g) which would be on the ground used as a receiver to communicate with the launch vehicle during flight. We still need to incorporate these objects into the simulated weight figure. Once the entire section is built, we will be able to obtain a more accurate weight measurement to incorporate into our simulation to better predict altitude and flight parameters.

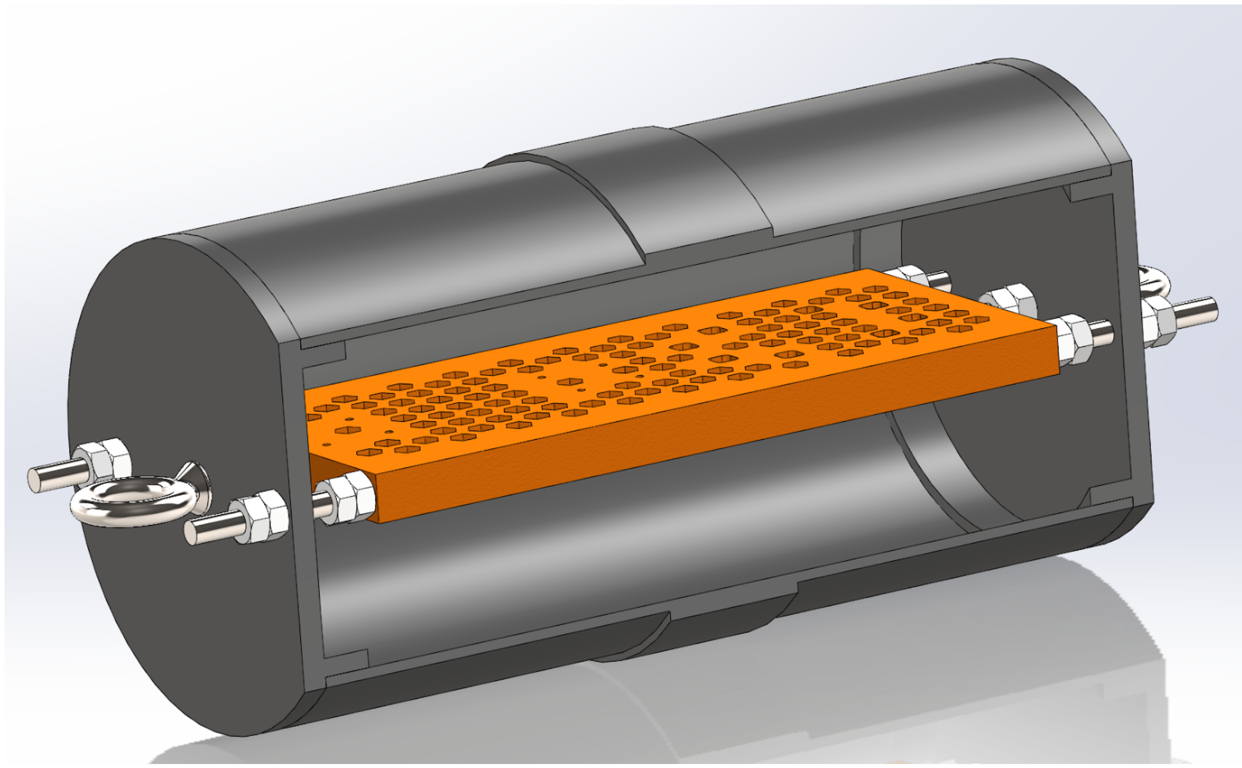
4.3. Avionics Sled

4.3.1. Design Alternatives With Pros And Cons

In order to get to our final design choice, we had two main design approaches. One approach was having rods parallel to the mounting plane, and the other approach was having rods perpendicular to the mounting plane. Approach one allows easy wiring with everything mounted on one piece, but leaves unused space above and below the sled. Approach two uses less space, but complicates wiring.

4.3.2. Leading Choice





We have chosen approach one because it gives us enough space to mount both sets of altimeters and batteries, with each set mounted on one side of the sled. Our leading avionics sled design is essentially a 3D printed rectangular prism. It is supported by rods running down either side, parallel to the mounting plane (8'' long). On the mounting plane of the sled, we have placed patterned hexagonal cutouts between the two rods (rods are 3" center-to-center) to aid in weight reduction, with screw holes where needed for the altimeters. Additionally, two pairs of rectangular holes will allow the two batteries to be secured with zip ties along both axes.

4.3.3. Estimated Mass

We estimate the mass of the 3D printed sled to be 0.37 lbs. Once we have obtained the physical component, we will have a more accurate weight measurement that can be updated in our simulation model.

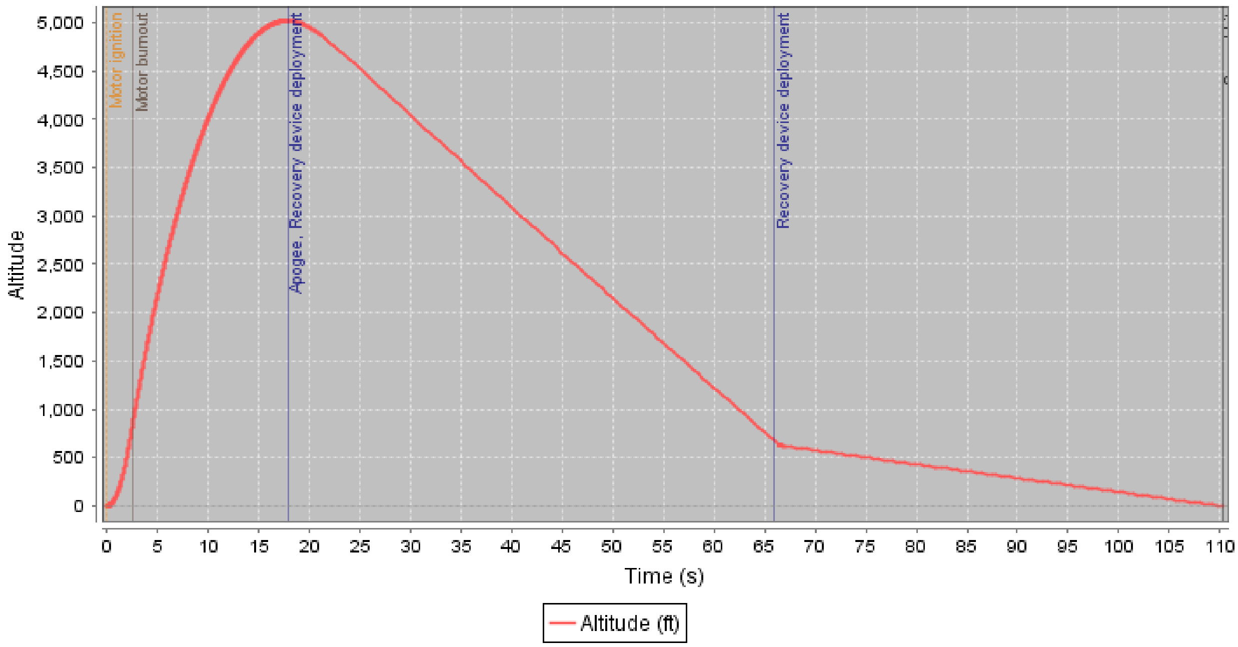
4.4. Mission Performance Predictions

4.4.1. Altitude Predictions

4.4.1.1. Declaration of Altitude

The team's official launch day target altitude will be 4,950 feet.

4.4.1.2. Graph Of Altitude Vs. Time



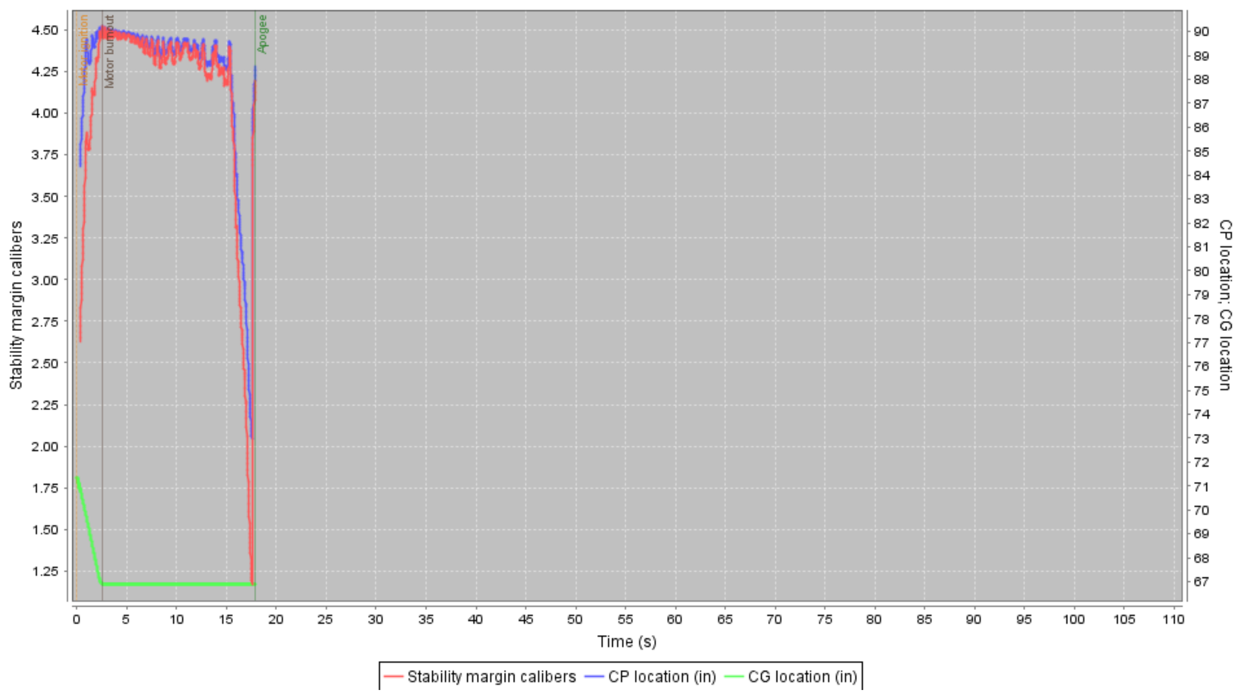
As can be seen from the graph above, our rocket is simulated to reach a maximum altitude of 5,023 feet above ground level. This is 73 feet above our target altitude of 4,950 feet above ground level. The team is currently deliberately incorporating this excess altitude due to the fact that we do not currently have a physical model to base our computer simulations on. Once our group has constructed our flight vehicle, we will have a more accurate weight measurement for the rocket that can then be entered into the simulation program. Because the rocket is anticipated to weigh more than the simulation shows, as weight is added into the computer model our altitude will decrease.

Other factors, such as surface finish and the cross sectional airfoil of the fins, are variables that we do not have implicit control over. Our team cannot accurately measure surface smoothness to compare the real and digital models, which will account for some difference in our actual and expected altitudes. In addition, the only choices presented to us by OpenRocket when varying the cross section of the fins are “square, rounded, or airfoiled”. There is no direct input for edge thickness or taper length, further limiting our simulations.

All altitude simulations from which the graph above is derived were accomplished using OpenRocket 15.03 using the extended Barrowman calculation method and a six-degree-of-freedom Runge-Kutta 4 simulation method. Geodetic calculations were evaluated using spherical approximation, and a 0.02 second time step for simulation calculations was used. Further altitude calculations will be done in RASAero II using similar parameters, and will be discussed later.

4.4.2. Stability Margins

Graph Of CP, CG, And Stability Vs. Time



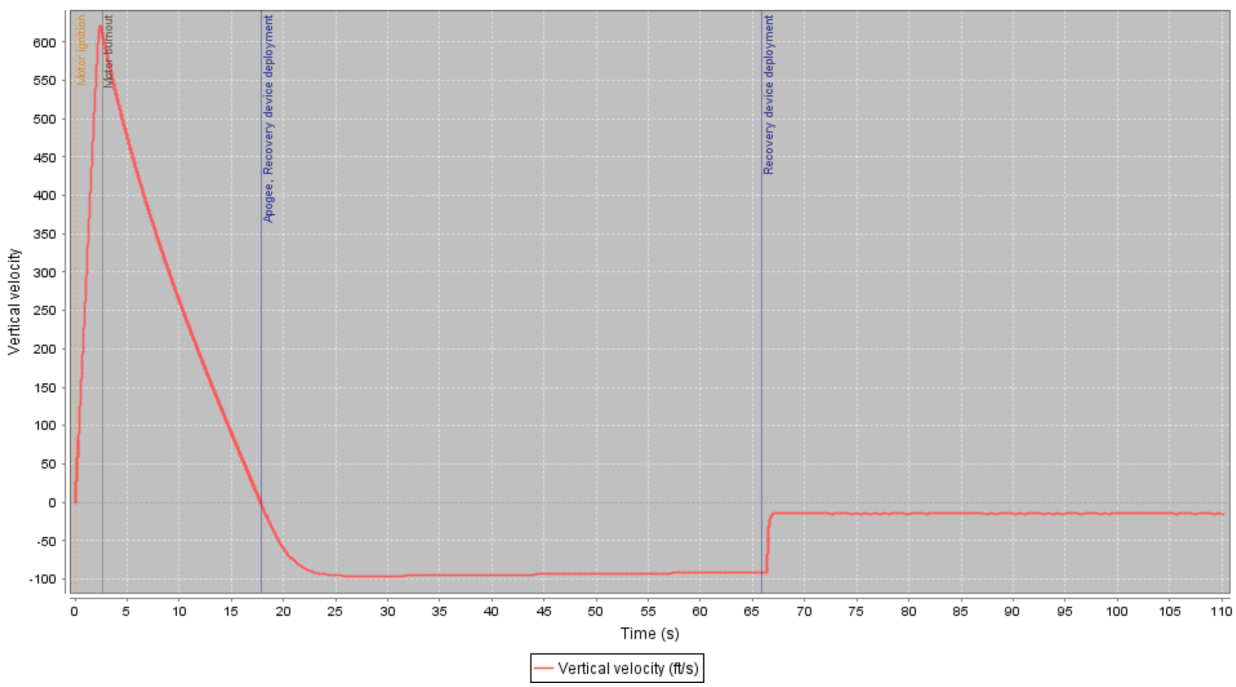
As seen from the graph above, the rocket exits the twelve foot long, one and a half inch launch rail with a minimum stability margin of 2.71 calibers, meeting the minimum requirement of two calibers. During the ascent phase, the rocket does not experience a significant drop in stability until it reaches a low enough velocity that the fins cannot maintain aerodynamic stability. At this point, the rocket begins slowing down significantly due to drag and gravity and starts arcing over as it approaches apogee. Despite this, the rocket maintains over 4.25 calibers for nearly all of the boost and coast phase.

The center of pressure, the node where the total sum of all pressures acts on the vehicle, starts at a distance of 89.782 inches from the datum, which is deemed to be the tip of the nose cone. During the entire flight profile, the location of center of pressure closely follows the stability margin calibers when graphed and remains approximately five inches aft of its original location until the rocket has slowed enough to begin arcing. This movement is in itself only one caliber, as the maximum shift is approximately equal to the diameter of the rocket airframe.

The center of gravity, a node where all moments about an axis of rotation equally oppose each other, begins at a distance of 71.345 inches from the datum of the rocket, placing it 18.437 inches ahead of the center of pressure. During the burn time of the motor, the center of gravity moves forward at a constant rate due to the constant burn rate of the solid propellant. The total shift is approximately 4.5 inches, or almost one full caliber.

4.4.3. Landing Energy Calculations

4.4.3.1. Graph Of Velocity Vs. Time



The figure above illustrates the vertical velocity of the rocket over time. The rocket accelerates quickly during boost and begins to decelerate before reaching apogee, where it then deploys a drogue parachute and descends rapidly at an estimated 96.25 ft/s. At an altitude of 700 feet above ground level, the main parachute will deploy to slow the vehicle considerably before touching down at a speed of approximately 13.7 ft/s. The total landing energy, assuming a burnout mass of 35.42 lb and impact speed of 13.7 ft/s, will be 103.31 ft-lb.

4.4.3.2. Motor/Lower Airframe/Mid Airframe Landing Energy

The bottom section of the rocket that will be falling independently while remaining tethered to the remainder of the vehicle is expected to weigh 16.71 pounds at touchdown, as it weighs 20.79 lb before the 4.08 lb of propellant are burned. This will consist of the lower airframe and motor assembly, the middle airframe, and the drogue recovery gear. Assuming the landing velocity is still 13.7 ft/s, the landing energy for this section will be 48.74 foot pounds.

4.4.3.3. Avionics/Upper Airframe Landing Energy

The middle section of the rocket that will be falling independently while remaining tethered to the remainder of the vehicle is expected to weigh 7.52 pounds at touchdown. This will consist of the avionics bay, upper airframe, and main recovery gear. Assuming the landing velocity is still 13.7 ft/s, the landing energy for this section will be 21.93 foot pounds.

4.4.3.4. Payload/Nose Cone Landing Energy

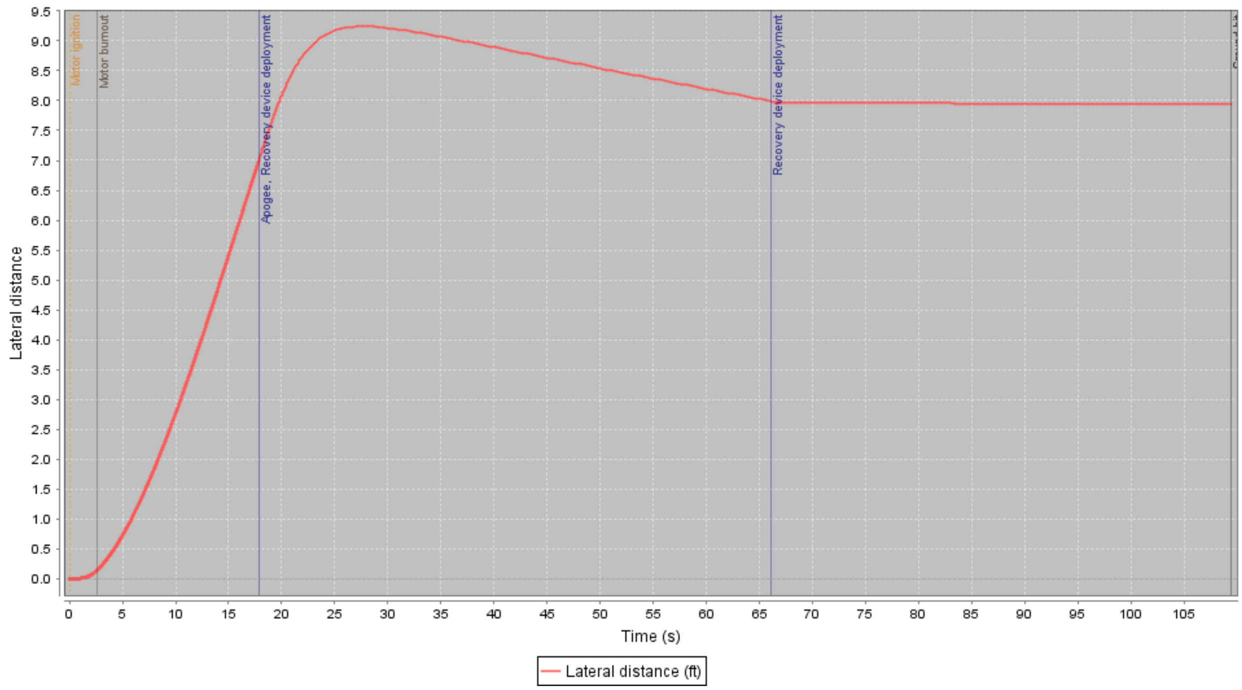
The nose section of the rocket that will be falling with the payload while remaining tethered to the remainder of the vehicle is expected to weigh 10.84 pounds at touchdown. This will consist of the nose cone and the nose coupler with the payload bay inside. Assuming the landing velocity is still 13.7 ft/s, the landing energy for this section will be 31.62 foot pounds.

4.4.4. Expected Descent Times

As each section of the rocket remains attached to the others during descent, the entire rocket has the same expected descent time of 92.19 seconds, calculated from the altitude plot in section 4.4.1.2.

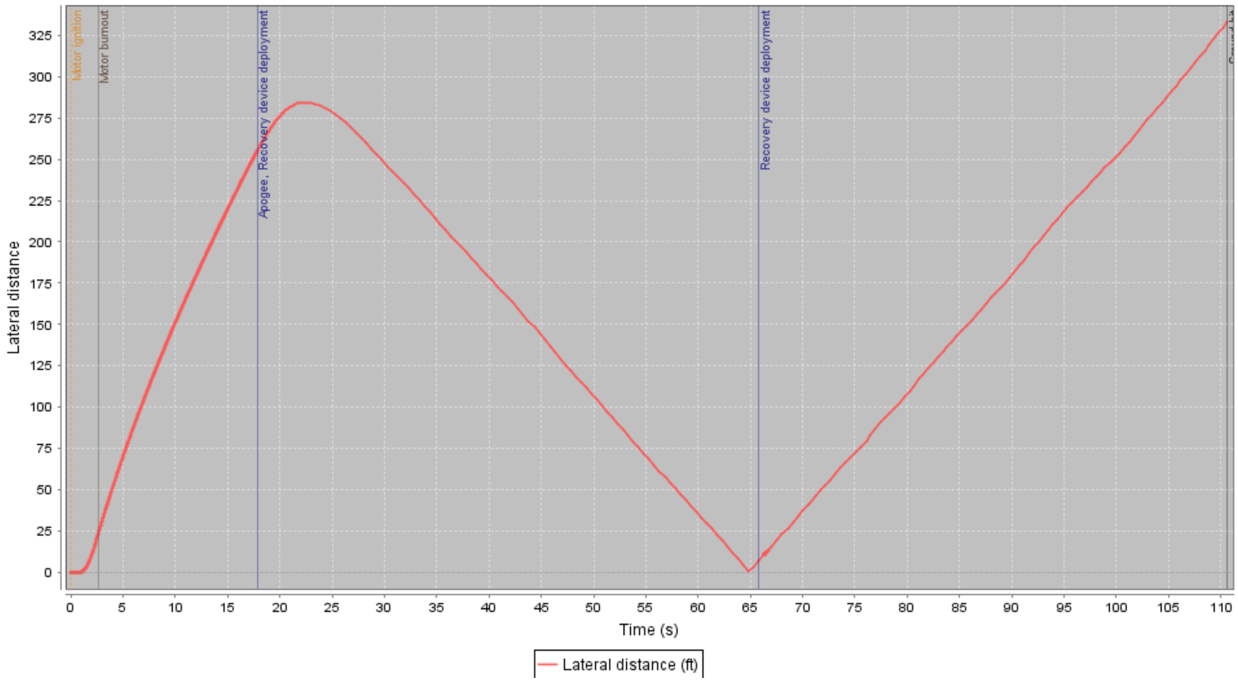
4.4.5. Drift Distance Calculations

4.4.5.1. 0 MPH Wind



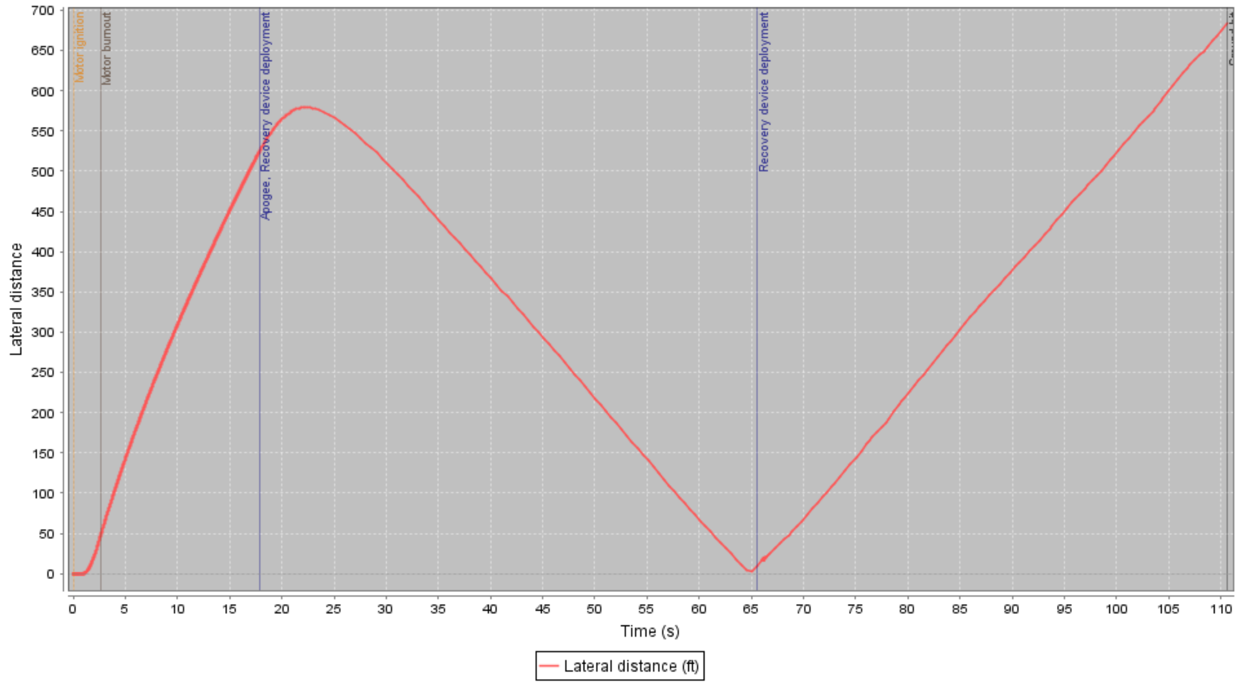
With an average wind speed of zero miles per hour with zero standard deviation and zero percent turbulence intensity, our simulated maximum drift distance during flight is roughly 9.24 feet, with touchdown occurring only 7.93 feet away from the point of origin. As we approach our target altitude of 4950 feet, which is lower than our current projected altitude, we expect these figures to drop.

4.4.5.2. 5 MPH Wind



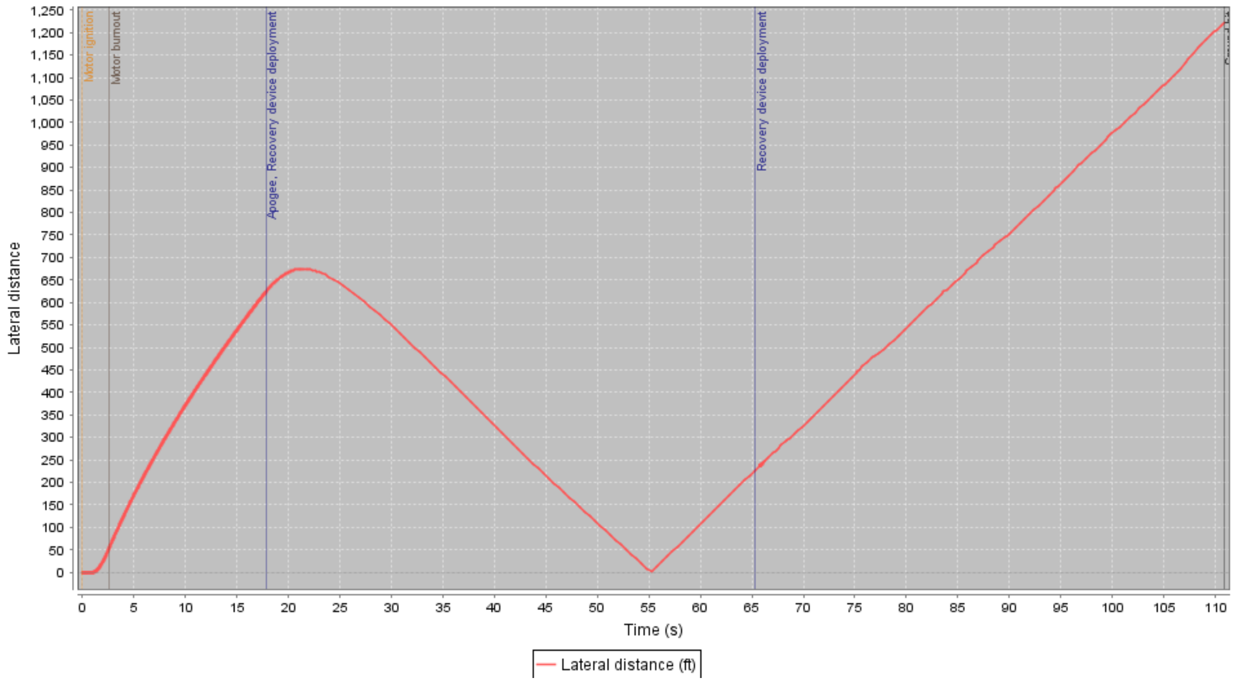
With an average wind speed of 5 miles per hour with a standard deviation of 0.5 miles per hour and ten percent turbulence intensity, our simulated maximum drift distance during flight is roughly 333.31 feet, which occurs at touchdown. As we approach our target altitude of 4950 feet, which is lower than our current projected altitude, we expect these figures to drop.

4.4.5.3. 10 MPH Wind



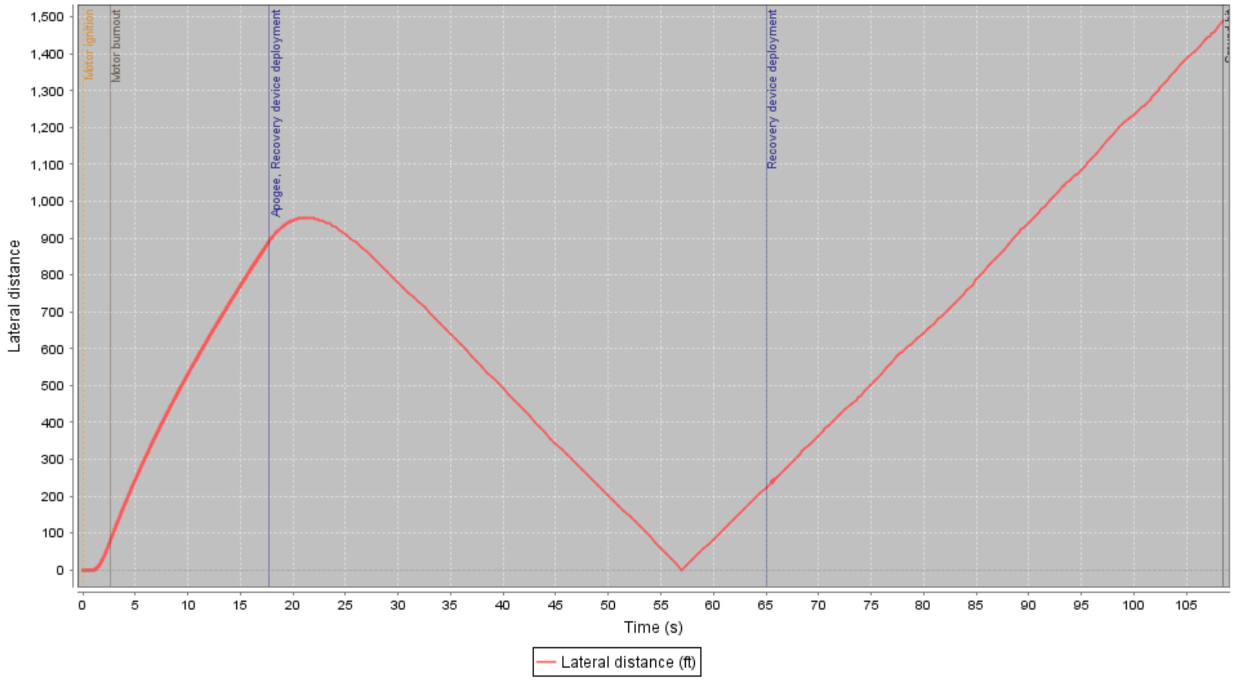
With an average wind speed of 10 miles per hour with a standard deviation of 1 mile per hour and ten percent turbulence intensity, our simulated maximum drift distance during flight is roughly seven hundred and forty feet, which occurs at touchdown. As we approach our target altitude of 4950 feet, which is lower than our current projected altitude, we expect these figures to drop.

4.4.5.4. 15 MPH Wind



With an average wind speed of 15 miles per hour with a standard deviation of 1.5 miles per hour and ten percent turbulence intensity, our simulated maximum drift distance during flight is roughly 1221.36 ft, which occurs at touchdown. As we approach our target altitude of 4950 feet, which is lower than our current projected altitude, we expect these figures to drop.

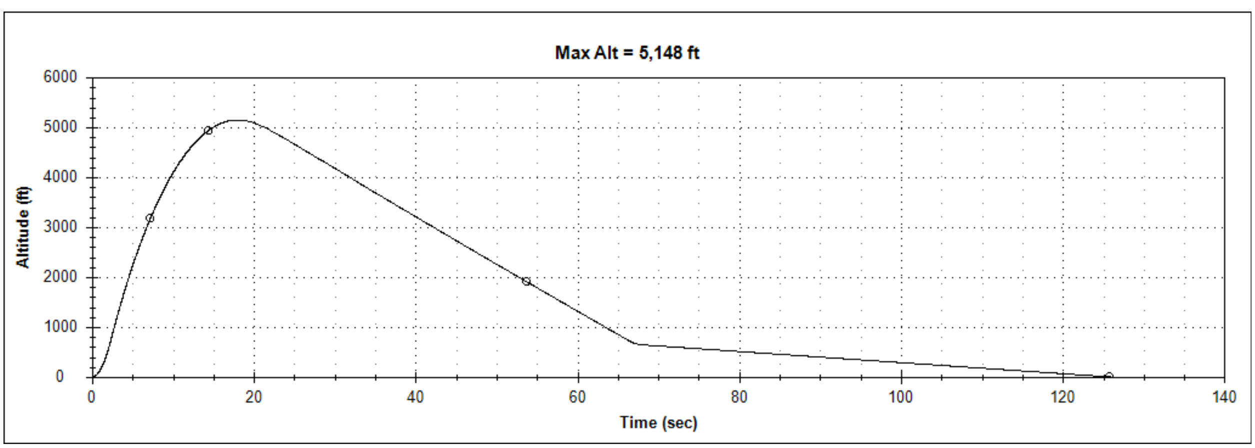
4.4.5.5. 20 MPH Wind



With an average wind speed of 20 miles per hour with a standard deviation of 2.0 miles per hour and ten percent turbulence intensity, our simulated maximum drift distance during flight is roughly 1489.27, which occurs at touchdown. As we approach our target altitude of 4950 feet, which is lower than our current projected altitude, we expect these figures to drop.

4.4.6. RASAero Calculations

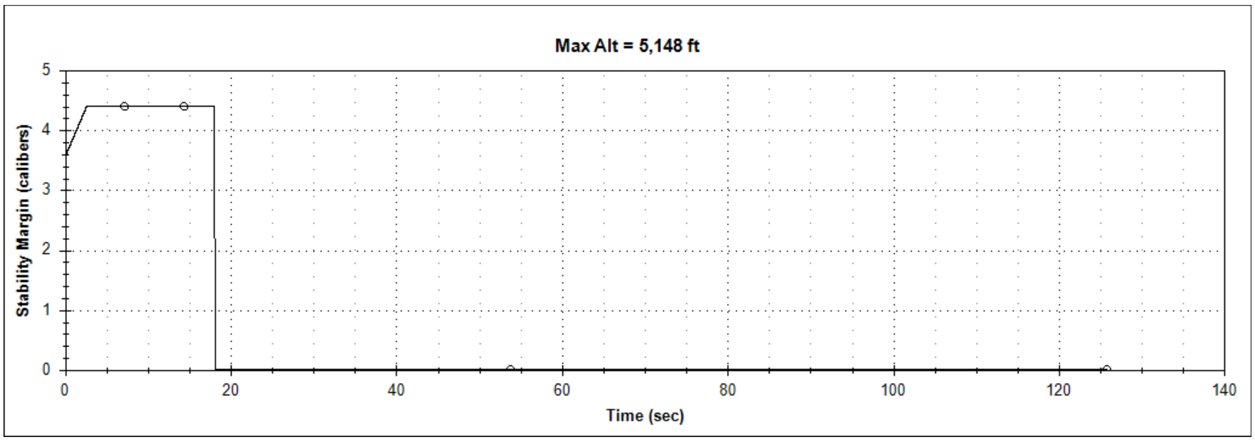
4.4.6.1. Altitude Predictions



The graph above, which was produced using RAS Aero II, is a result of running an identical simulation as the team performed with OpenRocket 15.03. All simulation settings were the same, and the vehicle dimensions and metrics were input manually.

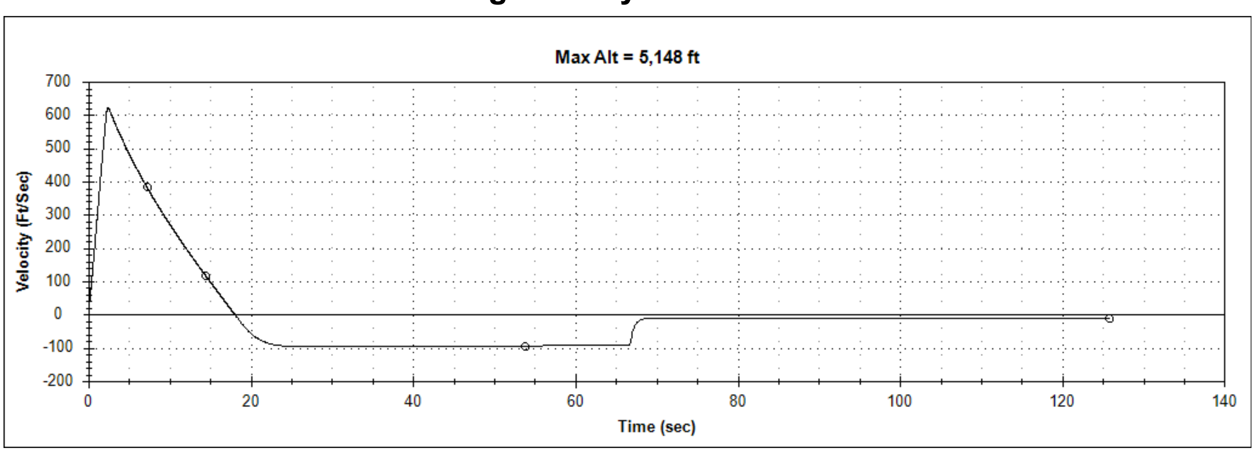
As a result, the same rocket flying on the same motor is predicted to achieve a maximum altitude of 5,148 feet above ground level. This is an increase of 125’ over the OpenRocket simulations. We believe that the difference is due to the requirement of creating manual inputs for the fin cross sectional geometry, whereas OpenRocket calculates the geometry and resulting drag automatically.

4.4.6.2. Stability Margins



The stability margin graph shown above, produced using RASAero II, shows similar results to the stability curve produced in OpenRocket. The static stability is approximately 3.6 calibers, but is higher than the stability at the time of launch rail clearance which is estimated by OpenRocket to be nearly 2.5 calibers. OpenRocket does, however, calculate the static stability to be 3.38 calibers, so these estimates do in fact reinforce each other. Furthermore, RASAero predicts the stability during the coast phase to be approximately 4.4 calibers after expelling all of the propellant mass. This, again, is roughly equal to the stability predicted by OpenRocket.

4.4.6.3. Landing Velocity



The graph above was created using RASAero II and depicts the vertical velocity of our vehicle during the flight. Just as in OpenRocket, the terminal velocity during drogue descent is roughly ninety feet per second and terminal velocity during main descent is approximately twelve feet per second. These figures are nearly identical between the two independent simulation platforms.

4.4.6.4. Differences Between Calculations

Generally speaking, the two simulation platforms produce nearly identical numbers for altitude, stability, and descent velocity. The altitude predicted from RASAero, which had the highest variance, was still within a five percent margin of error of the OpenRocket estimate. As we mature our computer simulations to match our real world weights and metrics, we predict that the differences between the simulations will decrease. If this is not the case, we will begin simulating the vehicle in a third platform, such as RockSim.

5. Safety

5.1. Safety Officer Information

The Safety Officer for the Purdue SL Team participating in the 2019 competition will be Jory Lyons. As Safety Officer, this team member is responsible for the safety and well-being of all personnel throughout the course of the competition. This involves ensuring that everybody is constantly aware of the safety plans, emergency procedures, necessary precautions, and personal protective equipment (PPE) required to perform project activities. Once procedures and plans are set by the team, any amendments to them must be authorized by the Safety Officer. The Safety Officer will be required to be present at all meetings when fabrication, testing, or assembly is planned to occur. It will also be required of the Safety Officer to have a working knowledge of all facility, equipment, and organizational rules set outside the realm of the team and personnel. This includes adherence to the NAR and TRA high power rocketry safety codes, NFPA 1127, and Federal Aviation Regulations 14 CFR. The Safety Officer will be responsible for the following:

- Creating and maintaining risk analysis matrices to be used throughout the competition
- Creating preflight, flight, and postflight checklists to be carried out
- Creating and enforcing the team's safety plans and procedures
- Ensuring that all team members are properly trained and supervised to be carrying out their current task
- Ensuring that all team members are wearing appropriate PPE for the task they are conducting
- Ensuring that all team members are following proper operating procedures for using facilities and equipment
- Enforcing all laws and regulations set for the team by authorities and governing bodies
- Attending all build sessions and launches
- Attending all educational opportunities or events where legal minors are expected to be present

5.2. NAR/TRA Personnel Procedures

Victor Barlow, the NAR mentor currently working with the team, will be responsible for the handling and loading of the motors used during launches. He will also be responsible for the purchase, safe storage, and transportation of these motors when necessary. Professor Barlow will be on location whenever the launch vehicle is being launched to serve as Range Safety Officer, will work with the Safety Officer to ensure that all team members follow the NAR High Power Rocket Safety Code during all launches, and will prepare motors and ejection charges during full-scale flights as needed, even though other team members have certification for such tasks.

5.3. Briefings on Hazard Recognition/Avoidance and Launch Procedures

Prior to the first construction meeting, the team will hold a short briefing on basic launch vehicle construction safety, in which all team members will be instructed on fundamental safety procedures (e.g. wearing protective eyewear during construction), as well as how to use lab equipment and recognize any potential hazards associated with it. In addition, the team will compose a checklist prior to all launches detailing the exact procedures that must be performed in order to ensure success and maximize launch safety, and all inexperienced flyers will receive an additional briefing about basic launch safety (e.g., not standing immediately next to the launch pad as the launch control officer prepares to ignite the propellant situated on top of it).

Briefings will be carried out before major events and launches. A dedicated seminar during a team meeting will initially be provided to students on hazard recognition and accident avoidance to promote safety and keep students aware of the potential threats that exist. Historical and fictional examples will be generated to exemplify potential hazards and avoidance. Students will be required to sign a form acknowledging the potential threats as described at the seminar. Students must sign the form to ensure that safety is met and understood. The briefings and seminar will be made available through the group so that all members have permanent access. Dedicated pre-launch briefings will be presented and required to be acknowledged to attend a launch. Additional briefings and seminars will similarly be posted and required to ensure problems or concerns are addressed.

Briefings will cover the following topics and more:

- Lawful launch procedures which comply with FAA regulations, federal laws, and Purdue University policies
- What to do if the launch vehicle poses a threat at the time of launch
- What to do if the launch vehicle poses a threat during the flight
- What to do if the launch vehicle causes injury to a student or personnel
- What to do if the launch vehicle veers off the calculated course
- What to do in the case of unpredicted weather on the day of the launch

5.4. Caution Statements and Personal Protective Equipment Advisories

The safety officer will deliver a briefing on how to properly use the Personal Protective Equipment (PPE) this project necessitates. These necessary caution statements will be included before documented plans and procedures as to maintain a reminder of potential threats or concerns. All lab equipment will be labeled with the basic safety protocols associated with its use, including any PPE required to operate it, and all hazardous materials will be stored in labeled containers.

The current established procedures for PPE, which will be updated throughout the course of the project, are as follows:

- All team members must secure loose hair and clothing and remove jewelry before participating in construction and fabrication processes or launches and before handling hazardous materials. Apparel should be metal-free and non-static producing.
- ANSI Z87.1-certified protective eyewear must be worn at all times during construction and fabrication processes, when handling hazardous materials, and during launches. Any safety glasses used must include a side shield.
- Thermal protection such as leather or canvas gloves must be used when working with hot objects. Such objects include, but are not limited to, recently-fired launch vehicle motors or objects which are being heated for construction or fabrication purposes. Team members must at the least wear cotton clothing for thermal protection.
- Proper NIOSH/MSHA-approved respiratory equipment must be worn in situations where airborne particle debris will be present as the result of a construction or fabrication process with limited ventilation.
- Measures must be taken to cover exposed skin when working with materials that are hazardous on contact such as epoxy. Nitrile rubber gloves and a lab coat or apron must be worn when working with these types of materials. Shoes that cover the entire foot must also be worn. In the case of a large spill or prolonged contact, boots must be worn. If clothing is soiled or contaminated, it should be removed ASAP.
- Ear protection must be worn when using equipment which creates a noise 85 decibels or louder. Earplugs or earmuffs should always be worn when operating power tools which create loud noises.
- Closed-toe shoes should be worn during all construction and fabrication processes.
- If using a machine with an instructor or teaching assistant, follow all instructions given both by this aide and the machine manual as to what PPE to use.

5.5. Facilities and Equipment

5.5.1. Zucrow Propulsion Labs

Zucrow Propulsion Labs is a facility with various research capabilities that encompass many disciplines within aeronautical and astronautical engineering. The team will be utilizing this facility, and more specifically the High Pressure Labs within Zucrow, to store hazmat materials such as the motors or other energetic devices (black powder, CO2 canisters, ignition supplies, etc.). The team will also be using the area to conduct deployment charge ground tests to ensure proper separation of the vehicle components at apogee and main parachute deployments. The team's contact for the site is Professor Scott Meyer, who is the Zucrow Managing Director, and is the only required personnel for the building. As a safety precaution to limit liability to team personnel, he will be the sole person with access into the secure areas where supplies will be stored in a safe and controlled environment. He will be available between 7 A.M. and 5 P.M.

Hours of Operation	7 A.M. - 5 P.M. or by appointment
Required Personnel	Scott Meyer for access, Jory Lyons as safety officer
Necessary Equipment	Equipment specified by Scott Meyer and on-site instructions.
Safety Precaution	Limited access through Scott Meyer, climate controlled environment, and secured areas
General Use	Storage of potentially dangerous materials, such as high energy devices (motor, compressed gas, igniters, black powder, etc.)

5.5.2. Aerospace Science Labs (ASL)

The Aerospace Science Labs (henceforth referred to as ASL) is an annex attached to the Purdue University Airport that specializes in manufacturing and wind tunnel testing. It is also where Purdue SEDS has their storage area. Although the building is only publicly open between the hours of 7 A.M. and 5 P.M., the team will have full access around the clock thanks to Chris Nilsen who is president of the Purdue SEDS Executive Board and has a keypad code to the doors. The team will use this area for general assembly as it is where the majority of the team's parts, building supplies, and tools will be stored. The team will be utilizing basic manufacturing equipment such as drill presses, table saws, rotary tools, and vertical bandsaws. The team will also have access to construction equipment including adhesives, abrasives, craft knives, and common hand tools (pliers, screwdrivers, wrenches, taps, etc.).

Hours of Operation	Around the clock access with use of key
Required Personnel	Chris Nilsen for access, Jory Lyons as safety officer
Necessary Equipment	Drill presses, table saws, vertical bandsaws, adhesives, abrasives, and common hand tools
Safety Precaution	Team members must be briefed on proper safety precautions for using the ASL's equipment by the safety officer before being allowed to use the building's resources. PPE in the form of earplugs and safety glasses is available on-site.
General Use	Vehicle assembly, light manufacturing

5.5.3. Bechtel Innovation Design Center (BIDC)

The Bechtel Innovation Design Center (BIDC) is an advanced prototyping facility and machine shop which is located on campus and is available to all Purdue students. All students who enter the shop must take a series of online quizzes for each type of tool or machine they wish to use, and will be paired with a teaching assistant or Purdue employed machinist for the duration of their project. These rules, safety concerns, and safety protocols will be applied to all machining and safety for every location used by the team (Zucrow, ASL, etc.) to where all must be briefed before working with construction or operations. The BIDC is only open from 9 A.M. to 5 P.M. during the business week since a trained professional must always be present to minimize safety hazards. The team will use equipment such as sandblasters, mills, CNC's, paint booths, laser cutters, belt sanders, routers, and similar manufacturing machines at this facility for fabrication of custom or complex parts. All proper PPE will be worn in addition to the machinery having emergency protocols with emergency stop buttons and guards.

Hours of Operation	9 A.M. - 5 P.M.
Required Personnel	TA supervisor or Purdue employed machinist
Necessary Equipment	Sandblasters, mills, CNC's, paint booths, laser cutters, belt sanders, routers, etc.
Safety Precaution	TAs or employed machinists must always be present when using machines, team members must take quizzes and

	undergo training before using machines
General Use	Fabrication of custom or complex parts

5.5.4. Purdue BoilerMAKER Lab

The Purdue BoilerMAKER Lab specializes in additive manufacturing and the team will be using their lab space and equipment in order to rapidly prototype parts. This can be done for testing tolerances and function, creating tool guides and jig assemblies, or creating mounting surfaces for the payload and electronics systems. The makerspace operates between the hours of 10 A.M. to 7 P.M. from Monday through Thursday and 10 A.M. to 4 P.M. on Friday, and is closed for the weekends. Due to the high temperatures associated with 3D printing, the team will be letting the lab assistants and technicians handle the machinery and parts as they are being produced. The team member who designed the part will then be responsible for going and retrieving the part from the lab.

Hours of Operation	10 A.M. - 7 P.M. M-Th, 10 A.M. - 4 P.M. Fr
Required Personnel	Lab assistants, part designer
Necessary Equipment	3D Printer, various types of plastic filament, CAD software, computer station
Safety Precaution	Lab assistants will handle the machinery and parts during production to avoid burns to the team members and will oversee the machines to ensure no problems arise
General Use	Rapid prototyping and development

5.6. Risk Assessment Matrices

The seriousness of a risk will be evaluated by two criteria: the likelihood of an event to occur and the impact of the event should it happen or fail to be prevented. Categories of likelihoods and impacts are discussed below:

5.6.1. Likelihood of Event

Category	**Value**	**Gauge**
Remote	1	Less than 1% chance of occurrence.
Unlikely	2	Less than 20% chance of occurrence.
Possible	3	Less than 40% chance of occurrence.

Likely	4	Less than 80% chance of occurrence.
Very Likely	5	Greater than 80% chance of occurrence.

5.6.2. Impact of Event

Category	Value	Gauge
Negligible	1	Minimal injury, damage to equipment or facility, or environmental effects. Flight continues as normal.
Minor	2	Minor injuries, major reversible damage to equipment or facility, and minor environmental impact. Flight proceeds with caution.
Moderate	3	Moderate injuries, reversible failure, and reversible environmental impact. Flight is put on hold until effects are reversed.
Major	4	Potentially serious injuries, partial failure, and serious reversible environmental effects. Flight is scrubbed or put on hold until system is removed.
Disastrous	5	Potentially life threatening injury, total failure, and serious irreversible environmental damage. Flight is scrubbed or completely destroyed

By cross examining the likelihood of an event with the impact it would have if it occurred, a total risk can be calculated which is detailed in the table below. The color code displayed is as follows:

- Green: Minimal risk
- Yellow: Low risk
- Orange: Medium risk
- Light red: High risk
- Dark red: Very high risk

Category	Negligible	Minor	Moderate	Major	Disastrous
Remote	1	2	3	4	5
Unlikely	2	4	6	8	10
Possible	3	6	9	12	15

Likely	4	8	12	16	20
Very Likely	5	10	15	20	25

Risks that are above medium must be signed off by the team lead, safety officer, and project manager. Hazards that have above a medium risk will be continuously designed to where the risk will be lowest. Since most risk occurs during launch and it is at this time when probability for hazards to occur is expected to be highest, the mitigations and verifications will be strictly followed at launches. Additionally, possible failures to the program according to the following analyses must be addressed ahead of time to where individuals are safe and the team continues to thrive. Additionally, for the protection of individuals and the team, PPE will always be on and verified by team members for working on a task.

For all subsequent safety tables, the hazards, likelihood, severity, risk, mitigation, and verification will be considered, in addition to consideration of occurrence. Verification and mitigation will be different in that verification will to be to prove a control is in place while mitigation is the intended plan to control a situation. Final verifications will exist by showcasing design, analysis, testing, PPE/procedures, or another reference. These analyses shall help demonstrate the collective understanding of all components needed to complete the project and how risk/delays impact the project.

5.7. Preliminary Personnel Hazard Analysis

The following hazards are threats to team members and launch observers presented by the project:

Hazard	Likelihood (Cause)	Severity (Effect)	Risk	Mitigation	Verification
Burns From Motor Exhaust	1 (Proximity To Launch Pad)	3 (Mild To Moderate Burns)	3, Low	Maintain minimum safe launch distances	200 feet border will be established after mounting of rocket onto launcher as compliance to NAR safety standards
Contact with Airborne Chemical Debris	3 (Airborne particulate debris)	2 (Minor burns, abrasions)	6, Low	Wear appropriate PPE such as gloves or lab coats, wash with water	No contact allowed without call out before use to make sure PPE worn

Dehydration	3 (Failure to drink adequate amounts of water)	3 (Exhaustion and possible hospitalization)	9, Medium	Ensure all members have access to water at launch	Mandatory water breaks will happen every hour
Direct Contact with Hazardous Chemicals	3 (Chemical spills, improper use of chemicals)	3 (Moderate burns, abrasions)	9, Medium	Wear appropriate PPE such as gloves or lab coats, wash with water	No contact allowed without call out before use to make sure PPE worn
Dust or Chemical Inhalation	3 (Airborne particulate debris)	3 (Short to long-term respiratory damage)	9, Medium	Wear appropriate PPE or respirator, work in well ventilated area	No contact allowed without call out before use to make sure PPE worn
Electrocution	3 (Improper use of equipment, static build-up)	4 (Possible explosion, destruction of electrical tools or components, possible severe harm to personnel)	12, Medium	Give labels to all high voltage equipment warning of their danger; ground oneself when working with high-voltage equipment	Guaranty no open electrical components. Allow only one member to work on electrical components at a time with proper PPE and student supervising
Entanglement with Construction Machines	2 (Loose hair, clothing, or jewelry)	5 (Severe injury, death)	10, Medium	Secure loose hair, clothing, and jewelry; wear appropriate PPE	No contact allowed without call out before use to make sure PPE worn. Make sure rules followed as set forth by machining rules
Epoxy Contact	3 (Resin Spill)	3 (Exposure to Irritant)	9, Medium	Wear appropriate PPE such as gloves or lab coats, wash with water	No contact allowed without call out before use to make sure PPE worn
Eye Irritation	3 (Airborne particulate debris)	2 (Temporary eye irritation)	6, Low	Wear appropriate PPE or	Guaranty PPE worn at all times during manufacturing. Call

				protective eyewear, wash with water	out before use to make sure PPE worn
Falling Hazards	3 (Improper use of ladders, attempting to climb unstable objects)	4 (Bruising, abrasions, possible severe harm if falling into construction equipment)	12, Medium	Do not climb objects which are not ladders, when using ladders have another person present to stabilize the ladder	No contact allowed without call out before use to make sure PPE worn and area clear and avoid unless necessary; have two people minimum to make sure ladder is stabilized and held
Heatstroke	3 (High temperatures on launch day)	3 (Exhaustion and possible hospitalization)	9, Medium	Wear clothing appropriate to the weather, ensure all members have access to water at launch	Team members must have adequate clothing, safety team will report violators to the project lead to decide if the violator should be dismissed to a colder area; water will be provided
Hearing Damage	2 (Close proximity to loud noises)	4 (Long term hearing loss)	8, Medium	Wear appropriate PPE such as ear muffs when using power tools	PPE equipment check must be done by a safety team member before conducting construction
Hypotherm ia	3 (Low temperatures on launch day)	3 (Sickness and possible hospitalization)	9, Medium	Wear clothing appropriate to the weather, ensure all members have access to a warm area to rest at launch	Team members must have adequate clothing, safety team will report violators to the project lead to decide if the violator should be dismissed to a warmer area
Kinetic Damage to Personnel	1 (Failure to take appropriate care around unburned fuel,	5 (Possible severe kinetic damage to personnel)	5, Low	Extinguish any fires before recovering, wait for motors	Make sure area is evacuated and designated individuals are to

	post-landing launch vehicle explosion)			to burn fully before recovering, wear appropriate PPE when recovering	recover components at a designated time when determined to be safe; no contact allowed without call out before use to make sure PPE worn
Launch Pad Fire	2 (Dry Launch Area)	3 (Moderate Burns)	6, Low	Have fire suppression systems nearby and use a protective ground tarp	Make sure area is evacuated and designated individuals are to recover components at a designated time when determined to be safe; no contact allowed without call out before use to make sure PPE worn
Injury from Ballistic Trajectory	3 (Recovery System Failure)	5 (Severe Injury, Death)	15, High	Keep all eyes on the launch vehicle and call “heads up” if needed	Make sure area is evacuated and designated individuals are to recover components at a designated time when determined to be safe; no contact allowed without call out before use to make sure PPE worn
Injury from Falling Components	3 (Failure to keep all components securely attached to the launch vehicle; result of improper staging constraints, part failure, or excessive vibration)	5 (Severe injury, death)	15, High	Keep eyes on the launch vehicle at all times; make sure all team members who cannot watch the launch vehicle have spotters nearby; alert others if the	Make sure area is evacuated and designated individuals are to recover components at a designated time when determined to be safe; no contact allowed without call out before use to make sure PPE

				launch vehicle enters a ballistic trajectory	worn
Injury from Navigating Difficult Terrain	2 (Uneven ground, poisonous plants, fast-moving water)	4 (Broken bones, infections, drowning, etc.)	8, Medium	Do not attempt to recover the launch vehicle from atypically dangerous areas	Make sure to inform team on whether or not it is possible to recover the launch vehicle based off of identifying if terrain is dangerous and can be reached without inflicting harm
Injury from Projectiles Caused by Jetblast	1 (Failure to properly clean launchpad, failure to wear proper PPE, failure to stand an appropriate distance from the launch vehicle during launch)	3 (Moderate injury to personnel)	3, Low	Clean the launchpad before use, ensure all members are wearing proper PPE for launch, ensure all team members are an appropriate distance from the launch vehicle when launching	Make sure area is evacuated and designated individuals are to recover components at a designated time when determined to be safe; no contact allowed without call out before use to make sure PPE worn; follow procedures to make sure launchpad clean and members past minimum distance
Physical Contact With Heat Sources	3 (Contact with launch vehicle parts which were recently worked with, improper use of soldering iron or other construction tools)	3 (Moderate to severe burns)	9, Medium	Wear appropriate PPE, turn off all construction tools when not in use, be aware of the safety hazard that parts which were recently worked with present)	Guaranty no open heat sources/components; allow only one member to work on heat components at a time with proper PPE and student supervising; no contact allowed without call out before use to make sure PPE worn. Label hot components

Physical Contact with Falling Construction Tools or Materials	3 (Materials which were not returned to a safe location after use)	5 (Bruising, cuts, lacerations, possible severe physical injury)	15, High	Brief personnel on proper clean-up procedures, wear shoes that cover the toes	No contact allowed without call out before use to make sure PPE worn; make sure heavy tools only used with closed-toe shoes as designated by machining rules
Premature Ignition	2 (Short Circuit)	2 (Mild Burns)	4, Low	Prepare energetic devices (batteries, black powder, etc.) only immediately prior to flight	Deemed unsafe to arm electronics until prior to ignition; allow no possibility of ignition until launch by keeping separately secured from team. No contact allowed without call out before use to make sure PPE worn
Power Lines	2 (Launch vehicle Becomes Entangled In Lines)	5 (Fatal Electrocution)	10, Medium	Call the power company and stand clear until proper personnel arrive	No contact allowed at all; call out when recognized to safely call power company for them to handle
Power Tool Cuts, Lacerations, and Injuries	3 (Carelessness)	4 (Possible Hospitalization)	12, Medium	Secure loose hair, clothing, and jewelry; wear appropriate PPE; brief personnel on proper construction procedures	PPE equipment check must be done by a safety team member before conducting construction
Recovery Related Injury	2 (Uneven Ground, Poisonous Plants, Fast Moving Water)	4 (Broken Bones, Infections, Drowning, Etc.)	8, Medium	Do not attempt to recover from atypically dangerous areas	If equipment is to be recovered, ensure that area is safe and recovery can be done with little to no potential for harm.

Tripping Hazards	3 (Materials which were not returned to a safe location after use, loose cords on or above the ground during construction processes)	4 (Bruising, abrasions, possible severe harm if tripping into construction equipment)	12, Medium	Brief personnel on proper clean-up procedures, tape loose cords or wires to the ground if they must cross a path which is used by personnel	Guaranty no hazards exist by following the manufacturing rules; follow all rules set forth by safety and make sure all possible hazards are acknowledged and/or moved out of personnel access
Unintended Black Powder Ignition	2 (Accidental exposure to flame or sufficient electric charge)	5 (Possible severe hearing damage or other personal injury)	10, Medium	Label containers storing black powder, one may only handle the black powder if he/she possesses a low-explosives user permit	Keep ignition sources at least 50 feet away from fuel; prohibition of smoking or other potential ignition sources will be enforced by a safety team member
Workplace Fire	2 (Unplanned ignition of flammable substance, through an overheated workplace, improper use or supervision of heating elements, or improper wiring)	5 (Severe burns, loss of workspace, irreversible damage to project)	10, Medium	Have fire suppression systems nearby, prohibit open flames, and store energetic devices in Type 4 magazines	Make sure workplace has updated fire safety protocol; in case of a fire, ensure that the workplace had updated fire suppression systems nearby

5.8. Preliminary Failure Mode And Effects Analysis (FMEA)

Hazard	**Likelihood (Cause)**	**Severity (Effect)**	**Risk**	**Mitigation**	**Verification**
Airframe Failure	1 (Buckling or shearing on the airframe from poor construction	5 (Partial or total destruction of vehicle, ballistic	5, Low	Use appropriate materials according to extensive mathematical and physical analyses of	Use a construction checklist which ensures mathematical

	or use of improper materials, faulty stress modeling)	trajectory)		the body tube, bulkheads, fasteners and shear pins, make use of reliable building techniques, confirm analyses with test launches	analyses match physical analyses, if the airframe does not perform well in test launches perform another test launch with a new airframe design before converting to full-scale, and use the launch checklists to ensure both before and after launch that the airframe is in good condition.
Failure To Launch	2 (Lack of continuity)	1 (Recycle launch pad)	2, Minimal	Check for continuity prior to attempted launch	Ensure continuity checked by checklist
CATO	1 (Motor defect, assembly error)	5 (Partial or total destruction of vehicle)	5, Low	Inspect motor prior to assembly and closely follow assembly instructions	Ensure motor inspected by checklist during test runs and launch
Instability	1 (Stability margin of less than 1.00)	5 (Potentially dangerous flight path and loss of vehicle)	5, Low	Measure physical center of gravity and compare to calculated center of pressure	Use a construction checklist which ensures the center of gravity has been measured and simulated and these measurements have been compared. These measurements should be made available to the entire team
Motor	1 (Improper	5 (Risk of	5, Low	Use positive retention	Ensure motor

Expulsion	retention methods)	recovery failure and low apogee)		method to secure motor	secured by checklist during test runs and launch
Premature Ejection	1 (Altimeter programming , poor venting)	5 (Zippering)	5, Low	Check altimeter settings prior to flight and use appropriate vent holes	Ensure altimeter set by checklist during test runs and launch
Fin Loss or Damage	1 (Poor construction or improper materials used, faulty aerodynamic modeling, damage after landing from previous flights)	5 (Partial or total destruction of vehicle, ballistic trajectory)	5, Low	Use appropriate materials according to extensive mathematical and physical flight analyses, make use of reliable building techniques, run stability tests, confirm analyses with test launches, check to make sure the fins are still in good condition before launches - especially if launching the same rocket twice	Use a construction checklist which ensures mathematical analyses match physical analyses, if fins do not perform well in test launches perform another test launch with new fins before converting to full-scale, and use the launch checklists to ensure both before and after launch that the fins are in good condition.
Loss of Nose Cone	1 (Poor construction or improper materials used)	5 (Partial or total destruction of vehicle)	5, Low	Use appropriate materials and high powered building techniques	Ensure that nose cone is secured well before ejection during test runs, otherwise alter
Loss of Parachute	3 (Poor construction or improper materials used)	5 (Partial or total destruction of vehicle)	15, Medium	Use appropriate materials and high powered building techniques	Ensure that parachute is secured well before ejection during test runs, otherwise alter to lower speed
Ejection	4 (Not	5 (Ballistic	20, High	Ground test charge	Test charge

Charge Failure	enough power, electrical failure)	trajectory, destruction of vehicle)		sizes at least once before flight	before final launch to ensure that charge does not fail
Altimeter Failure	3 (Loss of connection or improper programming)	5 (Ballistic trajectory, destruction of vehicle)	15, High	Secure all components to their mounts and check settings	Ensure altimeter works with prior tests
Payload Failure	3 (Electrical failure, program error, dead battery)	4 (Disqualified, objectives not met)	12, Medium	Test payload prior to flight, check batteries and connections	Ensure that payload is fully functioning prior to flight by conducting tests
Heat Damaged Recovery System	2 (Insufficient protection from ejection charge)	4 (Excessive landing velocity)	8, Medium	Use appropriate protection methods, such as Kevlar blankets	Ensure (prior to final launch) that proper materials are readily working and available in case heat damage occurs.
Broken Fastener	1 (Excessive force)	5 (Ballistic trajectory)	5, Low	Use fasteners with a breaking strength safety factor of 2	Ensure by design and testing that secure
Joint Failure	1 (Excessive force, poor construction)	5 (Partial or total destruction of vehicle, ballistic trajectory)	5, Low	Use appropriate joint design according to extensive mathematical and physical flight analyses, make use of reliable building techniques, confirm analyses with test launches	Ensure by design and testing that secure
Centering Ring Failure	1 (Excessive force from motor, poor construction)	5 (Partial or total destruction of vehicle, ballistic trajectory)	5, Low	Use appropriate centering rings according to extensive mathematical and physical flight analyses, make use of reliable building	Ensure by design and testing that secure

				techniques, confirm analyses with test launches	
Motor Mount Failure	1 (Faulty motor or motor mount preparation, poor construction, damage to motor mount)	5 (Partial or total destruction of vehicle, ballistic trajectory)	5, Low	Use mathematical and physical analyses to ensure the motor mount works as planned, test the motor mount with subscale flights, check the motor mount for damage before flight, team members who prepare the motor must be supervised by at least one other team member	Ensure by design and testing that secure
Destruction Due To Drag Forces	1 (Poor construction or improper materials used)	5 (Partial or total destruction of vehicle)	5, Low	Use appropriate materials and high powered building techniques	Ensure that proper materials are being used to construct the vehicle securely, so that destruction due to drag forces does not occur.
Airframe Zipper	2 (Excessive deployment velocity)	5 (Partial destruction of vehicle)	10, Medium	Properly time ejection charges and use an appropriately long tether	Ensure by design, simulations, and testing that secure
GPS Lock Failure	2 (Interference or dead battery)	5 (Loss of vehicle)	10, Medium	Ensure proper GPS lock and battery charge before flight	Verify that GPS lock and battery charge are properly secured.
Excessive Landing Speed	3 (Parachute damage or entanglement , improper load)	5 (Partial or complete destruction of vehicle)	15, High	Properly size, pack, and protect parachute	Ensure that parachute is well secured in on the aircraft and that it opens as planned. Test the parachute before final

					launch.
Battery Overcharge	3 (Unsupervised/undocumented charge)	3 (Destruction of battery)	9, Medium	Ensure batteries are documented and supervised if charging	Ensure alarms set and other individuals are aware batteries charging
Battery Puncture	2 (Landing damage)	5 (Partial or complete destruction of vehicle)	10, Medium	Ensure design has sufficient distance / protection from outside, and motor, charges, and batteries	Ensure by design and testing that secure from other systems or puncture
Blackpowder Ignition	2 (Accidental exposure to flame or sufficient electric charge)	5 (Partial or complete destruction of vehicle	10, Medium	Ensure design has sufficient distance / protection from outside, and motor, charges, and batteries	Ensure by design and testing that secure from other systems or puncture
Charge ignition close to motor	3 (Poor design location leads to damage)	5 (Partial or complete destruction of vehicle	15, High	Ensure design has sufficient distance / protection from motor, charges, and batteries	Independently ensure design is safe; ensure by isolated testing charge may work
Destruction of Bulkheads	1 (Poor construction or improper bulkheads chosen which cannot withstand launch forces, faulty stress modeling)	5 (Partial or total destruction of vehicle, ballistic trajectory)	5, Low	Use appropriate materials according to extensive high-stress mathematical and physical analyses, make use of reliable building techniques, run stability tests, confirm analyses with test launches	Ensure by design and testing that secure
Destruction of Nose Cone	1 (Poor construction, damage from previous flights, poor storage, or transportation)	3 (Lower rocket stability, possible deviations from flight path)	3, Low	Check the nose cone for damage before and after each launch, choose a nose cone which is strong enough to withstand launch forces according to mathematical and	Ensure by design and testing that secure

				physical flight simulations, confirm choice of nose cone with subscale launches	
Motor Tube Angled Incorrectly	1 (Poor construction, damage from previous flights, poor storage, or transportation)	3 (Lower rocket stability, rocket does not follow desired flight path well)	3, Low	Ensure proper measurements and alignments are made during construction, ensure there is no rush to attach the motor tube, double-check the alignment of the motor before each flight, test that the desired motor alignment is correct with subscale flights	Ensure by design and testing that secure
Motor Tube Comes Loose	1 (Poor construction, damage from previous flights, poor storage, or transportation, faulty motor preparation)	5 (Ballistic trajectory, catastrophic destruction of vehicle)	5, Low	Check the motor and motor tube for damage before each launch, run mathematical and physical flight simulations to ensure the tube performs as planned, confirm simulations with subscale launches	Ensure by design and testing that secure
Component Destruction Due To Drag Forces	1 (Poor construction or improper materials used)	5 (Partial or total destruction of vehicle, ballistic trajectory)	5, Low	Use appropriate materials according to mathematical and physical analyses, make use of reliable building techniques	Ensure by design and testing that secure
Premature Stage Separation	1 (Premature ejection, poor choice of shear pins or fasteners)	5 (Possible recovery failure and damage to or loss of vehicle, ballistic trajectory)	5, Low	Check altimeter settings prior to flight, use appropriate vent holes, and run thorough analyses to determine which types of shear pins and fasteners should be used	Ensure by design and testing that secure

Forgotten or Lost Components	3 (Carelessness with rocket components, failure to take note of inventory before attempting to launch)	4 (Rocket does not launch at the desired launch time)	12, Medium	Have spares for components which are small and easy to lose, have an inventory of all rocket parts to be checked before moving the rocket to a launch site	Ensure components are secured and follow checklist
Poorly placed center of gravity	2 (Carelessness with rocket design, weight which was not considered in mathematical or physical analyses)	3 (Lower rocket stability)	6, Low	Extensive, up-to-date, and detailed simulations and models of the rocket and its flight, adding and leaving room to add extra ballast as needed	Ensure by design and testing that secure
Poorly placed center of pressure	2 (Carelessness with rocket design, design aspects which were not considered in mathematical or physical analyses)	3 (Lower rocket stability)	6, Low	Extensive, up-to-date, and detailed simulations and models of the rocket and its flight, changing design aspects such as fin size as needed	Ensure by design and testing that secure
Premature Ejection	1 (Altimeter programming, poor venting)	5 (Zippering, possible recovery failure and damage to or loss of vehicle)	5, Low	Check altimeter settings prior to flight and use appropriate vent holes	Ensure by design and testing that secure
Ejection Charge Failure	4 (Not enough power, electrical failure)	5 (Ballistic trajectory, destruction of vehicle)	20, High	Ground test charge sizes at least once before flight	Ensure by design and testing that secure

Rocket Disconnects from the Launch Rail	2 (High wind speeds, failure to properly use the rail buttons, faulty rail buttons)	5 (Partial or total destruction of vehicle, ballistic trajectory which endangers personnel, onlookers, and property on the ground)	10, Medium	Use mathematical and physical analyses to ensure the rail buttons are properly aligned and working as planned, double check the rail buttons are properly attaching the rocket to the launch pad before launch, test rail buttons with subscale flights)	Ensure by design and testing that secure
Flightpath Interference	2 (Wildlife in the air, unforeseen obstacles such as a loose balloon)	4 (Minor to severe change in the vehicle's flightpath, possible ballistic trajectory)	8, Medium	Ensure there are clear skies above before launching, ensure an FAA waiver has been obtained for the designated launch area	Ensure launch site is designated and secure
Unplanned Amounts of Friction Between Rocket and Launch Rail	2 (Faulty setup of launch rail, faulty installation of rocket on launch rail, failure to properly lubricate launch rail as needed, weather conditions cause excess friction)	2 (Rocket does not follow the designated flight path well, lower maximum height)	4, Low	Set up the rail using instructions which come with the product, use lubrication on the rail as needed according to weather and rail type, ensure the rocket is properly installed on the launch rail	Ensure by design and testing that secure
Failure to Ignite Propellant	1 (Faulty motor preparation, poor quality of propellant, faulty igniter, faulty igniter power source,	5 (Rocket does not immediately launch and is a considerabl e hazard until it is confirmed	5, Low	Purchase propellant and motors only from reliable sources, team members who prepare the motor and igniters must be supervised by at least one other team member, determine if	Ensure by design and testing that secure

	damage to motor)	that it will not launch, changes to igniters or rocket required)		the igniters chosen work well during subscale testing	
Propellant Fails to Burn for Desired Duration	1 (Faulty motor preparation, poor quality of propellant, damage to motor)	3 (Rocket does not follow the designated flight path well, lower maximum height, if drastic change in maximum height the ejection charges for recovery may not deploy)	3, Low	Purchase propellant and motors only from reliable sources, check the motor for damage prior to launching, team members who prepare the motor must be supervised by at least one other team member	Ensure by design and testing that secure
Propellant Burns Through Rocket Components	1 (Faulty motor preparation, poor quality of propellant, poor construction, damage to motor, damage to propellant casing)	5 (Ballistic trajectory, catastrophi c destruction of vehicle)	5, Low	Purchase propellant and motors only from reliable sources, check the motor for damage prior to launching, team members who prepare the motor must be supervised by at least one other team member, test propellant casing in subscale flights	Ensure by design and testing that secure
Propellant Explosion	1 (Faulty motor preparation, poor quality of propellant, damage to motor)	5 (Ballistic trajectory, catastrophi c destruction of vehicle, possible harm to bystanders)	5, Low	Purchase propellant and motors only from reliable sources, check the motor for damage prior to launching, team members who prepare the motor must be supervised by at least one other team member	Ensure by design and testing that secure

Payload Computer Failure	3 (Electrical failure, program error, poor setup of wiring causes a connection to come undone, forgotten connection, battery failure)	5 (Disqualified, objectives not met, loss of electronic control)	15, High	Test payload prior to flight, check batteries and connections before flight	Ensure by design and testing that secure
Altimeter Failure	3 (Loss of connection, improper programming, altimeter comes dislodged, forgotten connection, battery failure)	5 (Ballistic trajectory, destruction of vehicle, improper timing for ejection of parachutes and stages)	15, High	Secure all components to their mounts and check settings, check batteries and connections before flight	Ensure by design and testing that secure
GPS Lock Failure	2 (Interference or dead battery)	5 (Loss of vehicle)	10, Medium	Ensure proper GPS lock and battery charge before flight	Ensure by design and testing that secure
Power Loss to Avionics Bay and/or Payload	3 (Faulty wiring, battery failure, poor setup of wiring causes a connection to come undone, forgotten connection)	5 (Disqualified, objectives not met, failure to correctly trigger ejection charges)	15, High	Test the reliability of the wiring and batteries through subscale flights, check batteries and connections before flight	Ensure by design and testing that secure
Improper Avionics and Payload Insulation	1 (Poor construction, damage to rocket body, avionics bay, or payload)	4 (Avionics bay and payload do not perform as planned, possible failure to	4, Low	Take efforts to properly seal avionics and payload such as the use of putty, follow proper construction procedures, check	Ensure by design and testing that secure

		trigger ejection charges at correct time, possible failure to meet mission objectives, possible recovery failure, possible ballistic trajectory)		the avionics bay, payload, and rocket body for damage before launch, check insulation of avionics bay and payload through test launches	
Avionics Bay Fire	3 (Faulty wiring, battery failure, poor setup of wiring, adverse weather)	5 (May be disqualified if objectives are not met, possible failure to trigger ejection charges, damage to internal rocket components)	15, High	Thermal protection of avionics bay, do not overload avionics bay with wiring, only purchase avionics and payload equipment from reliable sources, check avionics bay and payload performance with test launches	Ensure by design and testing that secure
Human Error When Arming Avionics and Payload	3 (Forgotten connection, forgetting to activate avionics bay components or payload prior to launch)	5 (Disqualified, objectives not met, failure to correctly trigger ejection charges)	15, High	Leave reminders in multiple places to check that the avionics bay and payload are armed and ready before launch, follow launch checklists closely	Ensure follow safety checklist to ensure properly armed
Arming System Failure	3 (Faulty arming system, faulty wiring, battery failure, poor setup of	5 (Disqualified, objectives not met, failure to correctly	15, High	Ensure the avionics bay is successfully communicating with the team prior to flight, test arming system through test launches	Ensure by design and testing that secure

	wiring causes a connection to come undone, forgotten connection)	trigger ejection charges)			
Poor Spacing Between the Ejection Charge and the Parachute	2 (Failure to properly consider the requirements of the recovery system, poor budgeting of space in rocket, failure to read instructions that come with parachute and/or ejection charges)	5 (Partial or total damage to the parachute, parachute does not launch from the rocket, possible recovery failure)	10, Medium	Read all instructions which come with the parachute and ejection charges, establish clear requirements of the recovery system early in the design process, run mathematical and physical analyses on the design of the rocket, ensure the parachute is spaced properly with subscale test flights	Ensure by design and testing that secure
Airframe Zipper	2 (Excessive velocity when recovery system is deployed)	5 (Partial yet severe destruction of vehicle)	10, Medium	Properly time ejection charges and use an appropriately long tether	Ensure by design and testing that secure
Stage Fails to Separate	2 (Faulty ejection charge, excessive strength is used to hold stages together, altimeter failure)	4 (Rocket does not follow desired flight path, possible ballistic trajectory, lower maximum height, damage to the rocket)	8, Medium	Any team member who loads the ejection charges must be supervised by at least one other team member, examine ejection charges for damage before launch, ensure proper functionality of the altimeters, ejection charges, and interstage joints and fasteners through test flights and mathematical and physical analyses, have a secondary	Ensure by design and testing that secure

				ejection charge for each stage separation	
Main Parachute Fails to Deploy	2 (Poor design of where parachute is in rocket, poor sealing of parachute chamber, poor loading of parachute, faulty parachute or ejection charge, altimeter failure)	5 (Main parachute does not slow down the rocket, recovery failure, ballistic trajectory)	10, Medium	Any team member who seals or packs the parachute chamber must be supervised by at least one other team member, examine parachute and ejection charges for damage before launch, run mathematical and physical analyses as well as subscale tests to ensure parachute is in the right position in the rocket, have a secondary ejection charge in case of emergency which is larger than the first	Ensure by design and testing that secure
Drogue Parachute Fails to Deploy	2 (Poor design of where parachute is in rocket, poor sealing of parachute chamber, poor loading of parachute, faulty parachute or ejection charge, altimeter failure)	5 (Drogue parachute does not slow down the rocket, recovery failure, ballistic trajectory)	10, Medium	Any team member who seals or packs the parachute chamber must be supervised by at least one other team member, examine parachute and ejection charges for damage before launch, run mathematical and physical analyses as well as subscale tests to ensure parachute is in the right position in the rocket, have a secondary ejection charge in case of emergency which is larger than the first	Ensure by design and testing that secure
Parachute Canopy	1 (Poor canopy	4 (Possible recovery	4, Low	Only buy parachutes from reliable sources,	Ensure by design and

Breaks or Tears	materials, improper ejection of recovery system, damage from previous flights or transportation)	failure, ballistic trajectory)		remove threats to parachute integrity from the parachute housing, test the recovery system through mathematical and physical analyses as well as subscale flights, check the recovery system for damage before launch	testing that secure
Parachute Shroud Lines Break	1 (Poor shroud line materials, improper ejection of recovery system, damage from previous flights or transportation)	4 (Possible recovery failure, ballistic trajectory)	4, Low	Only buy parachutes from reliable sources, remove threats to parachute integrity from the parachute housing, test the recovery system through mathematical and physical analyses as well as subscale flights, check the recovery system for damage before launch	Ensure by design and testing that secure
Shock Cord Break or Disconnect	1 (Faulty shock cord, damage to shock cord, poor connection to the rocket)	5 (Parachute disconnect from the rocket, recovery failure, ballistic trajectory)	5, Low	Any team member who connects the shock cord to the rocket must be supervised by at least one other team member, check the shock cord for damage before and after flight, only buy shock cords from reliable sources, analyze the shock cord with test flights	Ensure by design and testing that secure
Tangled Parachute or Shock Cord	1 (Faulty or damaged shock cord or parachute, poor packing of shock cord and/or	4 (Shock cord or parachutes may not fully achieve their goal,	4, Low	Only buy parachutes and shock cords from reliable sources, any team member who seals or packs the parachute chamber must be supervised	Ensure by design and testing that secure

	parachutes, poor sizing of parachutes or shock cord, unstable or ballistic flight)	possible ballistic trajectory, possible failed recovery)		by at least one other team member, examine parachutes and shock cord for damage before launch, check performance of parachutes and shock cord in test flights, appropriately follow recommended sizings for shock cord and parachutes	
Parachute Comes Loose from Rocket	1 (Failure of recovery system mount on the rocket body, poor shroud line materials, improper ejection of recovery system, damage from previous flights or transportation)	5 (Recovery failure, ballistic trajectory)	5, Low	Only buy parachutes from reliable sources, test the recovery system through mathematical and physical analyses as well as subscale flights, check the recovery system for damage before launch, double check that the recovery system is properly mounted before launch	Ensure by design and testing that secure
Heat Damage to Parachute or Shock Cord	1 (Not enough space given between ejection charge and parachute, poor insulation of parachute, poor parachute packing, faulty or poorly chosen ejection charge)	4 (Shock cord or parachutes may not fully achieve their goal, possible ballistic trajectory, possible failed recovery)	4, Low	Any team member who packs the parachute or ejection charges must be supervised by at least one other team member, use recommended sizing methods for ejection charges, confirm proper placement and packing methods of ejection charges and parachutes with test flights	Ensure by design and testing that secure

Parachute or Shock Cord Catch Fire	1 (Not enough space given between ejection charge and parachute, poor insulation of parachute, poor parachute packing, faulty or poorly chosen ejection charge)	5 (Shock cord or parachutes do not fully achieve their goal, possible ballistic trajectory, possible failed recovery, damage to internal rocket components)	5, Low	Any team member who packs the parachute or ejection charges must be supervised by at least one other team member, use recommended sizing methods for ejection charges, confirm proper placement and packing methods of ejection charges and parachutes with test flights	Ensure by design and testing that secure
Excessive Landing Speed	3 (Parachute damage or entanglement, improper load, lower coefficient of drag for the parachutes than needed, lower surface area of the parachutes than needed)	5 (Partial or total destruction of vehicle)	15, High	Properly size, pack, and protect parachute, check the parachute for damage before and after launch, use subscale flights to determine if the subscale parachutes were accurately sized	Ensure by design and testing that secure
Insufficient Landing Speed	3 (Improper load, higher coefficient of drag for the parachutes than needed, higher surface area of the parachutes than needed)	2 (Unexpected changes in flightpath and landing area, increased potential for drift)	6, Low	Use subscale flights to determine if the subscale parachutes were accurately sized, use recommended and proven-to-work parachute sizing techniques	Ensure by design and testing that secure

5.9. Environmental Hazards / Concerns

The following hazards are either threats to the project from the environment or threats to the environment from the project:

Hazard	Likelihood (Cause)	Severity (Effect)	Risk Before	Mitigation	Verification	Risk After
High Air Pressure	2 (Poor air pressure forecast)	4 (Premature drag separation)	8, Medium	Use appropriate amount of shear pins and vent holes	Keep records of the number of shear pins and vent holes included in the rocket in the safety section and double check that number with the number shown to be needed by testing and analysis	Low
Crowded Landscape	3 (Trees, brush, water, power lines)	5 (Inability to recover the rocket, obstacles that may be dangerous to personnel during recovery)	15, High	Launch only in designated areas that are generally open; if needed, angle rocket into wind as necessary to reduce drift	Follow strict designated areas	Low
Collisions with Man-made Structures or with Humans	2 (Failure to properly predict trajectory, failure to choose an appropriate launch area)	5 (Damage to public property or private property not owned by the team, damage to team equipment, serious damage to team personnel or passerby)	10, Medium	Do not launch under adverse conditions which may affect the course of the rocket, run a large number of tests which analyze the rocket's trajectory mathematically and physically, choose a launch area which is not close to civilization, follow launch procedures closely	Run tests to analyze and estimate the rocket's trajectory so that the rocket's path is known to the team; do not launch rocket under adverse weather conditions and choose a launch location which allows for open space to avoid accidents	Low

Unstable Ground	2 (Poor choice of launch site, inclement weather creating mud or softening the ground)	3 (Personnel may slip or fall and damage equipment or themselves, launch pad may sink into the ground and cause an unexpected trajectory)	6, Low	A rigid system which can be used to support the launch pad, such as wooden planks (if needed to reduce their flammability, they may be wetted directly underneath the rocket), choice of a launch site which has rigid ground, observation of launch pad condition shortly before launch	Use designated launch areas as designated to which must strictly follow this rule to be approved	Low
Wildlife Contact with Rocket	1 (Failure to accurately predict trajectory, unexpected appearance of wildlife, poor choice of launch area)	4 (Damage to vehicle components , damage to wildlife, unexpected trajectory close to the ground)	4, Low	Launch in an open area with high visibility, be aware of the surroundings when choosing a launch area and launching	Ensure that the launch area is in a safe area where surroundings don't stand in the way of the launch or have a chance of getting damaged.	Minimal
Wildlife Contact with Launch Pad	1 (Failure to monitor the launch pad, poor choice of launch area)	4 (Possible inability to launch the rocket, unpredictable launch behavior or trajectory)	4, Low	Have at least one team member monitoring the launch pad at all times, launch in an open area with high visibility, be aware of the surroundings when choosing a launch area and launching, if animals tamper with the launchpad do	Ensure that the launch pad is in a safe area where surroundings don't stand in the way of the launch pad or have a chance of getting damaged by the launch.	Minimal

				not launch		
High Humidity	3 (Climate, poor forecast)	1 (Rust on metallic components , expansion of rocket components and difficulty assembling the rocket because of this)	3, Low	Use as little metal as possible, apply rust prevention techniques, store the rocket indoors, choose a launch site with a desirable climate, choose not to launch if heat expansion makes assembly necessitate drastic adaptation	Ensure that launch site does not have any undesirable conditions. Ensure that electronics are well protected and will not have contact with wet conditions. Do not launch if there is rainfall.	Minimal
Wet Condition s	3 (Climate, poor forecast)	3 (Threats to electronic performance , possible short circuit)	9, Medium	Choose a launch site with a desirable climate, read accompanying instructions for any electronics with regard to wet conditions, do not launch during rainfall which is more than a light sprinkle	Ensure that launch site does not have any undesirable conditions. Ensure that electronics are well protected and will not have contact with wet conditions. Do not launch if there is rainfall.	Low
Dry Condition s	2 (Climate, poor long-term forecast)	3 (Increased chance of launch pad fire if there is dry brush present near to the launch pad)	6, Low	Clear all dry brush away from the launch pad area before launch, choose a launch area with a climate that is not often dry, do not launch if there is an unavoidable fire hazard present due to dry conditions	Ensure team is notified of all weather on day of launch or manufacturing to wear proper clothing; do not launch if too dry; ensure mitigation is strictly followed due to weather notification	Minimal

Lightning	3 (Poor forecast)	4 (Threats to electronics and team personnel)	12, Medium	Do not launch during storms or attempt to launch if there is a storm approaching, check the forecast for the day in advance	Check the forecast days ahead of launching. In the event that there is a storm on launch day, do not launch.	Low
High Wind Speeds	3 (Poor forecast)	4 (Inability to launch, excessive drift, unpredictable trajectory, destruction of parachute or damage to rocket parts, loose equipment blown away)	12, Medium	Angle into wind as necessary and abort if wind exceeds 20 mph	In the event that there are high wind speeds, angle the rocket to accomodate for the weather conditions. Do not launch if wind speeds exceed 20 mph.	Low
High Temperatures	3 (Poor forecast)	3 (Heat-related personnel injuries, failure in rocket structure, launchpad fires from overheated components or dry brush, excessive friction on the launch rail [especially if the heat is from sun exposure])	9, Medium	Ensure team is protected from the sun through shade and sunscreen and stays hydrated, choose a launch location with small amounts of brush, store the rocket in an area with regulated temperature	Ensure team is notified of all weather on day of launch or manufacturing to wear proper clothing; do not launch if weather above designed intent of rocket; ensure mitigation is strictly followed due to weather notification	Low
Low Temperatures	3 (Poor forecast)	3 (Cold-related personnel injuries, Frost on	9, Medium	Ensure team is wearing appropriate clothing for extended	Ensure team is notified of all weather on day of launch or manufacturing	Low

		ground, ice on vehicle, clogging of vehicle ventilation, change in rocket rigidity and mass, higher drag force on rocket)		periods of time in cold environments, keep the rocket at room temperature or bundled in materials which hold in heat, if ice appears anywhere on the rocket do not launch and return it to a warm location	to wear proper clothing; do not launch if weather below designed intent of rocket; ensure mitigation is strictly followed due to weather notification	
Pollution from Exhaust	5 (Combustion of APCP motors)	1 (Small amounts of greenhouse gases emitted)	5, Low	Carpool to events to reduce pollution from exhaust in another way	Ensure team members with only high attendance may go, and be carpooled, to save energy	Low
Chemical Pollution to Water Sources	2 (Fuel leakages, battery fluid leakages, launch too close to a water source)	4 (Danger of sickness to wildlife or humans which rely on the water sources)	8, Medium	Do not launch if the launching area is within 750 meters of a water source, check the rocket for leakages before launch	Use designated launch areas as designated to which must strictly follow this rule to be approved	Low
Pollution from Team Members	2 (Failed disposal of litter, improper cleanup procedures, members walk through important plantlife, farming fields, sod, etc.)	4 (Litter may degrade extremely slowly, wildlife may consume harmful litter)	8, Medium	Brief team members on proper cleanup procedures, foster a mindset of leaving no trace at launch sites, only the minimum number of required team members should retrieve the rocket	Follow societal standards and leave cite cleaner than was found; make sure disposable equipment is kept track of and guaranteed to remain at designated locations, not with retrieval	Minimal
Pollution from	2 (Loss of component	4 (Materials degrade	8, Medium	Properly fasten all	Follow MSDS protocols and	Medium

Vehicle	s from vehicle, debris scattering from a crash or mid-flight explosion)	extremely slowly, wildlife may consume the materials)		components;ensure components that can fall off have low impact on environment and / or are biodegradabile	fulfill design requirements and derived requirements while using no excess components	

5.10. Project Hazards / Delays

The following hazards threaten the progress or completion of the project as a whole:

Hazard	**Likelihood (Cause)**	**Severity (Effect)**	**Risk**	**Mitigation**	**Verification**
Improper Funding	3 (Lack of revenue)	5 (Inability to purchase parts)	15, High	Create and execute a detailed funding plan properly, minimize excessive spending by having multiple members check the necessity of purchases	Project lead shall keep track of budget to have an account of funding coming in and a timeline of what to have purchased, completed, or obtained by when; must have a plan B
Failure To Receive Parts	2 (Shipping delays, out of stock orders)	5 (Cannot construct and fly vehicle)	10, Medium	Order parts while in stock well in advance of needed date	Keep list of parts required and checklist for when purchased
Damage to or Loss of Parts	2 (Failure during testing, improper part care during construction, transportation, or launch)	5 (Cannot construct or fly vehicle without spare parts)	10, Medium	Have extra parts on hand in case parts need to be replaced, follow all safety procedures for transportation, launch, and construction	Keep extra parts list and list of parts with potential of failure and delivery time to have time to fix or replace parts; check all shipping orders and ensure that extra parts are ordered
Rushed Work	2 (Rapidly approaching deadlines, unreasonable schedule expectations)	4 (Threats of failure during testing or the final launch due to a lower quality of	8, Medium	Set deadlines which both keep the project moving at a reasonable pace and leave room	Keep team updated on all deadlines by maintaining effective communication; project lead

		construction and less attention paid to test data)		for unforeseen circumstances	enforces milestones; urges team to work proactively.
Major Testing Failure	2 (Improper construction of the rocket, insufficient data used before creating the rocket's design)	5 (Damage to vehicle parts, possible disqualification from the project due to a lack of subscale flight data, an increase in budget for buying new materials, delay in project completion)	10, Medium	Only include reliable elements in the design which have been confirmed to work through prior designs or extensive mathematical and physical analysis	Follow safety measures in place to make sure failure does not occur in first place; have contingency plan to easily replace the components from spare components if failure occurs, as listed above; safety team will compare the construction with drawings/ CAD models to verify construction quality.
Unavailable Test Launch Area	2 (Failure to locate a proper area to launch subscale rockets for testing, failure to receive an FAA waiver for the test launch)	5 (Disqualification from the project due to a lack of subscale flight data)	10, Medium	Secure a reliable test launch area and FAA waiver well in advance of the dates on which test launch data is required	Make sure to secure multiple backup test launch areas in advance in case of unavailability of other launch areas or failure to receive an FAA waiver; project lead must present any related documents upon request for verification
Loss or Unavailability of Work Area	1 (Construction, building hazards, loss of lab privilege)	4 (Temporary inability to construct vehicle)	4, Low	Follow work area regulations and have secondary spaces available	Keep a list of backup work areas in case there is a need for a temporary work area (due to construction in primary work location)
Failure in Construction	1 (Improper long-term maintenance	3 (Possible long-term delay in	3, Low	Ensure proper maintenance and use of	Keep equipment safe following proper protective

Equipment	of construction equipment, improper use or storage of equipment)	construction)		construction equipment and have backup equipment which can be used in case of an equipment breakdown	measures to keep first the user safe and then the equipment. Have backup construction equipment
Insufficient Transportation	1 (Insufficient funding or space available to bring all project members to launch sites or workplace)	3 (Loss of labor force, team members lose knowledge of what is happening with the project, low attendance to the final launch)	3, Low	Organize and budget for transportation early and keep track of dates on which large amount of transportation are needed	Have list of team members going and have list of maximum transportation amounts; make sure permanent funding exists for transportation; utilize an attendance roster well in advance before travel.
Design Flaw	2 (Program logic error, improper data entry, oversight)	5 (Inability to complete objectives or construct vehicle)	10, Medium	Collaborate and share design files for peer evaluation	Make sure all sub team leads and responsible team members review design before assembly.
Lack of Communication	3 (Members fail to keep other members updated on their personal progress and pertinent information they are aware of)	3 (Possible oversight of important deadlines or project aspects, possible delays to the project from a design which does not mesh well)	9, Medium	Encourage members to talk to each other about the project, have an organized group of subteams within the project and obtain updates from subteam leaders weekly	Employment of attendance tracking methods such as a sheet and utilization of electronic communications such as Slack.
Inactivity	2 (Members are unable or unwilling to work)	5 (Low attendance, loss of team members, labor shortages, inability to	10, Medium	Train all members to work in all areas necessary	Utilization of work time table.

		construct vehicle)			
Low Availability of Personnel	2 (Classes become extremely involved, other extracurriculars have events which cannot be skipped)	2 (Labor shortages, low attendance, specific responsibilities of absent team members are overlooked)	4, Low	Determine who has time to complete tasks and declare those members responsible, ensure the schedule and deadlines are known by all team members so they can work around them, have team members prevent their semester schedules from being too strenuous	Attendance
Personnel Injury	2 (Members are unable to work)	3 (Temporary loss of team member and labor force)	6, Low	Keep first aid kit on hand at all times and train all members to follow procedures	Ensure team members disclose injury to be attended to or call for additional assistance
Damage By Non-Team Members	1 (Accidental damage caused by other workspace users)	4 (Extensive repairs necessary, delay in construction)	4, Low	Separate all components from other areas of the workspace as necessary	Ensure only team members as known can have access to components
Improper Transit Availability for Rocket	1 (No safe way to transport the subscale rockets or final rocket to the launch site)	5 (Failure to launch)	5, Low	Organize rocket transportation well in advance	Ensure transportation is set in advance; Known to have transportation
Damage During Transit	2 (Mishandling)	5 (Inability to fly rocket)	10, Medium	Protect all rocket components during transit	Ensure rocket safety secured by testing
Calendar	3 (Overlap	4 (Inability of	12,	Inform professors	Ensure professors

Conflicts	with classes)	team members to travel)	Medium	and concerned persons about overlap ahead of time	are aware of calendar conflicts as documented once new semester starts and checklist
Failure to Plan for Breaks and Holidays	1 (Unreasonable expectations of team members)	1 (Slight delay in project progress)	1, Minimal	Do not expect a large amount of progress over breaks and holidays, as members will likely be busy and/or distanced from the designated workplace	Purdue Academic Calendar known in advance
Weather Delays	3 (Poor weather conditions during test launches, such as high wind speeds, ice and frost, or storms)	5 (Possible disqualification from the project due to a lack of subscale flight data)	15, High	Have multiple dates available on which test launches can be conducted in case of adverse weather conditions	Have backup date planned before

5.11. Checklists

5.11.1. Pre-Launch Checklist

General Safety

- ❏ Ensure that at least two people are using this checklist to prep for launch
- ❏ Ensure that a trained Range Safety Officer is present
- ❏ Have first aid equipment and at least one phone available for use nearby
- ❏ Designate a "rapid response" person or persons to be the one(s) to perform duties such as administering first aid in the case of an emergency
- ❏ Designate spotters to keep track of the rocket's descent and to point out its location as it falls
- ❏ Have adequate fire suppression equipment available for use nearby
- ❏ A fire blanket has been placed under the pad if conditions at launch are dry enough to require it

General Rocket Construction (To be done after prepping avionics and reloads)

- ❑ Ensure computer simulations have already been run of the rocket in its current construction state before launch to analyze both normal and ballistic scenarios
- ❑ Check that all fins and lugs are secure and aligned
- ❑ Check that the body tube is in good condition
- ❑ Check that the motor and ejection system are in good condition, are functional, and are securely installed
    - ❑ Ensure the proper motor and ejection have been selected for the desired flight profile and that they are certified by NAR, Tripoli, or CAR
    - ❑ Check the reload motor for proper build-up, paying special attention to the O-rings
    - ❑ Ensure the ejection charge is properly installed, and is the proper amount according to the table at the end of this checklist (Figure 2)
    - ❑ Check that the motor mount is secure, is in good condition, and will not deflect motor thrust
- ❑ Check that the recovery system is in good condition, is functional, is securely installed, and is strong enough to withstand recovery loads
    - ❑ Check that shock cords are securely attached and are not cracked, burned, or frayed
    - ❑ Check that shroud lines are not burned or tangled
    - ❑ Check that all hardware, such as snap swivels and screw eyes, is in good condition and secure
    - ❑ Check that parachute protection is installed properly and is in good condition
- ❑ Check that the electronics bay is in good condition, is functional, and is securely installed
    - ❑ Have each altimeter checked the **night before** the flight
    - ❑ Ensure the altimeters are properly installed
    - ❑ Check that the avionics are initially disarmed and that an “Arm before flight” reminder is in use
    - ❑ Check that the electronics bay is properly vented and that wires do not cover any ports
    - ❑ Check that the drogue and main wiring are in good condition
    - ❑ Check that all electronics bay hardware and electrical connections are secured against acceleration forces
    - ❑ If appropriate, check the settings of the mach lock-out / mach delay
    - ❑ Ensure the battery or batteries being used are charged and in operational condition, and secure battery positions with masking tape
    - ❑ Check that the ejection charges are properly set up
    - ❑ Close and secure the electronics bay

Flight Check

- ❏ Check the nose cone and any stage or payload couplers for a secure and proper fit
- ❏ Check that the motor is securely installed
- ❏ Check for continuity, resistance, and cracks or flaws in the pyrogen of the igniters; all igniters must touch the propellant, have adequate electrical current flowing to them, and have no shorts
- ❏ If clustering, ensure thrust symmetry
- ❏ Check that staging delay is less than one second
- ❏ Ensure that the center of gravity and center of pressure are in their expected positions
- ❏ Perform manufacturer's checking instructions on the avionics
- ❏ Check that shear pins are installed for main parachute compartment
- ❏ Ensure drogue ejection will not cause main to deploy

Pad Distance

- ❏ Only the minimum number of personnel are at the pad to prep for launch
- ❏ All team personnel and spectators are a safe distance from the pad based upon a minimum distance table; use the table at the end of this checklist (Figure 1)
- ❏ Ensure barriers are in place to keep spectators away from the launch area

Pad Installation

- ❏ Ensure the launch controller is disarmed prior to installing the rocket onto the pad
- ❏ Ensure the launch pad is stable and is an adequate size for the rocket being used
- ❏ Ensure that enough electrical current will reach the igniters of the rocket
- ❏ Verify that the igniter clips are clean and the leads are secured to the pad
- ❏ Verify that the rocket moves smoothly on the launch rail; clean the rail and rocket as necessary
- ❏ Ensure that the igniter clips are clean and secure them to the pad; install igniter into motor
- ❏ Connect launch leads to motor igniter
- ❏ Arm the avionics system once the rocket is on the pad
    - ❏ Ensure that the Raspberry Pi systems are all turned on!

Flight Trajectory

- ❏ Ensure the launch and the flight will not be angled towards any spectators

- ❑ Double check that the rocket will not fly higher than its permitted clearance waiver; know the expected performance of the model
- ❑ Check cloud bases and winds and make sure the skies around the launch area are clear
- ❑ If needed, use a wind speed indicator to avoid launching during extremely windy intervals
- ❑ Ensure there are no obstructions or hazards in the launch area

Beginning the Launch

- ❑ Shortly before the countdown, give a loud announcement that the rocket will be launched; if applicable to the situation, use a PA system
- ❑ Ensure that all spectators are aware of the launch and that parents are in close contact with all children
- ❑ When launching, give a loud countdown of “5, 4, 3, 2, 1, launch!”

5.11.2. Launch Checklist

- ❑ Ensure that at least two people are using this checklist to observe the launch
- ❑ Ensure the stability of the model is being monitored
- ❑ Ensure that the recovery system is successfully deployed.
- ❑ Carry out a safe recovery of the model
- ❑ If radio control is used for flight functions (e.g. recovery), check that the operating frequency is in the 27, 50, 53, or 72 megahertz bands. Use of 75 megahertz for flight functions is not permitted.
- ❑ Ensure rocket trajectory is being tracked during flight. Be aware of tilt or drift from mass/aerodynamic imbalance, wind, or other sources. **Do not turn off the altimeters.**
- ❑ Ensure crosswind positioning of spectators and vehicles
- ❑ Ensure that the launch pad is being monitored after takeoff in case any dangers arise at the pad
- ❑ Ensure all passerby and spectators are aware of the launch
- ❑ Call a loud “Heads up!” (If needed, sound an air horn) in the case of any rockets approaching the prep area or spectators; all who see the incoming rocket should point at it as it descends.
- ❑ Monitor the flight path, using binoculars if necessary
- ❑ Make sure whoever is responsible for recovery is kept fully aware of the status of the rocket (failed to launch, nominal in-flight, mid air failure, returning for recovery, etc.)
- ❑ Communicate launch progress effectively to NASA officials, if needed

In the case of a misfire:

- ❏ Wait a minimum of one minute
- ❏ Disarm launch controller and avionics
- ❏ Remove failed igniter and motor if needed

5.11.3. Post-Launch Checklist

- ❏ Ensure that at least two people are using this checklist after launch
- ❏ Double check that there are no hazards which have gone unnoticed during the launch before approaching the launch pad or the rocket for clean-up.
    - ❏ If there are hazards, notify emergency personnel
- ❏ Let NASA officials verify the results of the launch, if necessary
- ❏ Double check that all necessary data from the avionics bay has been retrieved
    - ❏ If so, disarm the avionics
- ❏ Disarm the launch controller
- ❏ Place cap on launch rods, if necessary
- ❏ Take down the launch pad, if necessary
- ❏ Retrieve the main rocket body and all components which may have landed separately
    - ❏ Check them for any failed ejection charges
    - ❏ If there are failed ejection charges, safe all ejection circuits and remove any non-discharged pyrotechnics

5.12. Plan for Compliance with Laws

Each team shall provide a plan for complying with federal, state, and local laws regarding unmanned rocket launches and motor handling (specifically, regarding the use of airspace, Federal Aviation Regulations 14 CFR, Subchapter F, Part 101, Subpart C; Amateur Rockets, Code of Federal Regulation 27 Part 55: Commerce in Explosives; and fire prevention, NFPA 1127 “Code for High Power Rocket Motors”). The project team will follow regulations listed in NFPA 1127 and CFR 27 Part 55 and will store all motors, black powder, and other flammable materials in a Type 4 Magazine. These materials will only be removed immediately prior to flight. All launches will be conducted in an area with an active FAA waiver that extends beyond 5,623 feet, the projected altitude of the launch vehicle. All team members present at these launches will closely follow the NAR High Power Rocket Safety Code and the safety agreement, which both encourage lawful rocketry.

Hazard	**Likelihood (Cause)**	**Severity (Effect)**	**Risk**	**Mitigation**

Damage of Property	Low	High	Legal Repercussions	Insurance
FAA Violations	Low	High	Legal Repercussions	Adhere to regulations
NAR/TRA Violations	Low	High	Legal Repercussions	Adhere to regulations
OSHA Violations	Low	High	Legal Repercussions	Adhere to regulations
Personal Injury	Low	High	Legal Repercussions	Individual / independent calculations and safety protocols / preparedness

5.13. Plan to Purchase, Store, Transport, and Use Hazardous Materials

Hazardous materials which will be used on this project include: black powder, ammonium perchlorate composite propellant, pre-made rocket motor igniters, and potentially compressed carbon dioxide. Hazardous materials will be stored off-site, within the Zucrow Labs research facilities adjacent to the Purdue University Airport. Certain members of the team working on the project currently hold a Low Explosives User Permit (LEUP), and these are the members who will handle the acquisition, transportation, and storage of the hazardous materials involved in this project. All team members will be given a briefing on the plan to properly purchase, store, transport, and use hazardous materials by the safety officer. This safety brief will provide knowledge of and access to Material Safety Data Sheets (MSDS) for all potentially hazardous substances which will be used on the project and will ensure the use of proper PPE when handling hazardous materials. The MSDSs are to be referred to when a hazard occurs in order to execute the most effective mitigation and ensure all safety concerns are addressed. All MSDSs are available to the team at all times and are required to be understood before working with potentially hazardous materials as to help increase awareness to reduce the potential for a hazard or likelihood of failure.

5.14. Team Safety Statement

The following statement will be printed out for all team members to sign:

As a member of the Purdue Space Program Student Launch (PSP-SL) team, I agree to:

1. Adhere to any and all relevant local, state, and federal laws and regulations.
2. Adhere to the NAR High Power Rocket Safety Code.
3. Comply with all instructions given to me by the Safety Officer and by the Range Safety Officer.
4. Wear appropriate personal protective equipment whenever constructing or operating the launch vehicle.
5. Understand the hazards of each material or machine I plan to use or operate.
6. Never misuse the materials or equipment I will work with in this project for any reason.
7. Acknowledge that the Range Safety Officer will inspect the launch vehicle prior to all flights.
8. Acknowledge that the Range Safety Officer reserves the right to approve or deny the flight of the launch vehicle for any relevant reason.
9. Acknowledge that my team will not be allowed to fly if it does not comply with each of the aforementioned safety regulations.

My signature confirms that I have read and understood the aforementioned agreements. I recognize that any violation of these agreements may result in being unable to participate in Project Walker or the PSP-SL program. I recognize that although the safety team is in charge of overall safety, I am individually responsible for remaining safe and following the rules set forward by these statements.

Name____

Signature____ Date_______________

6. Payload Criteria

6.1. Selection, Design, And Rationale Of Payload

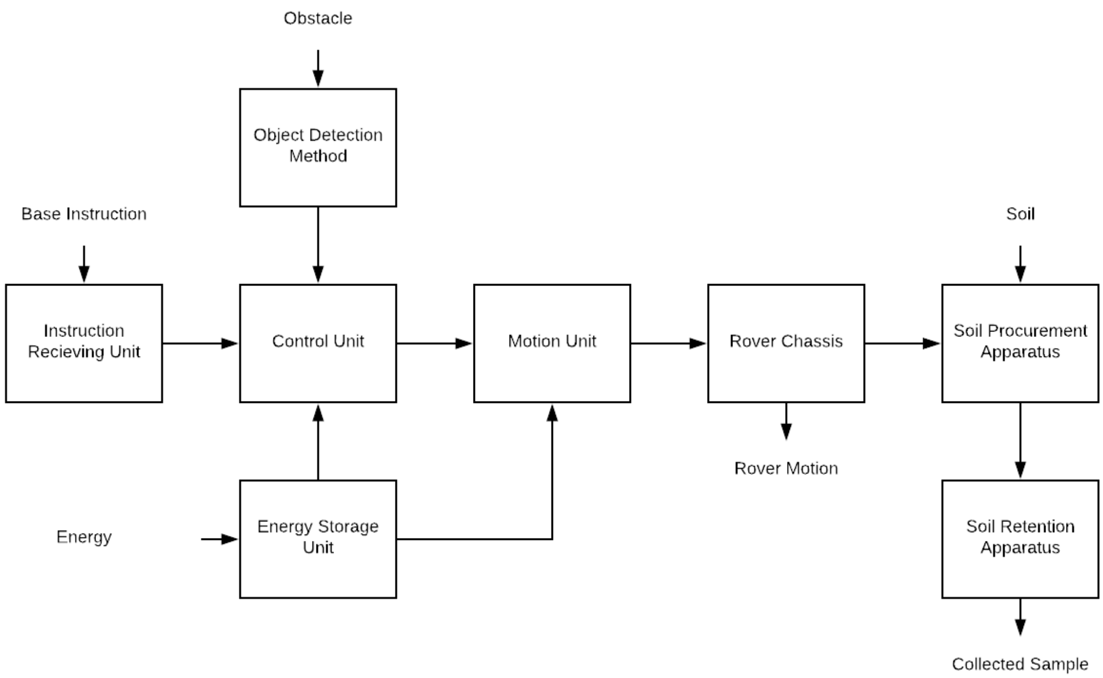
6.1.1. Mission Statement And Mission Success Criteria

Mission Statement:
Design an onboard rover that will successfully deploy from the flight vehicle upon safe landing and collect a soil sample at least ten feet from any part of the flight vehicle.

Mission Success Criteria:

- The payload bay must be located in a section independent from the recovery bay
- The payload must not be damaged or treated harshly during flight by its containment system
- The payload must fit within a tube that is 12 inches in length and 4.815 inches in diameter
- The payload must have a rover that will deploy independently
- The payload excluding the bay itself must weigh less than or equal to 6 pounds
- The payload rover must autonomously travel a distance of at least 10 feet from all parts of the rocket
- The payload rover must collect at least 10 mL of soil and store it safely

6.1.2. Overall Payload Design



Overview:
Given the two options for payload missions, this team will launch a payload of an autonomous rover and soil sampling system. The rover will be deployed from the payload bay upon landing and must drive at least 10 feet away from any part of the rocket. This motion will employ a system of sensory data collection and execution of obstacle avoidance maneuvers. Once it has travelled at least the decided upon distance from the closest located rocket part, it will begin soil sampling.

The rover will consist of two large wheels on either side of a chassis. The chassis will hold the control unit, power system, motion unit, as well as the object detection method needed for navigation. The soil collection apparatus will be deployable from the rear of the chassis.

The payload will be deployed from the rocket after landing. Once the payload bay has landed completely, a signal will be sent to deploy the rover. When the payload bay receives the signal, a black powder charge will ignite, launching a fairing capsule out of the payload bay. The fairing will open via spring loaded hinges, and the rover will deploy. At this point in the design phase there is still the concern that the fairing will not deploy correctly. We are considering different ideas to hold the fairing in place during flight such as shear pins and destructible covers. This retention system will need to withstand forces from flight and landing but also need to break or be removed for deployment of the payload. We will determine the best option for retention by testing each idea. Additionally, we are concerned that the fairing will hit obstructions on the way out of the payload bay. To minimize this risk we have decided to use a rounded “pill shape” fairing so there will not be any hard edges to catch on debris.

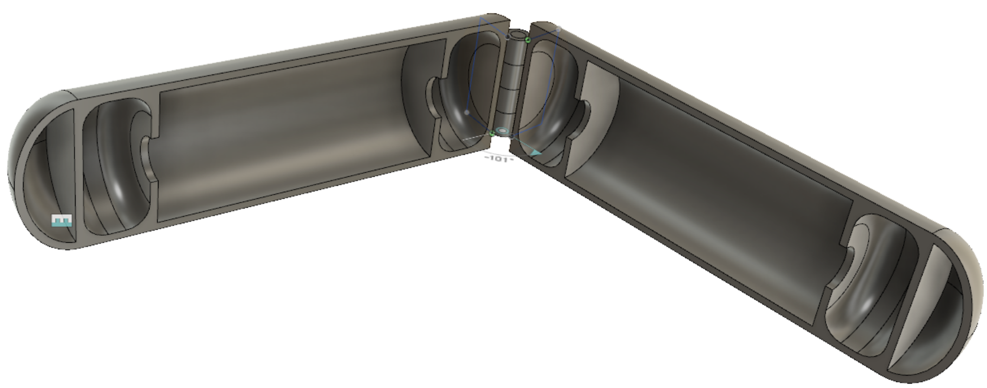
Chassis Overview:
The onboard control unit, detection methods, motion units, energy storage unit, and soil collection apparatus will be mounted to a custom fabricated chassis. At each end will be mounted a wheel with a radius greater than the radius from the axis of the wheels to the outermost point of the cross section of the chassis and its attached components. This will allow for the motion unit to translate and rotate with low possibility of chassis collision with terrain obstacles. The chassis will be weighed and supported in such a way so as to maintain a constant orientation as the motion unit causes its translation. The onboard computer control unit, energy storage unit, and motion unit will be fastened to the platform of the chassis, providing them with protection from terrain debris as well as having wire access. The soil collection apparatus will be attached to the rear of the chassis, a position conducive to an apparatus design that trails behind the rover as it collects its sample.

Control Unit Overview:
The control unit will be able to receive instructions wirelessly as well as take sensory input from an object detection method mounted on the chassis. This method will likely involve a sensor(s) capable of detecting distance to nearby objects within line of sight. The control unit will then be able to process these inputs and execute driving maneuvers to the motion unit. The control unit will be able to intake power from the onboard battery unit and distribute it to subsystems. The onboard battery will be affixed to the chassis platform near to the control unit.

Soil Collection Overview:
The soil collection apparatus will be contained at the rear of the rover. This apparatus will be deployed and will drag along the ground. This apparatus will function similarly to a rake. This will loosen and collect soil as the rover drives, sealing the samples in a container that can be stored beneath the chassis. The apparatus will also serve as a counter balance for the wheels, preventing the chassis from rotating about the wheels while driving.

6.1.3. Preliminary Vehicle To Payload Interface

To successfully complete the mission, once the rocket lands the rover shall be deployed from the rocket. In addition to this, while the rocket is in flight, the payload also has to be actively retained in the body of the rocket. The payload must also be in the correct orientation once it is deployed from the rocket. We must ensure that the deployment of the payload does not get stuck in the ground. With these requirements in mind the system we designed involves containing the payload in a fairing system, as pictured below:



This fairing is shown in the “open configuration” in the picture above. The fairing is a 3D printed tubular capsule with the front side rounded. The back side is flat and has a hinge. This hinge will be spring loaded so that the fairing will open automatically once outside of the rocket. The outer diameter of this tube will have to be 4.8 inches, the inner diameter of the rocket, to fit snugly. It must fit snugly to reduce movement during flight and for the ejection method to work more effectively. The length of the fairing at the moment will be 10 inches, but this may be shortened or lengthened as the payload evolves.

The inside of this fairing will be mostly hollow to contain the rover. The configuration in the picture above shows the leading design for the interior. There are three main compartments, one large one in the center with a smaller one on either side. The walls separating these compartments have a hole in the center. A wheel will be able to be contained in each of these smaller compartments, with the main rover body being in the center compartment. The hole is for the axle between the motors and the wheel. The wheels should fit snugly in their compartments, this will keep the rover secured in the fairing. The dimensions and shapes for the inside are not decided yet, as we are still deciding on components of the rover. Because we are planning to 3D print it, we will have a lot of flexibility in the prototyping phase for this.

The leading choice for securing the payload fairing in the rocket is to use shear pins. These will attach the fairing to the body, either directly or indirectly. Once the rocket has landed and is on the ground, a black powder charge, located near the flat part of the capsule, will ignite. This will push the capsule out the front of the payload section with the rounded face first. The rounded face is to prevent the rocket from getting stuck when firing out of the rocket due to the ground or other unpredicted obstacles.

Alternate Methods

- Capsule

Criteria	**Weight**	**Clam-shell Fairing (Score (weighted Score))**	**Hinged Prism Design (Score (weighted Score))**
Strength	10%	4 (8)	3 (6)
Cost	10%	3 (6)	3 (6)
Reliability	40%	4 (32)	2 (16)
Development Time	20%	4 (16)	2 (8)
Orientation Ability	20%	3 (12)	2 (8)
Totals (/100)	100%	74	44

    - Clam-shell fairing (Current)
        - This is the current design as described above, with a pill like fairing like capsule.
    - Hinged prism design
        - This design involves constructing a shape similar to a long octagonal prism. The rover would be inside of this.
        - Each of the edges would be hinged
        - Once ejected, one hinge would disconnect, and the capsule would be unfolded, and the rover could drive out.

- Ejection

Criteria	Weight	Black Powder (Score (weighted Score))	Compressed Gas (Score (weighted Score))	Mechanical (Score (weighted Score))
Reliability	30%	5 (30)	4 (24)	3 (18)
Cost	20%	4 (16)	2 (8)	4 (16)
Development Time	20%	4 (16)	3 (12)	2 (8)
Damage to ejection Capsule	15%	2 (6)	3 (9)	5 (15)
Safety	15%	2 (6)	4 (12)	5 (15)
Totals (/100)	100%	76	65	72

- Black powder (current)
  - This is the design described above that we are using
- Compressed gas
  - This is also described above
  - Would involve a canister of compressed gas. This gas would be used to push the capsule out
- Mechanical
  - This would involve a system that uses motors to push out the capsule
  - This option never became specific, but the primary idea included pushing out the capsule on a track

- Active retention system (Will likely use multiple methods)

Criteria	Weight	Shear Pins (Score (weighted Score))	Breakable Faceplate (Score (weighted Score))	Mechanical /Electronic System (Score (weighted Score))	Magnetism (Score (weighted Score))

Reliability to detach	30%	5 (30)	4 (24)	3 (18)	3 (18)
Safety	10%	5 (10)	5 (10)	5 (10)	5 (10)
Retention Ability	30%	3 (18)	4 (24)	5 (30)	2 (12)
Development Time	20%	5 (20)	4 (16)	2 (8)	1 (4)
Cost	10%	5 (10)	4 (8)	3 (6)	3 (6)
Totals (/100)	100%	88	82	74	50

- Shear pins
    - This is a common design
    - Involves bolts which are designed to break at a certain pressure.
    - They will stay together when the rocket is launched, but then break when the black powder lights.
- Breakable face plate
    - A plate will go on either side of the capsule.
    - The front plate on the capsule will break at the pressure from the black powder charge.
    - The hinges of the plate, or the plate itself can break.
- Mechanical/electronic
    - This would involve some fastener or front plate which would be controlled by a motor.
    - At landing, this retention will be removed.
- Magnetism
    - This will involve using electromagnets to hold in the capsule
    - The magnets will be deactivated once landed

6.1.4. Control Unit

6.1.4.1. Design Alternatives With Pros And Cons

At the center of the payload design exists the need for an on-board computer, controlling all sensory inputs and outputs for the entire system. Such a system must have the capability to manage inputs from sensors on the vehicle and receive basic remote commands from the team. Additionally, this processing unit must be able to intelligently control the actuation of motors for vehicle locomotion, as well as for control of the soil sampling system. These considerations and others are listed below.

Payload Processing Unit Requirements
1. Unit must fit in payload chassis 2. Unit must be easily programmed 3. Unit must have enough electronic inputs to facilitate multiple sensors 4. Unit must have enough electronic outputs to run all motors and actuators on the vehicle 5. Unit must have PWM digital outputs to allow for motion control 6. Unit should have standard power requirements – 3.3 or 5 V

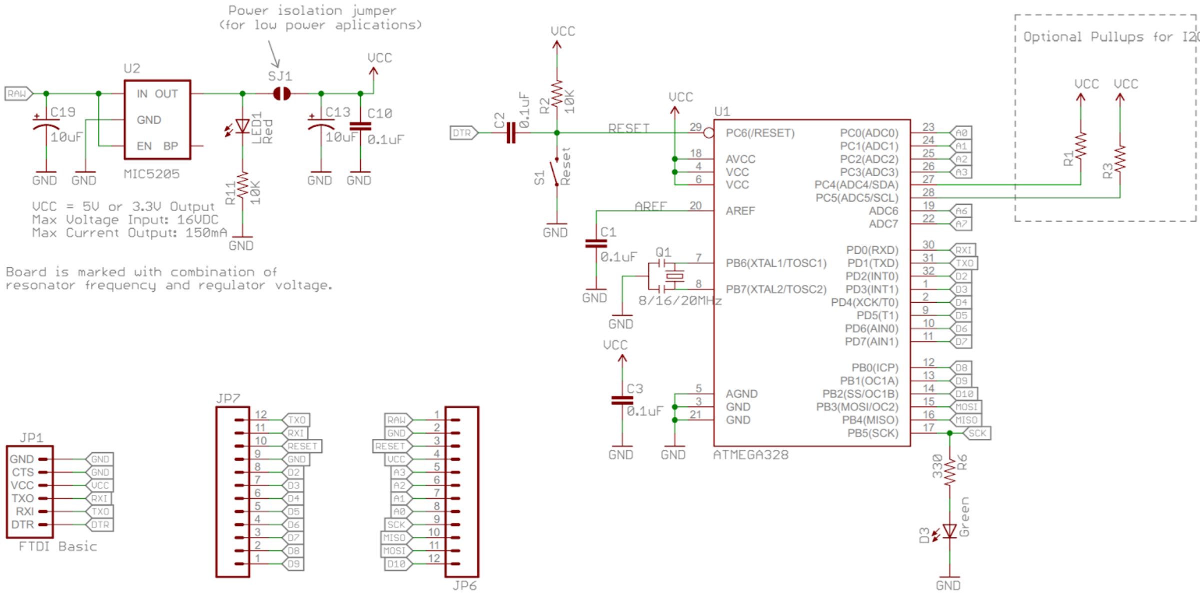
With these preliminary requirements, research was done on commercial-off-the-shelf (COTS) devices that would fulfill these needs. Emphasis was placed on products with sizeable user bases and online resources. A selection of components that were considered are listed below.

Product	**Inputs**	**Outputs**	**Power**	**Dimensions**	**Cost**	**Clock Speed**
Arduino Pro Mini	8 analog inputs; 14 digital inputs	14 digital outputs (6 PWM)	5V	1.3x0.7”	$9.95	16 MHz
Arduino Mega 2560	16 analog inputs; 54 digital inputs	54 digital outputs (14 PWM)	7-12V	4x2.1”	$45.95	16 MHz
Raspberry Pi 3	27 GPIO pins	27 GPIO pins (2 PWM)	5V (2.5A)	3.3x2.2”	$39.95	1.4 GHz
Raspberry Pi Zero	27 GPIO pins	27 GPIO pins (2 PWM)	5V (1.2A)	2.6x1.2”	$10.00	1 GHz

6.1.4.2. Leading Choice

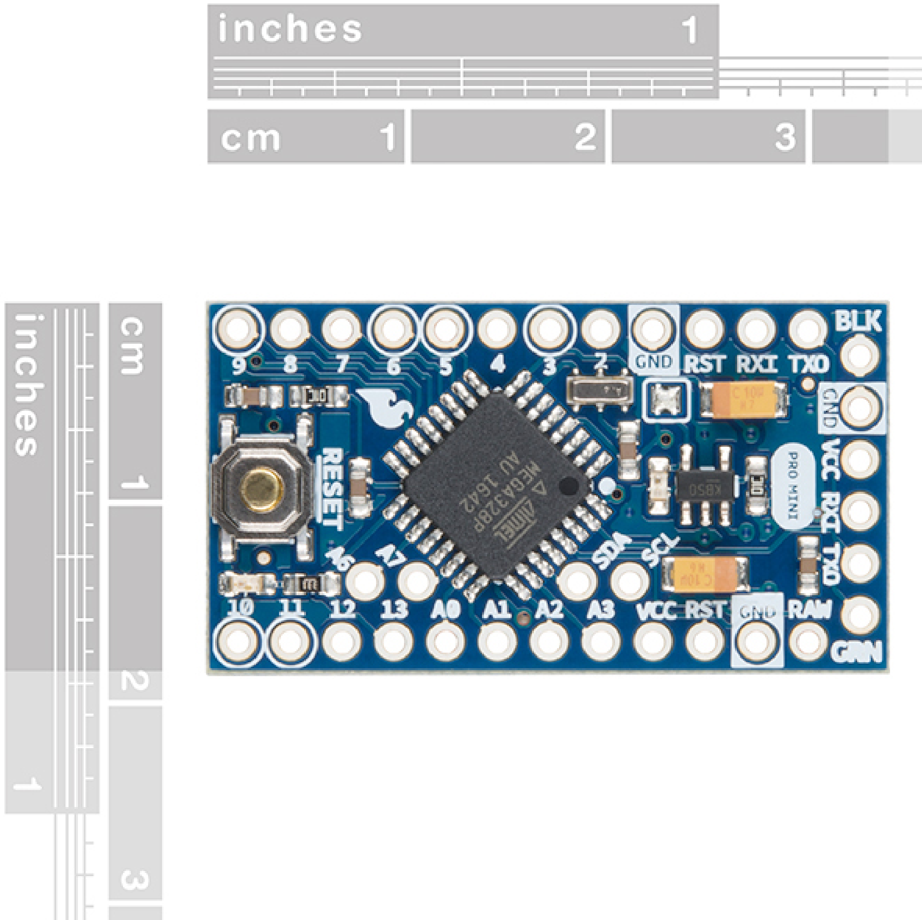
After evaluating the above choices, the Arduino Pro Mini was chosen as the best processing unit for this task. While some of the other choices have much more computing power, tasks such as motor control or raw sensor data input lend themselves to the use of a microcontroller. The Arduino Pro Mini also had the smallest footprint of all of the devices and was the most cost effective, while still having enough inputs and outputs to support the mission.

6.1.4.3. Wiring



Source: https://www.arduino.cc/en/uploads/Main/Arduino-Pro-Mini-schematic.pdf

6.1.4.4. Dimensional Drawing



Source: https://www.sparkfun.com/products/11113

6.1.4.5. Estimated Mass

The off-the-shelf weight of the Arduino Pro Mini is approximately 2 grams.

6.1.5. Motion Unit

6.1.5.1. Design Alternatives With Pros And Cons

One of the rover’s primary mission requirements is to autonomously move itself at least 10 feet away from the rocket. Historically, remotely deployed rovers have had many different varieties of locomotion systems. This specific mission has constraints that have informed preliminary design decisions of the rover’s motion system. These constraints include:

1. Must fit within active retention system on-board the rocket
2. Must traverse landing site obstacles—corn stalks, rocks, dirt, etc.
3. Must be controlled by on-board processing unit
4. Must meet rocket weight rocket requirements

To fit within these design constraints, a weighted decision matrix was employed for determining an optimal starting point for the motion system's configuration. This decision matrix can be seen below.

Motion System Decision Matrix							
Criteria	**Weight**	**4 Wheel Design**		**4 Motor "Tread" Design**		**2 Wheel Design**	
		Rating	Total	Rating	Total	Rating	Total
Fit within rocket	5	2	10	1	5	5	25
Control ease	2	5	10	4	8	3	6
Weight	3	2	6	1	3	4	12
Mobility	5	4	20	4	20	2	10
TOTAL:			46		36		53

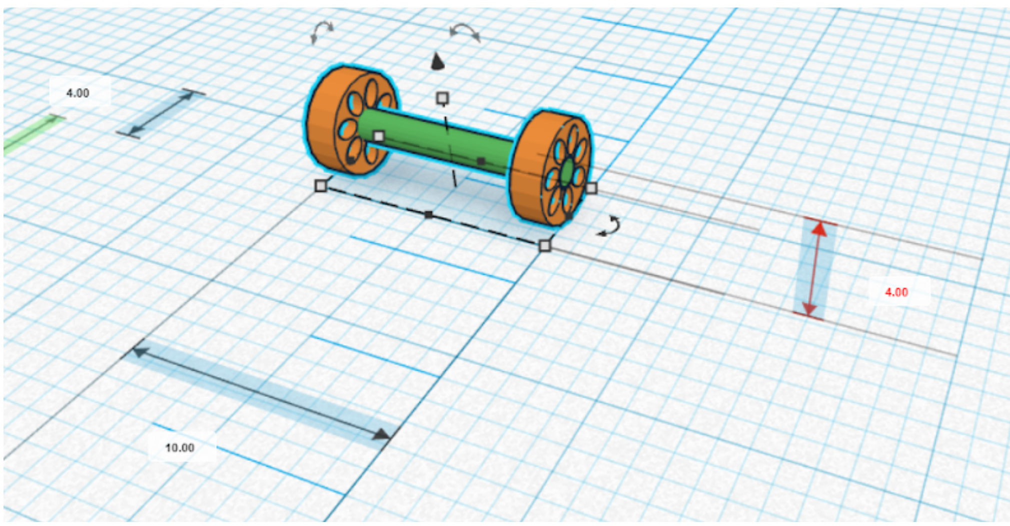
6.1.5.2. Leading Choice

After making the above considerations, it was determined that a 2-wheel design would provide the best platform for mission success. The relative ease with which this design can fit within the payload active retention system was a leading factor in making this decision. Relying on only 2 wheels allows for a physically narrow chassis. Not only is this more conducive to an easier fit within the rocket, it also allows for larger wheels to be used - there must be sufficient traction on the tires to efficiently move on the Alabama red clay the team expects the payload to deploy on. While a 4-motor design would be easier to navigate over obstacles, some of this benefit would be mitigated by the fact that each of the 4 wheels would have to be small enough to fit within the retention system.

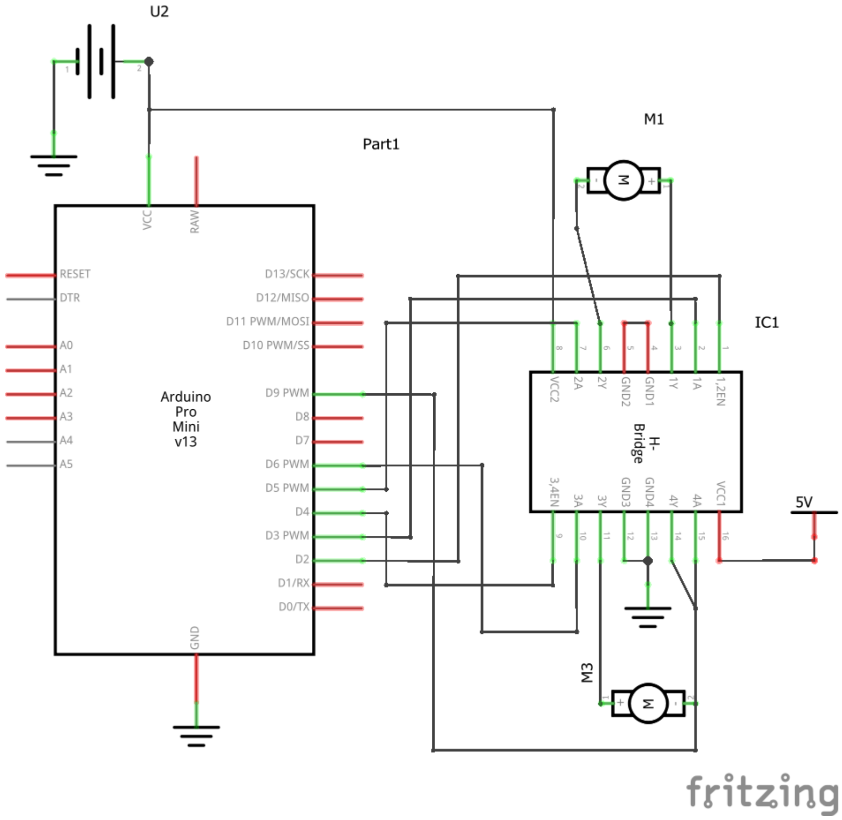
The potential instability caused by a 2-wheel design can also be mitigated by additional chassis design choices. For example, the chassis of the vehicle will be designed such that its center of gravity is below the axis of rotation for each wheel. Additionally, the soil sampling system will provide a third point of contact with the ground. This will eliminate the need for a feedback control system to balance the vehicle on two wheels.

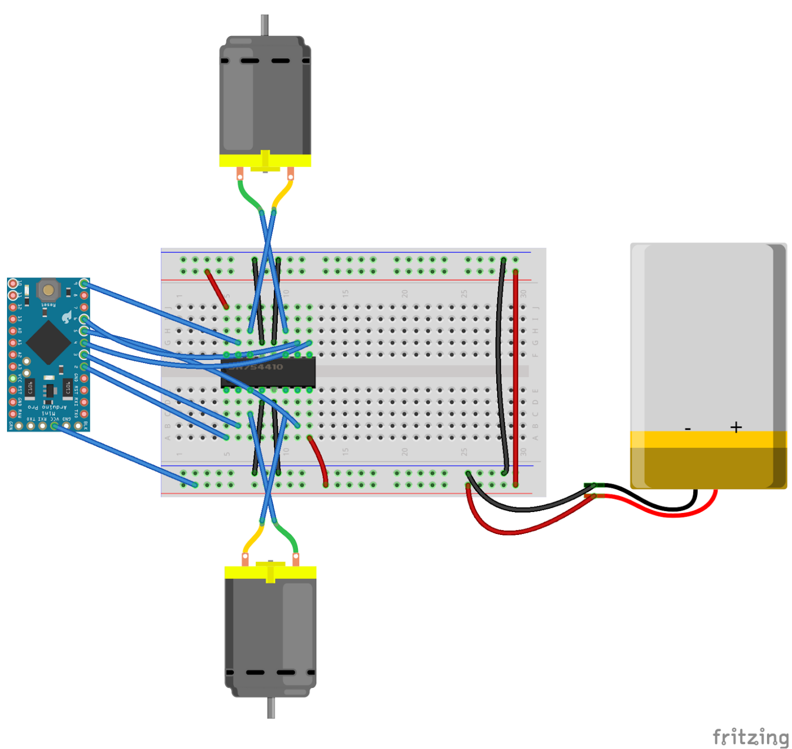
To drive the wheels, brushed DC motors will be employed. Other types of motors like brushless DC motors, stepper motors, and servo motors were considered, but it was determined that brushed DC motors would be best for this application. DC motors provide high torque, high efficiency, and are ubiquitous for small robotics applications. Stepper motors were considered for their superior control properties, but were ultimately discarded because of their poor performance under continuous rotation with varying load. Additionally, DC motors can be made easier to control with the addition of a simple feedback system with quadrature encoders. Brushed motors were chosen instead of their brushless counterparts for their simplicity. Brushless motors are often used in applications that require high-speed output. The rover in this application does not require this. Additionally, the control circuitry needed for proper operation of brushless motors was deemed more complicated than needed. Finally, brushed motors were found to be more cost-effective when compared to the other types of motors.

6.1.5.3. Dimensional Drawing



6.1.5.4. Wiring Diagram





6.1.5.5. Estimated Mass

The estimated weight of the motion system is about 350 grams.

6.1.6. Battery Power

6.1.6.1. Design Alternatives With Pros And Cons

There are many power supply categories available, and there are hundreds of options within each category. In order to narrow down the possibilities between the variety of options available to the team, a list of basic requirements was created. Although the list was not lengthy, it narrowed down the field of possibilities quite a bit. The requirements on this list are as follows:

1. The battery must be less than $30
2. The battery must be less than 200 grams
3. The battery must deliver a voltage of between 5 and 12 volts
4. The battery must have a capacity of 1000 maH
5. The battery, along with its mounting hardware, must have a width less than that of the chassis
    a. This ensures that the battery does not collide with terrain objects, causing damage to the battery
    b. This ensures that the battery will be able to fit inside the 4.815 inch diameter payload bay

Based on these requirements, the top five options were chosen and listed along with defining options in a spreadsheet which can be seen below

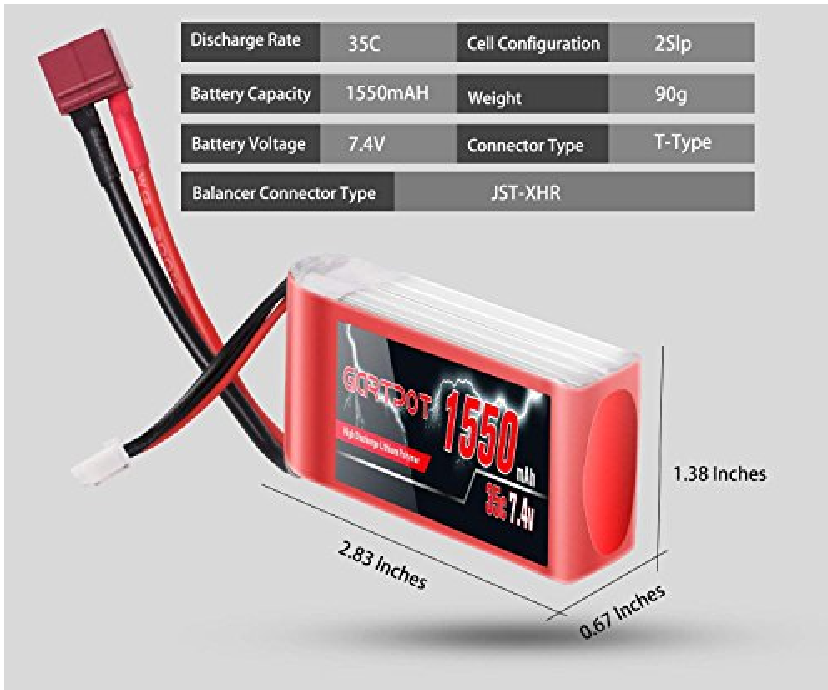
Battery (Supplier)	mAh	L (in)	W (in)	H (in)	m (g)	Price ($)	Volts (V)
Lithium Ion Battery -850mAh (Sparkfun)	850	1.75	1.37	0.236	20	$9.95	3.7V
Lithium Ion Battery - 2200mAh 7.4v (Sparkfun)	2200	5.45	1.87	0.965	206	$15.95	7.4 V
Turnigy 2200mAh 3S 25C Lipo Pack (Hobby King	2200	4.1	1.3	0.945	186	$10.99	11.1 V
Lithium Ion Battery - 1000mAh 7.4v (SparkFun)	1000	2.7	1.38	0.7	85	$9.95	7.4 V
GARTPOT 35C 2S LiPo Battery Pack (Amazon)	1550	2.83	1.38	0.67	89.8	$11.99	7.4 V

6.1.6.2. Leading Choice

Battery Supply Decision Matrix											
Criteria	Weight	Lithium Ion Battery -850mAh		Lithium Ion Battery - 2200mAh		Turnigy 2200mAh 3S 25C Lipo Pack		Lithium Ion Battery - 1000mAh		GARTPOT 35C 2S LiPo Battery Pack	
		Ranking	Total	Ranking	Total	Ranking	Total	Ranking	Total	Ranking	Total
Price	1	5	5	3	3	4	4	5	5	5	5
Weight	3	5	10	2	6	3	9	4	12	4	12
Voltage	3	1	3	5	15	4	12	5	15	5	15
Capacity	2	1	2	5	10	5	15	2	6	4	12
Size	4	4	16	1	4	2	8	4	16	4	16
Total			**40**		**38**		**48**		**54**		**60**

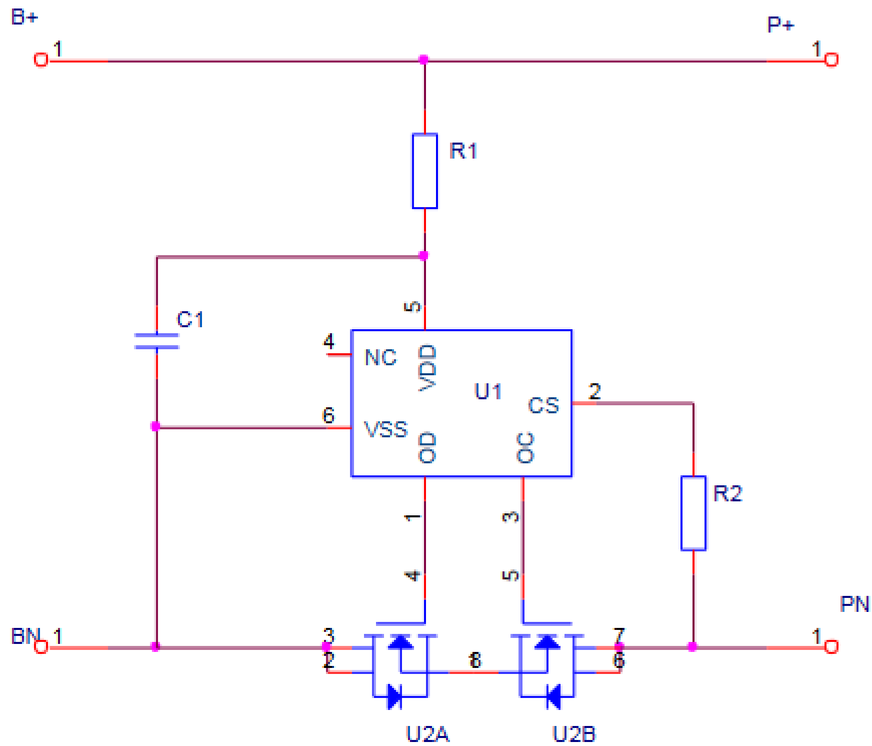
The leading choice for the power supply is GARTPOT 35C 2S LiPo Battery Pack with 1550 mAh for the battery. This option completes all of the requirements that the team has decided upon.

6.1.6.3. Dimensional Drawing



Source: https://www.wishlist.com/shop/product?asin=B07DR76XSV

6.1.6.4. Wiring Diagram



Source: https://cdn.sparkfun.com/datasheets/Prototyping/850mah-en-1.0ver.pdf

6.1.6.5. Estimated Mass

The estimated mass of the power supply is approximately 90 grams.

6.1.7. Payload Software and Algorithms

6.1.7.1. Programming Language Alternatives and Final Selection

The main programming language that will be used will be C++. This language is being chosen because of preexisting libraries that exist for the Arduino that are written in C++. The Arduino has an integrated development environment made specifically for programming the Arduino so that will be used in development. Using this IDE allows code to be compiled to the specific unit that we will be using. It also allows easy access to a wide array of user-created libraries that may prove useful to programming the payload.

The second choice in programming language that we could be using is Python. This language is very easy to both read and write, so that both beginner and more advanced programmers on the team will be able to learn and work with the software. Python is also a top contender because it is able to run on most of the alternatives that are being considered for computing power, such as the Raspberry Pi or Arduino.

6.1.7.2. Autonomous Payload Algorithm

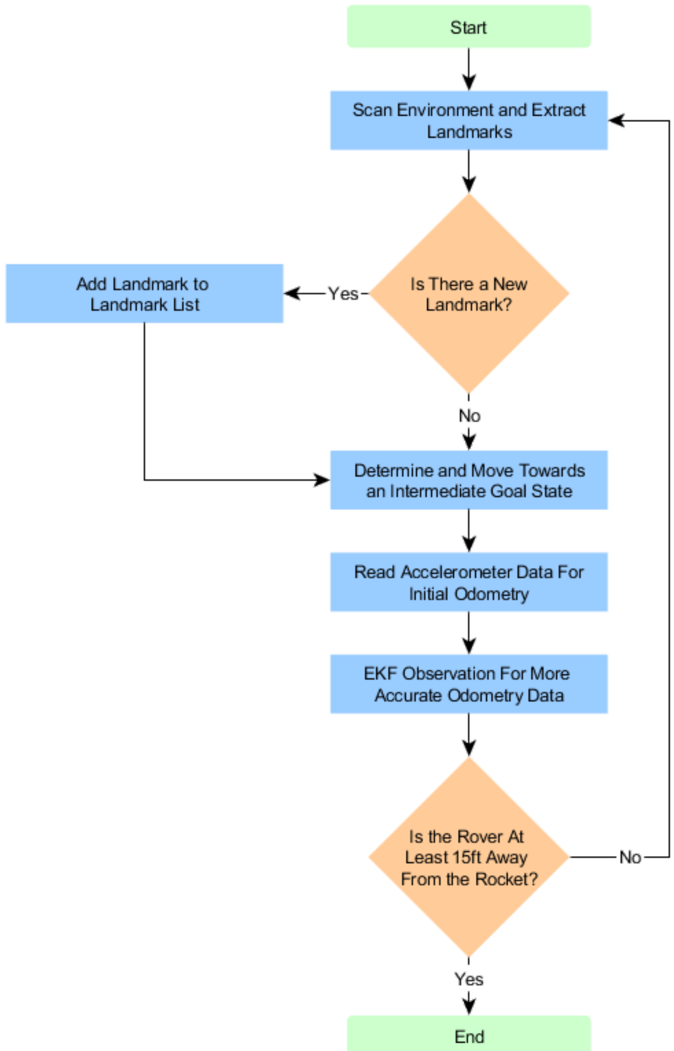
The autonomous path-planning algorithm will have to solve the problem of determining the rover's pose and configuration relevant to rocket components and other environmental objects, distinguishing between objects that are rocket components or environmental objects, determining a least cost path between an initial state and a calculated goal state, and finally estimating and measuring the rover's motion and final state. The algorithm must complete all of these tasks before it can administer commands to the motion unit that will ultimately move the rover to complete its mission. It is assumed that the rover will be placed in a static environment once deployed, that the position of the rover and location of the objects can be sufficiently mapped on a 2-D plane, and that the odometer along with the range sensing units have an inherent error.

In order to determine the rover's pose and configuration, range-finding sensors are necessary to construct an updated map, and must be able to store, compare, and align this map to a previous state. For an initial map taken right after rocket deployment, landmark extraction will be used to create new landmarks that can be used to compare subsequent maps to the initial map for accurate pose estimation. By relating where several landmarks are compared to an initial point to where they are at a later point allows for accurate pose estimation and is a solution to the erroneous odometer.

In order to distinguish between rocket components and environmental objects, rocket component characteristics, such as length and diameter, will be stored and compared to specific objects and landmarks in the environment. Knowing that rocket body components are primarily cylindrical (excluding the nose cone and the lower airframe with fins), a map can be extracted from the range-finding sensors where relatively long and linear boundaries will be seen. Using algorithms like RANSAC (Random Sampling Consensus), a best fit line can be made for each of the scanned rocket components giving easy to follow landmarks, and important parameters, such as landmark length and distance, which can then be easily compared to the already known rocket dimensions.

Calculating a least cost path to a determined end goal will involve the search of a point that is not in the direction of any rocket components and is a non-occupied position in free space. Given the assumed 2-D layout of the terrain, the least cost path should be a line that connects the initial and end point that passes only through free space. Predicting and measuring the rover's pose after a movement is an inherently difficult task. The range-finding sensors on the rover will only be accurate to a certain degree, the measurements from the inertial measurement unit (IMU) will only be so accurate when calculating velocity and position, and the terrain will not be 2-D. Accurate measurements and estimation of the rover's pose can be made if the range-finding sensors, the IMU, and previously identified landmarks are used together. Using a method called the Extended Kalman Filter (EKF), the position of the rover can be most accurately determined by combining odometry data with observed landmarks. First, the robot's odometry data is used to estimate the rover's position. Then, the rover's environment is subsequently mapped and landmarks seen previously are used to estimate the rover's position.

The rover's autonomous path-planning algorithm will involve a simplified and discrete implementation of a simultaneous localization and mapping algorithm (SLAM). SLAM involves the continuous reading and interpretation of sensor data into both localization and mapping information that must be continuously refined for an accurate estimate of the rover's position. This involves firstly of landmark extraction that will be used for localization, data association to relate different maps, state estimation to estimate rover pose, and finally the addition of any new landmarks found in the environment. Below is a simple flowchart diagram of the described autonomous path-planning algorithm.



6.1.8. Range-Finding Sensors

6.1.8.1. Design Alternatives With Pros and Cons

Range-finding sensors will be necessary for object detection, map construction, landmark extraction, and localization of the rover. Due to the limited computational resources of the selected microcontroller, the range-finding sensor will have to be non-visual and must be capable of interfacing with the microcontroller. Currently, there are three different methods that allow for cheap and relatively small range-finding sensors: infrared, sonar, and LIDAR. Infrared sensors allows for primarily short-range range-finding, are relatively cheap, and be used to distinguish material type. Sonar sensors have medium-range range-finding, are simple to set-up, relatively cheap, has a high pinging frequency, and can detect point objects. LIDAR sensors are accurate and long-range, but are relatively expensive and bulky.

Product	Sensor Type	Range	Accuracy	Weight	Cost
LIDAR-Lite v3	LIDAR	130ft	.4in	22g	$129.99
LIDAR-Lite v3HP	LIDAR	130ft	.4in	34g	$149.99
GP2Y0A21YK0F	IR	2.6ft	.1in	3.5g	$13.00
HC-SR04	Sonar	13ft	.1in	20g	$1.89
HY-SR05	Sonar	14.5ft	.1in	20g	$2.00

6.1.8.2. Leading Choice

The leading choice for the range-finding sensor is the LIDAR-Lite v3 due to its extensive range and accuracy that will be more than necessary to meet the sensor range requirement. The LIDAR-Lite v3 is also easy to interface with the Arduino microcontroller. This extensive range with accuracy, however, comes with a high cost of funding and weight.

	Range	Accuracy	Weight	Cost	Total	
Weight	10	5	8	3	26	**Rank**
LIDAR-Lite v3	10	3	3	1	17	1
LIDAR-Lite v3HP	10	3	2	1	16	2
GP2Y0A21YK0F	2	5	5	2	14	5
HC-SR04	3	5	3	3	14	4
HY-SR05	4	5	3	3	15	3

6.1.8.3. Estimated Mass

The estimated mass of the range-finding sensor is 22 grams for the individual sensor without any fasteners, connections, or supporting actuators.

6.1.9. Soil Collection

6.1.9.1. Design Alternative Summaries

General Strategy: This method has three steps. First, loosen the soil - preferably with no grass nearby. Next, collect the required amount of soil. Finally, contain it on-board the rover. Several strategies were developed to accomplish these steps.

Comb and Hopper: The first, and by far the simplest, is to attach an extending container (a prism or cylinder) to the chassis of the rover. This is a passive apparatus that requires little design and and easily 3D-printed and tested. A set of combs will precede the hopper that will collect and contain the soil.

Drill: This method involved drilling via an auger or drill bit into the ground and extracting a sample. Seeing as there is no requirement for depth over sheet mining, this method is likely unfeasible especially since there exists the concern of the rover's ability to counter the digging force. This method was tossed aside on account of its complexity, which would likely cause size restriction. However, this method could be beneficial for the future should requirements change.

Clamshell Scoop: This method involved using a quasi clam-shell system to grab a sample from a predetermined location around the rover. This would require multiple actuators to control the height of the arm and the motion of one shell, so it was also not chosen due to its complexity. However, this method could be useful depending on what type of environment the rocket lands in.

6.1.9.2. Design Alternatives With Pros And Cons

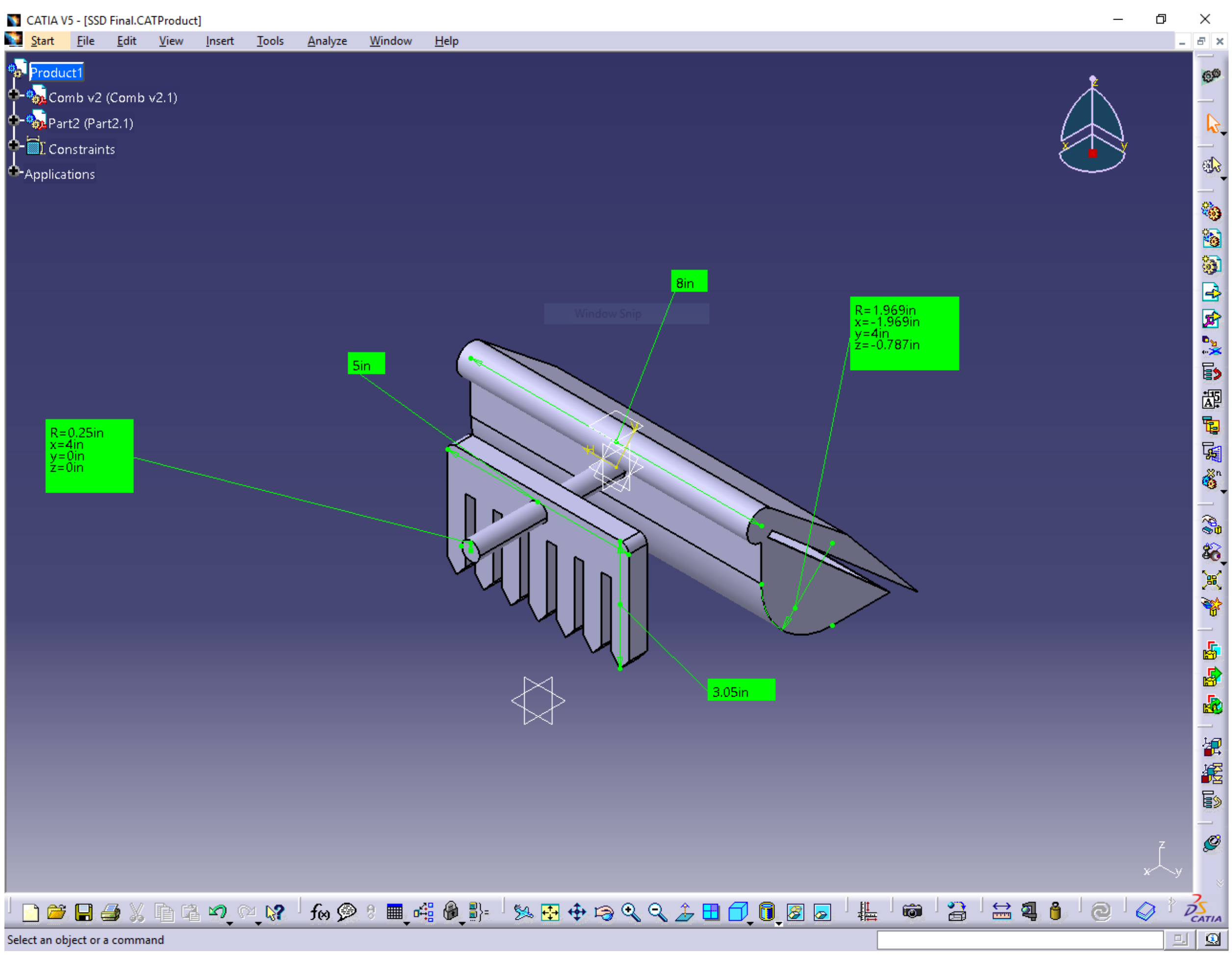
Design	Pros	Cons
Comb and Hopper Design	● Light weight ● Non-Electric Architecture ● Works well with Alabama Red Clay ● Adaptable ● Testable ● Acts like a third wheel for stability	● Collection is dependent on terrain
Drill	● Reliable ● Solid construction	● Expensive ● Design intensive ● Torque required to drill in would require counterforce, perhaps more than suppliable by the weight of the robot
Clamshell Scoop	● Can perform on any terrain	● Complicated ● Involves several space consuming

		actuators

6.1.9.3. Leading Choice—Comb and Hopper Design

This design shall resemble that of the rear scoop on a backhoe loader (see https://www.cat.com/en_US/products/new/equipment/backhoe-loaders/center-pivot/18390350.html). Further up the extending arm two combs will act as hoes to loosen the ground as the rover drives forward. The purpose of two combs is that we can offset their teeth and thus loosen practically all the soil the rover drives over. As the scoop passes over the loosened soil, a flap, attached inside the scoop via a rubber band will extend beyond the scoop and feed the soil into the hopper.

6.1.9.4. Dimensional Drawing



6.1.9.5. Estimated Mass

In order to counteract any bouncing forces that the hopper might experience, the system shall have some weight to it. This is estimated to be 227- 907 grams depending on how much is spared for this apparatus.

7. Project Plan

7.1. Requirements Verification

7.1.1. General Requirements Verification Plan

General requirements will be met by ensuring that each subteam operating within the scope of the project are aware of their respective tasks, plans, and procedures. In addition, all team members will become familiar with tasks, plans, and procedures of other subteams in order to understand how each team is interconnected and affects the project as a whole. Furthermore, members will be able to work in multiple disciplines and participate in subteams that they are not directly assigned to in order to make them a more rounded individual and gain a broader understanding of everything taking place within the group. Lastly, everyone will gain firsthand experience in design, construction, and launching of high powered rockets prior to the completion of the competition in Huntsville, Alabama. By ensuring the transparency and fluidity of group work, team members will cooperate in a manner that mitigates any risks to the general requirements.

7.1.2. Vehicle Requirements Verification Plan

Vehicle requirements will be verified by conducting a series of ground tests and electronics tests followed by at least one subscale test flight and one full scale test flight. Ground testing will be done before any test flights to ensure that ejection charges are appropriately sized and supply enough pressure to successfully deploy the drogue and main recovery gear. Electronics testing will also be done before test flights to ensure that our circuits are operating properly without any indication of a short or open in the system. [In place of energetics, we will use light bulbs as an indication that the circuit is complete and the bulbs illuminate, signaling an ejection charge]. A minimum of one subscale flight will be performed to ensure that our vehicle is stable and follows the predicted flight path, our electronics operate as intended, and our recovery devices deploy as expected. It will also give us an opportunity to test our experiment. Lastly, a full scale flight test will be performed to further validate the vehicle's stability, flight path, electronics and payload systems, and recovery. It will give us an additional chance to properly size our ejection charges, become familiar with the launch procedures and checklists, and give the team practice using GPS and telemetry receivers for vehicle tracking.

7.1.3. Recovery System Requirements Verification Plan

The recovery system will be tested on the ground as well as in at least one subscale flight and one full-scale flight. The avionics will remain the same for all flights, and we will ground test with them to ensure that they work as designed. The team will ensure they properly ignite the ejection charges, properly pressurize the airframe sections enough to break the shear pins, and fully deploy the recovery gear. Furthermore, before any launches happen each parachute will be subjected to a drop test in order to determine inflation time and altitude loss from the time it is deployed to the time it fully inflates.

7.1.4. Experiment Requirements Verification Plan

In order to verify the experimental requirements, extensive testing will be done to ensure that the payload can eject properly, travel away from the rocket consistently, and obtain soil samples. The rover will be tested by having it travel out of different positioning of the rocket components to a distance of over 20 feet away. This will be done in levels of increasing difficulty to make sure that the rover will function in any scenario. The soil collection system will be tested by having the rover dig in various soil conditions, such as bare dirt, grassy dirt, and clay. Rover deployment will be tested numerous times from a landed rocket configuration. Once travel distance, soil collection, and deployment have been tested thoroughly and work as intended, all three components will be tested together from a random rocket landing configuration. The payload will also fly on the full scale test flight to allow for more accurate testing on the robustness and feasibility of the payload as a whole.

7.1.5. Safety Requirements Verification Plan

The safety team prioritizes the wellbeing of all involved with the launch when making its requirements. The requirements of the safety team are verified by how well the people involved with the launch follow and are aware of safe procedures and how safe the launch is overall. In order to ensure all working on this project understand the safe practices which are relevant to it, all team members will sign the team safety statement from section 5.14. This statement is an affirmation by team members that they will comply with all relevant laws and regulations and the NAR High Power Rocketry Safety Code and will obey all instructions given by the Safety Officer and Range Safety Officer, whether verbally or through team safety documents. It also affirms that members are aware that safety breaches are dangers which can completely halt the launch of the rocket. As well as this, documents created by the safety team for this project and relevant safety resources (such as materials safety data sheets) will be discussed by the safety officer in front of the entire project team to keep them aware of proper project procedures and any dangers associated with high-power rocketry they may not have been aware of. All individual requirements will require different test, analysis, demonstration, or inspection to verify the requirement, as set forth by each requirement.

7.2. Team Derived Requirements

7.2.1. Vehicle Team Derived Requirements

The vehicle will follow these team derived requirements:

1. The vehicle will deliver the payload to an apogee altitude of 4,950 +/- 100 feet above ground level (AGL).
2. The vehicle will feature a retainment system which is able to maintain the condition of the payload during flight so that it remains in good condition to be fully operational for the next flight.
3. Upon reaching the ground, the vehicle will expel the payload such that it may operate autonomously without physical contact with the launch vehicle.
4. The vehicle will carry at least two commercially available, barometric altimeters for recording the official altitude.
5. Each altimeter will be armed by an arming switch that is accessible from the exterior of the rocket airframe when the rocket is in the launch configuration on the launch pad.
6. Each altimeter will have a separate, dedicated power supply.
7. Each arming switch will be capable of being locked in the ON position for launch (i.e. cannot be disarmed due to flight forces).
8. The launch vehicle will be designed to be fully recoverable and reusable. Reusable is defined as being able to launch again on the same day without repairs or modifications.
9. The launch vehicle will not horizontally drift more than 2000 feet from where it launches.
10. The launch vehicle must be able to maintain full functionality when launched on a day with at least 20 mph wind speeds.
11. The launch vehicle will achieve its objective using three sections in a dual-deployment recovery configuration.
12. The launch vehicle will be limited to a single stage.
13. The launch vehicle will be capable of being prepared for flight at the launch site within 3 hours of the time the Federal Aviation Administration flight waiver opens.
14. The launch vehicle will be capable of remaining in launch-ready configuration at the pad for a minimum of 1 hour without losing the functionality of any critical on-board components.

15. The launch vehicle will be capable of being launched by a standard 12-volt direct current firing system.
16. The launch vehicle will require no external circuitry or special ground support equipment to initiate launch (other than what is provided by Range Services).
17. The launch vehicle will 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).
18. Pressure vessels on the vehicle will be approved by the RSO and will meet the following criteria:
    a. The minimum factor of safety (Burst or Ultimate pressure versus Max Expected Operating Pressure) will be 4:1 with supporting design documentation included in all milestone reviews.
    b. Each pressure vessel will include a pressure relief valve that sees the full pressure of the valve that is capable of withstanding the maximum pressure and flow rate of the tank.
    c. Full pedigree of the tank will 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.
19. The total impulse provided by the launch vehicle will not exceed 5,120 Newton-seconds (L-class).
20. The launch vehicle will have a minimum static stability margin of 2.0 at the point of rail exit. Rail exit is defined at the point where the forward rail button loses contact with the rail.
21. The launch vehicle will accelerate to a minimum velocity of 52 fps at rail exit.
22. The launch vehicle will be proven to be airworthy via the construction and fully-successful operation of a 0.45x scale model by December 9, 2018.
23. The launch vehicle will utilize a single solid motor that does not expel titanium, is not forward-firing, and does not utilize friction fitting.
24. The full-scale rocket will be successfully launched and recovered in a test flight by March 3, 2019, configured in the same configuration that will be used on the final launch day. The purpose of this 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 this flight:
    a. The vehicle and recovery system will have functioned as designed.

b. The payload will be flown and retrieved in good condition.
c. No safety hazards are created by the launching of the full-scale vehicle other than the hazards introduced by any high power rocket.
d. 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 simulates, as closely as possible, the predicted maximum velocity and maximum acceleration of the launch day flight.
e. The vehicle must 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. Additional ballast may not be added without a re-flight of the full-scale launch vehicle.
f. After successfully completing the full-scale demonstration flight, the launch vehicle or any of its components will not be modified without the concurrence of the NASA Range Safety Officer (RSO).
g. If the Student Launch office determines that a re-flight is necessary, then another flight of the full-scale vehicle will be conducted before March 28th, 2018.

25. Any structural protuberance on the rocket will be located aft of the burnout center of gravity.
26. Vehicle Prohibitions
    a. The launch vehicle will not utilize forward canards.
    b. The launch vehicle will not exceed Mach 1 at any point during flight.
    c. Vehicle ballast will not exceed 10% of the total weight of the rocket.

7.2.2. Payload Team Derived Requirements

The payload team has six specific requirements for the rocket beyond the scope of the NASA guidelines as well as the necessary mission of the payload. They are as follows:

1. Successfully deploy the rover

   In order to successfully deploy the rover it shall be retained and secure in the rocket during flight, be ejected from the rocket once on the ground, and be oriented correctly during ejection.

   a. The rover should be secure in the rocket so that it stays in the rocket, and also stays in place in the rocket. For it to be retained and secure during flight, it must be able to withstand normal and abnormal forces during flight.
   b. It must be ejected out of the rocket. It should be ejected in a way that will not damage the rover. It must be ensured that it does not get stuck or

damaged from hitting the ground when being ejected. The system should also be reliable and able to withstand flight forces. If explosives are used for ejection, there should be redundant firing systems in case of a misfire.

c. For the rover to be correctly oriented during ejection it must either be able to orient itself, or be ejected and placed in the right orientation. Currently, the rover can be ejected in any orientation and still be able to operate.

2. Rover moves at least 20 feet away from the closest rocket component.

   The rover must drive at least 10 feet away from any part of the rocket. Therefore, an object detection method will locate the closest part of the rocket and the rover will drive away from that part. To ensure the minimum distance is reached, the rover will drive a distance of 20 feet before beginning soil collection. The wheels and drivetrain of the rover will be developed so that movement on Alabama red clay is as smooth as possible and there is no risk of flipping the rover or damaging the electronics systems.

3. A soil collection system will be used which shall effectively loosen the soil such that a hopper mounted on the payload can collect and contain a 10mL soil sample.

   The rover will first loosen the soil by moving back and forth, then will collect it into a hopper, in which it can be permanently stored.

4. Sum of the payload components must not exceed six pounds.

   Placing the payload in the rocket requires that the payload itself be small and light. A heavy payload can have drastic effects on the performance of the rocket. As such, the team as a whole decided that six pounds was sufficient enough to perform the actions necessary for the competition while also not overly affecting vehicle performance.

5. Battery supply power system must operate for at least three hours.

   Although the rocket will not be in the air for three hours, there are many factors that may influence the time between the rocket setup and the launch. Since the team members will be unable to interact with the rocket after it has been set for launch, the payload must be able to withstand the potentially long amount of time it may sit, untouched. Three hours was decided to be a sufficient amount of time to cushion the launch and thus, the battery must last at least three hours. This includes the time that the rover will need to be powered on after successful deployment from the launch vehicle. The battery shall be safely stored on-board the rover at all times.

6. The LIDAR sensor used on the payload will be able to detect objects within at least a 25-foot radius from the payload.

   A sensor will be mounted to the payload which will allow it to detect objects in the surrounding environment so that it can determine whether or not it has travelled the appropriate distance before sampling the soil. This radius value is chosen to accompany the 20 foot radius from the second payload derived requirement.

7.2.3. Recovery Team Derived Requirements

The recovery system will be tested to operate within the following requirements:

1. The launch vehicle will stage the deployment of its recovery devices, where a drogue parachute is deployed at apogee and a main parachute is deployed at an altitude of 700 feet.
2. If the drogue parachute does not immediately deploy at apogee, the secondary altimeter will detect this and eject the parachute at one second after reaching apogee.
3. If the main parachute does not immediately deploy once the vehicle reaches 700 feet AGL, the secondary altimeter will detect this and eject the parachute at 650 feet AGL.
4. A successful ground ejection test for both the drogue and main parachutes will be done prior to the initial subscale and full-scale launches.
5. At landing, each independent sections of the launch vehicle will have a maximum kinetic energy of 75 ft-lbf.
6. The recovery system electrical circuits will be completely independent of any payload electrical circuits.
7. All recovery electronics will be powered by commercially available batteries.
8. The recovery system will contain two redundant, commercially available altimeters.
9. Each altimeter will have a separate and distinct power source and wiring system.
10. On no occasion will the motor be ejected.
11. Removable shear pins will be used for both the main parachute compartment and the drogue parachute compartment.
12. Recovery area will be limited to a 2000 foot radius from the launch pads.
13. An electronic tracking device will be included on the vehicle to transmit the location of the tethered vehicle during descent.
14. The recovery system electronics will not be adversely affected by any other on-board electronic devices during flight (from launch until landing).
    a. The recovery system altimeters will be physically located in a separate compartment within the vehicle from any other radio frequency transmitting device and/or magnetic wave producing device.
    b. The recovery system electronics will be shielded from all onboard transmitting devices, to avoid inadvertent excitation of the recovery system electronics.

c. The recovery system electronics will be shielded from all onboard devices which may generate magnetic waves (such as generators, solenoid valves, and Tesla coils) to avoid inadvertent excitation of the recovery system.
d. The recovery system electronics will be shielded from any other onboard devices which may adversely affect the proper operation of the recovery system electronics.
e. The recovery system electronics will be at a suitable distance from any transmitting devices stored in the payload bay or any e-matches.

7.2.4. Safety Team Derived Requirements

The safety team has derived requirements for the rocket considering the scope of the NASA guidelines and the mission of the payload. Each derived requirement will follow the verification plan set forth by the individual task identifying whether test, analysis, demonstration, or inspection is required. They are as follows (in no particular order):

1. Achieve full compliance with local, state, and federal laws and maintain a positive reputation as a team which prioritizes lawful rocketry. This will be a binary test in acknowledging and following the laws set forth.
2. Provide each team member with the knowledge required to work safely with high-power rockets and any hazardous materials associated with these rockets. This will be accomplished by guaranteeing that members have signed and acknowledges all rules and safety set forth before working with construction or the launch.
3. Create and utilize fully-functional hazard analysis and contingency plans to both prevent and react optimally to any emergency situations. This will be a binary requirement in having a backup plan for when failure occurs.
4. Have an organized set of procedures which can be followed at all times to enforce safe construction and launch practices and to be fully prepared for any emergency. This includes adhering to the team safety statement and following established safety checklists for pre-launch, launch, and post-launch, similarly verified from contingency plans.
5. Help create other derived requirements and help prove why they are necessary to help justify why the requirement exists, and how it will be verified or attempted with.

7.2.5. General Team Derived Requirements

The general requirements for the team as a whole, as agreed on unanimously by the team members are as follows:

1. Create and maintain a functioning website and social media profile with regular project updates, documents, and milestones that highlight our progress as it relates to the scope of the project.
2. Not spend any money out of pocket using personal funds without a means of being fully reimbursed through Purdue SEDS or some other school related organization.
3. Have a successful subscale flight and recovery on a subscale motor while simulating a payload system.
4. Have a successful full scale test flight and recovery on a full scale motor while carrying a fully functional payload system.
5. Successfully design, build, and test a working on-board payload capable of meeting the requirements derived by the team and presented to us by NASA within the 2019 NASA Student Launch Handbook.
6. Fulfill and exceed all educational engagement requirements presented to us by NASA within the 2019 NASA Student Launch Handbook.
7. Have a functioning and attractive rocket booth that highlights the work done by our team, including a functional payload on display for viewers to see and a full scale rocket for spectators to interact with.
8. No disqualification by any means whatsoever.
9. No breaches of safety by any means whatsoever.
10. Successful completion of the competition in Huntsville, Alabama.

7.3. Budgeting and Timeline

7.3.1. Line Item Budget

7.3.1.1. Full Scale Rocket

Rocket Parts	Unit Cost	Quantity	Total
5:1 5" Von Karman FWFG Nosecone	108.95	1	108.95
5" Stepped AL Avionics bay lids	16	6	96
5" FWFG Airframe, 30" long	85	3	255
Custom Airframe Slotting, 3/16" wide, 15" long	6	3	18
5" FWFG Switch Band, 2" long	7	2	14
5" FWFG Coupler, 12" long	53	2	106
3" FWFG Motor Tube, 30" long	50	1	50
1/8" G10 FG Centering Ring	9	2	18
1/2" Plywood Centering	5	2	10

3/16" G10 FG Fins 6" tall, 15" root, 4" tip, 10" sweep	20	3	60
Skyangle Cert 3 XL Parachute	189	1	189
Skyangle Cert 3 Drogue Parachute	27.5	1	27.5
18" x 18" Nomex Parachute Protector	10.95	2	21.9
40' Long Double Looped Kevlar Tether	61	2	122
Large Rivet Package	4.5	2	9
1515 Series Rail Button Package of 4	7.95	1	7.95
75mm AeroPac Flanged Motor Retainer	50	1	50
5"/75mm SC Precision Thrust Plate	55.59	1	55.59
Aerotech 75mm 3G Hardware Set	450	1	450
Aerotech 75mm 3G L1520-T Reload	199	2	398
			2066.89

7.3.1.2. Sub Scale Rocket

Item	Unit Cost	Quantity	Total
5:1 3" Ogive Standard Wall FWFG Nosecone	58.95	1	58.95
3" G10 FG Avionics Bay lid	10	6	60
3" FWFG Standard Wall Airframe, 60" long	100	1	100
Custom Airframe Slotting, 3/32" wide, 9" long	5	4	20
3" FWFG Switch Band, 1" long	4	3	12
3" FWFG Coupler, 6" long	15	2	30
38mm FWFG Standard Wall Motor Tube, 30" long	32	1	32
1/8" G10 FG Centering Ring	6	2	12
1/4" Plywood Centering	3.55	2	7.1
3/32" G10 FG Fins	10	3	30
Top Flite 50" Main Parachute	26.95	1	26.95
Top Flite 15" Drogue Parachute	6.95	1	6.95
9" x 9" Nomex Parachute Protector	6.95	2	13.9
20' Long Double Looped 5/16" Kevlar Tether	26.99	2	53.98
Medium Rivet Package	3.5	2	7
1010 Series Rail Button Package of 4	6.95	1	6.95
38mm AeroPac Motor Retainer	25	1	25

CTI 38mm 4G Casing	50.6	1	50.6
CTI 38mm 4G I470 WT Reload	55	1	55
			608.38

7.3.1.3. Travel

Item	Unit Cost	Quantity	Total
Hotel Room	240	5	1200
Gas	40	18	720
			1920

7.3.1.4. Avionics

Item	Unit Cost	Quantity	Total
TeleMetrum - Altus Metrum	$300.00	1	$300.00
TeleDongle - Altus Metrum	$100.00	1	$100.00
RRC3+ Sport - Missile Works	$70.00	1	$70.00
Electronic Match	$1.00	25	$25.00
ALTIMETER MOUNTING POSTS	$3.68	2	$7.36
6g Charge well	$8.50	2	$17.00
Missle Works USB Interface Module	$32.95	1	$32.95
Pair Programming / Debug Cable	$5.00	1	$5.00
9V Battery Clip	1	1	1
9V Battery - Duracell	$6.00	4	$24.00
9V Battery Holder	$2.50	1	$2.50
Dual Altimeter Wiring Kit - Binder Design	$20.00	1	$20.00
3/4" Panel-Mount Key Switch - McMaster-Carr	$14.10	2	$28.20
National Hardware 1 Count 1/4-in to 20 x 2.5-in Stainless Steel Plain Eye Bolt with Hex Nut	$1.00	4	$4.00
Hillman 0.375-in x 36-in Standard (SAE) Threaded Rod	$2.90	2	$5.80

7.3.1.5. Payload

FULL SCALE			
Item	Unit Cost	Quantity	Total
Arduino Pro Mini	13.00	1	13.00

Battery	20.00	1	20.00
LIDAR sensor	130.00	1	130.00
Motors	25.00	2	50.00
Soil Collection System Materials	~50.00	1	~50.00
Antennae	30.00	2	60.00
Wheels	20.00	2	40.00
Black Powder	20.00	1lb	20.00
3D Printed Material (Payload Bay and Chassis)	20.00	1	20.00

7.3.1.6. Branding

Item	Unit Cost	Quantity	Total
T-Shirts	15	24	360
Polos	30	24	720
			1080

7.3.1.7. Social

Item	Unit Cost	Quantity	Total
Website	0	1	0
Instagram Boost	1	5	5
Facebook Boost	1	3	3
			8

7.3.2. Funding Plan

7.3.2.1. Sources Of Funding

Assuming that the team requires around $11000, there will be three primary ways funds will be made to support the NASA PSP-SL project:

1. Skip-a-meals and Campus Fundraisers: Skip-a-meals are social events where individuals can mention the name of our organization at a designated food establishment and a percentage (usually half) of money they spend at the establishment will be given to the team. These events usually last for a whole afternoon.

2. Non-profit and Educational Grants: Although these can easily fund a large chunk of our expected required budget, experiences have shown that finding private grants that specifically meet the criteria of a student organization can sometimes be hard to find. The team will consult both private companies and school

departments here on campus for this. SEDS, as our supervising organization, has provided us with some starting funds that will allow us to purchase materials for the subscale rocket, and potentially some of the required parts for the full scale, but nothing beyond that. We have identified a few grants that we have applied to, but are still awaiting responses from organizations.

3. Company Sponsorship and Community Donations: These sources of income are very much dependent on personal outreach and social image. We are reaching out to companies that we are buying parts from to sponsor our project and make monetary donations. In return, we will have their logo somewhere on the materials we bring to Huntsville. We also are using a GoFundMe page to produce funds for the project from interested community members who are invested in the project.

Our current goal is to have almost all of our methods of fund acquisition determined before the end of the fall semester. If the team is attempting to apply for grants, paperwork can take significant time to process. Doing grant applications in advance, especially if our team needs the money to be able to manufacture the rocket, is going to be very important. Our group has not created a chart for how much money will be made in each of these three categories, as the amounts can vary significantly. It is also important that everyone on the team reaches out to anyone they know who may have leverage to have a company sponsor us, or better yet, make a personal donation.

Events could not be organized earlier in the year, so the chart below is still only an estimate. This chart differs from the proposal's funding plan in that we now have a category for our crowdfunding campaign. Consultation from the director of digital fundraising on Purdue's campus has verified that $3500 is a reasonable amount to expect from our campaign.

Fund Source	**Funds Generated**
SEDS Treasury	$700
Restaurant Socials (4 throughout year)	$800 ($200 each)
Federal and Private Grants	$3000 (across multiple grants)
Crowdfunding Campaign	$3500
Company Sponsorship	$3000 (in materials)
TOTAL:	$11000

7.3.2.2. Allocation Of Funds

As of right now, and as it shall be until the end of November, individuals on the team will purchase parts using their own money. Once parts are ordered by an individual, they must keep their receipt or other proof of purchase. In addition, those who order an item must sign and submit a payment request reimbursement certificate, stating that the expenses presented for reimbursement are legitimate. The purchases will then be reimbursed by PSP-SL's mother organization, the Students for the Exploration and Development of Space, in collaboration with the funding subteam. It is worth noting that although we will likely receive funds from crowdfunding and restaurant socials earlier than company sponsorships, they have been allocated to expenses not directly involved with the rocket. This is because many companies and grants will require approval of the usage of the funds they provide.

Funding Type	When funds will be generated	Allocated to:
SEDS Treasury	Currently Available	Sub-scale and Full-scale rocket
Restaurant Socials	Begin late-November, end late-January	Branding materials and merchandise
Crowdfunding Campaign	Begin mid-December, end at end of January	Travel expenses
Company Sponsorship	Earliest mid-December	Full-scale Rocket
Federal and Private Grants	Earliest early-January	Full-scale Rocket

7.3.2.3. Material Acquisition Plan

We do not currently have a complete list of materials, but almost all materials will be obtained from online sources. Currently all materials will be acquired by purchasing items on a personal account and getting reimbursed through our parent organization. Once we have outside funds to purchase materials, they will be kept in an account moderated by our faculty advisor's department, Computer and Information Technology. This allows us to take funds immediately out of a moderated account if we need it.

7.3.3. Educational Engagement

In order to reach out to a majority of K-12 students as well as others, team members participated in the annual Purdue Space Day on Saturday, October 27, where they were in charge of a group consisting of 10-90 students. They created model rockets, astronaut arms, solar sails and many other space-related projects with the kids. They also showed them the different organizations around Purdue that were involved in STEM related projects. This allowed for the kids to have an understanding of space exploration as well as the impact Purdue University has on the space industry.

At Purdue Space Day, Astronaut Charles D. Walker (pictured above) interacted with the kids in attendance and gave a presentation on the benefits of STEM involvement and the excitement of space exploration. At this event the children were broken up into groups of 30 - 50 and participated in a variety of STEM related activities which varied by age range which were coordinated and led in part by PSP-SL members.

7.3.3.1. Documentation of Outreach

The STEM Engagement Activity Reports which were filled out by the team members who attended Purdue Space Day can be found in the following location:

https://drive.google.com/drive/folders/1Eu2VYxXYnDArzS3gj4UYcuKABaqxSReR?usp=sharing

7.3.3.2. Outcome of Outreach

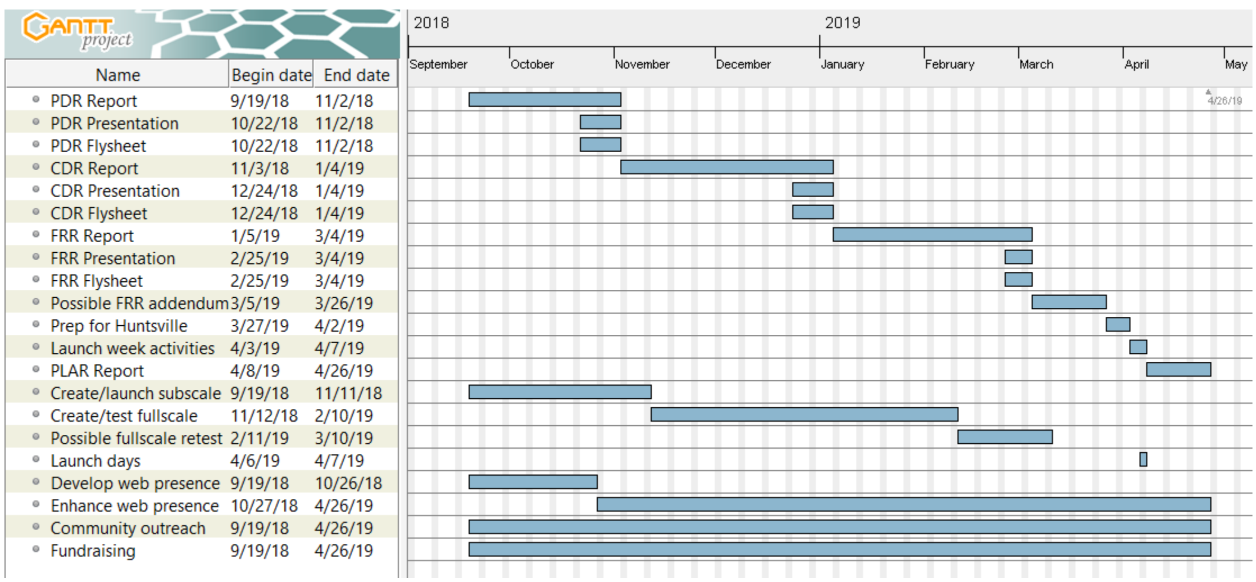
Team members which participated in Purdue Space Day were unable to see the evaluation reports the children gave to Space Day officials at the end of the day, but through word of mouth the team has heard that feedback was very positive in terms of both enjoyment and concepts learned. Team members also report that, in person, the kids made design choices with good judgement after being taught background information on their projects and were very excited to complete the activities which were set up for them and see their work in action, such as when their dry ice rockets launched.

7.3.3.3. Plans for Future Outreach

Through establishing relationships with Purdue University, outreach organizations like Mini-Maker Faire in the Lafayette area, and student organizations like AIAA and SEDS, Purdue's PSP-SL team plans on continuing their education and engagement of youth in the Lafayette and West Lafayette area.

7.3.4. Timeline

A GANTT chart of the PSP-SL team's responsibilities is shown below, followed by a timeline the team will be following. The GANTT chart highlights what the team needs to be working on and when. The timeline outlines events such as general team meetings, meetings or teleconferences with NASA officials, launch opportunities, deadlines, and miscellaneous events.



Name	Begin date	End date
PDR Report	9/19/18	11/2/18
PDR Presentation	10/22/18	11/2/18
PDR Flysheet	10/22/18	11/2/18
CDR Report	11/3/18	1/4/19
CDR Presentation	12/24/18	1/4/19
CDR Flysheet	12/24/18	1/4/19
FRR Report	1/5/19	3/4/19
FRR Presentation	2/25/19	3/4/19
FRR Flysheet	2/25/19	3/4/19
Possible FRR addendum	3/5/19	3/26/19
Prep for Huntsville	3/27/19	4/2/19
Launch week activities	4/3/19	4/7/19
PLAR Report	4/8/19	4/26/19
Create/launch subscale	9/19/18	11/11/18
Create/test fullscale	11/12/18	2/10/19
Possible fullscale retest	2/11/19	3/10/19
Launch days	4/6/19	4/7/19
Develop web presence	9/19/18	10/26/18
Enhance web presence	10/27/18	4/26/19
Community outreach	9/19/18	4/26/19
Fundraising	9/19/18	4/26/19

Date	Event
08/31-09/03/2018	AIRFest 24 @ Argonia, Kansas Rocket Pasture
09/02/2018	Purdue SL general meeting
09/03/2018	LABOR DAY
09/09/2018	Indiana Rocketry Launch
09/09/2018	Purdue SL general meeting

09/16/2018	Purdue SL general meeting
09/19/2018	Proposal due to project office by 3PM CDT
09/23/2018	Purdue SL general meeting
09/29-09/30/2018	ROCI HPR Sport Launch @ AMA Aeromodeling Center in Muncie
09/30/2018	Purdue SL general meeting
10/04/2018	Awarded proposals announced
10/07/2018	Purdue SL general meeting
10/08-10/09/2018	OCTOBER BREAK
10/12/2018	Kickoff, PDR Q&A
10/13/2018	ROCI HPR Sport Launch @ Federal Rd. Field in Cedarville
10/14/2018	Purdue SL general meeting
10/14/2018	Indiana Rocketry Launch
10/20/2018	ROCI HPR Sport Launch @ AMA Aeromodeling Center in Muncie
10/21/2018	Purdue SL general meeting
10/26/2018	Web presence established, URLs sent to project office by 8AM CDT
10/27/2018	ROCI HPR Sport Launch @ Federal Rd. Field in Cedarville
10/28/2018	Purdue SL general meeting
11/01-11/03/2018	SEDS SpaceVision @ San Diego
11/02/2018	PDR reports, slides, and flysheet posted online by 8AM CDT
11/02-11/04/2018	Midwest Power Launch
11/04/2018	Purdue SL general meeting
11/05/2018	PDR video teleconferences start
11/10/2018	ROCI HPR Sport Launch @ Federal Rd. Field in Cedarville
11/11/2018	Purdue SL general meeting
11/11/2018	Indiana Rocketry Launch
11/18/2018	Purdue SL general meeting
11/19/2018	PDR video teleconferences end
11/21-11/24/2018	THANKSGIVING BREAK
11/24/2018	ROCI HPR Sport Launch @ Federal Rd. Field in Cedarville
11/25/2018	Purdue SL general meeting
11/27/2018	CDR Q&A
12/2/2018	Purdue SL general meeting

12/08/2018	Quad Cities Rocket Society (QCRS) Launch
12/09/2018	Purdue SL general meeting
12/09/2018	Indiana Rocketry Launch
12/15-01/06/2019	WINTER BREAK
01/03/2019	Final day for subscale launch
01/03/2019	Final motor choice made for launch
01/04/2019	CDR reports, slides, and flysheet posted online by 8AM CDT
01/06/2019	Possible Purdue SL general meeting
01/07/2019	CDR video teleconferences start
01/13/2019	Purdue SL general meeting
01/13/2018	Indiana Rocketry Launch (?)
01/20/2019	Purdue SL general meeting
01/21/2019	MLK JR. DAY
01/22/2019	CDR video teleconferences end
01/25/2019	FRR Q&A
01/27/2019	Purdue SL general meeting
02/03/2019	Purdue SL general meeting
02/10/2019	Purdue SL general meeting
02/10/2019	Indiana Rocketry Launch (?)
02/17/2019	Purdue SL general meeting
02/24/2019	Purdue SL general meeting
03/03/2019	Purdue SL general meeting
03/03/2019	Final day for full scale launch/Vehicle Demonstration Flight
03/04/2019	Vehicle Demonstration Flight data reported to NASA
03/04/2019	FRR reports, slides, and flysheet posted online by 8AM CDT
03/08/2019	FRR video teleconferences start
03/10/2019	Purdue SL general meeting
03/10/2019	Indiana Rocketry Launch (?)
03/11-03/16/2019	SPRING BREAK
03/17/2019	Possible Purdue SL general meeting
03/21/2019	FRR video teleconferences end
03/24/2019	Purdue SL general meeting
03/25/2019	Payload Demo Flight/Vehicle Demonstration Re-flight deadlines

03/25/2019	FRR Addendum submitted to NASA by 8:00AM CDT (if needed)
03/31/2019	Purdue SL general meeting
04/03/2019	Travel to Huntsville, Alabama
04/03/2019	OPTIONAL – LRR for teams arriving early
04/04/2019	Launch week kickoff and activities
04/04/2019	Official LRRs if not done on 04/03
04/05/2019	Launch week activities
04/06/2019	Launch day
04/06/2019	Awards Ceremony
04/07/2019	Backup launch day
04/07/2019	Possible Purdue SL general meeting
04/14/2019	Purdue SL general meeting
04/21/2019	Purdue SL general meeting
04/26/2019	PLAR posted online by 8AM CDT

7. Appendix A

7.1. NAR High Power Safety Code

7.1.1. Certification. I will only fly high power rockets or possess high power rocket motors that are within the scope of my user certification and required licensing.

7.1.2. Materials. I will use only lightweight materials such as paper, wood, rubber, plastic, fiberglass, or when necessary ductile metal, for the construction of my rocket.

7.1.3. Motors. I will use only certified, commercially made rocket motors, and will not tamper with these motors or use them for any purposes except those recommended by the manufacturer. I will not allow smoking, open flames, or heat sources within 25 feet of these motors.

7.1.4. Ignition System. I will launch my rockets with an electrical launch system, and with electrical motor igniters that are installed in the motor only after my rocket is at the launch pad or in a designated prepping area. My launch system will have a safety interlock that is in series with the launch switch that is not installed until my rocket is ready for launch, and will use a launch switch that returns to the “off” position when released. The function of onboard energetics and firing circuits will be inhibited except when my rocket is in the launching position.

7.1.5. Misfires. If my rocket does not launch when I press the button of my electrical launch system, I will remove the launcher’s safety interlock or disconnect its battery, and will wait 60 seconds after the last launch attempt before allowing anyone to approach the rocket.

7.1.6. Launch Safety. I will use a 5-second countdown before launch. I will ensure that a means is available to warn participants and spectators in the event of a problem. I will ensure that no person is closer to the launch pad than allowed by the accompanying Minimum Distance Table. When arming onboard energetics and firing circuits I will ensure that no person is at the pad except safety personnel and those required for arming and disarming operations. I will check the stability of my rocket before flight and will not fly it if it cannot be determined to be stable. When conducting a simultaneous launch of more than one high power rocket I will observe the additional requirements of NFPA 1127.

7.1.7. Launcher. I will launch my rocket from a stable device that provides rigid guidance until the rocket has attained a speed that ensures a stable flight, and that is pointed to within 20 degrees of vertical. If the wind speed exceeds 5 miles per hour I will use a launcher length that permits the rocket to attain a safe velocity before separation from the launcher. I will use a blast deflector to prevent the motor's exhaust from hitting the ground. I will ensure that dry grass is cleared around each launch pad in accordance with the accompanying Minimum Distance table, and will increase this distance by a factor of 1.5 and clear that area of all combustible material if the rocket motor being launched uses titanium sponge in the propellant.

7.1.8. Size. My rocket will not contain any combination of motors that total more than 40,960 N-sec (9208 pound-seconds) of total impulse. My rocket will not weigh more at liftoff than one-third of the certified average thrust of the high power rocket motor(s) intended to be ignited at launch.

7.1.9. Flight Safety. I will not launch my rocket at targets, into clouds, near airplanes, nor on trajectories that take it directly over the heads of spectators or beyond the boundaries of the launch site, and will not put any flammable or explosive payload in my rocket. I will not launch my rockets if wind speeds exceed 20 miles per hour. I will comply with Federal Aviation Administration airspace regulations when flying, and will ensure that my rocket will not exceed any applicable altitude limit in effect at that launch site.

7.1.10. Launch Site. I will launch my rocket outdoors, in an open area where trees, power lines, occupied buildings, and persons not involved in the launch do not present a hazard, and that is at least as large on its smallest dimension as one-half of the maximum altitude to which rockets are allowed to be flown at that site or 1500 feet, whichever is greater, or 1000 feet for rockets with a combined total impulse of less than 160 N-sec, a total liftoff weight of less than 1500 grams, and a maximum expected altitude of less than 610 meters (2000 feet).

7.1.11. Launcher Location. My launcher will be 1500 feet from any occupied building or from any public highway on which traffic flow exceeds 10 vehicles per hour, not including traffic flow related to the launch. It will also be no closer than the appropriate Minimum Personnel Distance from the accompanying table from any boundary of the launch site.

7.1.12. Recovery System. I will use a recovery system such as a parachute in my rocket so that all parts of my rocket return safely and undamaged and can be flown again, and I will use only flame-resistant or fireproof recovery system wadding in my rocket.

7.1.13. Recovery Safety. I will not attempt to recover my rocket from power lines, tall trees, or other dangerous places, fly it under conditions where it is likely to recover in spectator areas or outside the launch site, nor attempt to catch it as it approaches the ground.

7.2. NAR Minimum Distance Table

Installed Total Impulse (Newton-Seconds)	Equivalent High Power Motor Type	Minimum Diameter of Cleared Area (ft.)	Minimum Personnel Distance (ft.)	Minimum Personnel Distance (Complex Rocket) (ft.)
0 — 320.00	H or smaller	50	100	200
320.01 — 640.00	I	50	100	200
640.01 — 1,280.00	J	50	100	200
1,280.01 — 2,560.00	K	75	200	300
2,560.01 — 5,120.00	L	100	300	500

5,120.01 — 10,240.00	M	125	500	1000
10,240.01 — 20,480.00	N	125	1000	1500
20,480.01 — 40,960.00	O	125	1500	2000

Note: A Complex rocket is one that is multi-staged or that is propelled by two or more rocket motors