PURDUE SEDS

Purdue University

Project Walker

500 Allison Road
West Lafayette, IN 47906

March 4th , 2019

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Summary of FRR Report

1.1. Team Summary

1.1.1. Team Name and Mailing Address

Purdue University Students for the Exploration and Development of Space
107 MacArthur Drive, Room 150 West Lafayette, Indiana 47906

1.1.2. Mentor Contact Information and TRA/NAR Certifications

Victor Barlow, NAR 88988 L3CC, TRA 6839 TAP, Level 3 Certified
vmbarlow@purdue.edu 765-414-2848 (Cell)

1.2. Launch Vehicle Summary

1.2.1. Size and Mass

The launch vehicle will be 120” tall when assembled and weigh an estimated 43.5 pounds when loaded with propellant and motor hardware. The rocket will have a nominal outer diameter of 5.15” and be constructed fully out of filament wound composite fiberglass.

1.2.2. Final Motor Choice

The launch vehicle will be using an Aerotech Rocketry L1520 Blue Thunder as the main means for propulsion. It is a 75mm diameter, 3 grain motor that produces a total impulse of 3,716 newton seconds over the course of a 2.4 second burn time. Peaking with a total thrust of about 1,779 Newtons. This motor also has a propellant weight of 1,854 grams and a loaded weight of 3,651 grams.

1.2.3. Recovery System

The launch vehicle will utilize standard dual deployment recovery methods, including redundant electronics and ejection charges using a Altus Metrum Telemetrum and Missile Works 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.

1.2.4. Rail Size

The launch vehicle will utilize a 1.5” rail guide that is 12’ tall and supplied at the launch field.

1.2.5. Milestone Review Flysheet

See attached flysheet.

1.3. Payload Summary

1.3.1. Payload Title

The experimental payload that will be flown in this launch vehicle will be known as the “Walker Texas Rover”.

1.3.2. Experiment Overview

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.

2. Changes Made Since CDR

2.1. Changes Made To Vehicle Criteria

The vehicle design the team presented at CDR was very nearly in final configuration. However, there were a few changes to be made. First of all, the team originally had U-bolts in the bulkplates connecting the various sections. Instead, the team has decided that eye bolts would be a better choice. This change was primarily due to inventory constraints. The team has access to a number of eye bolts at no cost to us, so in the interest of keeping the rocket as cheap as possible, the team elected to use the eye-bolts. In addition, the less holes in the bulkplates, the better as far as structural stability goes. While this was clearly not an issue due to the previous CDR FEA work, it never hurts to improve. Another change to the vehicle was related to number of holes. During construction, the team made sure to have all necessary holes for bolts and shear pins. With this, there were also vent holes added. While these were always in the plan, they had not been mentioned in the prior reports. The holes have all been added to the CAD models seen later in this document. Finally, the mid airframe was originally 30” long, but the payload team needed some extra space. The mid airframe was cut down to 27.5” and the payload bay was given the extra 2.5” as a switch band. Overall, the rocket remains the same height, but the height was redistributed slightly.

2.2. Changes Made To Payload Criteria

In order to ensure the safe and successful operation of the payload that follows the mission statement, changes were made to the payload criteria regarding placement in the launch vehicle and desired payload operation. The following list is comprehensive includes changes to the original criteria proposed in the Preliminary Design Review as well as the newly proposed or changed criteria:

- The payload bay shall be secured in the launch vehicle during vehicle ascent and descent and shall be completely independent from the recovery system
- All payload subsystems shall be entirely functional after flight and touchdown of the launch vehicle
- After successful touchdown of the launch vehicle, a radio unit shall remotely disengage and deploy the payload bay from the launch vehicle
- Once the payload bay is separate from the launch vehicle, the rover shall completely separate from the payload bay in an operational configuration
- Once separate from the launch vehicle, the rover shall autonomously navigate to a point least 10 ft from the closest launch vehicle component
- Once the rover is far enough from the launch vehicle, it shall collect and contain at least 10 ml of soil

2.3. Changes Made To Project Criteria

With our educational engagement requirements met, our focus on our project plan has shifted to fundraising through as many different sources and mediums as possible. The funding plan has been approved by the Purdue SEDS board of executives, our faculty mentor, and the office of the bursar.

3. Vehicle Criteria

3.1. Design and Verification Of Launch Vehicle

This section discusses the design and verification of the Project Walker full scale rocket, including the team's mission statement and the mission success criteria, any design alternatives to the full scale rocket from the subscale, and the dimensional drawings of the full scale rocket

3.1.1. Mission Statement and Mission Success Criteria

It is the goal of the PSP-SL team to design, build, test, and fly a launch vehicle that carries a functional payload to a predetermined altitude of 4950 feet. This payload will be a ground-deployable and autonomous soil sampling rover. Upon successful flight of the launch vehicle, this payload will be ejected from the launch vehicle and will move a set distance away from its landing point to collect a soil sample. A successful mission will satisfy the following criteria:

- The vehicle flight is stable during ascent
- The vehicle reaches within 5% of the desired altitude of 4950 feet above ground level (AGL), which is 4700-5200 feet
- All recovery gear is successfully deployed at the appropriate predetermined altitude
- The vehicle lands safely within the recovery zone boundaries
- The vehicle can be flown again without need for repairs or alterations
- The payload active retention system fully separates the fairing and rover from the payload bay after the vehicle returns to ground level
- The rover successfully reaches a distance of at least ten feet away from any part of the vehicle and collects a soil sample

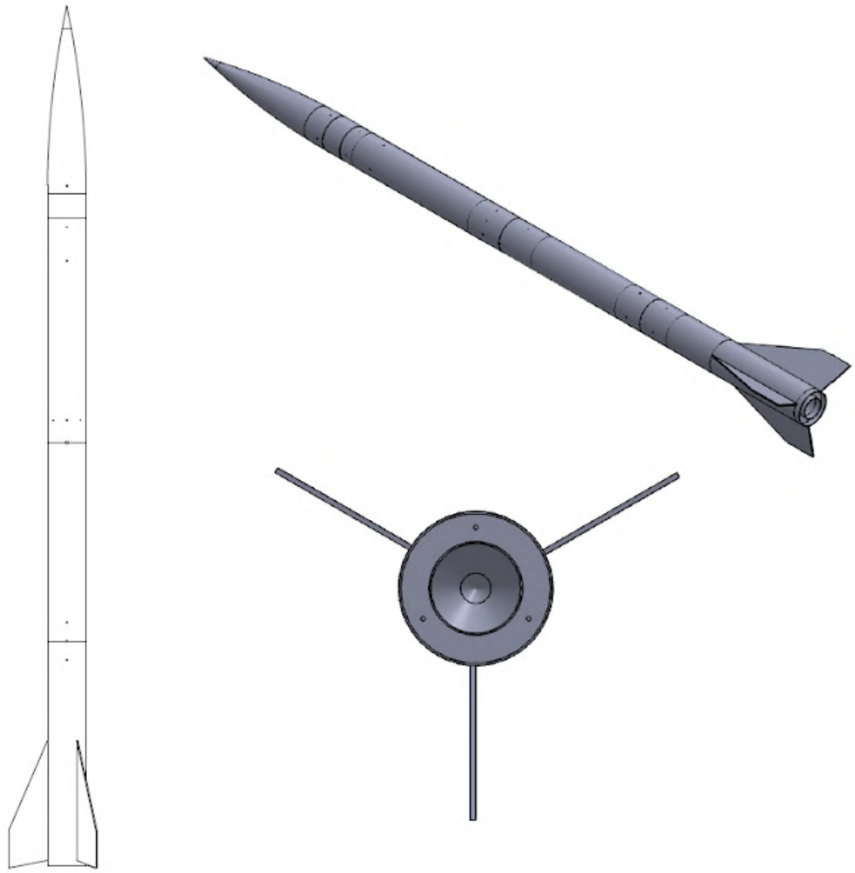
3.1.2. Chosen Design Alternatives From CDR

As mentioned above, the vehicle was not very ambiguous, even in early stages. For this reason, there were no specific design alternatives left to decide after submitting CDR. The full scale construction had already begun by the time CDR was submitted, so by that point all alternatives were mostly finalized.

3.1.3. Dimensional Drawings Using SolidWorks

This section discusses the dimensional drawings of the full scale rocket made in SolidWorks. The following subsections discuss the assembled launch vehicle, lower airframe subsystem, mid airframe subsystem, avionics bay subsystem, upper airframe subsystem, and the nose cone and payload subsystem.

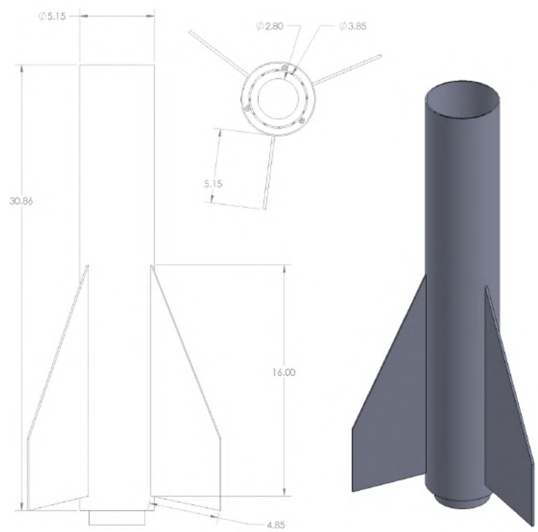
3.1.3.1. Assembled Launch Vehicle



The image above and all following drawings were created in SolidWorks 2018.

The assembled launch vehicle, as shown above, includes all fiberglass structural components that make up the body of the rocket and its subsystems, but does not include the recovery gear such as parachutes, fireproofing, tethers, or linkage. The motor casing, retainer, and thrust plate are also not shown. The detailed view of the rear end of the rocket shows how the motor retainer will be mounted to the thrust plate, as well as how the thrust plate will be secured to the rocket. These components will be discussed and shown in more detail in the next section.

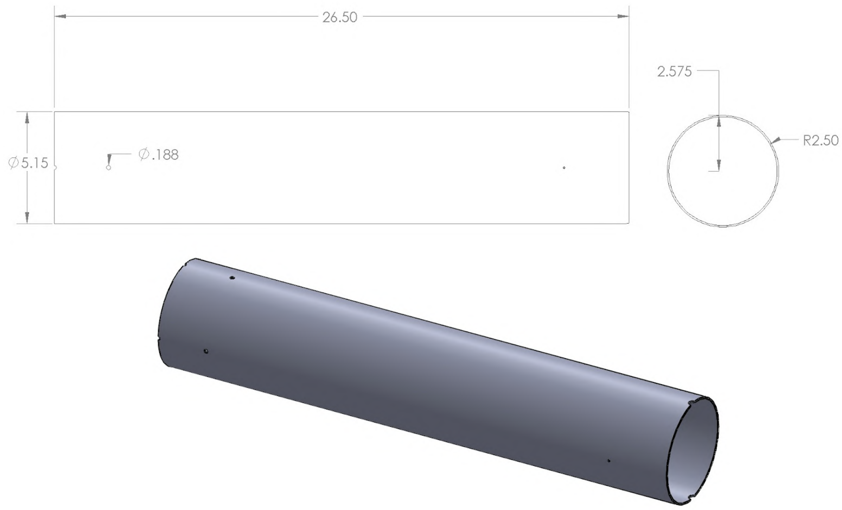
3.1.3.2. Lower Airframe Subsystem and Components



The lower airframe section will have a 5.15" outer diameter, 5.00" inner diameter, be 30" long, and have a fin span of 5.15". The top 5.00" of the tube will interface with the mid airframe. The tube itself will be slotted to allow for through the wall mounted fins, that will glue to both the motor tube and the airframe. The fin tabs will run the full length of the fins, and be notched to interface with wooden centering rings. These notches will serve to both align the fins perpendicular to the body and provide a lateral clamping force to distribute loads.

The bottom centering rings will be tapped and threaded to accept inserts, into which bolts will be screwed that hold on the thrust plate and motor retainer. The thrust plate itself will be 0.375" thick stepped aluminum that will align with the airframe concentrically and transfer thrust loads to the airframe, not the motor mount, fins, and glue joints. The thrust plate will also be tapped and threaded to accept bolts that secure the motor retainer into place, providing positive motor retention. The entire lower airframe and motor mount assembly will be bolted to the payload bay assembly of the rocket using removable metal rivets in order to prevent separation during flight.

3.1.3.3. Mid Airframe Subsystem and Components

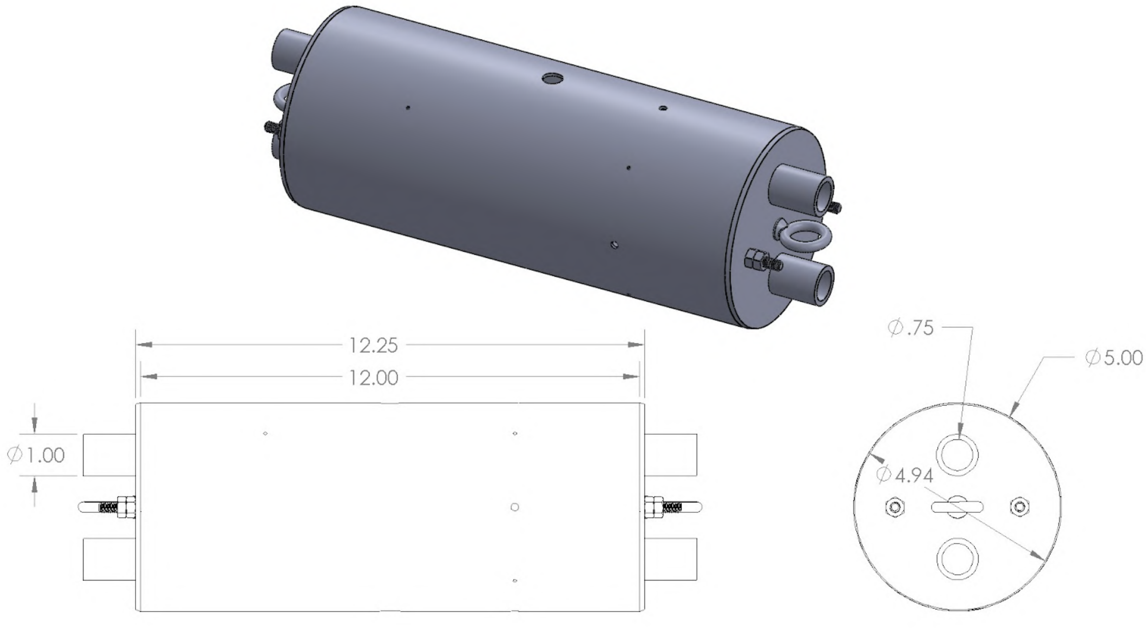


The mid airframe will have an outer diameter of 5.15”, and inner diameter of 5.00”, and will be 26.5” long. 5.00” of both ends of the tube will be used to interface with coupler tubes, leaving 16.5” of usable room for drogue recovery gear.

As mentioned in Changes to Vehicle Criteria, the team decided to cut down the standard 30” length of tubing to 26.5”. This still provides the team with ample room to pack the drogue recovery gear in while still allowing the payload team the space they need.

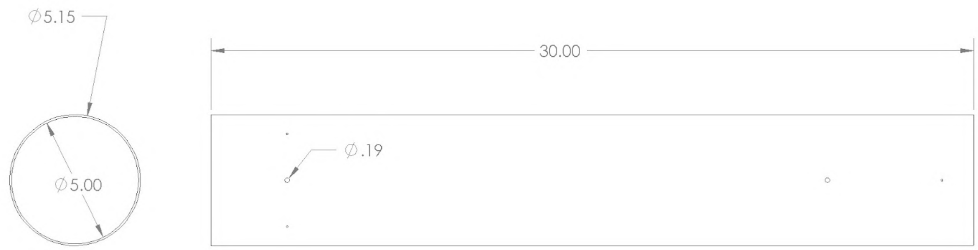
This tube will mate with the avionics bay coupler on the forward end, and an empty coupler on the aft end. The mid airframe will be secured to the lower coupler using multiple removable metal rivets to hold the lower sections of the rocket together during flight. The avionics bay and upper sections of the rocket will be shear pinned into place to eliminate the possibility of drag separation during ascent, and remain secured until the drogue parachute is deployed.

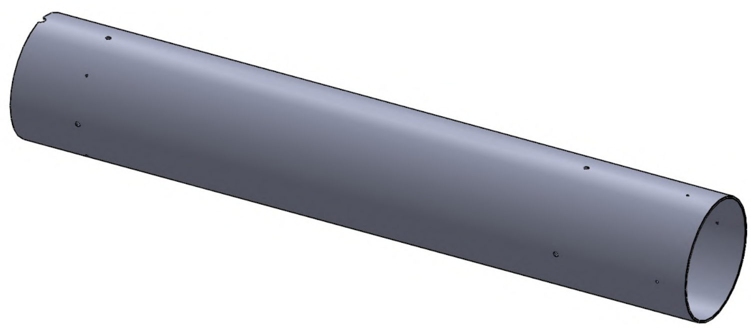
3.1.3.4. Avionics Bay Subsystem and Components



The avionics bay subsystem will be enclosed in a 12” coupler with 1.5” of tube interfacing with an airframe on either side. The bay will have a total length of 15.00” and 5.00” in diameter to interface with the mid and upper airframes. For simplicity, two independent rocker switch assemblies, accessible from the outside via holes in the coupler, will be used in place of a switch band. ¼”-20 threaded rods will run through fiberglass bulkheads and be secured with nuts and washers, clamping the bulkheads over the ends of the tube and sealing the avionics components inside from any gases produced by ejection charges. One end of the avionics bay coupler will be secured into place to the mid airframe using shear pins to prevent drag separation during flight until the drogue recovery gear is deployed. The other end of the avionics bay coupler will also be secured to the upper airframe using shear pins. The tethers for both the drogue and main recovery gear will be secured to the bulkheads using stainless steel eye bolts.

3.1.3.5. Upper Airframe Subsystem and Components



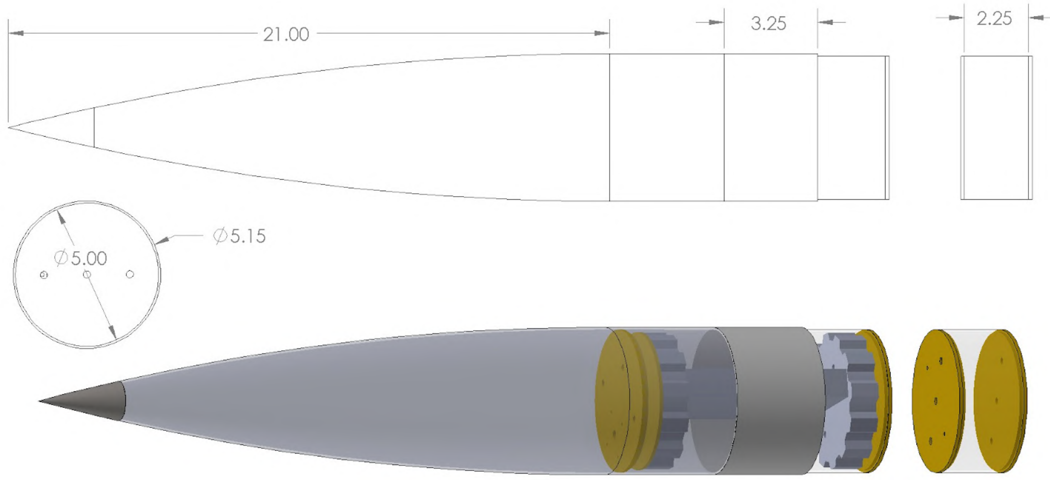


The upper airframe will have an outer diameter of 5.15”, and inner diameter of 5.00”, and will be 30” long. 5.00” of both ends of the tube will be used to interface with coupler tubes, leaving 20.00” of usable room for main recovery gear.

The team elected to use a standard 30” length of tubing. As a result, there is not the need to pay an extra fee to have the tube recut to a custom length and the center of gravity remains as far toward the aft of the rocket as possible. This also provides us with ample room to pack the main 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.

This tube will mate with the payload coupler on the forward end, and the avionics bay coupler on the aft side. The upper airframe will be secured to the avionics bay coupler using four shear pins to hold the sections of the rocket together during flight. The nose cone bay of the rocket will also use 4 shear pins into place to eliminate the possibility of drag separation during ascent, and remain secure until the main parachute is deployed.

3.1.3.6. Nose Cone and Payload Subsystem and Components



The payload bay consists of two separate components, the rover containment bay (upper portion) and the payload ejection bay (lower portion). The upper payload bay will be installed a length of 4.00’’ inside of the 29.00’’ nose cone and will interface with a 3.25’’ switch band fixed to the outside of the upper payload bay. The lower payload bay will be separated a distance of 1.00’’ from the nose cone and upper payload bay assembly and will extend a distance of 2.50’’.

The nose cone has a 5:1 length to diameter ratio with an ogive shape and a metal tip. This nose cone reduces drag over those with a lower aspect ratio, and increases the amount of internal space that is being used for payload electronics. The metal tip will be secured using a standard bolt and washer, and the nose cone will be securely fastened to the upper payload bay.

The payload bay will feature two separate enclosed sections that will be separated by a section of 1.00’’. The entire length of the payload bay is 12.75’’ with a 2.50’’ smaller section and a 9.25’’ larger section with a 3.50’’ band on the larger payload section. Of this 12.75’’ total length, a total of 6’’ will be entered into the upper airframe.

The smaller, aft-most section will enclose an electronics bay for payload deployment and has an eye bolt acting as an attachment point for the main parachute. This smaller section will be secured to the upper airframe using rivets. The larger section acts as the payload housing and contains the payload deployment mechanism that has two 12.00’’ rods, one of which is threaded. This larger section will be fixed to the upper airframe using shear pins. Both of these sections are sealed with bulkheads with the threaded rods and other fasteners holding the bulkheads together.

The switch band interfacing with the rocket body is 3.50'' to allow for a larger payload with a 3.50'' section fitting into the rocket nose cone and a 2.25'' section inside the upper airframe.

3.1.4. Completeness and Manufacturability

The majority of the parts used for the flight vehicle are commercially bought and will need little to no modification, with the exception of drilling holes to accept fasteners, switches, or vents. Parts such as the fins and plywood centering rings with indexing tabs will need to be custom fabricated and supplied by a third party contractor. All supplies needed for construction, such as sandpaper, adhesives, and solvents will be purchased with the materials or supplied by Purdue SEDS (Students for the Exploration and Development of Space). Overall, there is very little manufacturing that the team needs to perform in house outside of 3D printing.

3.1.5. Design Integrity

This section includes the design integrity of the fins of the rocket, as well as their shape and mounting process. It also discusses the materials used for the fins, bulkheads, and other structural components of the rocket. The mounting process for the motor is also discussed, as is the final mass of the overall rocket, as well as the mass of each section of the rocket, and how the mass affects the integrity.

3.1.5.1. Fin Shape and Style

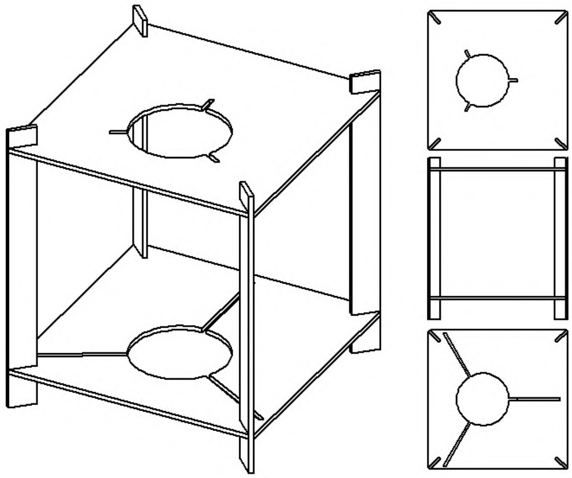
This year, it has been decided to adopt a swept fin shape.The swept fin shape is an extremely common style in model rocketry, and is especially beneficial when stability is needed at higher speeds. The shape helps reduce drag by reducing the amount of acceleration over the wing. This shape was combined with a shallower sweep angle to be more aerodynamic, as the swept fin shape moves the center of pressure back, and the shallower sweep angle reduces drag force at the higher speeds. This will allow for higher and longer flight time. The fin tabs that connect the fin to the wall of the rocket, increase bonding area and improving the strength of the joints.

3.1.5.2. Fin Mounting

Due to the problems that were encountered while constructing the subscale fins, the team decided to build a fin mount to keep the fins as straight as possible. This mount is designed to hold the fins to the rocket as the epoxy dries. The circular hole in the center is 5.25”. Holes in the base extend 5.15”, the exact distance out of the rocket that the fins should extend. Holes in the top of the base extend 0.88”. While the base attaches to the flat edge of the fin, the top holes are more of guides. The point is to keep the fins straight, but does not provide much pressure. The fin mount is made of ¼” plywood.

The bases of the mount are 14” by 14” to accommodate the length of the fins. The legs supporting the two bases are each 16.5" long, holding the two bases 13” apart.

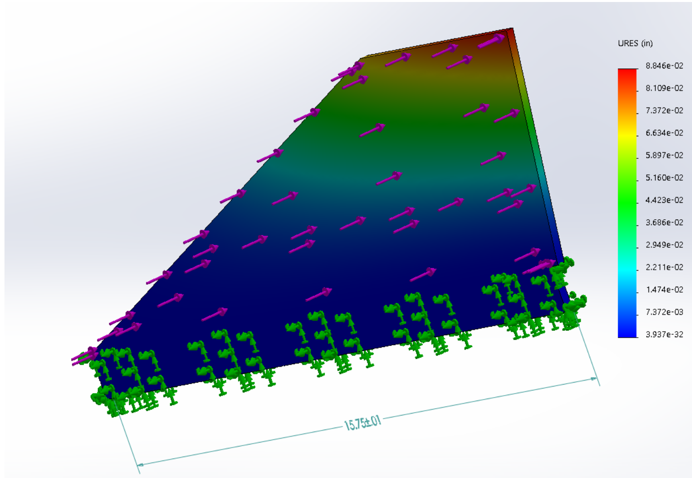
Dimensional Drawing



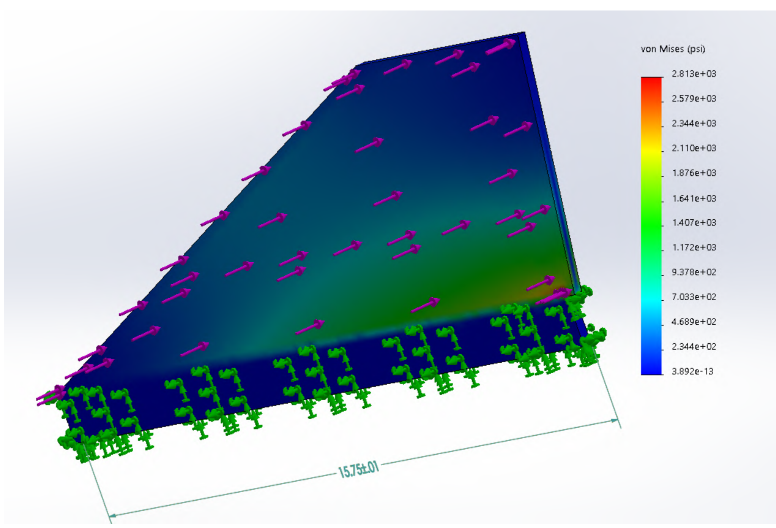
Actual Photo

3.1.5.3. Material Use For Fins, Bulkheads, and Structural Members

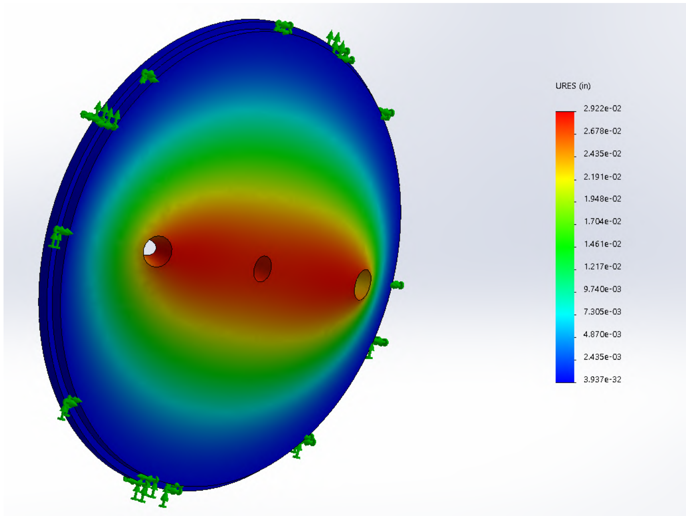
All fins and bulkheads will be constructed out of G10 fiberglass. In order to validate the fiberglass used in the fins, bulkheads, and structural members of the rocket finite element analysis was used within SolidWorks 2018. Each of these parts were designed by members of the team. In addition, each part was given appropriate approximate material properties, such as Young's Modulus, Yield Strength, and Poisson’s Ratio. The program then created a mesh around the part, and every part was given a mesh size of 0.1” and mesh sag of 0.01”. Afterwards, each structural member was clamped in the appropriate location to mimic their location and position within the rocket. Once the clamps were applied, loads and distributed forces were also applied to the part to best approximate the displacement and stress the parts would endure. Lastly, each part was simulated under the conditions applied to it and captured as an image. If a simulated part exceeded the materials yield strength, that part will not be considered adequate to withstand the expected flight forces and will need to be altered until simulations show that it is satisfactory. One final note before the presentation of data: in SolidWorks 2018, the material properties for the various fiberglasses is incomplete which causes the finite element analysis to run improperly. In order to test the fins, a custom material had to be made to simulate G10 fiberglass. The values for fiberglass are a range, not a specific value. Therefore, the team chose the lowest value in the range when another source could not verify the number in order to account for a worst-case scenario.



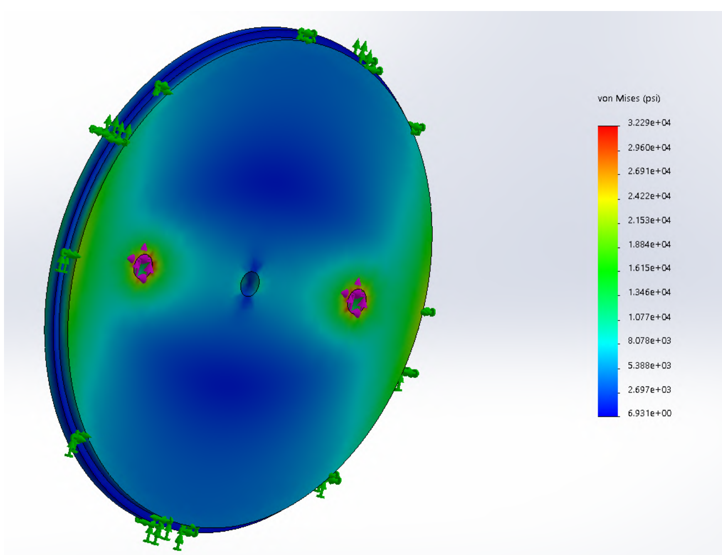
The figure above is a screen capture of the translational displacement of the rocket fin. The green arrows represent a fixed location on the part due to epoxy in this case. This mimics how the fin tab will be glued to the motor tube inside of the rocket, rendering it unable to move. At the top of the fin is a lateral distributed force of fifty pounds, which is greater than the landing energy the lower section of the rocket is expected to withstand during landing. The distributed force was placed at the tip of the fin, maximizing the distance between the clamp and the force, and thus maximizing the moment. With these settings, the maximum experienced translational displacement of the tip of the fin is expected to be 0.0846''. This is shown by the area of red within the image, according the the color legend shown on the right.



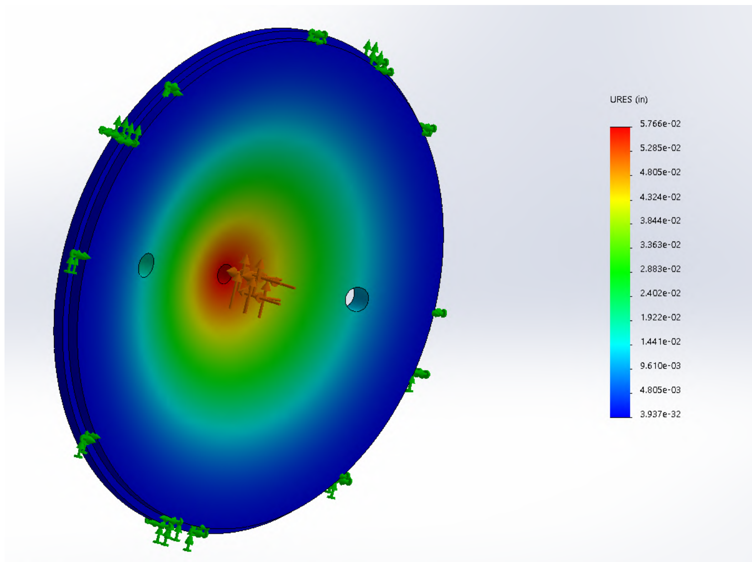
The image above is a screen capture of the Von Mises forces experienced by the vehicle's fin when exposed to the same clamping and displacement force as mentioned above. With these variables in place, the maximum expected stress within the component is simulated to be 2110 pounds per square inch, located on the back edge of the fin above the root where it would meet the airframe. This is well below the yield strength of the material, meaning that the fin will not experience any deformation past the elastic range. This demonstrates that the proper material and thickness for this component has been chosen to withstand the expected flight forces.



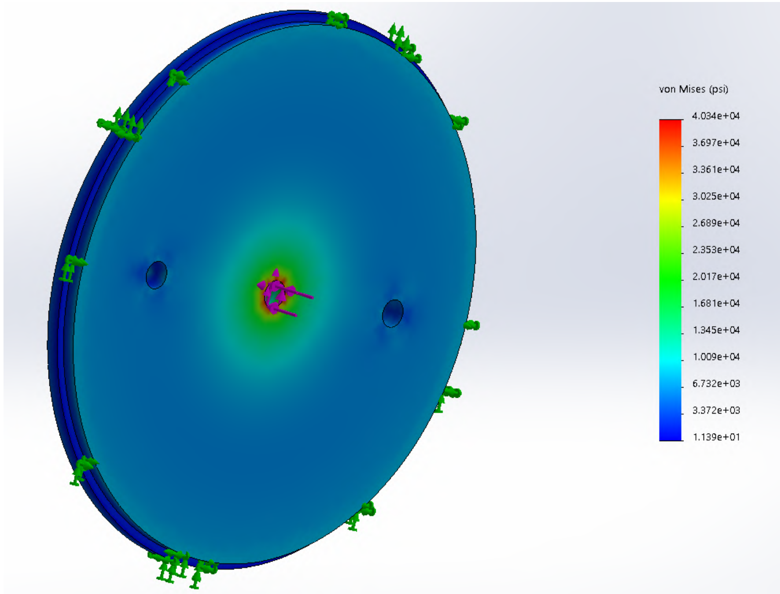
The figure above is a screen capture of the translational displacement of the rocket bulkhead when pulled against the coupling tube by the threaded rods that hold it in place within the rocket. On the perimeter of the bulkhead is a blue figure, representing a clamp on the part. A distributed force of one thousand pounds was then applied to the holes that would accept the threaded rod, mimicking the rods pulling on the bulkhead against the coupling tube. With these settings, the maximum experienced translational displacement of the center of the bulkhead is expected to be 0.029’’. This is shown by the area of red within the image, according the the color legend shown on the right.



The image above is a screen capture of the Von Mises forces experienced by the vehicle's bulkhead when exposed to the same clamping and displacement force as mentioned above. With these variables in place, the maximum expected stress within the component is simulated to be 2.153e+4 pounds per square inch, located around the holes that accept the threaded rods to hold the bulkhead in place. This is below the yield strength of the material, meaning that the bulkhead will not experience any deformation past the elastic range. This demonstrates that the proper material and thickness for this component has been chosen to withstand the expected flight forces.



The figure above is a screen capture of the translational displacement of the rocket bulkhead when pulled on by the eye-bolts that connect to the recovery harness. Within the holes that would accept threaded rods to hold the bulkhead in place is a blue figure, representing a clamp on the part. A distributed force of one thousand pounds was then applied to the holes that would accept the eye bolts, mimicking the force pulling on the bulkhead against the threaded rods. With these settings, the maximum experienced translational displacement of the center of the bulkhead is expected to be 0.0577''. This is shown by the area of red within the image, according the the color legend shown on the right.



The image above is a screen capture of the Von Mises forces experienced by the vehicle’s bulkhead when exposed to the same clamping and displacement force as mentioned above. With these variables in place, the maximum expected stress within the component is simulated to be 2.689e+04 pounds per square inch, located around the holes that accept the threaded rods to hold the bulkhead in place. This is below the yield strength of the material, meaning that the bulkhead will not experience any deformation past the elastic range. This demonstrates that the proper material and thickness for this component has been chosen to withstand the expected flight forces.

3.1.5.4. Motor Mounting and Retention

A flanged Aeropack RA75 motor retainer was chosen as the primary retention system. The flanged edition of the motor retainer can be directly screwed onto the team’s chosen thrust plate with #6 screws. This Aeropack retainer prevents the motor from sliding backwards and exiting the rocket. Also, the team is using an Aerotech 75mm aft closure as the primary way of preventing the motor from sliding forward and into the rocket during flight. The aft closure is slightly larger than the inner diameter of the motor mount which means the motor cannot go through the motor mount cleanly. The rear closure of the motor hardware acts as a thrust ring and has a larger nominal diameter than the motor tube itself, preventing the thrust of the motor from propelling the casing forward through the rocket.

3.1.5.5. Final Mass of Launch Vehicle and Subsystems

The final mass of the launch vehicle will be 41.5 lbs. At the launch vehicles current state, it sits at about 43.5 lbs. This includes the entirety of the airframe, the avionics and bay, the payload and bay, the hardware, and the motor. The final mass without propellant or propellant casing will be approximately 33.45 lbs. The mass was found by placing all parts on a scale, not by computation. The only other consideration for mass would be the accuracy level of the scale whereas a large scale is believed to be within one half a pound, and a smaller scale to be within one gram. This mass is higher than originally anticipated and will have an impact to the apogee on the launch vehicle. The team is working to reduce the weight as much as possible to help keep the numbers as favorable to the initial goal as possible. Several ideas on weight reduction are in consideration currently.

3.2. Subscale Flight Results

This section discusses the results of the subscale launch, including the flight data, scaling factors of the rocket (compared to the full scale rocket), constant and variable factors during the launch, and the conditions experienced on launch day versus the conditions set in the simulations.

3.2.1. Recorded Flight Data

On the subscale flight, the Missile Works RRC3+ Sport was the primary altimeter and the Jolly Logic AltimeterOne was used for redundancy. This allowed assurance that the team understood how the RRC3+ Sport operated and to verify that the max altitude was accurate. On the RRC3+ Sport the altimeter reached a max altitude of 895 ft and the AltimeterOne reached a max altitude of 884 ft. The main reason that these are slightly off is that the AltimeterOne was attached to the shock cord at a lower resting height than the AltimeterOne. Another possible reason for the differences is how the sampling rate on the RRC3+ Sport is higher than that of the AltimeterOne.

3.2.2. Scaling Factors

To create the subscale launch vehicle, the team chose a scaling factor of 0.45 : 1. This factor was chosen to create a vehicle which was large enough to prevent some of the problems which could arise during full-scale construction and launch, such as incorrectly hypothesizing what altitude it will reach. This factor was also chosen because the subscale rocket's body tube had to have an inner diameter which was large enough to house the team's avionics bay.

3.2.2.1. Constant Factors

The following aspects of the subscale launch vehicle were constructed in a manner which strictly followed the 0.45 : 1 scale:

- Fin profiles
- Body tube length and outer diameter
- The nose cone

3.2.2.2. Variable Factors

The following aspects of the subscale launch were not constructed to scale. The reason for this is included with each aspect below:

- The avionics (1 : 1 scale) because the same altimeters and batteries were used as will be used for full-scale flight
- Threaded rods used in the avionics bay (0.54 : 1) due to what was commercially available
- Wall thicknesses (1 : 1 scale) because of how the manufacturer constructed the body tubes. This also affected bulkhead and coupler diameters.
- The motor diameter (0.51 : 1) and length (0.35 : 1), as the motor was chosen according to what was commercially available, the permissions the team had for the launch field, and the allowable altitude given to the team by the Purdue air traffic control tower. The motor retainer and tube were also variable factors due to this.
- The centers of gravity and pressure, as the entire model did not exactly follow the 0.45 : 1 scale; however, launch vehicle stability values were still roughly the same

3.2.3. Launch Day Conditions and Simulation

On launch day, December 5th, there was an overcast weather in the West Lafayette area with sky mostly covered, adding on to that with snowfall on the days before the launch, there was still snow on the ground. There was a constant wind coming from the West at 14 mph, which was taken into consideration for the launch, which possibly influenced the path of the rocket after launch. The overall measured temperature for that day was varying between 27 - 29 degree Fahrenheit and a typical humidity of 72%. Overall there weren't any extreme weather conditions that impacted the launch, besides the wind.

3.2.4. Flight Analysis

This section discusses the analysis of the subscale launch, including the predicted data versus the actual recorded data, the errors and discontinuities present during the launch, the estimated drag coefficient for the full scale based on subscale results, and any changes to the full scale design as a result of the subscale launch.

3.2.4.1. Predicted Vs. Recorded Flight Data

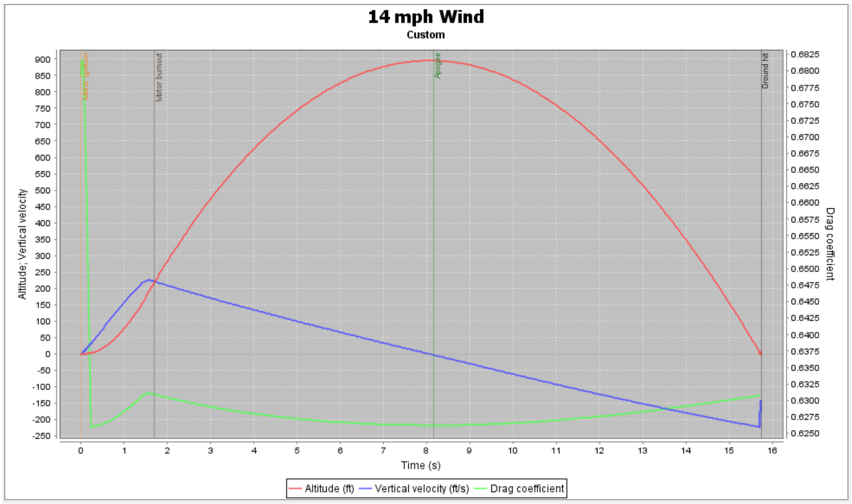
By creating a simulation of the subscale vehicle in OpenRocket 15.03, henceforth known as OpenRocket, an estimated apogee of 950 feet was obtained. This is not far off from the data returned from the altimeters, which stated the rocket had ascended to an apogee of either 884 feet or 895 feet. It should also be mentioned that some initial wavering of the vehicle while coming off the launch rail likely caused the rocket to reach an altitude which was lower than its ideal altitude. By addressing possible issues with the launch rod, launch lug, and fins, the team believes the OpenRocket estimations for the full-scale rocket will be accurate.

3.2.4.2. Errors and Discontinuities

The biggest error with the rocket dealt with the fins. The fins were not completely straight and were not spaced out properly. Although this discontinuity did not fail the subscale launch, it was certainly something that needs to be addressed for the full scale rocket. One key factor that was outside of control was the wind. While there is a current idea of the average wind speed, the gusts at any given moment were hard to accurately measure. However, the rocket performed well despite the fairly windy conditions, so it is likely that the full scale will have a similar success if the wind happens to be strong during the competition. Additional sources of error could include the launch lug and rod. As it was windy, the rod swayed back and forth slightly as the rocket rested on it, which could have caused the rocket to be sub-optimally positioned. The launch lug could have also been mounted at a slight angle, which could have resulted in the vehicle wavering as it came off the rod.

3.2.4.3. Estimated Full Scale Drag Coefficient

By adjusting the OpenRocket simulation to the exact conditions of the launch day (14 mile per hour winds and a tilt of the launch rod of approximately 5 degrees into the wind), the simulation (shown below) predicted an altitude of 895 feet, just as the RRC3+ altimeter returned. From this simulation, an average coefficient of drag for the subscale rocket was calculated by the program to be around 0.63. As the full-scale rocket's exterior is exactly similar to that of the subscale, the team estimates the full-scale vehicle's coefficient of drag will be around 0.63 on average as well.



3.2.5. Impacts to Full-Scale Design

As mentioned in section 3.2.4.2, the subscale vehicle's fins were not perfect. In an attempt to approach the wanted level of perfection, the team has devised a fin mount to use while attaching the fins. This should allow the fins to be attached at a proper distance apart (60 degrees) and be as straight as possible. Additionally, the full-scale vehicle will be launched using a launch rail to avoid the possible stability issues caused by the subscale vehicle's launch rod and launch lug.

3.3. Full Scale Flight Results

On February 25, 2019, the team conducted their full scale demonstration flight. This section discusses the results of the flight, including recorded flight data, the conditions of the launch versus the conditions set in the simulations, and analysis of the launch. During this launch, the team also attempted to conduct the active retention system flight to ensure that the payload would stay in place through the duration of the flight.

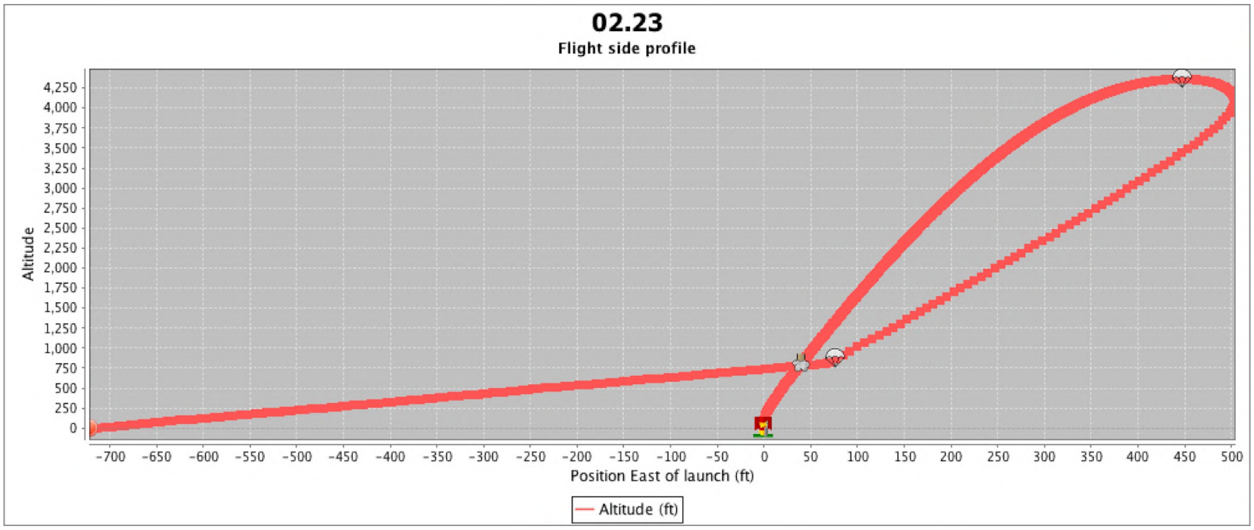
3.3.1. Launch Day Conditions

The launch day weather conditions were near perfect. Throughout the duration of the day, the skies were almost completely clear, the wind speed was slow (~5-7 mph) with gusts (~10-12 mph) of wind. Launch occurred at approximately 2:00pm CST. The temperature was varying between high teens and low thirties (~17-31) degrees Fahrenheit and an overall humidity of 40%.

3.3.2. Flight Analysis

This section discusses the analysis of the launch of the full scale rocket, including the predicted data versus the actual recorded data, the error between the simulations and the actual data, the estimated drag coefficient from the launch data, and the launch simulation from Google Earth.

3.3.2.1. Predicted Versus Actual Data



The above figure shows the total position change of the launch vehicle simulated in OpenRocket. This simulation was using the following:

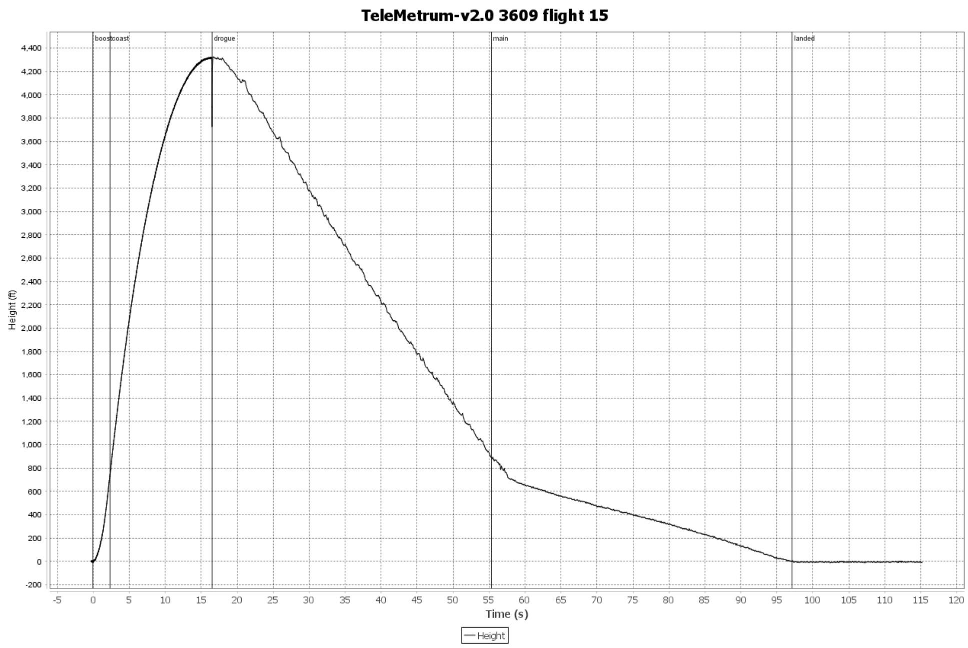
Gross Lift-Off Weight (lbs)	43.5
Wind Speed (mph)	10
Main Deployment Altitude (ft)	900
Simulated Motor	L1520
Launch Rod Length (ft)	8

From the figure above, assuming that the drogue parachute opens directly above the launch pad, there is an approximate drift distance of 1,300 ft. This simulation was done post launch to ensure accurate data was given to the simulation. The simulation gave the following data:

Velocity Off Rail (ft/sec)	61.3
Apogee (ft)	4285
Velocity At Deployment (ft/sec)	94.2
Maximum Velocity (ft/sec)	553
Maximum Acceleration (ft/sec^2)	257

Time To Apogee (sec)	16.7
Flight Time (sec)	112

Below is the flight data collected by the TeleMetrum.



During full scale vehicle demonstration flight, the following data was gathered from the vehicle demonstration flight:

Apogee (ft)	4285
Flight Time (sec)	97
Landing Velocity (ft/sec)	17.78
Largest Section Landing Kinetic Energy (ft-lbf)	68.8
Time To Apogee (sec)	16
Main Deployment (ft)	900
Main Open Time (Sec)	2.5
Main Parachute Open (ft)	~750

3.3.2.2. Error Between Predicted And Actual Data

	Actual	OpenRocket	RASAero II
Apogee (ft)	4285	4738	4498
Flight Time (sec)	97	98.9	126.78
Landing Velocity (ft/sec)	17.78	14.2	11.8
Largest Section Landing Kinetic Energy (ft-lbf)	68.8	N/A	N/A
Time To Apogee (sec)	16	17.4	17.2
Main Deployment (ft)	900	900	900
Main Open Time (Sec)	2.5	2.1	2.5
Main Parachute Open (ft)	~750	795	829

3.3.2.3. Estimated Drag Coefficient And Post Flight Simulation

According to the OpenRocket simulations, the drag coefficient of the rocket was found to be about 0.63, as had been predicted from the subscale results. This value was found by rerunning the simulations and setting the parameters as close as possible to those present during the actual launch of the rocket.

3.4. Comparison Between Full and Sub Scale Flight Results

It can be hard to compare the flights of the subscale rocket and the full scale rocket for many reasons. First, the subscale was single deploy while the full scale is dual deploy. Also, the subscale had no payload while the full scale had a significant payload and many changes to the airframe to accommodate it. However, there are a couple things to be said about the two flights. While subscale flight was nearly nominal, full scale was not so. The full scale was a slightly overweight which led to a non-optimal apogee height. In addition, the active retention system (which was not included on the subscale rocket) failed during the demonstration flight. While subscale was a good test to show understanding, the full scale demonstration shows how much work still needs to be completed before competition in only a month.

4. Safety

4.1. 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. 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 standards are met and understood. The briefings and seminar will be made available throughout 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

4.2. 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 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. 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 must 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.

4.3. Facilities and Equipment

4.3.1. 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, Safety Officer for safety
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.)

4.3.2. 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 Ben Walbaum, current Purdue SEDS president and Chris Nilsen who is last years 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, Safety officer for safety
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

4.3.3. 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

4.3.4. Purdue BoilerMAKER Lab

The Purdue BoilerMAKER Lab specializes in additive manufacturing. 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 designs a 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

4.4. Safety and Environment (Vehicle and Payload)

The seriousness of the risks discussed in this section 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:

4.4.1. 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 50% chance of occurrence.
Likely	4	Less than 80% chance of occurrence.
Very Likely	5	Greater than 80% chance of occurrence.

4.4.2. 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, as designated in orange to have higher safety importance with respect to likelihood and/or impact, 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 risks occur 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 specifically and importantly 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. 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 risks/delays impact the project. Each verification will include strictly following the mitigation as a procedures/checklist in order to lower the risk. Verifications will use all information available and will constantly be improved to include more test data, design analysis, written procedures and checklists, and as-built configuration drawings. Similarly, verification will be done by testing, analysis, inspection, and demonstration with different criteria for design requirements or subsequent success. Verification by testing is the most rigorous way to verify as it is a planned method of checking for a specific parameter defined by a pass or fail criteria and involves collecting data and comparing it to an expected or predicted outcome. Verification by analysis relies heavily on data from previous studies or tests to create models and equations of the scenario and can be done through simulation, calculation, or survey of the system with a follow-up work to determine if it passes or fails. Verification by inspection of a system or subsystem can determine the condition and status of the system and is used if the result can be easily determine without calculation with a criteria and expectations. Lastly, verification by demonstration showcases the performance of a system or subsystem and implies that current success of a task implies future success of the same task but still with no guarantee.

4.4.3. Project Risks

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

Hazard	Likelihood (Cause)	Severity (Effect)	Risk	Mitigation	Verification	Risk After
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	High
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; attempt to use universal components dealt by multiple companies	Keep list of parts required and checklist for when purchased; set at minimum a week deadline to purchase components necessary before required and to make minute final adjustments in the remaining week	Medium
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; attempt to use universal components dealt by multiple companies; keep parts secured in designated safe	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; set at minimum a week deadline to purchase components necessary to core functionally before required; ensure after testing, construction, or launch that parts are	Low

				location	stored in the designated safe location as designated, and listed in the checklist	
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 construction and less attention paid to test data)	8, Medium	Set deadlines which both keep the project moving at a reasonable pace and leave room for unforeseen circumstances; ensure at least two people are working to ensure safety and quality work	Keep team updated on all deadlines by maintaining effective communication; project lead enforces milestones and urges team to work proactively; have at least two people working with group checklist	Medium
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	Medium
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; have team lead and Safety lead agree on mutual area	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	Medium
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)	Low

Failure in Construction Equipment	1 (Improper long-term maintenance of construction equipment, improper use or storage of equipment)	3 (Possible long-term delay in construction)	3, Low	Ensure proper maintenance and use of construction equipment and have backup equipment which can be used in case of an equipment breakdown	Keep equipment safe following proper protective measures to keep first the user safe and then the equipment; have backup construction equipment	Low
Insufficient Transporta-tion	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	Low
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; only include reliable elements in the design which have been confirmed to work through prior designs or extensive mathematical and physical analysis	Make sure all sub team leads and responsible team members review design before assembly; 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	Medium
Lack of Communica-tion	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; use Google Docs and Slack to document attendance and ensure communication	Low
Inactivity	2 (Members are unable or unwilling to work)	5 (Low attendance, loss of team members, labor shortages,	10, Medium	Train all members to work in all areas necessary; have an organized group of subteams	Utilization of work time table; employment of attendance tracking methods such as a sheet and utilization of	Low

		inability to construct vehicle)		within the project and obtain updates from subteam leaders weekly	electronic communications; use Google Docs and Slack to document attendance and ensure communication	
Low Availability of Personnel	2 (Classes become extremely involved, other extracurricular s 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; ensure new team members may join and help if personnel are unable to attend mandatory events, avoidable if mitigation is followed to where dates are determined by group members to ensure availability is not a significant issue	Low
Personnel Injury	2 (Members are unable to work)	5 (Temporary loss of team member and labor force)	10, Medium	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	Medium
Damage By Non-Team / 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, for organization, management, and safety concerns, in the designated area accessible only by team members to ensure in most safe and secure location that is unable to be inadvertently damaged	Ensure only team members as known can have access to components by following the mitigation as accessible to only members; ensure a lead is present to surveil; ensure storage location is in most safe and secure location that is unable to be inadvertently damaged by gently moving the launch components to ensure fixed or stable	Low
Improper Transit Availability	1 (No safe way to transport the	5 (Failure to launch)	5, Low	Organize rocket transportation well in advance;	Ensure transportation is set in advance and known to have transportation;	Low

for Rocket	subscale rockets or final rocket to the launch site)			ensure transportation can be sent to rocket location and capable of fitting rocket; fill out driver transportation form	ensure all drivers have filled out the necessary necessary form to ensure drivers are safe and permitted through the University to drive students and team members to launch sites and potentially design sites	
Damage During Transit	2 (Mishandling)	5 (Inability to fly rocket)	10, Medium	Protect all rocket components during transit; ensure rocket is secured at multiple locations to make sure no movement	Ensure rocket safety secured by testing movement of rocket secured at least two points; have teammate able to see and handle rocket in case error were to occur	Low
Calendar Conflicts	3 (Overlap with classes)	4 (Inability of team members to travel)	12, Medium	Inform professors and concerned persons about overlap ahead of time	Ensure professors are aware of calendar conflicts as documented once new semester starts and checklist or at least a week away	Medium
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; ensure team leads are active over break and have longer meeting once break is over to complete what must have been completed	Minimal
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 with multiple days shared as workable	High

4.4.4. Personnel Hazard Analysis

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

Hazard	Likelihood (Cause)	Severity (Effect)	Risk	Mitigation	Verification	Risk After
Assembly Malfunction	2 (Rocket destruction, splintering, etc.)	3 (Minor scraps, splinters, bruising, abrasions, possible tripping debri)	6, Low	Ensure instructions are followed and rocket is gently assembled in order to not break the rocket or injure personnel; wear appropriate PPE such as protective eyewear, gloves, face mask, and/or lab coat; follow any other rule set forth through Safety and written procedures and checklists;	Ensure verification by inspection with safety lead ensuring components are safe to assemble and that the assembler is supervised; strictly follow the mitigation and have a team lead assemble the rocket to ensure it is assembled correctly without possibility of other hazards	Minimal
Black Powder Incorrectly Measured	3 (Bad calculation or communicatio n	5 (Severe injury, death)	15, High	Ensure with multiple calculations and measurements by at least three individual workers and at least one lead that correct measurement in addition to testing said amount in a secure area to ensure safe with test data; ensure labelled and secured; create a written procedure of how to measure the exact amount and try to use the same individual who measured the powder to repeat for later use with the safety lead continuously supervise	Strictly follow the mitigation and use testing and the written procedure of how to measure the exact amount; have the individual who measured the powder only handle the black powder if the individual possesses a low-explosives user permit and is supervised by the safety lead; guaranty PPE worn and checked during handling by a safety team member before and during use	Medium
Burns From	2 (Close	3 (Mild to	6, Low	Clean the	Ensure 200 feet border	Low

Motor Exhaust	proximity to launch pad)	moderate burns)		launchpad before use, ensure all members are wearing proper PPE for launch, ensure all team members are a minimum clear distance of at least 30 meters from the launch vehicle when launching and maintain minimum safe launch distances	be established after mounting of rocket onto launcher as compliance to NAR safety standards; prior PPE check must be done by a safety team member before ignition; 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	
Cuts or Lacerations from Damaged Rocket Components	3 (Sharp edges from damaged parts)	3 (Moderate cuts or lacerations to personnel retrieving the rocket)	9, Medium	Check the rocket for sharp edges before recovering, wear appropriate PPE when recovering; secure loose hair, clothing, and jewelry; wear appropriate PPE such as protective eyewear, gloves, face mask, and/or lab coat; brief personnel on proper construction procedures; follow rules set before use and by workshop requirements	Prior PPE check must be done by a safety team member before conducting recovery; rules must be known before to use in addition to mandatory supervision to ensure proper use and safety	Low
Contact with Airborne Chemical Debris	3 (Airborne particulate debris)	4 (Minor burns, abrasions)	12, Medium	Wear appropriate PPE such as protective eyewear, gloves, face mask, and/or lab coat; wash hands with water and soap; alert others that substances are in use before and during use; follow any other rule set forth through Safety	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 chemicals are secure and safely used; guarantee PPE worn at all times during manufacturing; call out prior to use for PPE	Medium

				and written procedures and checklists; wash with water and if direct contact, rinse eye with cool water for at least 15 minutes and get emergency	check to be completed by safety team	
Dehydration	3 (Failure to drink necessary amounts of water to remain hydrated)	4 (Exhaustion and possible hospitalization)	12, Medium	Ensure all members have access to water at launch; make sure backup of water for full mission; brief personnel on timeline and need for water	Mandatory water breaks will happen every hour; water must be brought or offered by team leads to any trip to ensure hydration	Low
Direct Contact with Hazardous Chemicals	3 (Chemical spills, improper use of chemicals)	4 (Moderate burns, abrasions)	12, Medium	Wear appropriate PPE such as protective eyewear, gloves and/or lab coat; wash hands with water and soap; alert others that substances are in use before and during use; follow any other rule set forth through Safety and written procedures and checklists; wash with water and if direct contact, rinse eye with cool water for at least 15 minutes and get emergency	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 chemicals are secure and safely used; guarantee PPE worn at all times during manufacturing; call out prior to use for PPE check to be completed by safety team	Medium
Dust or Chemical Inhalation	3 (Airborne particulate debris)	3 (Short to long-term respiratory damage)	9, Medium	Wear appropriate PPE of a respirator, safety glasses, and gloves; work in well ventilated and visible but isolated area	No contact allowed without call out before use to make sure PPE worn; PPE check must be done by a safety team member for dust mask; area must be away from others and be ventilated	Low
Electric	3 (Improper	4 (Possible	12,	Ensure labelled and	Strictly follow the	Medium

Matches Misuse	use of equipment, static build-up, unexpected / accidental discharge)	explosion, destruction of electrical tools or components, possible severe harm to personnel)	Medium	secured; create a written procedure of how to setup to repeat for later use with the safety lead continuously supervising; ensure secured then secured properly directly before launch	mitigation and use testing and the written procedure of how to measure; guaranty PPE worn and checked during handling by a safety team member before and during use; follow checklist and ensure followed similarly to subscale	
Electrocution	3 (Improper use of equipment, static build-up, unexpected / accidental discharge)	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; brief personnel on proper clean-up procedures and to wear appropriate PPE of gloves and ground; brief on proper construction procedures and to ground oneself when working with high-voltage equipment; follow rules set before use and by workshop requirements; turn off all construction tools when not in use	Guarantee no open electrical components; allow only one member to work on electrical components at a time with proper PPE and student supervising with prior PPE check; PPE check must be done by a safety team member before conducting construction; rules must be known before to use in addition to mandatory supervision to ensure proper use and safety	Medium
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 of secured hair, rolled up / short sleeves, no jewelry, and safety glasses	No contact allowed without call out before use to make sure PPE worn; make sure rules followed as set forth by machining rules and checked by personnel supervising	Low
Epoxy Contact	3 (Resin spill, resin contact during application or while drying)	3 (Exposure to Irritant)	9, Medium	Wear appropriate PPE such as gloves, face mask, and / or lab coats; wash with water and alert safety; work in well ventilated and visible but isolated area; have epoxy	No contact allowed without call out before use to make sure PPE worn; PPE check must be done by a safety team member; ensure epoxy cleanser, soap, and water accessible before epoxy use	Low

				cleanser, soap, and water available with use		
Eye Irritation	3 (Airborne particulate debris)	2 (Temporary eye irritation)	6, Low	Wear appropriate PPE such as protective eyewear, eye goggles or eye glasses; follow any other rule set forth through Safety and written procedures and checklists; wash with water and if direct contact, rinse eye with cool water for at least 15 minutes and get emergency medical attention and/or call 911	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 chemicals are secure and safely used; guarantee PPE worn at all times during manufacturing; call out prior to use for PPE check to be completed	Low
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	Low
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 and a cold area to rest at launch; brief personnel on appropriate PPE of safety glasses and temperature to require short sleeve shirts	Team members must have necessary / adequate clothing, safety team will report violators to the project lead to decide if the violator should be dismissed to a colder area with enough space predetermined for entire group; water will be provided	Low
Hearing Damage	3 (Close proximity to loud noises)	4 (Long term hearing loss)	12, Medium	Wear appropriate PPE such as ear muffs when using power tools or explosive testing; brief personnel on proper PPE for	PPE check must be done by a safety team member before conducting construction or explosive testing; stay behind cover to avoid shock waves from	Low

				anywhere in vicinity of workshop	explosion testing; rules must be known before to use in addition to mandatory supervision to ensure proper use and safety	
Hypothermia	2 (Low temperatures on launch day)	3 (Sickness and possible hospitalization)	6, Low	Wear clothing appropriate to the weather, ensure all members have access to a warm area to rest at launch; brief personnel on appropriate PPE of safety glasses and temperature / wind chill to require warm clothes	Ensure people scheduled to attend have been mandatorily briefed on the temperature and rocket; ensure team members must have necessary / adequate clothing for sufficient warmth, safety team will report violators to the project lead to decide if the violator should be dismissed to a warmer area with enough space predetermined for entire group	Minimal
Kinetic Damage to Personnel after Launch	1 (Failure to take appropriate care around unburned fuel, post-landing launch vehicle explosion)	5 (Possible severe kinetic damage to personnel)	5, Low	Extinguish any fires before recovering, wait for motors to burn fully before recovering, wear appropriate PPE of safety glasses and gloves when recovering	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	Low
Launch Pad Fire	3 (Dry Launch Area)	3 (Moderate Burns)	3, Medium	Have fire suppression systems nearby and use a protective ground tarp; follow relevant safety procedures when handling batteries, e-matches, and other potentially combustible materials	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 and PPE; ensure PPE protocols are followed at all times;	Low
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	Make sure area is evacuated and individuals are	Medium

				needed	designated 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 launch vehicle enters a ballistic trajectory; brief personnel on proper recovery to stay in cover until rocket is grounded and then for select designated group to recover the rocket	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; ensure group is designated before launch and walks with partners to ensure to be aware and regard safety	Low
Injury from Fabrication	3 (Failure to keep all components securely attached, failure to wear proper PPE)	5 (Severe injury, death, cuts, burns, etc)	15, High	Wear appropriate PPE such as eye goggles, eye glasses, respirators, gloves, ear plugs, etc., wash with water; follow any other rule set forth through Safety and written procedures and checklists	PPE check must be done by a safety team member before conducting construction; team members must guarantee someone is there to watch and ensure safety	Low
Injury from Rocket Launch	3 (Explosion, rocket blast, falling components, etc.)	5 (Severe injury, death, cuts, burns, etc)	15, High	Follow all launch safety procedures, stay out of rocket safety circle, inspect rocket launch parts such as launch guide and motor casing, follow NAR/TRA safety code requirements, have first aid kit present	PPE check must be done by a safety team member before conducting launch; team members must guarantee someone is there to watch and ensure safety of each other; follow written procedures and checklists	Low

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 from atypically dangerous areas; brief personnel on proper recovery to stay in cover until rocket is grounded and then for select designated group to recover the rocket	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; ensure group is designated before launch and walks with partners to ensure to be aware and regard safety	Low
Injury from Projectiles Caused by Jetblast	2 (Failure to properly clean launchpad, failure to wear proper PPE, failure to stand an appropriate listed distance from the launch vehicle during launch)	3 (Moderate injury to personnel)	6, Low	Clean the launchpad before use, ensure all members are wearing proper PPE for launch, ensure all team members are a minimum clear distance of at least 30 meters from the launch vehicle when launching and maintain minimum safe launch distances	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	Low
Material Safety Data Sheet (MSDS) Availability	3 (Failure to share or secure MSDS)	5 (Injury to personnel)	15, High	Ensure team is briefed on material safety data sheets (MSDS) and that they are shared and available to the team; share through group drive and ensure have universal axis at all times including launch; notify before the purchase of any materials to make certain that there is a safety plan sufficient to address any new safety issues, to proactively identify and acquire any required PPE, and to compile and	All team members will be given a briefing on the plan to properly purchase, store, transport, and use hazardous materials by the safety officer; safety brief will provide knowledge of and access to 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; MSDSs are to be referred to when a hazard occurs in order to execute the most effective mitigation and ensure all safety concerns are	Low

				maintain all MSDSs and other safety information; all MSDSs are available to the team at all times and are required to be understood before working with potentially hazardous materials	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	
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; extended fire)	9, Medium	Brief personnel on proper clean-up procedures, wear appropriate PPE such as shoes that cover the toes; brief personnel on proper construction procedures; follow rules set before use and by workshop requirements; turn off all construction tools when not in use, be aware of the safety hazard of parts which were recently worked with	PPE check must be done by a safety team member before conducting construction; rules must be known before to use in addition to mandatory supervision to ensure proper use and safety; guaranty no open heat sources / components; allow only one member to work on heat components at a time with proper PPE and student supervising; label hot components	Low
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 and to wear appropriate PPE such as shoes that cover the toes; brief personnel on proper construction procedures; follow rules set before use and by workshop requirements	PPE check must be done by a safety team member before conducting construction; rules must be known before to use in addition to mandatory supervision to ensure proper use and safety; make sure heavy tools only used with closed-toe shoes as designated by machining rules	Medium
Premature Ignition	2 (Short Circuit; misfire)	5 (Burns)	10, Medium	Prepare energetic devices (batteries, black powder, etc.) only immediately prior to flight; allow proper ignition to	Deemed unsafe to arm electronics until prior to ignition; allow no possibility of ignition until launch by keeping separately secured from	Low

				only occur on launch pad and otherwise avoid contact	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 to inspect and/or fix	No contact allowed at all; call out when recognized to safely call power company for them to handle; ensure safety lead and team lead notified or present to confirm as set forth by designated recovery team	Low
Power Tool Cuts, Lacerations, and Injuries	3 (Carelessnes s)	4 (Possible Hospitalization)	12, Medium	Secure loose hair, clothing, and jewelry; wear appropriate PPE of safety glasses and face mask; brief personnel on proper construction procedures; follow rules set before use and by workshop requirements	PPE check must be done by a safety team member before conducting construction; rules must be known before to use in addition to mandatory supervision to ensure proper use and safety	Medium
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; brief personnel on proper recovery to stay in cover until rocket is grounded and then for select designated group to recover the rocket	If equipment is to be recovered, ensure that area is safe and recovery can be done with little to no potential for harm; ensure group is designated before launch and walks with partners to ensure to be aware and regard safety	Low
Soldering and Wiring Electronics	3 (Airborne particulate debris)	3 (Short to long-term respiratory damage)	9, Medium	Proper NIOSH/MSHA-appr oved 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	No contact allowed without call out before use to make sure PPE worn; PPE check must be done by a safety team member for dust mask; area must be away from others and be ventilated; must have safety supervision or previous experience as instructed through	Medium

				ventilation; work in well ventilated and visible but isolated area; have safety supervision or previous experience	building presentation and knowledge known before having access to soldering and wiring electronics	
Testing	3 (Improper contact with testing apparatus)	5 (Bruising, abrasions; moderate to severe burns; extended fire; possible severe hearing damage or other personal injury)	15, High	Brief personnel on proper setup procedures and wear appropriate PPE such as shoes that cover the toes; brief personnel on proper testing procedures; follow rules set before use and by workshop requirements; ensure all personnel be aware of the safety hazard	PPE check must be done by a safety team member before conducting testing; rules must be known before to use in addition to mandatory supervision to ensure proper use and safety; guaranty no open heat sources / components; allow only one member to work on heat components at a time with proper PPE and student supervising; label hot components	Medium
Tripping Hazards	3 (Materials 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; leave better and cleaner than what was arrived at	Guaranty no hazards exist by following the manufacturing rules and mitigation; follow all rules set forth by safety and make sure all possible hazards are acknowledged and/or moved out of personnel access	Low
Unintended Black Powder Ignition	2 (Accidental exposure to flame or sufficient electric charge, improver handling or storage)	5 (Possible severe hearing damage or other personal injury)	10, Medium	Properly store, handle, and label containers storing black powder; only handle the black powder if the individual possesses a low-explosives user permit and is supervised by the safety lead	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; guaranty PPE worn and checked during handling by a safety team member before and during use	Medium
Workplace Fire	2 (Unplanned ignition of flammable	5 (Severe burns, loss of workspace,	10, Medium	Have fire suppression systems nearby,	Make sure workplace has updated fire safety protocol; in case of a	Medium

	substance, through an overheated workplace, improper use or supervision of heating elements, or improper wiring)	irreversible damage to project)		prohibit open flames, and store energetic devices in Type 4 magazines	fire, ensure that the workplace had updated fire suppression systems nearby	

4.4.5. Failure Mode And Effects Analysis (FMEA)

The following hazards are threats to the vehicle used in the project and its successful completion of the mission:

Hazard	**Likelihood (Cause)**	**Severity (Effect)**	**Risk**	**Mitigation**	**Verification**
Airframe Failure	1 (Buckling or shearing on the airframe from poor construction or use of improper materials, faulty stress modeling)	5 (Partial or total destruction of vehicle, ballistic trajectory)	5, Low	Use appropriate materials according to extensive mathematical and physical analyses of the body tube, bulkheads, fasteners and shear pins, use materials such that the rocket is lightweight but has the proper structural characteristics to withstand rocket launch and forces within a safety factor, make use of reliable, standard building techniques as designated by the manufacturing facility, confirm analyses with test launches, make sure composite materials are not delaminated; recheck that airframe is sufficient for the described design requirements	Use a construction checklist which ensures mathematical 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
Inadvertent rocket motor or pyrotechnic initiation	2 (Miswired onboard avionics, poor design of onboard electronics, failure of avionics, launch relay box failure)	5 (Partial or total destruction of vehicle, potentially no failure)	10, Medium	Have multiple individuals and the team check that the avionics is designed properly and wired to NASA's standards, ensure the electronics have been previously used in similar application for comparison sake and to ensure that it has the opportunity to function properly	Ensure multiple individuals, or at least two, verify that the avionics is set up properly, ensure that multiple individuals monitor the launch initiation and ignition to ensure checklist is properly followed

Failure To Launch	2 (Lack of continuity)	1 (Recycle launch pad)	2, Minimal	Check for continuity prior to attempted launch, ensure launch pad is properly connect prior to additional matters or rocket setup; re-setup system or have alternative system	Ensure continuity checked by checklist, ensure officials agree that the setup is proper and will be sufficient for uninterrupted launch
Catastrophic rocket motor malfunction "CATO")	2 (Motor failure; motor defect, assembly error; improper igniter or positioning; improper cable length; improper storage of motor)	5 (Partial or total destruction of vehicle)	10, Medium	Inspect motor prior to assembly and closely follow assembly instructions; mathematically ensure and test that chamber pressure cannot exceed limits of motor hardware as assembled; ensure all team members are a minimum clear distance of at least 30 meters from the launch vehicle when launching and maintain minimum safe launch distances; teach team on handling and storage of motor procedures	Ensure all team members are still an appropriate distance of at least 30 meters from the launch vehicle when launching and maintain minimum safe launch distances; ensure team is taught on handling and storage of motor procedures before allowed to contact motor; ensure motor inspected by checklist during test runs and launch
Instability	1 (Stability margin of less than 1.00, stability margin less than design requirement)	5 (Potentially dangerous flight path and loss of vehicle)	5, Low	Measure physical center of gravity and compare to calculated center of pressure; ensure center of gravity and center of pressure theoretically yield a stable flight within the margin for the previously stated design requirement; ensure design is stable before manufacturing; if understable after, change the center of gravity to increase stability	Ensure construction checklist 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 and checked before additional designing
Motor Expulsion	1 (Improper retention methods)	5 (Risk of recovery failure and low apogee)	5, Low	Use positive retention method to secure motor; ensure motor properly secured by Level 3 and LEUP holder; follow the previously tested motor procedures and/or external setup process	Ensure motor secured by checklist during test runs and launch; ensure properly mounted by Level 3 and LEUP holder and / or official
Premature Ejection	1 (Altimeter programming, poor venting)	5 (Zippering)	5, Low	Check altimeter settings prior to flight and use appropriate vent holes of four holes at every 90 degrees to ensure a symmetric intake of air for sensor readings; ensure ejection charges are properly	Ensure altimeter set by checklist during test runs and launch, ensure vent holes are present to allow for sensor readings

				timed and tested during ejection tests	
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, use materials such that the rocket is lightweight but has the proper structural characteristics to withstand rocket launch and forces within a safety factor, make use of reliable, standard building techniques as designated by the manufacturing facility, 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), if using composites, make sure material is not delaminated	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	3 (Poor construction or improper materials used; improper active retention system)	5 (Partial or total destruction of vehicle)	15, High	Use appropriate materials according to extensive mathematical and physical flight analyses, use high powered building techniques and materials such that the rocket is lightweight but has the proper structural characteristics to withstand rocket launch and forces within a safety factor, make use of reliable, standard building techniques as designated by the manufacturing facility, run stability tests, confirm analyses with test launches, check to make sure the structure is still in good condition before launches (especially if launching the same rocket twice), if using composites, make sure material is not delaminated; ensure system is calculated to be properly retained with backup in case of failure	Ensure that nose cone is secured well before ejection during test runs and otherwise alter; ensure nose cone ejects as intended during ejection tests; ensure nose cone ejection method has no statistically no room for failure by the active retention system being calculated to only function when intended, or follow high safety factor with backup shock chord as to not lose the nose cone

Loss of Parachute	3 (Poor construction or improper materials used)	5 (Partial or total destruction of vehicle)	15, Medium	Use appropriate materials according to extensive mathematical and physical flight analyses, use high powered building techniques and materials such that the rocket is lightweight but has the proper structural characteristics to withstand rocket launch and forces within a safety factor, make use of reliable, standard building techniques as designated by the manufacturing facility, run stability tests, confirm analyses with test launches, check to make sure the structure is still in good condition before launches (especially if launching the same rocket twice), make sure no tears, punctures, holes, etc. are present	Ensure that parachute is secured well before ejection during test runs, otherwise alter to lower speed; ensure through multiple simulations that within the designed safety factor that the shock chord would not fail nor be destroyed during ejection, testing, or any other event during launch
Ejection Charge Failure	4 (Not enough power from black powder combustion, electrical failure)	5 (Ballistic trajectory, destruction of vehicle)	20, High	Ensure ground test charge sizes at least once before flight; ensure backup ejection charge of greater size than the first charge to be used to ensure ejection is successful; ensure ejection charges are properly timed and tested during ejection tests	Ensure test charge before final launch to ensure that charge does not fail; ensure ejection charge calculated by multiple individuals and cross checked with different methods
Altimeter Failure	3 (Loss of connection or improper programming)	5 (Ballistic trajectory, destruction of vehicle)	15, High	Ensure that all components are secured to their mounts and check settings before any test or launch; utilize multiple altimeters and strictly ensure altimeter checklist is followed	Ensure altimeter works with prior tests; ensure altimeter checklist is followed as previously tested to ensure functionality works as intended
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 payload checklist is followed; ensure payload is tested before launch and on other random occasions to ensure system is functional and viable for the design requirements	Ensure that payload is fully functioning prior to flight by conducting tests; ensure payload checklist is followed as previously tested to ensure functionality works as intended
Heat	2 (Insufficient	4 (Excessive	8,	Use appropriate protection	Ensure (prior to final

Damaged Recovery System	protection from ejection charge)	landing velocity)	Medium	methods, such as Kevlar blankets, use appropriate materials according to extensive mathematical and physical flight analyses, use high powered building techniques and materials such that the rocket is unlikely to fail during heat and has the proper structural characteristics within a safety factor as designated by the manufacturing facility; make sure no, punctures, holes, etc. are present	launch) that proper materials are readily working and available in case heat damage occurs; ensure that recovery system is designed and calculated to not receive heat damage or non-negligible heat transfer
Broken Fastener	1 (Excessive force)	5 (Ballistic trajectory)	5, Low	Use fasteners with a breaking strength safety factor of 2 or higher safety factor set by the design requirement; test during testing including but not limited to ejection testing	Ensure by design and testing that fasteners are secure by following the mitigation in addition to running FEA simulations and generally testing the structural stability
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, standard building techniques as designated by the manufacturing facility, confirm analyses with test launches; test during testing including but not limited to ejection testing	Ensure by design and testing that joints are secure by following the mitigation in addition to running FEA simulations and generally testing the structural stability
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, standard building techniques as designated by the manufacturing facility, confirm analyses with test launches; test during testing including but not limited to ejection testing	Ensure by design and testing that the centering rings secure by following the mitigation in addition to running FEA simulations and generally testing the structural stability
Motor Mount Failure	1 (Faulty motor or motor mount preparation, poor construction, damage to motor	5 (Partial or total destruction of vehicle, ballistic	5, Low	Use mathematical and physical analyses to ensure the motor mount works as planned, test the motor mount with subscale flights, check the	Ensure by design and testing that the motor mount secure by following the mitigation in addition to running

	mount)	trajectory)		motor mount for damage before flight, team members who prepare the motor must be supervised by at least one other team member	FEA simulations and generally testing the structural stability and rigidity
Component or Rocket 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; use appropriate materials according to mathematical and physical analyses, make use of reliable, standard building techniques as designated by the manufacturing facility	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 through calculation completed by multiple individuals and cross checked to ensure proper sequence of events; test during testing including but not limited to ejection testing	Ensure by design, simulations, and testing that secure by following the mitigation in addition to running FEA simulations and generally testing the structural rigidity
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 following the checklist and ensuring secure by applying a force and simply checking	Verify that GPS lock and battery charge are properly secured by following the mitigation in addition to running FEA simulations and generally testing the structural stability
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 complete destruction of vehicle)	15, High	Properly size, pack, and protect parachute; ensure parachute properly rolled by checklist standards and ensure that proper parachute chosen by unique calculations from multiple individuals; use subscale flights to determine if the subscale parachutes were accurately sized	Ensure that parachute is well secured in on the aircraft and that it opens as planned; test the parachute before final launch via a drop test and by simply ensuring the parachute is unbroken
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	2 (Landing	5 (Partial or	10,	Ensure design has sufficient	Ensure by design and

Puncture	damage)	complete destruction of vehicle)	Medium	distance / protection from outside, and motor, charges, and batteries; test during testing including but not limited to ejection testing	testing that secure from other systems or puncture by ensuring it is secured and away from moving components with protection to prevent puncture
Black Powder 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; test during testing including but not limited to ejection testing to ensure sufficient design with respect to design requirements	Ensure by design and testing that secure from other systems or puncture; ensure during testing that is isolated from individuals and is successfully accomplished with respect to the design requirements
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; test during testing including but not limited to ejection testing to ensure sufficient design with respect to design requirements	Independently ensure design is safe; ensure by isolated testing charge may work; ensure during testing that is isolated from individuals and is successfully accomplished with respect to the design requirements and mathematical modelling that sufficiently distant from critical rocket components such as the motor
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, standard building techniques as designated by the manufacturing facility, run stability tests, confirm analyses with test launches	Ensure by design and testing that secure as ensured during simple checks, including during checklist, in addition to mathematical modelling and additional testing including ejection testing
Destruction of Nose Cone	1 (Poor construction, damage from previous flights, poor storage, or	3 (Lower rocket stability, possible deviations	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	Ensure by design and testing that secure as ensured during simple checks, including during checklist, in

	transportation)	from flight path)		according to mathematical and physical flight simulations, confirm choice of nose cone with subscale launches	addition to mathematical modelling and additional testing including ejection testing
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 as ensured during simple checks, mathematical modelling, and additional testing including ejection testing; ensure design is straight as manufactured by simply ensuring motor is perpendicular to airframe or as intended
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 as ensured during simple checks, including during checklist, in addition to mathematical modelling and additional testing including ejection testing
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 and that separation occurs strictly when desired, as ensured by the checklist that must be similarly strictly followed
Forgotten or Lost Component	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 to ensure that all components that are necessary are accounted for and brought to launch, building, or other events
Poorly placed	2 (Carelessness with rocket	3 (Lower rocket	6, Low	Extensive, up-to-date, and detailed simulations and	Ensure by design and testing that secure

center of gravity	design, weight which was not considered in mathematical or physical analyses)	stability)		models of the rocket and its flight, adding and leaving room to add extra ballast as needed	during rocket design and that the proper verification is followed as listed
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 during rocket design and that the proper verification is followed as listed; determined during design so ensure is a key fundamental step in designing the rocket
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; test during testing including but not limited to ejection testing; ensure avionics properly set up as validated through testing and checklists	Ensure by design and testing that secure; ensure checklist is followed as to check for this failure mode that if it occurs the proper verification as listed will be followed
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 tested multiple times to ensure ejection charge checklist is sufficient and that ejection charge is sufficient for stable ejection	Ensure by design and testing that secure; ensure checklist is followed as to check for this failure mode that if it occurs the proper verification as listed will be followed; ensure during testing that is isolated from individuals and is successfully accomplished with respect to the design requirements
Rocket Disconnect s 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,	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; ensure checklist is followed as to check for this failure mode that if it occurs the proper verification as listed will be followed

		and property on the ground)			
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; ensure sky is clear during launch on day that is officially approved with the appropriate waver
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; ensure checklist is followed as to check for this failure mode that if it occurs the proper verification as listed will be followed; test via checklist
Failure to Ignite Propellant	1 (Faulty motor preparation, poor quality of propellant, faulty igniter, faulty igniter power source, damage to motor)	5 (Rocket does not immediately launch and is a considerable hazard until it is confirmed that it will not launch, changes to igniters or rocket required)	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 the igniters chosen work well during subscale testing	Ensure by design and testing that secure; ensure the area is properly thermally insulated and that there is an insignificant chance for a fire; ensure protection is sufficient by having official approval in addition to allowing no contact with flammable matter; ensure calculated heat transfer deemed insignificant
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	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; ensure the area is properly thermally insulated and that there is an insignificant chance for a fire; ensure protection is sufficient by having official approval in addition to allowing no contact with flammable matter; ensure

		charges for recovery may not deploy)			calculated heat transfer deemed insignificant
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, catastrophic 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; ensure the area is properly thermally insulated and that there is an insignificant chance for a fire; ensure protection is sufficient by having official approval in addition to allowing no contact with flammable matter; ensure calculated heat transfer deemed insignificant
Propellant Explosion	1 (Faulty motor preparation, poor quality of propellant, damage to motor)	5 (Ballistic trajectory, catastrophic 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; ensure the area is properly thermally insulated and that there is an insignificant chance for a fire; ensure protection is sufficient by having official approval in addition to allowing no contact with flammable matter; ensure calculated heat transfer deemed insignificant; ensure by structural analysis that if explosion were to occur that system would not become fragmented
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; test during testing including but not limited to ejection testing to ensure sufficient design with respect to design requirements	Ensure by design and testing that secure and that the electionics stay powered as intended and as previously calculated, including while in launch and testing conditions; ensure checklist is followed to ensure proper setup

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; test during testing including but not limited to ejection testing to ensure sufficient design with respect to design requirements	Ensure by design and testing that secure and that the electionics stay powered as intended and as previously calculated, including while in launch and testing conditions; ensure checklist is followed to ensure proper setup
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 trigger ejection charges at correct time, possible failure to meet mission objectives, possible recovery failure, possible ballistic trajectory)	4, Low	Take efforts to properly seal avionics and payload such as the use of putty, follow proper construction procedures, check the avionics bay, payload, and rocket body for damage before launch, check insulation of avionics bay and payload through test launches; test during testing including but not limited to ejection testing to ensure sufficient design with respect to design requirements	Ensure by design and testing that secure; ensure the area is properly thermally insulated and that there is an insignificant chance for a fire; ensure protection is sufficient by having official approval in addition to allowing no contact with flammable matter; ensure calculated heat transfer deemed insignificant
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; test during testing including but not limited to ejection testing to ensure sufficient design with respect to design requirements	Ensure by design and testing that secure and that fire would not occur during launch; ensure the area is properly thermally insulated and that there is an insignificant chance for a fire; ensure protection is sufficient by having official approval in addition to allowing no contact with flammable matter; ensure calculated heat transfer deemed insignificant
Human Error When	3 (Forgotten connection,	5 (Disqualified,	15, High	Leave reminders in multiple places to check that the	Ensure follow safety checklist to ensure

Arming Avionics and Payload	forgetting to activate avionics bay components or payload prior to launch)	objectives not met, failure to correctly trigger ejection charges)		avionics bay and payload are armed and ready before launch, follow launch checklists closely; test during testing including but not limited to ejection testing to ensure sufficient design with respect to design requirements	properly armed; ensure continuity checked by checklist, ensure officials agree that the setup is proper and will be sufficient for uninterrupted launch; ensure during testing that arming works and that checklist is utilized to follow the proper steps
Arming System Failure	3 (Faulty arming system, 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	Ensure the avionics bay is successfully communicating with the team prior to flight, test arming system through test launches; check for continuity prior to attempted launch, ensure launch pad is properly connect prior to additional matters or rocket setup; test during testing including but not limited to ejection testing to ensure sufficient design with respect to design requirements	Ensure by design and testing that secure; ensure continuity checked by checklist, ensure officials agree that the setup is proper and will be sufficient for uninterrupted launch; ensure during testing that arming works and that checklist is utilized to follow the proper steps; test during testing including but not limited to ejection testing to ensure sufficient design with respect to design requirements
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; test during testing including but not limited to ejection testing to ensure sufficient design with respect to design requirements	Ensure by design and testing that secure and the stages separates during ejection tests and, prior to that, through mathematical modelling; test during testing including but not limited to ejection testing to ensure sufficient design with respect to design requirements
Stage Fails to Separate	2 (Faulty ejection charge, excessive strength is used	4 (Rocket does not follow desired flight path,	8, Medium	Any team member who loads the ejection charges must be supervised by at least one other team member, examine	Ensure by design and testing that secure and the stages separates during ejection tests

	to hold stages together, altimeter failure)	possible ballistic trajectory, lower maximum height, damage to the rocket)		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 ejection charge for each stage separation	and, prior to that, through mathematical modelling; test during testing including but not limited to ejection testing to ensure sufficient design with respect to design requirements
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 avionics properly set up for parachute to deploy; ensure by testing that checklist is sufficient to allow for parachute to deploy; test during testing including but not limited to ejection testing to ensure sufficient design with respect to design requirements
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 avionics properly set up for parachute to deploy; ensure by testing that checklist is sufficient to allow for parachute to deploy; test during testing including but not limited to ejection testing to ensure sufficient design with respect to design requirements
Parachute Canopy Breaks or Tears	1 (Poor canopy 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 and test that after numerous ejection tests the shock cord and / or parachute do not become tangled or break; test during testing including but not limited to ejection testing to ensure sufficient design with respect to design

					requirements
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 and test that after numerous ejection tests the shock cord and / or parachute do not become tangled or break; test during testing including but not limited to ejection testing to ensure sufficient design with respect to design requirements
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 and test that after numerous ejection tests the shock cord and / or parachute do not become tangled or break; test during testing including but not limited to ejection testing to ensure sufficient design with respect to design requirements
Tangled Parachute or Shock Cord	1 (Faulty or damaged shock cord or parachute, poor packing of shock cord and/or parachutes, poor sizing of parachutes or shock cord, unstable or ballistic flight)	4 (Shock cord or parachutes may not fully achieve their goal, possible ballistic trajectory, possible failed recovery)	4, Low	Only buy parachutes and shock cords from reliable sources, any team member who seals or packs the parachute chamber must be supervised 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;	Ensure by design and testing that secure and test that after numerous ejection tests the shock cord and / or parachute do not become tangled or break; test during testing including but not limited to ejection testing to ensure sufficient design with respect to design requirements
Parachute Comes Loose from Rocket	1 (Failure of recovery system mount on the rocket body, poor shroud line materials, improper ejection of recovery	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	Ensure that parachute is secured well before ejection during test runs, otherwise alter to lower speed; ensure through multiple simulations that within the designed safety

	system, damage from previous flights or transportation)			recovery system is properly mounted before launch	factor that the shock chord would not failure or be destroyed during ejection, testing, or any other event during launch
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; ensure checklist is followed to ensure proper steps are followed; ensure by calculation that heat transfer would not be significant to ignite the rocket
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; ensure checklist is followed to ensure proper steps are followed; ensure by calculation that heat transfer would not be significant to ignite the rocket; test during testing including but not limited to ejection testing to ensure sufficient design with respect to design requirements
Fire	2 (Blast deflection insufficient, motor failure, hot igniter falls, on-ground ejection)	5 (Partial or total destruction of vehicle)	10, Medium	Clear out vicinity and have adequate blast deflectors by ensuring that only an insignificant amount of heat transfer would reach flammable matter, utilize fire blankets and maintain the previously listed distances	Ensure blast deflection is in place and is sufficient by having official approval in addition to no contact with flammable matter, and/or calculated heat transfer being deemed insignificant
Insufficient Landing Speed	3 (Improper load, higher coefficient of drag for the parachutes than needed, higher surface area of the parachutes	2 (Unexpected changes in flightpath and landing area, increased potential for	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 by following the mitigation in addition to running simulations and generally testing the landing speed by

	than needed)	drift)			individual unique calculations
Shock Cord / Parachute Stops Payload	3 (Shock cord stuck in payload or payload bay)	3 (Shock cord or parachutes may not fully achieve their goal and block payload)	9, Medium	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	Verification by testing and demonstration to ensure the shock cord and parachute may not get stuck; ensure by design and testing that secure; test during testing including but not limited to ejection testing to ensure sufficient design with respect to design requirements

4.4.6. Environmental Hazard Analysis

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 as determined by launch officials and rocketry safety standards	Low
Collisions with Man-made Structures or with Humans	2 (Failure to properly predict trajectory, failure to	5 (Damage to public property or private property not	10, Medium	Do not launch under adverse conditions which may affect the course of the rocket, run a large number of	Run tests to analyze and estimate the rocket's trajectory so that the rocket's path is known to the team;	Low

	choose an appropriate launch area isolated and safe (described in checklist))	owned by the team, damage to team equipment, serious damage to team personnel or passerby)		tests which analyze the rocket's trajectory mathematically and physically, choose a launch area which is not close to civilization, follow launch procedures closely	do not launch rocket under adverse weather conditions and choose a launch location which allows for open space to avoid accidents	
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 not launch	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
High Humidity	3 (Climate, poor forecast)	1 (Rust on metallic components, expansion of	3, Low	Use as little metal as possible, apply rust prevention techniques, store the rocket	Ensure that launch site does not have any undesirable conditions; ensure that	Minimal

		rocket components and difficulty assembling the rocket because of this)		indoors, choose a launch site with a desirable climate, choose not to launch if heat expansion makes assembly necessitate drastic adaptation	electronics are well protected and will not have contact with wet conditions; do not launch if there is rainfall	
Wet Conditions	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 Conditions	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 accommodate for the weather conditions; do not launch if wind speeds exceed 20 mph	Low
High Sun exposure	3 (Sunny day)	3 (Skin damage, eye	9, Medium	Ensure team is protected from the sun	Ensure team is notified of all weather on day	Medium

		irritation)		through shade and sunscreen to prevent UV light and/or the sun from causing a sunburn; ensure team has access to sunscreen; ensure team is aware of weather to bring sunglasses	of launch or manufacturing to wear proper clothing; ensure mitigation is strictly followed due to weather notification to prevent sunburn; with rocket and water, ensure sunscreen is provided from a lead; ensure protection area available to rest and avoid sun and stay in shade	
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 ground, ice on vehicle, clogging of vehicle ventilation, change in rocket rigidity and mass, higher drag force on rocket)	9, Medium	Ensure team is wearing appropriate clothing for extended 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	Ensure team is notified of all weather on day of launch or manufacturing to wear proper clothing; do not launch if weather below designed intent of rocket; ensure mitigation is strictly followed due to weather notification	Low
Pollution from	5	1 (Small	5, Low	Carpool to events to	Ensure team members	Low

Exhaust	(Combustion of APCP motors)	amounts of greenhouse gases emitted)		reduce pollution from exhaust in another way	with only high attendance may go, and be carpooled, to save energy	
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 Vehicle	2 (Loss of components from vehicle, debris scattering from a crash or mid-flight explosion)	4 (Materials degrade extremely slowly, wildlife may consume the materials)	8, Medium	Properly fasten all components; ensure components that can fall off have low impact on environment and / or are biodegradabile	Follow MSDS protocols and fulfill design requirements and derived requirements while using no excess components	Medium

4.5. Launch Concerns and Operation Procedures

4.5.1. Final Assembly and Launch Procedures

4.5.1.1. Recovery Preparation

General Information:

- PPE required for all recovery and post-flight inspection procedures: ANSI Z87.1 safety glasses, leather or canvas gloves, closed-toe shoes or boots, and clothing which covers all exposed skin from the neck down.

- Do not attempt to recover the rocket from atypically dangerous areas, such as confined environments (especially woods) or uneven ground to avoid personnel injury from dangerous terrain
- If the rocket becomes entangled with power lines upon its return to the ground, call the power company and stand clear until proper personnel arrive to avoid electrocution hazards. Ensure launch officials (NASA, Indiana Rocketry Inc., or other launch officials) are aware of this concern in order to take the necessary precautions and procedures.
- Leave no trace of materials or other destruction during retrieval to minimize pollution from team members and to ensure the vicinity is safe and clean for future use by other teams or individuals

Preparation for retrieval:

- Ensure the rocket is being launched in an area which will not complicate retrieval; there should be an extremely minimal chance that the rocket will collide with personnel or onlookers, man-made structures, or wildlife, and the area which the rocket is expected to land in should not feature dangerous terrain or power lines.
- Carefully pack each parachute using the “burrito” technique to prevent shroud line tangling. The parachute is pinched at the four corners separated 90 degrees in the parachute, and then the shock cord is tucked into the parachute. From there, ensure the parachute is then folded as much as possible to reduce its size by then rolling it into a “burrito” with a smaller outside diameter than the airframe inner diameter. Any team member who packs the parachute or connects the shock cord must be supervised by at least one other team member who is using the safety checklists.
- Completely tighten all quick links, shear pins, screws, and motor retainers prior to flight to reduce the chance of parts falling from the rocket.

During retrieval:

- Before approaching the rocket, observe whether or not it seems there is still fuel present within. This may be recognized through an obviously incomplete launch with noticeable signs of unburned fuel, typically denoted by flames, smoke, and /or an explosion during flight. If unburned fuel is present, wait for the fuel to safely burn away. If the fuel is not burning away, clear the surrounding area of fire hazards while exercising extreme caution by going the direct opposite direction of the area with all available PPE worn in site, then ensure the motor is isolated and/or the fuel is safely disposed of by the proper authorities as determined by the launch officials. Fire protection services or a designated official may be needed for the accomplishment of this task.

- Double-check the area around the rocket before approaching to ensure there are no hazards from nearby terrain or man-made structures such as power lines.
- Extinguish any fires present to avoid burn hazards and care for the surrounding environment through fire retardant or provided extinguishers or water present at official launches.
- Double-check for sharp edges from damaged parts to avoid cuts or lacerations, especially before making physical contact with the rocket.
- Once the above points have been acknowledged appropriately in their entirety, and all post-flight inspection procedures have also been followed, the rocket may be prepared for transport.
- If the rocket was damaged enough during flight for parts to fall off, ensure these parts are also retrieved appropriately and securely with PPE and extreme caution so unwary passerby do not get involved with them. Ensure all known parts are accounted for and collected, and search the 10 meter radius of the rocket landing for other components. Apply the same safety procedures to each part as it would be with the rocket as a whole.
- Do not forget to also check the launchpad for damage, clean it, and take it down to prepare it for travel.

After retrieval:

- Double-check the rocket thoroughly for any damage which may have occurred during flight to avoid possible mishaps during the next use of the rocket.
- Replace/charge all batteries prior to or in between flights to ensure they are ready for the next use of the rocket.
- Securely attach all batteries to their electronics sled using both zip ties and electrical tape to ensure they are secure and will not be lost.
- Securely prepare the rocket and launchpad during transportation to prevent damage during the journey to the next destination.

4.5.1.2. Motor Preparation

Instructions regarding the chosen motor and its preparation will be supplied with the purchase of the motor. The preparation procedures defined by the supplier and the safety code must be followed word-for-word by team members when preparing the motor. If the motor is not prepared properly, the following hazards could occur:

- CATO (catastrophic failure)
- Fire or unexpected ignition
- Motor ignition failure
- Combustion instability
- Unpredicted launch time

- Unstable rocket flight
- Motor exits the rocket at ignition or during boosts

Before working with the motor, all team members must secure loose hair and clothing, wear closed-toe shoes, and remove jewelry. Team members must also wear ANSI 787.1-certified safety glasses with a side shield and heat-resistant leather or canvas gloves for protection in the case of an accident.

To accompany the supplier's instructions, general guidelines for motor preparation are as follows:

- Double check to ensure the motor is suitable for the desired flight profile and certified by NAR, Tripoli, or other certifying amateur rocketry organizations or groups.
- The motor casing should be insulated with a liner or similar material to prevent the motor casing or launch vehicle from melting or expanding due to excessive heat.
- Ensure the motor is unused, has not been tampered with in any way, and is being used for a purpose recommended by the manufacturer.
- Ensure the motor casing and nozzle are in good condition and have no defects or cracks.
- Check that the motor mount is secure, is in good condition, and will not deflect motor thrust.
- Ensure the use of a blast deflector to prevent the motor's exhaust from hitting the ground.
- Check the stability of the rocket after installing the motor.
- Ensure the nose cone does not fit too tightly into the body tube as this can cause the motor to be expelled by the ejection charge.

It is important to closely follow proper safety procedures and the manufacturer's instructions when preparing the motor, as doing so greatly reduces the chances of an accident. To ensure proper procedures are followed, two team members must supervise the preparation of the motor while filling out the pre-launch checklist. Additionally, this procedure is built into the checklist to ensure its correct completion in order.

4.5.1.3. Setup On Launch Pad

General Information and Requirements:

- PPE required for all launch setup procedures: ANSI Z87.1 safety glasses, leather or canvas gloves, closed-toe shoes or boots, and clothing which covers all exposed skin from the neck down.

- Ensure conditions are appropriate for launch before beginning setup. Check hazard analysis and contingency plans for all conditions which threaten the safety of the launch, such as lightning or excessive wind speeds.
- Have appropriate first aid materials, such as a first aid kit, and fire-fighting materials, such as a fire extinguisher, on hand to deal with a medical emergency or launchpad fire.
- Have a communication device with which to contact emergency personnel in the case of a launchpad fire or serious injury.
- Have a backup launching area and backup launch dates in case the planned launch area is unavailable for some reason. Doing this can prevent delays in retrieving launch data.

Before setup:

- Choose a launch site at which rigid ground is available to prevent personnel from falling and to prevent the launch pad from sinking and causing an unplanned trajectory.
- Choose a launch site which is greater than 750 meters from any water sources.
- Choose a launch site with high visibility and no threats, or officially-approved minimal threats, from and to passerby, wildlife, man-made structures, or dangerous terrain.
- Choose a day with weather such that the launch vehicle may successfully launch without concern of rain, snow, excessive winds, or other launch-hazardous weather conditions.

During setup:

- Ensure the ground is stable and even before placing the launch pad. If there are minor worries about unstable ground, place a rigid system which can be used for support underneath the launch pad, such as wooden planks. If there are serious worries about unstable ground, find a better launch site.
- At least one personnel member must be watching the launch pad at all times after placing it to ensure it does not change from its intended position and no wildlife or weather tampers with its condition.
- Ensure launch rails are not bent or twisted to prevent an unplanned or ballistic trajectory.
    - Inspect the launch rails to confirm that there are no abrasions or other damage to ensure the rocket starts in a vertical trajectory.
    - Unfold launcher legs and place the launchpad on firm ground.
    - Make sure said ‘firm ground’ is dry and has minimal amounts of dust to ensure a clean ignition.

    - Clear all obstructions and keep any flammable objects (barring the rocket itself) up to 100 feet away from the launcher.
- Ensure launchpad support struts are not bent, cracked, rusted, or showing other signs of damage to prevent an unplanned or ballistic trajectory.
- Ensure the launch rail is properly lubricated, if necessary, so all planned ejections occur and the rocket achieves the planned height and follows the planned trajectory with minimal friction to ensure a stable and unimpeded launch.
- Clean launchpad of any dust, pebbles, or anything that can turn into a projectile due to jetblast to prevent injury to onlookers.
- Double-check to ensure that the launch pad has not sunk from its intended position due to unstable ground.
- After observing the above safety precautions, carefully transport the launch vehicle to the launchpad without damaging it. Then, slide the launch vehicle onto the rail, ensuring it is firmly secured and all rail buttons are well-aligned and are properly attaching the rocket to the launchpad.
- Once the rocket is firmly attached to the launch rail, check it over at least two times for damage or leakages.
- Double-check that all batteries in the rocket are firmly secured and are at a desirable charge level to prevent payload or avionics bay failure, which can result in failure of the mission goals or failure to eject parachutes at the desired time.
- Make the necessary adjustments to the payload and the avionics bay to prime everything for performance during the launch. Ensure the rocket is structurally complete and that the deployment is executed as intended by its design and testing. Double-check that all connections have been properly made in the avionics bay and to the payload, that both the avionics bay and payload have not been damaged, and that the avionics bay and payload are thermally insulated since any of these issues can cause payload or avionics bay failure.
- Check to make sure the igniters have not been damaged in any way, are functional, and have been obtained from a reliable source and then attach the igniters to the rocket. This process must be done under the supervision of at least one other team member who is using the safety checklists.
- Double-check to make sure all components of the rocket are securely attached and fastened.
- If no damage is found on the rocket or launch pad, the rocket is securely attached to the launch pad and control systems, and the launch pad and control systems are in good condition, retreat to a safe distance and proceed with ignition procedures.

4.5.1.4. Igniter Installation

Before working with the igniters, all team members must secure loose hair and clothing, wear closed-toe shoes, and remove jewelry. Team members must also wear ANSI 787.1-certified safety glasses with a side shield and heat-resistant leather or canvas gloves for protection in the case of an accident.

The igniters used in this project will be supplied with the purchase of the chosen motor through the supplier. The installation procedures for the igniters will be defined by the accompanying instructions from the supplier using the appropriate PPE required of safety glasses and any other PPE deemed necessary. This requires the personnel with the Low Explosives User Permit (LEUP) and the Safety Lead in order to safely and securely setup the igniter. These instructions must be followed word-for-word by team members. If the igniters are not installed properly, the rocket may misfire or launch too early.

To accompany the supplier's instructions, general guidelines for igniter installation are as follows:

- Before approaching the rocket with the igniters, inspect the launch control mechanism to ensure it is disabled and not communicating with the rocket. For example, ensure any safety keys being used are removed before connecting the wires of the igniters to their clips.
- Inspect the igniter wires before installation to ensure they are not touching each other.
- Inspect the igniter clips before installation to ensure they are clean.
- Use an igniter plug/holder to keep the igniter in place once it is installed.

It is important to closely follow proper safety procedures and the manufacturer's instructions when installing the igniters, as doing so greatly reduces the chances of an accident. To ensure proper procedures are followed, two team members must supervise the installation of the igniters while filling out the pre-launch checklist.

4.5.1.5. Troubleshooting

If any step in these procedures and checklists is skipped, additional hazards that are not described in the instructions below may occur.

Construction:

- Machine failure: Consult online information, the machine manual, or any staff members who may work with the machine about how to fix the problem. Prepare an identical machine to use as a backup or a similar replacement to accomplish the same goal with potentially a longer manufacturing period while the machine is being fixed.

- Damage to, loss of, or failure to receive parts: Attempt to order new parts and have them sent through expedited shipping. Extra parts should be kept in storage in case an issue like this arises.
- Loss or unavailability of work area: If not done previously, select another work area and obtain permission to work in that area. Preferably, a secondary work area should be chosen and prepared prior to the occurrence of any emergency.

Vehicle Components:

- Rust or component expansion: Attempt to find suitable non-metal replacements for metal parts and store the rocket indoors. Consider that humidity might be the cause of the expansion.
- Part failure, loss, or damage: Run simulations through OpenRocket and RASAero of the rocket's flight as well as stability and load-bearing tests using FEA (Finite Element Analysis) and examine the affected area to determine how to improve the design of the rocket. Use spare parts to replace any lost parts or order new ones with expedited shipping if no spare parts are available.
- Poorly aligned motor tube: Realign the motor using a level, and do not rush the process. Double-check the alignment of the motor before all flights.

Ignition and Launch:

- Rocket does not launch when the electrical launch system is used: Remove the launcher's safety interlock or disconnect its battery and wait 60 seconds after the last launch attempt before allowing anyone to approach the rocket.
- Ignition failure: Ensure a physical connection exists between the ignition controller's power source and the ignitor. Check for dust or damage on the alligator clips. Ensure all pyrotechnic compound used is dry, has no dust on it, and is unburnt and undamaged. Make sure the fuel grain has no dust or moisture on or in it and is undamaged. Ensure proper motor packing procedures were followed.
- Loss or unavailability of launch area: If not done previously, select another launch area and obtain an FAA waiver for that area. Preferably, a secondary launch area should be chosen and prepared prior to the occurrence of any emergency.
- Rocket disconnects or is unstable on the launch rail: Ensure the launch rail buttons are properly aligned and working as planned, double check that the rocket was attached to the launch rail buttons using proper procedures, and ensure that the rail itself was set up using instructions which came with the product.

Aerodynamics:

- Adverse effects (including undesired forces acting on the rocket and decreased velocity) from drag: Ensure the appropriate amount and locations of shear pins, fasteners, and vent holes are being used as determined by the design and testing and as described in the vehicle criteria section.
- Unpredictable trajectory: High wind speeds, mid-air collisions, or damage to rocket components may have caused this. Wait for wind speeds to lessen, ensure there are no obstacles in the flight path, and check all components of the rocket for damage.
- Instability: Measure the full-scale launch vehicle's physical center of gravity through balancing and compare it to the calculated center of pressure through simulated stability tests in RASAero and OpenRocket. If the physical center of gravity and the calculated center of pressure are not the same, make adjustments to ensure these quantities are the same. Make changes as necessary to increase the stability margin by adding ballast or slightly altering the fin geometry or fin size.

Avionics and Payload:

- Altimeter failure or loss of continuity: Between rounds, check and secure motor connections with alligator clips and masking tape. Double check altimeter settings. Check batteries and electronic connections to ensure they are working as planned.
- Loss of signal from GPS: Postpone flight and check the GPS unit, signal continuity, and batteries for problems before the next flight
- Arming system failure: Consult the manufacturer's instruction manual, ensure the system is undamaged, and communicate how to properly arm the system with the team before initiating the next flight.
- Overheating of avionics or payload: Ensure the avionics bay and payload are properly thermally insulated to prevent blistering. If they are not, take efforts to insulate them with a liner or similar material. Ensure the avionics bay and payload are not overloaded with wiring, as this can cause overheating and fire hazards.
- Mistimed, failed, or lack of ejection: Check altimeters for damage and ensure they are being run with proper settings. If everything is in working condition, check remaining ejection charges for damage and ensure they are being properly packed.

- Payload fails: Test the payload in general by inspecting its functionality and determining what is not working. If issue undetermined or persists, try launching on a different date or at a different location.
- Payload camera fails or takes poor quality pictures: Test the payload camera on the ground, double-check batteries and connections related to the camera, check the performance of the payload computer used by checking its batteries and connections, and double check that the rocket followed its planned flight path and was stable.
- Poor overall electronic performance: Test the reliability of the wiring and batteries. If doing so yields no results, weather (especially overly wet atmospheric conditions) or failure of other rocket components may have caused this. If the issue cannot be determined or persists despite adjustments, try launching on a different date or at a different location.

Recovery:

- Parachute deployment failure: Ensure proper parachute and ejection charge packing procedures are being followed, check that there was no damage to the parachute beforehand, ensure proper spacing between the ejection charges and parachutes, check for altimeter failure, and ensure there is no excessive velocity when the parachute system is being deployed. The recovery system mount for the parachute should also be examined to see if it is working as planned and is undamaged.
- Stage separation failure: Ensure faulty ejection charges are not being used, ensure ejection charges are being packed properly, double check the design of the rocket to ensure the strength of the bonds (made using shear pins, screws, or epoxy) holding the stages together is not excessive, and check for altimeter failure.
- Shock cord failure: Ensure the shock cord is of the proper size and is being packed properly, ensure the shock cord has been bought from a reliable source and is not damaged, and ensure any parachute which the shock cord may have been tangled in is the correct size for the rocket.
- Excessive or insufficient landing speed: Check parachutes for damage and ensure they are properly sized, packed, and protected from harm.

Personnel:

- Low / insufficient amounts of communication: 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.

- Inactivity: Train all members to work in all areas necessary, track and encourage meeting attendance, encourage members to bring friends to meetings, improve communication.
- Low availability of personnel: 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, and attempt to help team members prevent their semester schedules from being too strenuous by advising individuals on time management.
- Conflicts of important academic or personal events with team events: Talk to the parties concerned well in advance of the conflicting event to try and work out a change of date.
- Hypothermia: Call medical personnel immediately if hypothermia is suspected. Warm the person slowly, focusing on warming the chest area first as warming the limbs before the core may cause shock. Dry the person and remove wet clothing, if needed. Do not immerse the person in warm water and do not directly apply heat sources such as water bottles or heat packs to the person without first wrapping them in cloth. Give the person CPR if necessary and, if they are responsive, give them warm water to increase body temperatures. As body temperature rises, warm the person's head and neck as well.
- Heatstroke or heat exhaustion: Call 911 if the situation is serious, i.e. the affected person is being extremely unresponsive. Attempt to lower the body temperature of the affected person using cold water, ice, or cooling blankets. Get the affected person to a shaded or air-conditioned place, and give them water to hydrate.
- Physical injury: Call medical personnel immediately if the injury is serious. Attempt to slow any bleeding using cloth or a similar substance - if safety procedures have been followed, a first aid kit should be nearby. Treat the affected person for shock if the wound is of moderate severity or greater; however, be cautious of moving the affected person if it is believed that doing so could cause them more harm. If that is the case, the situation is best left to medical personnel and other individuals should not attempt to move the affected person unless officially designated.
- Electrocution: Immediately separate the person from the electrical power source by turning it off or, if that is not possible, standing on a non-conductive surface and using a non-conductive object (such as a wood-handled broom) to remove the person from the source. Do not the victim if he or she is still in contact with the electrical power source. Have someone call for emergency medical assistance immediately. Do not try to separate the person from a current if there is a feeling of a tingling sensation in the legs and lower body as this indicates the proximity to a high-voltage electrical power source. After removing the affected

person, do CPR if necessary and check for other injuries while waiting for medical personnel to arrive.

- Chemical contact: Shower the chemical off the affected area with water; if the chemical got in the eyes, apply water to the eyes, preferably with the use of an eyewash station. If a chemical was ingested, call the poison hotline immediately at (800) 222-1222. If a dangerous situation persists after washing the area with water, call 911 and again ensure that the launch officials are aware of the situation.
- Follow any other personnel safety concern as listed in the Personnel Hazard Analysis.

4.5.1.6. Post-Flight Inspection

General information:

- PPE required for all recovery and post-flight inspection procedures: ANSI Z87.1 safety glasses, leather or canvas gloves, closed-toe shoes or boots, and clothing which covers all exposed skin from the neck down.
- *Leave the avionics and payload* ***alone and armed*** *until otherwise mentioned. Ensure PPE mentioned above worn at all times until the end of cleanup.*
- Be aware that before beginning inspection, it is necessary for the competition that officials verify the results of the launch.
- Components of the rocket which have been damaged during flight may be dangerous to touch. Take extra care to observe the rocket closely before making physical contact with it, especially in the area which will be touched.
- Components of the rocket may also be hot to the touch for a small span of time after the fuel stops burning. Be aware of this and be sure to wear appropriate PPE of safety glasses and grab the rocket by the airframe if deemed not hot. If hot, wear the appropriate PPE of thermal-protective gloves before making physical contact with the rocket.

Exterior rocket inspection:

- Before approaching the rocket, observe whether or not it seems there is still fuel present within. If unburned fuel is present, wait for the fuel to safely burn away. If the fuel is not burning away, clear the surrounding area of fire hazards while exercising extreme caution, then ensure the motor is isolated and/or the fuel is safely disposed of; fire protection services may be needed for this task.
- After handling unburned fuel check the rocket for any missing parts. If there are missing parts, enforce the team’s best efforts to locate them in order to minimize pollution to the environment and to recover as much of the rocket as possible.

- Make sure all fasteners, joints, and shear pins are undamaged and secured in place and that each hole, including vent holes, is in the correct state as shown before launch. Ensure that none of the holes are cracked or otherwise damaged.
- Check the nose cone for damage such as cracks, holes, or warping.
- Check the body tube for damage. Look for any bending or twisting of the body tube and make sure there are no holes other than the ones necessary for the payload. Dry off the body tube of any water accumulated during flight, either from vapor or upon landing.
- Check the fins and any other aerodynamic surfaces for twisting or cracking.

Interior rocket inspection:

- *Leave the avionics and payload alone and armed* until the entirety of this list is completed.
- Ensure that all ejection charges were successfully and safely deployed. If ejection charges remain unfired in the rocket even though they should have gone off, exhibit extreme care when removing and disposing of them, ensuring that proper PPE is worn and no flammable objects are nearby. Remove and dispose of the rest of the ejection charges safely and with care as well.
- Verify that the recovery system was fully and successfully deployed and that it suffered no damage throughout the rocket's flight. Check to make sure there are no tears in the parachute, the shock cord and parachute shroud lines are in good condition, and the recovery system mount on the rocket is firmly secured and free of signs of stress such as cracks or torsion. Also, check the recovery system for signs of heat damage, as that means the packing methods being used are poor or the spacing between the recovery system and the ejection charges is incorrect.
- Check the motor for damage such as cracks or nozzle bending and check the centering rings and motor mount for signs of strain such as cracks or bending. Ensure the motor tube is still angled correctly and is tightly secured if the rocket is to be used again in the future.
- Check bulkheads for damage such as cracks, bending, or other visible data.
- Check the avionics bay and the payload for internal damage and failures. In the event of a hazardous material leak, such as that from damaged lithium ion batteries, notify fire personnel and clear the immediate area.
- Recover any data and footage from the flight; *only after* retrieving the data should the avionics and payload be disarmed. After disarming the avionics bay and payload, disarm the launch controller.

Pad inspection:

- Ensure the launch rails show no signs of damage, such as deformation, bending, cracks, breaks, or other catastrophic damage.
- Ensure the launchpad's support legs and struts show no signs of damage, such as cracks or deformities.
- Clean the pad of dust left by the rocket exhaust or any other dirt which has accumulated. Ensure this waste is disposed of safely in the proper disposal facilities or as determined by launch officials.
- Once the launch pad has been checked for damage and cleaned properly, it may be taken down and prepared for safe transportation.

The additional procedures for the payload and avionics are built into the checklist in order to ensure their completion in addition to it being in order. All launch components may be put for future reuse after careful transportation and inspection that all design criteria are still met and that no damage is present, other than possible visual damage other than that what would otherwise affect the performance of the rocket.

4.6. Checklists

4.6.1. Pre-Launch Checklist

General Safety:

- ❏ Ensure that at least two people simultaneously are using the checklist and following all procedures to prepare for launch included but not limited to a team lead in order to successfully complete a step or to witness and sign off verification of a step
    - If only one person has the checklist, there is more chance that something is misinterpreted or missed, leading to failure
- ❏ Ensure safety protection glasses are worn at all times for full duration of the 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 call for an emergency or administering basic first aid
- ❏ Designate spotters to keep track of the rocket's descent and to point out its location to the rest of the team and spectators as it falls
- ❏ Have adequate fire suppression equipment including but not limited to fire extinguisher, fire retardant, or fire blanket available for use nearby
- ❏ If conditions at launch are dry enough to deem it necessary, a fire blanket must be placed under the pad

- ❏ Prep payload (more in-depth instructions, if necessitated, are included in payload section)
    - ❏ Plug wired connections to battery on rover
    - ❏ Calibrate the accelerometer
    - ❏ Check XBee connection to stepper motor
    - ❏ Setup and install payload bay on rocket
        - ❏ Setup ejection charges
        - ❏ Setup shear pins
    - ❏ Make sure limit switch is flush with the payload bay for arming the rover
    - ❏ When rover is armed the LED on the arduino blinks 1/s (If NOT armed the LED will be constant)
- ❏ *Prep avionics and reloads* (more in-depth instructions, if necessitated, are included in avionics section)
    - ❏ Setup teledongle
        - ❏ Screw in the six purple rods, with the two shorter rods being on the top, and the rod with the teledongle attached being on the bottom
        - ❏ Connect the teledongle to the antenna
        - ❏ Connect the teledongle to the computer
        - ❏ Open AltOS
            - ❏ Select Monitor Flight and select the Teledongle
        - ❏ Set the frequency and baud to what was noted to the Telemetrum configuration
    - ❏ Setup RRC3+ Sport
        - ❏ Plug USB IO Dongle into computer using a working USB mini B cable
        - ❏ Make sure USB IO Dongle dip switch is ON
        - ❏ Launch mDACS.exe
        - ❏ In mDACS.exe, go to System Preferences, and select the Active COM port (if does not function, may need to click Clear Active Port first.)
        - ❏ Go to RRC3 settings tab
        - ❏ Click RRC3 Host Connect
            - ❏ A 20 second timer will count down
            - ❏ Before the timer finishes, connect the USB IO Dongle to the RRC3+ Sport using the COMM port on both devices
        - ❏ Check all settings to make sure they are correct. Then, unplug the connector cable from the COMM port on the RRC3+ Sport.
        - ❏ Avionics now prepped until on the pad
    - ❏ Setup Telemetrum

- ❏ Use a working micro-usb cable to connect the telemetrum to a computer with AltOS installed
- ❏ To recognise the telemetrum, the battery and switch must be connected
    - The battery will charge using the power from the computer's usb port. It may be necessary to leave the telemetrum plugged into the computer for a while to ensure the battery is fully charged
- ❏ Open AltOS
    - ❏ A small window will appear: It is a good idea to delete all previous flights, as storage space on the telemetrum is very constrained. To do this, click Save Flight Data, and check the boxes to delete runs, and then exit the window.
- ❏ Click "Configure Altimeter" and then turn on the Telemetrum using the switch
    - ❏ Select the telemetrum
        - ❏ *Note that if the teledongle antenna setup is connected, that will show up too if needed*
- ❏ Select all settings as desired
    - ❏ It is a good idea to set the flight log size at the largest possible, assuming the previous flights were cleared
- ❏ TAKE NOTE OF THE FREQUENCY AND TELEMETRY BAUD RATE, AS WELL AS THE PAD ORIENTATION
    - ❏ Click save and temporarily turn the altimeter switch to OFF
    - ❏ The pad orientation should be pointing down with the current design
- ❏ Require verification and recheck of this list to ensure all steps have been completed or the system may not work and the rocket fails

❏ Ensure that the avionics are initially disarmed as previously checked and that an "arm before flight" reminder is in use

General Rocket Construction:

- ❏ 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 without cracks or other failures whereas it may be flown
    - ❏ Ensure there are no cracks or other signs of damage

- ❏ 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 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
    - ❏ 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
- ❏ Check that the motor and ejection system are in good condition before installation
- ❏ Ensure the proper motor and ejection system have been selected for the desired flight profile and that they are certified by NAR, Tripoli, or other amateur rocketry organizations or groups
- ❏ Check the reload motor for proper build-up, paying special attention to the motor being centered
- ❏ Install the black powder ejection system
    - ❏ Payload ejection charges
        - ❏ Cut off the finger of a disposable glove
        - ❏ Fill the fingertip of the glove with the 2 and 3 gram amount of 4F black powder needed
        - ❏ Insert ejection charge into black powder
        - ❏ Close off the fingertip by tightly twisting the glove around the e-match wire and putting two zip ties around the twisted glove and wire
            - ❏ Truncate the zip ties

- ❏ Feed the connection end of the ematch through the charge well and pull through so that the glove tip is inside the charge well
    - ❏ Pack the glove tip/black powder down into the charge well and pack dog barf on top
    - ❏ Seal the top of the charge well with tape and foil
  - ❏ Avionics ejection charges
    - ❏ Cut off the finger of a disposable glove
    - ❏ Fill the fingertip of the glove with the 4 and 5 gram amount of 4F black powder needed
    - ❏ Insert ejection charge into black powder
    - ❏ Close off the fingertip by tightly twisting the glove around the e-match wire and putting two zip ties around the twisted glove and wire
      - ❏ Truncate the zip ties
    - ❏ Feed the connection end of the ematch through the charge well and pull through so that the glove tip is inside the charge well
    - ❏ Pack the glove tip/black powder down into the charge well and pack dog barf on top
    - ❏ Seal the top of the charge well with tape
  - ❏ Verify and ensure the ejection charge is properly installed, and is the proper amount according to the table at the end of this checklist
- ❏ Check that the motor mount is secure, is in good condition, and will not deflect motor thrust
- ❏ Install motor
  - ❏ Ensure setup strictly by LEUP holder and Level 3 certification following instructions provided by manufacturer and by following the steps in the motor preparation
  - ❏ Ensure that motor properly inserted into rocket and securely attached
  - ❏ Ensure that the motor is properly installed

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 so that all igniters must touch the propellant, have adequate electrical current flowing to them as determined by the motor specifications, and have no shorts by being fully inserted
- ❏ Ensure thrust symmetry in case of clustering or mass imbalance

- ❏ Check that staging delay is less than one second
- ❏ Ensure that the rocket's center of gravity is in its expected position with respect to the rocket's geometry and with respect to the rocket's center of pressure
- ❏ Perform manufacturer's checking instructions on the avionics
- ❏ Check that shear pins are installed, including for the main parachute compartment
- ❏ Ensure drogue ejection will not cause main parachute to deploy

Pad Distance:

- ❏ Ensure only the minimum number of personnel are at the pad to prep for launch
- ❏ Ensure barriers are in place to keep spectators away from the launch area
- ❏ Ensure all team personnel and spectators are a safe distance from the pad based upon NASA or other officials approval and the attached minimum safe distance table)

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 as determined by the rocket parachute sizing equation
- ❏ Ensure that enough electrical current will reach the igniters of the rocket
- ❏ Verify that the igniter clips are clean
- ❏ Ensure that the launch rail and rocket are clean to verify that the rocket moves smoothly on the launch rail
    - ❏ Install the rocket on the launch rail and verify that this is true
- ❏ Ensure that the igniter clips are secure them to the pad
- ❏ Install igniter into motor by following igniter procedure instructions
- ❏ Connect launch leads to motor igniter
- ❏ Arm the avionics system once the rocket is on the pad:
    - ❏ Checklist for the RRC3+ Sport avionics system
        - ❏ Wire the battery
            - ❏ Connecting to the altimeter, red is positive, black is negative, and the 9V connector only goes on one way. Set the switch to OFF, wire the switch and ejection charges to RRC3+ Sport, according to the Wiring Diagram below.
        - ❏ Turn on RRC3+ Sport using the switch
            - ❏ A long 5 second beep will sound during startup.
        - ❏ Listen for three beeps in a row
            - ❏ This indicates continuity on Main and Drogue

- ❏ Turn the RRC3+ Sport off: When it's time to close avionics bay and it's time to launch: turn switch back on and make sure there are 3 beeps to indicate continuity on Main and Drogue
    - ❏ Ensure that the systems are all turned <u>on</u>
- ❏ Telemetrum
    - ❏ Plug LiPo battery into the battery port with the red wire as positive and black wire as negative
    - ❏ Screw in switch wires into the appropriate slots
    - ❏ Screw in drogue and main e-match wires into the appropriate slots
    - ❏ Before powering on the Telemetrum, ensure that it is in an upside-down orientation
    - ❏ Use the switch to power on the Telemetrum when the rocket is ready to launch
    - ❏ Ensure the telemetrum emits the following sets of beeps:
        - ❏ Four beeps, pause, one beep - Battery voltage
        - ❏ Dit, dah, dah, dit - Indicates pad mode; waiting for launch
            - ❏ If only dit, dit - Indicates idle mode; ensure Telemetrum is in correct orientation
        - ❏ Dit, dit, dit - Continuity on both drogue and main e-matches
            - ❏ If only brap - Indicates continuity on neither drogue nor main e-matches
            - ❏ If only dit - Indicates continuity on only drogue e-match
            - ❏ If only dit, dit - Indicates continuity on only main e-match
            - ❏ If warble - Storage is full; need to delete extraneous flights
    - ❏ Require verification and recheck of this list to ensure all steps have been completed or the system may not work and the rocket fails
- ❏ Close the avionics bay

Flight Trajectory:

- ❏ Ensure the launch and the flight will not be angled towards any spectators
- ❏ Know the expected performance of the model: double check that the rocket will not fly higher than its permitted clearance waiver
- ❏ 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

4.6.2. Launch Checklist

- ❏ Ensure that safety glasses are worn
- ❏ Ensure that the procedures for troubleshooting and procedures are followed and have been read
- ❏ Ensure that at least two people are using this checklist to observe the launch
- ❏ Ensure the stability of the model is being monitored
- ❏ 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 and ensure that all avionics and payload are in the proper state for launch**
- ❏ Ensure that spectators and vehicles are in the crosswind (perpendicular to the wind) positioning to ensure that the rocket will not unsafely drift in that vicinity
- ❏ 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

Beginning the Launch:

- ❏ Shortly before the countdown, give a <u>loud</u> announcement that the rocket will be launched
  - ❏ If too loud or otherwise applicable to the situation, use a PA system
- ❏ Ensure that all spectators are aware of the launch and are safely positioned
- ❏ When launching, give at least a <u>loud</u> 5-second numerical countdown followed by shouting “launch”
- ❏ Ensure that the recovery system is successfully deployed
- ❏ Carry out a safe recovery of the model
- ❏ Call a loud “Heads up” (If needed, sound an air horn) in the case of any rockets approaching the prep area or spectators and ensure all see the incoming rocket
  - ❏ If somebody cannot see the rocket, ensure everyone points 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 or other relevant officials

In the case of a misfire:

- ❏ Wait a minimum of one minute unless officially notified otherwise

- ❏ Disarm launch controller and avionics by following the same steps as below by simply turning off systems or as safely determined dependent on the failure
- ❏ Remove failed igniter and motor if officially deemed feasible

- ❏ **Ensure rocket has successfully landed**
- ❏ Ensure permission by NASA or other official range safety officer to deploy payload
    - ❏ Turn on "Power" switch on control box and verify
    - ❏ Flip the "Arm" switch and verify by checking frequency of blinking LED
    - ❏ At the moment further permission is provided by the official, press "Eject" button and verify the LED turns solid
    - ❏ Hold for 30 seconds
    - ❏ Hit "Deploy" button

4.6.3. Post-Launch Checklist

- ❏ Ensure that PPE worn as required for all recovery and post-flight inspection procedures, including but not limited to: safety glasses, leather or canvas gloves, closed-toe shoes or boots, and clothing which covers all exposed skin from the neck down
- ❏ *Leave the avionics and payload **alone and armed** in their current state until otherwise mentioned*
- ❏ Follow post-flight inspection procedures
- ❏ 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 or other launch officials verify the results of the launch, if necessary
- ❏ Double check that all necessary data from the avionics bay has been retrieved
    - ❏ Record weather data for determining additional characteristics for calculation
- ❏ Disarm the avionics by simply turning off 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 for any failed ejection charges
    - ❏ Safely disable / remove all ejection circuits and remove any non-discharged pyrotechnics

4.7. 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 1122 “Code for Model rocketry”, 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

With this, the Safety Officer will be in charge and share the responsibility with the Team Leader to inform the team of any laws and regulations listed above in additional to any that may apply set by the NAR/TRA.

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

Some of the materials that will be used on this project require extreme care and caution. Team members will be reminded and required to have knowledge of the safety rules based on storage, transport, and use of the hazardous materials by use of Material Safety Data Sheets (MSDS).

Hazardous materials used on this project include but are not limited to black powder, fiberglass, epoxies and other adhesives, ammonium perchlorate composite propellant, pre-made rocket motor igniters, and compressed carbon dioxide. Hazardous materials will be stored off-site, within the Zucrow Labs research facilities adjacent to the Purdue University Airport.

The Team Lead or Safety Officer will be notified and engaged before the purchase of any materials to make certain that there is a safety plan sufficient to address any new safety issues, to proactively identify and acquire any required PPE, and to compile and maintain all MSDSs and other safety information. Additionally, 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 MSDS (Material Safety Data Sheets) 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 MSDS 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 MSDS 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 and likelihood of failure.

As fiberglass will be a primary component of the rocket and a hazard most team members will be working with, the team will be required to properly use the PPE of safety goggles, dust masks, and gloves at all times when cutting, sanding, and painting to prevent dust from entering any orifices primarily including any eyes or lungs. All proper clothing will be worn including pants and closed-toe shoes to prevent injury to the legs from any objects.

4.9. 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_______________

5. Avionics & Recovery Systems

5.1. Recovery Subsystem

5.1.1. Chosen Design Alternatives From CDR

The design for the avionics bay has remained mostly unchanged but there have been a few changes:

- The ejection charges were previously intended to all contain 3g of 4F black powder. In the new design, the main parachute primary ejection charge will contain 4g of 4F black powder, and the main parachute backup ejection charge will contain 5g of 4F black powder. The primary drogue ejection charge will continue to contain 3g of 4F black powder, but the drogue parachute backup ejection charge will contain 4g of 4F black powder.
- The main parachute primary ejection charge was previously mounted on the top bulkhead of the avionics bay. In the new design, this ejection charge is run past the main parachute and positioned on the opposite side of the main parachute. This is to avoid having the main parachute pushed back into the upper airframe when ejection charges go off.
- To avoid premature separation, the new design will use stronger 4-40 shear pins to attach the avionics bay to the upper airframe.
- The telemetrum antenna was previously not secured in any way inside the avionics bay. In the new design, a holder for the antenna will prevent it from being loose during flight.
- In the previous design, ejection charges were connected directly to the altimeters and were fed through holes in the bulk heads to reach the charge wells. In the new design, terminal blocks have been mounted on the outside of the bulk heads. The altimeter ejection charge terminals will be wired to the terminal blocks on the outside, and the ejection charges will be wired to the opposite end of the terminal blocks for easy setup from the outside.

5.1.2. Parachute, Harnesses, Fireproofing, Bulkheads, & Attachment Hardware

The recovery systems will use the Skyangle Cert 3 Drogue Parachute as a means of drogue recovery. This choice of parachute is constructed of zero porosity, 1.9 ounce per square yard, silicone coated balloon cloth. Four suspension lines attach at the bottom to a 1,500 pound rated nickel-plated swivel. Each shroud line is made of ⅝” military-spec tubular nylon with a tensile strength of 2,250 pounds. The parachute has a tested drag coefficient of 1.26 and a surface area of 6.3 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. 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 pounds.

The team will be using the Skyangle Cert 3 XL Parachute as a means of main recovery. This parachute was chosen because it has a high drag coefficient (2.59) and is rated for a load capacity appropriate for our launch vehicle (32.6-70.6 in). It is sized at 89.0 square feet, providing a slow enough landing so that that no section of the launch vehicle 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, increasing the caliber of stability. The option chosen is constructed of the same zero porosity, 1.9 ounce per square yard, silicone coated balloon cloth as the drogue parachute. Just like the drogue, four shroud lines attach at the bottom to a 1,500 pound rated heavy duty, nickel plated swivel, and each shroud line is made of ⅝" military spec tubular nylon with a tensile strength of 2,250 pounds. 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. 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.

The shock cords in the launch vehicle were decided to be 40' long sections of ½" tubular kevlar. It is lightweight, fire resistant, volumetrically efficient, and has a high tensile strength. The tethers are rated for 7,200 pounds lifting force, which will be more than adequate for the purpose of this project, based on the weight of the launch vehicle. Each shock cord is attached to the avionics bay using the previously mentioned quick links. The estimated mass of the tether, not including the mass of quick links that attach the shock cord to the launch vehicle and parachute, is 0.5 pounds.

Two 18" Nomex blankets are used as a means of fireproofing the 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 via a hole in the corner and attached directly to the parachute. As a result, the parachute can be tightly wrapped inside of the material, as opposed to simply packing insulation around it, risking a gap in the fireproofing. Both the drogue and main parachute will be protected using this method. The total mass of both the drogue and main Nomex blankets is estimated to be approximately 0.25 pounds.

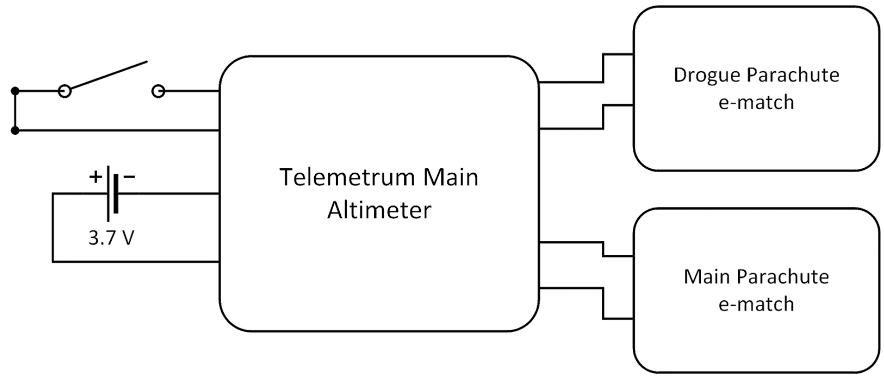
The bulkheads that are used for the launch vehicle are constructed from 0.25" thick G10 fiberglass, and contain five 0.25" holes. Two of these holes will be spaced 3.0" apart from center to center and will accept threaded rods that secure the bulkheads to the coupler tube via locknuts. There will be one eye-bolt in the center of each bulkplate that attaches the launch vehicle to one of the recovery tethers. Each bulkhead will also have two charge wells, and a 4x2 terminal block. These bulkheads will accept the shock of deployment and carry the weight of the launch vehicle during descent, so it is imperative that they be exceptionally strong. Each bulkhead is estimated to weigh 0.45 pounds, for a total of 2.7 pounds with all six bulkheads.

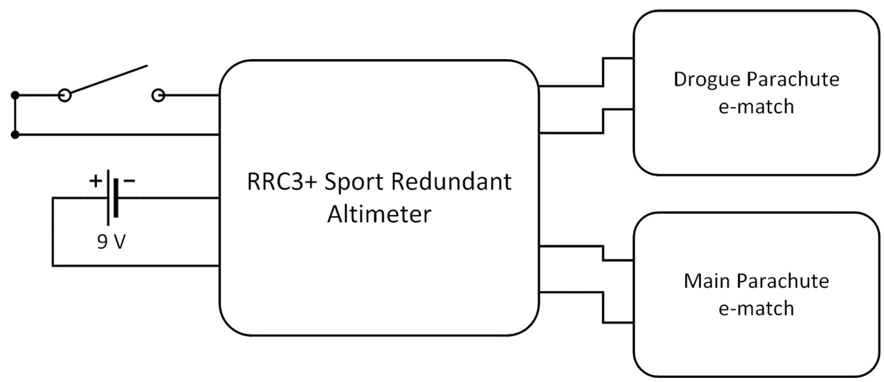
All attachment hardware, including nuts, bolts, washers, eye-bolts, and quick links will be high strength stainless steel, either type 316 or 18-8 depending on availability and sourcing. These alloys were chosen for their strength, corrosion resistance, and general robustness. They will not oxidize in the presence of residue from the black powder ejection charges, and will maintain their properties for many flights. The estimated weight of the attachment hardware is approximately one pound.

5.1.3. Avionics Components & Redundancy Features

The avionics team decided to use the Telemetrum as the primary altimeter and GPS and the RRC3+ Sport as the secondary altimeter. 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, black powder charges were decided to be used. The backup charges contain 20-25% more black powder than the primary charges.

5.1.4. Electrical Components & Schematics





The two electrical schematics above show the electrical circuits for the Telemetrum main altimeter (top image) and the RRC3+ Sport redundant altimeter (bottom image). Each altimeter is powered by its own battery, and is turned on using its own switch. Each altimeter connects to e-matches for the drouge and main parachutes.

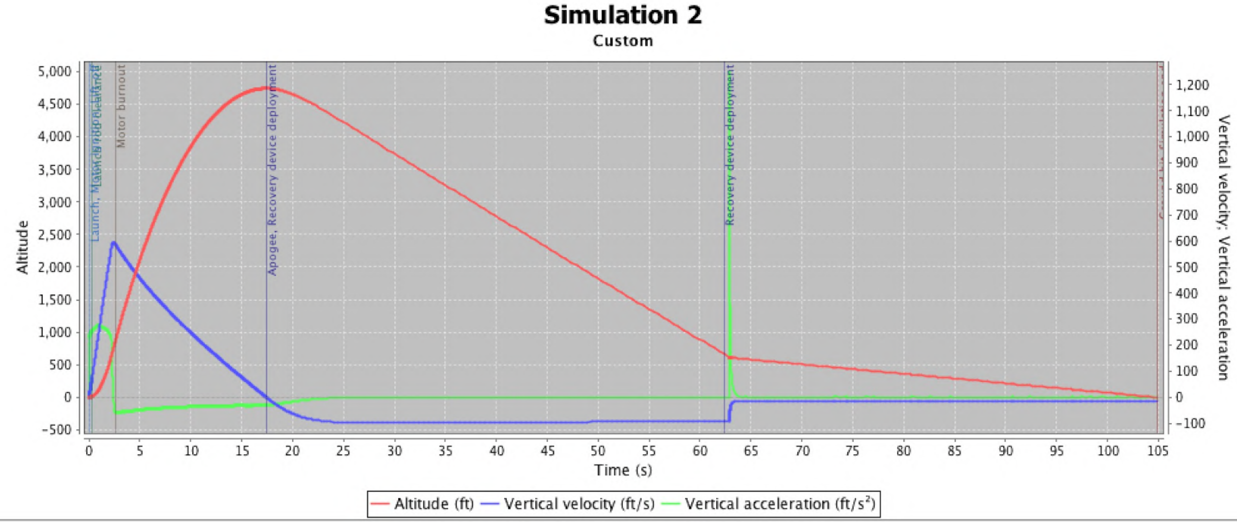
5.1.5. Locating Tracker Operating Frequency

The Telemetrum can transmit GPS data. It will be set to use the 434.550 MHz channel, which is the frequency that is recommended on the Altus Metrum website. The Teledongle will be used in combination with the Arrow II Model 440-3 3 Element Yagi Beam antenna to read the transmissions from the Telemetrum in flight.

5.1.6. As Built Parachute Sizes & Descent Rates

5.2. Mission Performance Predictions

5.2.1. Altitude Predictions with Simulated Vehicle Data

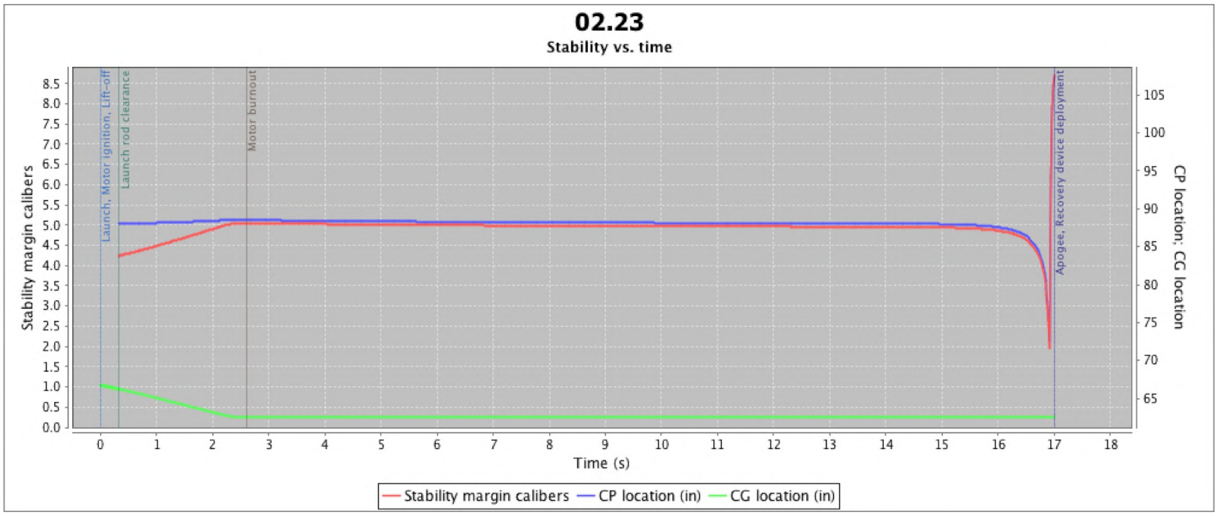


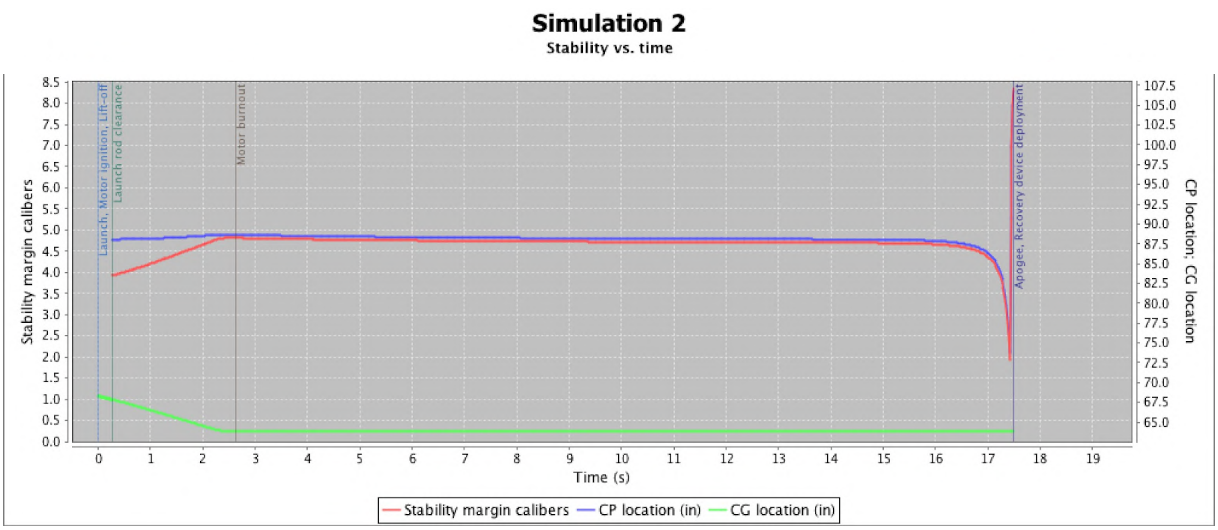
As can be seen from the graph above, the launch vehicle is simulated to reach a maximum altitude of 4,853' above ground level. This is under the target altitude of 4,950' above ground level. Now that the launch vehicle has been constructed, there is a more accurate weight measurement that can then be entered into the simulation program.

Other factors such as surface finish and the cross sectional airfoil of the fins are variables that do not have the opportunity to have implicit control over. The surface smoothness could not be accurately measured to compare the real and digital models, which will account for some difference in the actual and expected altitudes. In addition, the only choices presented to us when varying the fins' cross section are "square, rounded, or airfoiled." There is no direct input for edge thickness or taper length, further limiting the simulations.

All altitude simulations from which the graph above is derived were accomplished using OpenRocket 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.

5.2.2. Stability Margins with CP/CG Relationships and Locations





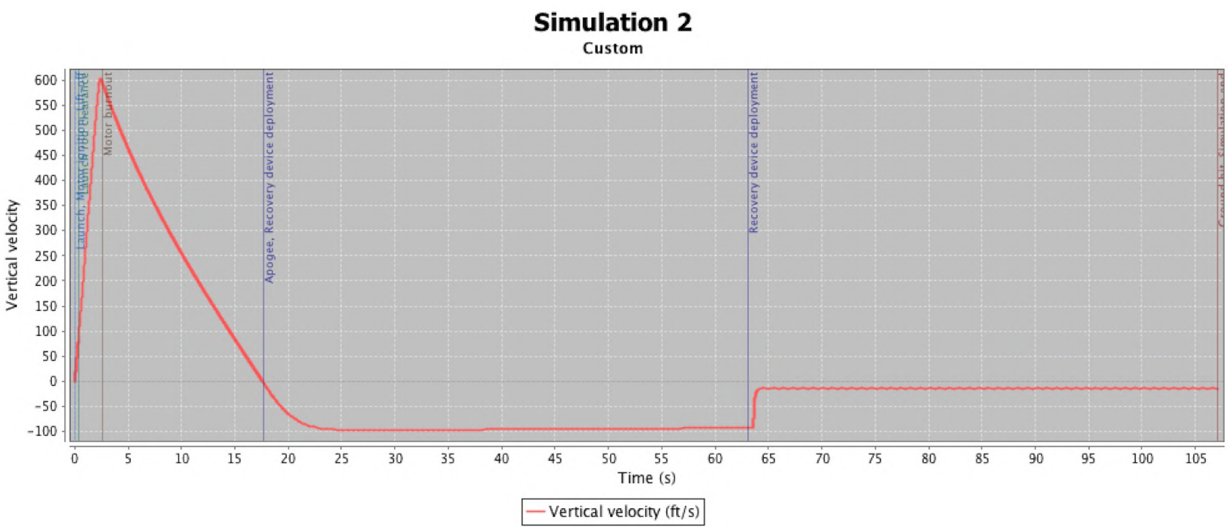
As seen from the graph above, the rocket exits the 96” long, 1.5” launch rail with a minimum stability margin of approximately 3.5 calibers, meeting the minimum requirement of 2 calibers. During the ascent phase, the rocket does not experience a significant drop in stability until it reaches a low enough 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 roughly 4.5 calibers for nearly all of the boost and coast phase.

The center of pressure, a node where the total sum of all pressures acts on the vehicle, starts at a distance of nearly 88.5” 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 does not move more than 5” 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 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 approximately 69.471” from the datum of the rocket, placing it roughly 17.5” ahead of the center of pressure. During the burn time of the motor, the center of pressure moves forward at a constant rate due to the constant burn rate of the solid propellant. The total shift is nearly 4”, or almost a full caliber.

5.2.3. Kinetic Energy at Landing

5.2.3.1. 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 decelerate before reaching apogee, where it then deploys a drogue parachute and descends rapidly at an estimated 61 miles per hour. At an altitude of 700’ above ground level, the main parachute will deploy to slow the vehicle considerably before touching down at a speed of approximately 10.3 miles per hour. The total landing energy, assuming a burnout mass of 36.1 pounds and impact speed of 10.3 miles per hour, will be approximately 127.9 foot pounds.

5.2.3.2. Lower Section Kinetic Energy at Landing

The bottom section of the rocket that will be falling independently while remaining tethered to the remainder of the vehicle is expected to weigh 18 pounds at touchdown. This will consist of the lower airframe and motor assembly, middle airframe, and drogue recovery gear. For a landing velocity of 14.3 ft/s, the landing energy for this section will be roughly 57 ft-lbs.

5.2.3.3. Mid Section Kinetic Energy at Landing

The middle section of the rocket that will be falling independently while remaining tethered to the remainder of the vehicle is expected to weigh 3 pounds at touchdown. This will consist of the avionics bay, upper airframe, and main recovery gear. For a landing velocity of 14.3 ft/s, the landing energy for this section will be approximately 10 ft-lbs.

5.2.3.4. Upper Section Kinetic Energy at Landing

The nose section and payload section of the rocket that will be falling independently while remaining tethered to the remainder of the vehicle is expected to weigh 14.9 lbs at touchdown. This will consist of the nose cone, Multitronix Telemetry Pro, and nose coupler. For a landing velocity of still 14.3 ft/s, the landing energy for this section will be roughly 38 ft-lbs.

5.2.4. Rocket Descent Time

The total descent time of the rocket is approximated to be 89.4 seconds, or approximately a minute and a half. This calculation does not include time to eject the parachutes and the corresponding reaction time.

5.2.5. Drift Distance Calculations

This section will discuss the calculations of the drift distance of the rocket measured from when it reaches its apogee to when it touches down. To determine the drift distance of the rocket, its drift distance was calculated in several steps, first by calculating the descent velocity using Equation I shown below.

$$v = \sqrt{\frac{2 * W}{Cd * \rho * A}}$$

Equation I. Equation for descent (terminal) velocity, where v is the descent velocity, W is the weight of the section of the rocket, Cd is the drag coefficient, ρ is the air density (at standard sea level), and A is the area of the parachute being used.

The weight of the upper section of the rocket is 14.9 lbs, and the weight of the bottom section is 18 lbs after parachutes are deployed and the motor is empty. The coefficient of drag of the full scale rocket was found from the OpenRocket simulations to be about 0.63. The air density at standard sea level was found from online sources to be about 0.07967 lbs/ft^3. The drogue parachute has a radius of approximately 1 foot, and its area is roughly 3.14 ft^2. The main parachute has a radius of approximately 4.167 ft and an area of about 54.54 ft^2.

Table 1 below lists the values used for descent velocity calculations. The weight of the rocket sections, and drag coefficient are in lbs, the air density is in lb/ft^3, and the areas of both parachutes are in ft^2.

Variable	Value
W (upper)	14.9
W (lower)	18
CD	0.63
ρ	0.07967
A (drogue)	3.141593
A (main)	54.54154

Table I. Variables used and their values

Using Equation I, we substitute the values from Table 1 to get the lower section descent velocity to be 12.4 ft/s and the upper section descent velocity to be 10.3 ft/s. The average is 11.4 ft/s.

After the descent velocity was calculated, the descent time was calculated using Equation II, shown below.

$$t = \frac{alt}{v_d}$$

Equation II. Equation for the descent time, where t is the descent time, alt is the altitude, and v_d is the average descent velocity.

The main parachute deploys from an altitude of 700 ft. Using the descent velocity of 11.4 ft/s, we get a decent time (after main deploy) of 61.6 s.

Finally, Equation III was used to calculate the drift distance of the rocket, dependent on the wind speed.

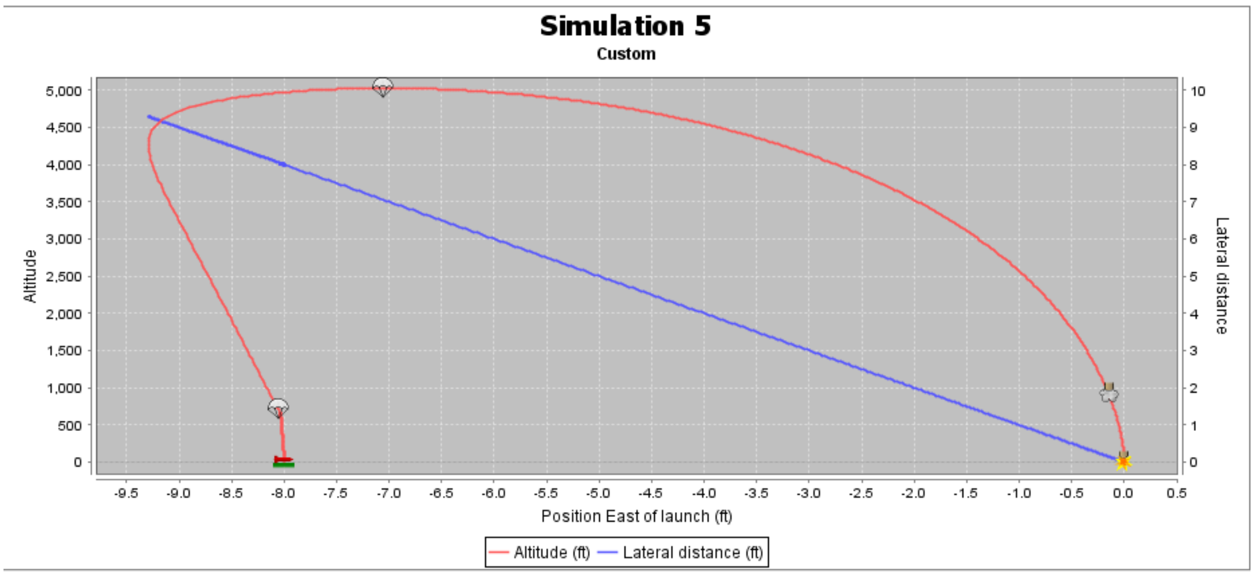
$$D = v_w t$$

Equation III. Equation for the drift distance, where D is the drift distance, v_w is the wind velocity, and t is the descent time from Equation II.

For the calculations listed above, the following assumptions were made:

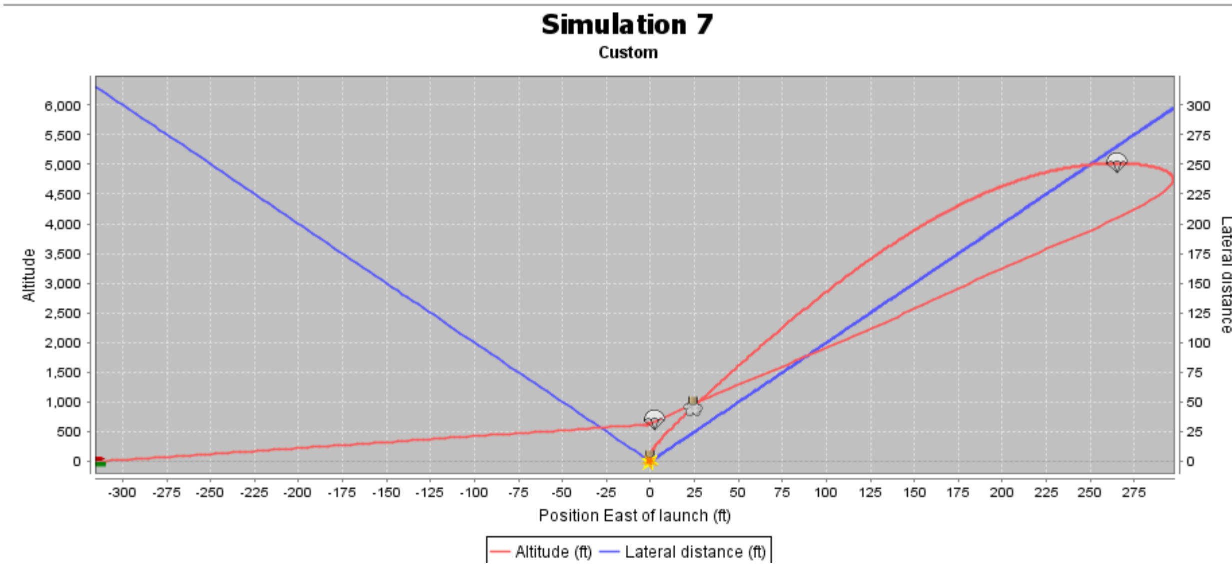
- The horizontal drift velocity of is equal to the horizontal wind velocity.
- Both the drogue and the main parachute are perfect circles, allowing their areas to be calculated using the equation $A = \pi r^2$.
- The mass of the lower section of the rocket does not include the mass of the propellent.
- The overall descent velocity is the average of the descent velocity of the upper and lower sections

5.2.5.1. 0 MPH Drift Distance Calculations



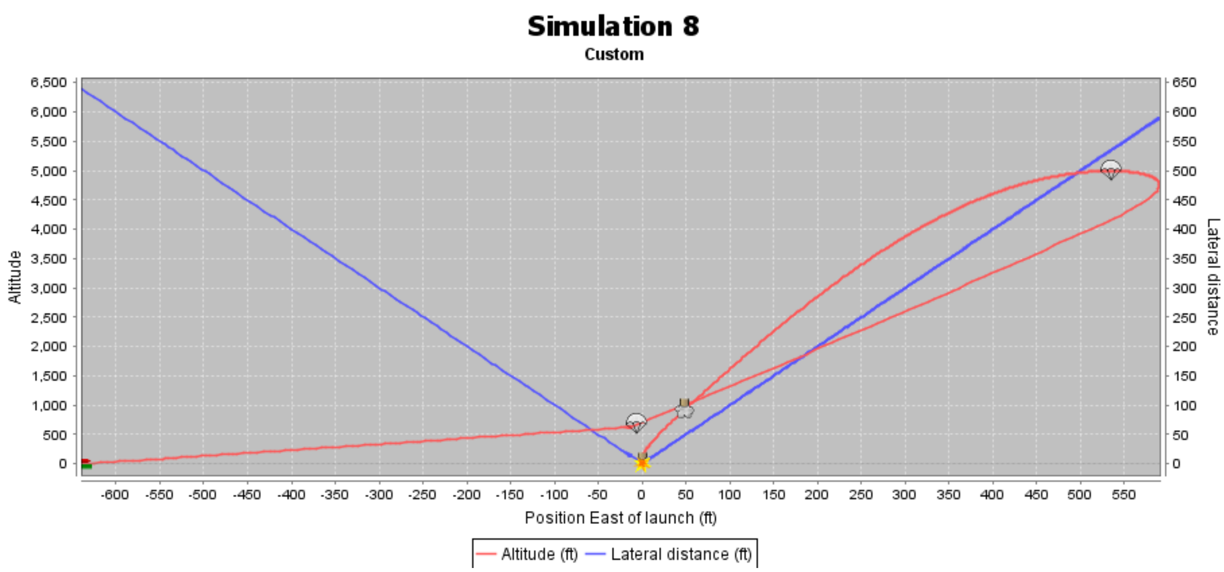
With an average wind speed of zero miles per hour with zero standard deviation and zero percent turbulence intensity, the simulated maximum drift distance during flight is almost ten feet. However, the calculations suggest that the rocket's drift distance with no wind is 0 ft, as the equation for drift distance multiplies the descent time by the wind velocity. Realistically, the rocket will have some drift even if there is no wind, but it will be minimal.

5.2.5.2. 5 MPH Drift Distance Calculations



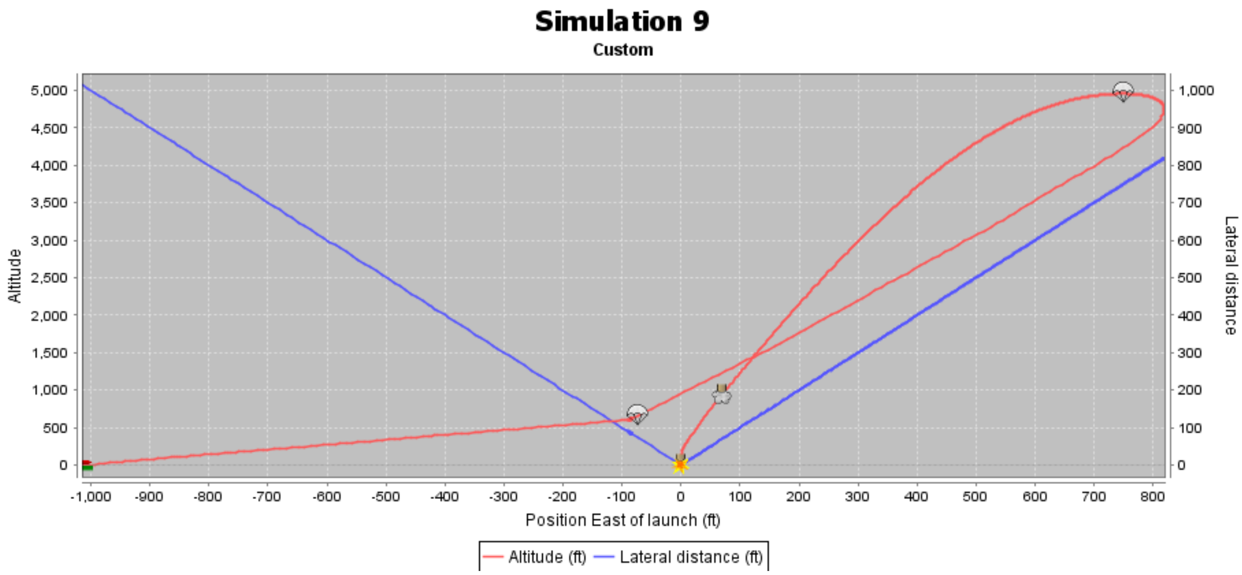
After falling for 61.6 s with a horizontal speed of 5 MPH, the launch vehicle should drift about 498 ft. Depending on other conditions present at launch, the actual drift distance may be slightly more or less than this.

5.2.5.3. 10 MPH Drift Distance Calculations



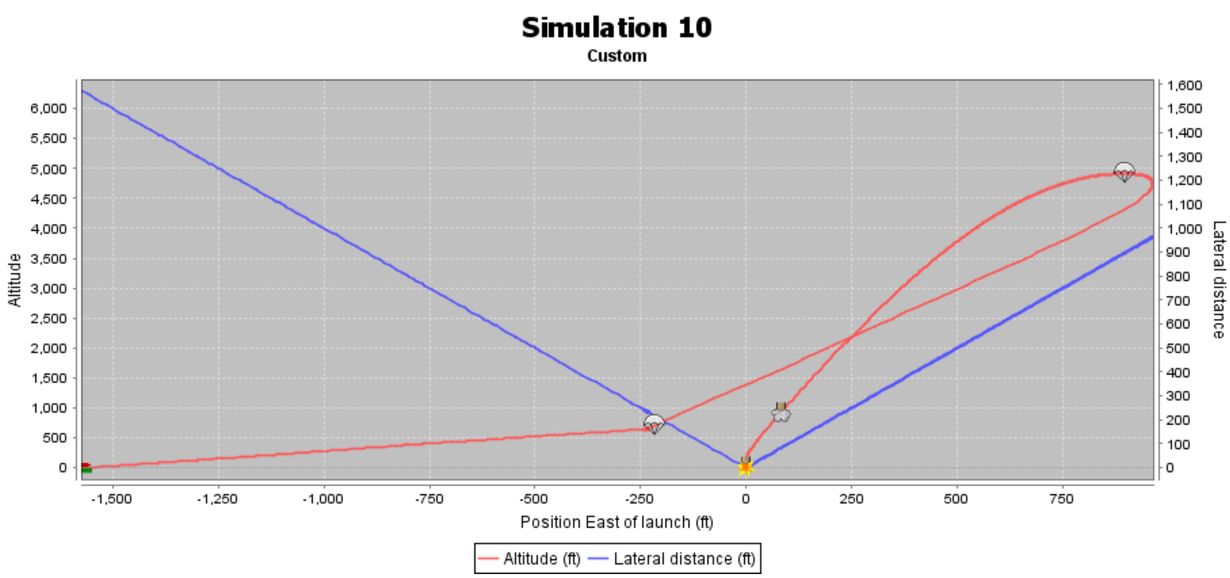
After falling for 61.6 s with a horizontal speed of 10 MPH, the launch vehicle should drift about 996 ft. Depending on other conditions present at launch, the actual drift distance may be slightly more or less than this.

5.2.5.4. 15 MPH Drift Distance Calculations



After falling for 61.6 s with a horizontal speed of 15 MPH, the launch vehicle should drift about 1494 ft. Depending on other conditions present at launch, the actual drift distance may be slightly more or less than this.

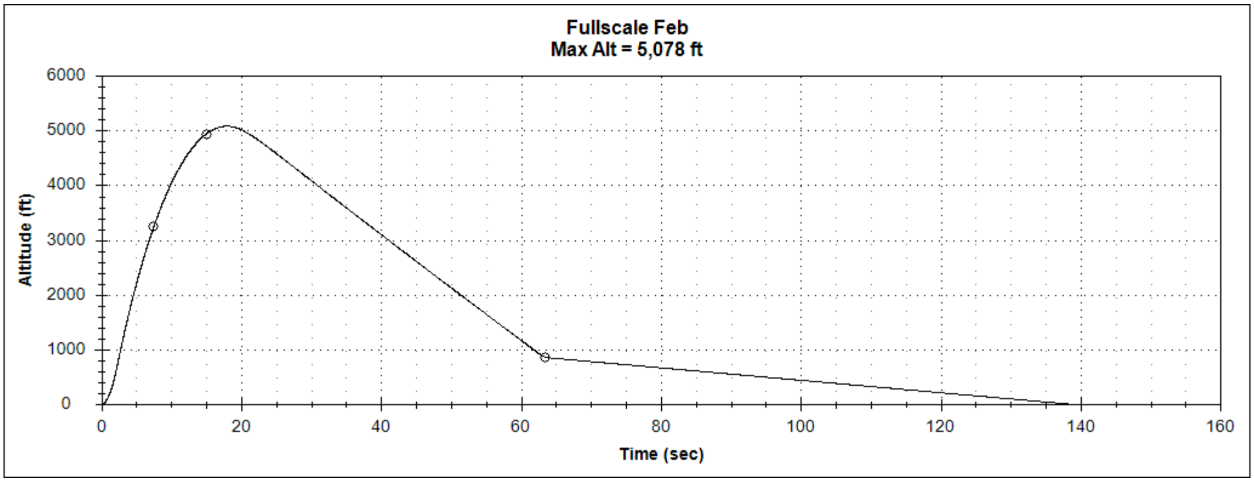
5.2.5.5. 20 MPH Drift Distance Calculations



After falling for 61.6 s with a horizontal speed of 20 MPH, the launch vehicle should drift about 1992 ft. Depending on other conditions present at launch, the actual drift distance may be slightly more or less than this.

5.2.6. RASAero Calculations

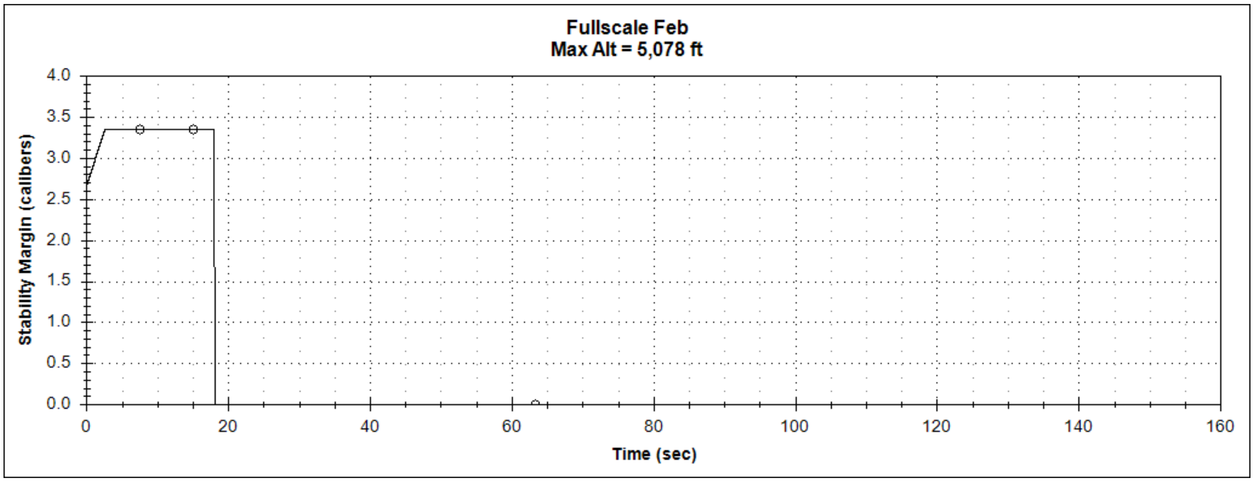
5.2.6.1. Altitude Predictions with Simulated Vehicle Data

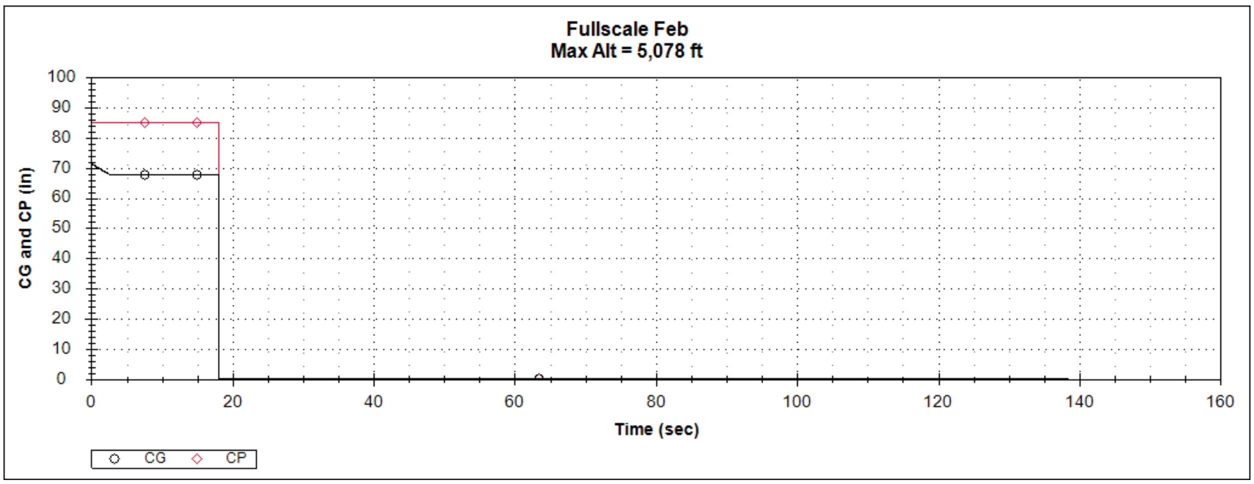


The graph above, which was produced using RASAero II, is the result of running an identical simulation as the one the team performed with OpenRocket. All simulation settings were the same, and the vehicle dimensions and metrics were input manually. As a result, the same rocket flying on the same motor is predicted to achieve a maximum altitude of 5,078 feet above ground level. This is an increase of [191’] over the OpenRocket simulations, and a total of 128’ over the target altitude of 4,950 ft. This is a significant difference, but with the current weight problems, it may be best to have some altitude cushion.

As the two programs are made by different companies and use different parameters to estimate rocket performance, the difference in the two projected altitudes is expected. However, the two models can approach each other to give what the team believes is a valid estimation. As such, the team will continue to iterate the design to be more accurate to reality in both programs as changes are made and weights are updated. In time, it is expected that the difference in the models is to decrease.

5.2.6.2. Stability Margins with CP/CG Relationships & Locations

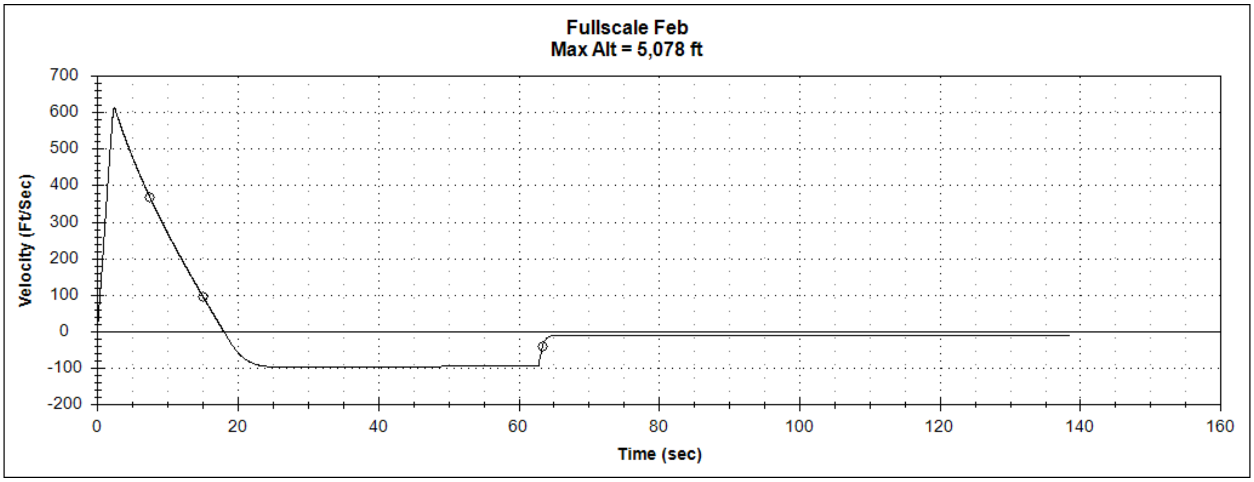




The stability margin graph shown above, produced using RASAero II, shows similar results to the stability curve produced in OpenRocket. The static stability is approximately 3.4 calibers, but stability off the launch rail clearance - which is estimated by OpenRocket to be around 2 calibers - is around 2.7 calibers. OpenRocket does, however, calculate the static stability to be [3.38] calibers, so these estimates do in fact reinforce each other.

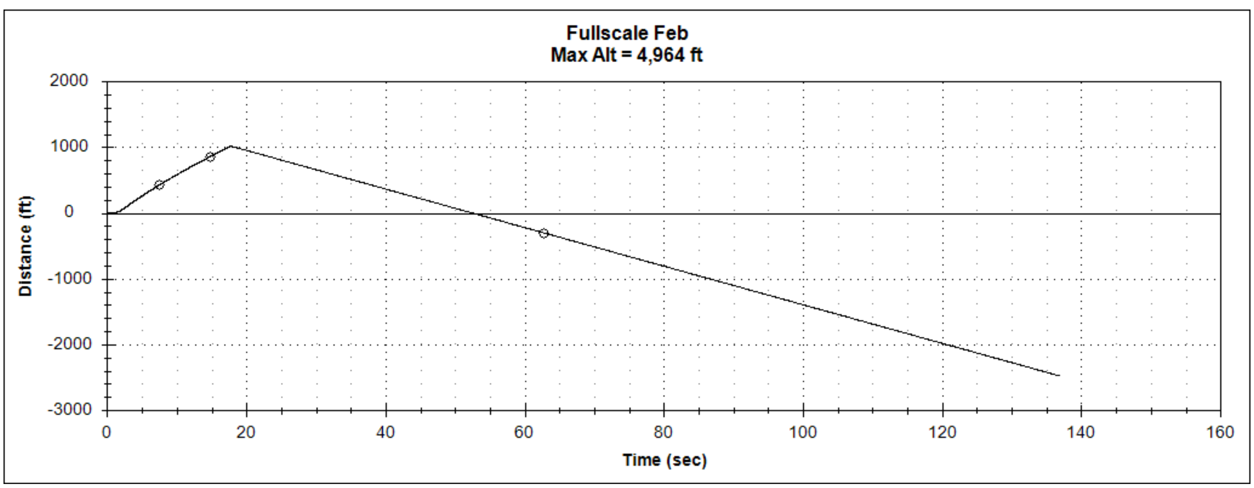
In addition, the location and change in both the center of pressure and center of gravity are approximately equal to those in OpenRocket. The center of gravity starts at 71” from the datum and moves forward around 2”. The center of pressure in OpenRocket started at around [81”] from the tip of the nose cone and moved aft to approximately [90”], whereas RASAero places the center of pressure at 86” and remains constant throughout the flight.

5.2.6.3. Kinetic Energy at Landing



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

5.2.6.4. Drift Distance Calculations



The image above shows the drift of the launch vehicle while flying in twenty mile per hour winds, similar to the drift model created in OpenRocket. The rocket originally drifts approximately 1,014’ in one direction as it tilts into the wind on ascent. At apogee, the rocket begins drifting back towards the launch site, passing it and continuing to drift a further 2,480.5’ past the point of origin. The total drift distance of 3,494.5’ is very troubling, but there will likely not be sustained winds of this level during the launch. The

[2000'] drift distance is a close approximation of the model created in the other simulation platform, but RASAero II predicts that the rocket will tilt into the wind and travel an additional [250'] than OpenRocket predicted. As a result of this increased tilt, the apogee altitude varies slightly as well. The original RAS model simulated a maximum altitude of 5,078', but only reaches 4,964' when factoring wind and tilting.The full scale flight, however, demonstrated that in low winds, the vehicle drift is well within the range. By checking other sources for drift calculations, the team believes that a more accurate drift calculation can be achieved than that from this simulation.

5.2.7. 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 4 percent margin of error of the OpenRocket estimate. As the computer simulations are matured to match the real weights and metrics, the team predicts that the differences between the simulations will decrease. If this is not the case, the team will consider simulating the vehicle in a third platform, such as RockSim.

6. Payload Criteria

6.1. 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 ten milliliter soil sample at least ten feet from any part of the flight vehicle.

Mission Success Criteria:

- The payload bay shall be secured in the launch vehicle during vehicle ascent and descent and shall be completely independent from the recovery system
- All payload subsystems shall be entirely functional after flight and touchdown of the launch vehicle
- After successful touchdown of the launch vehicle, a radio unit shall remotely disengage and deploy the payload bay from the launch vehicle
- Once the payload bay is separate from the launch vehicle, the rover shall completely separate from the payload bay in an operational configuration
- Once separate from the launch vehicle, the rover shall autonomously navigate to a point least 10 ft from the closest launch vehicle component
- Once the rover is far enough from the launch vehicle, it shall collect and contain at least 10 ml of soil

6.2. Payload Changes Since CDR

In order to ensure the safe and successful operation of the payload that follows the mission statement, changes were made to the payload since CDR regarding the chassis, soil retention device, and the electronic storage. The following list is a comprehensive look into all of the changes that have made since CDR:

- To accommodate the soil retention system, the shape of the baseplate of the chassis had to be changed to rectangle with smaller rectangles cut out at the front corners.
- The soil retention system was originally a rake and a scoop put together at the back of the rover. Now, it has been separated and placed the rake at the front of the rover and the scoop at the back of the rover.
- In order to fit all of the components onto the baseplate of the chassis, a shelving unit had to be created to hold the LIDAR and protoboards for the rover electronics.
- To ensure that the rover would have enough traction to move forward, a new wheel tread was created that would allow for easier traversal over varying terrain.

- To make room for the soil sampling system, the battery was moved from the bottom of the rover to the top.
- The original motors moved too fast and it did not work well for the rover so the motors were switched to ones with a much lower RPM.
- Originally, a third wheel was on the front of the rover to help support it while it was moving. The third wheel was decided to be removed as it did not do much to support the rover and so it would not hinder the soil sampling system.
- Dimensional changes have been made in the piston bulkplate that pushes the payload out to improve movement and prevent blockage.
- There will be two forged eye bolts with a shock cord between the Ejection Bay and the Rover Containment Bay so that the payload will not free fall if the shear pins do not hold.
- Originally, the launch vehicle had 4x 2-56 shear pins, which were were unable to hold the payload bay to the rocket. They have now been changed to 4x 4-40 shear pins.

6.3. Payload Demonstration Flight

6.3.1. Date of Flight

The payload demonstration flight occurred on February 25, 2019. A second payload demonstration flight is scheduled for the week of March 17, 2019.

6.3.2. Success Criteria

The payload team defined the following criteria for a successful demonstration flight of the payload:

- The payload will be securely retained inside the payload bay at all times during the flight.
- The payload will not sustain any functional damage throughout the duration of the flight.
- The payload's active retention system will keep the rover inside the main payload bay during the flight.
- After the rocket has landed, the payload will be remotely separated from the rocket, via a black powder charge, by a distance of least 3 feet.
- The rover will be successfully deployed from the rocket via the stepper motor in the payload bay. Deployment will be considered successful if the rover is placed completely outside of the rocket in a configuration ready to maneuver away from the rocket.
- The rover will autonomously begin its excursion from the rocket *after* it has been successfully deployed.

6.3.3. Results of Flight

The payload demonstration flight that occurred on February 25, 2019 failed to meet the aforementioned success criteria. An anomaly occurred in-flight during the separation of the main parachute from the launch vehicle. The shear pins designed to secure the payload bay to the upper-airframe of the rocket failed during this event, causing the payload bay to enter a ballistic descent from an altitude of approximately 750 feet. While the active retention system did successfully retain the rover inside the payload bay, the rover along with other components in the payload bay were completely destroyed.

6.3.4. Analysis of Retention System Performance

The payload's retention system failed to safely retain the payload within the rocket throughout this demonstration flight. The payload's retention system has been designed with a number of features to secure the payload in the rocket, one of which was the cause of the anomaly that occurred during the demonstration flight. The rover is secured inside the payload bay via two bulkplates, a guide rod, and a lead screw attached to a stepper motor. This part of the system successfully retained the rover inside the payload bay throughout the flight, despite the extreme forces exerted on it upon impact with the ground. The second part of the retention system is designed to secure the payload bay to the upper airframe of the rocket. This was done utilizing 2-56 shear pins. These were selected so that the payload bay could be remotely ejected with a black powder charge from the rest of the rocket after the flight. This part of the retention system was the source of the anomaly that occurred. Upon the ejection of the main parachute, the payload bay experienced a concentrated force that exceeded what was predicted by the payload team, causing the shear pins to fail.

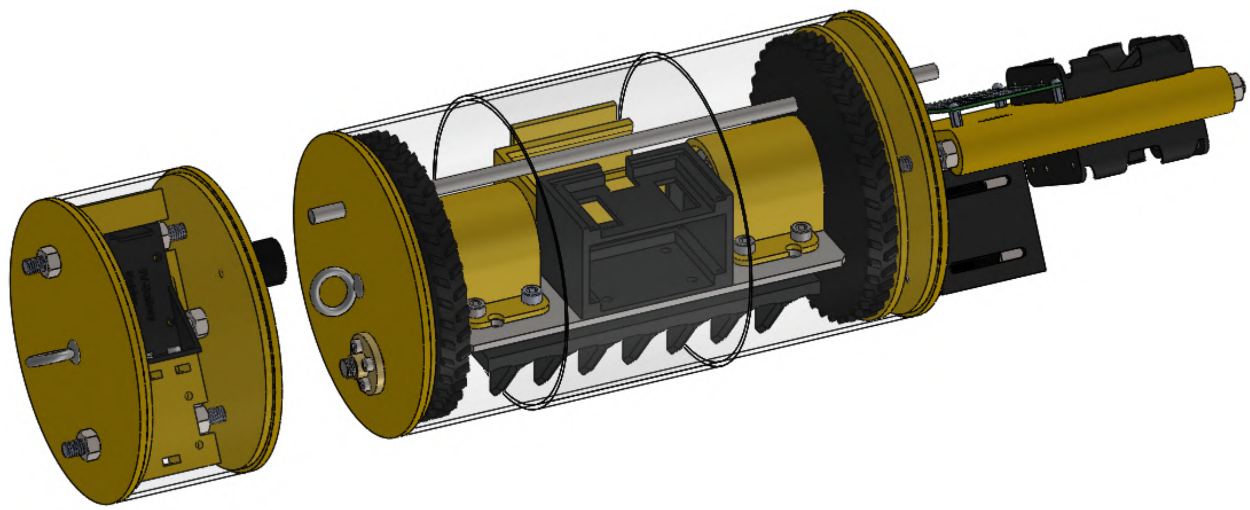
While the payload team is disappointed with the results of this test flight, a number of design changes to this part of the retention system will be implemented going forward to ensure such a similar anomaly does not happen again.

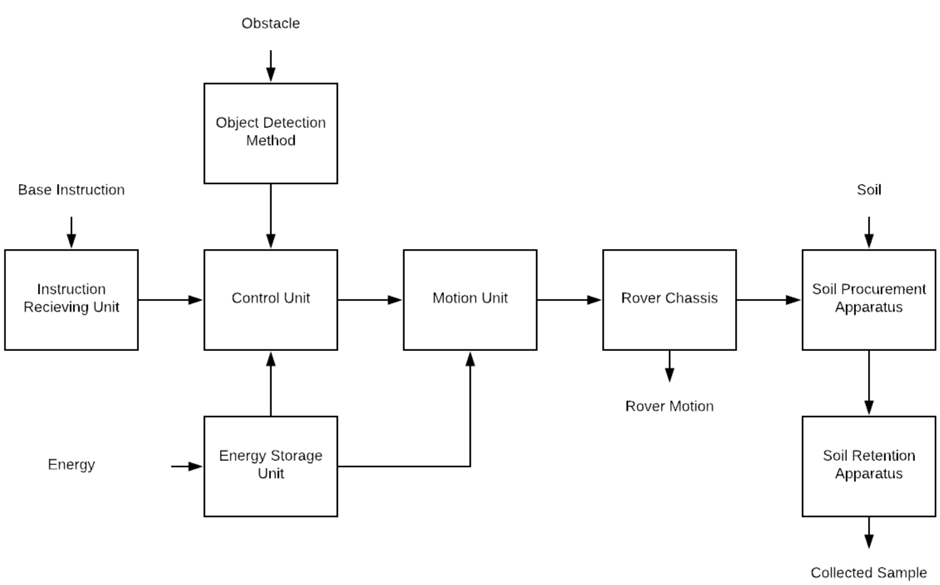
First, the main parachute will be moved closer to the forward attachment point on the ejection bay. This will reduce the amount of force concentrated on the ejection bay at the moment of main parachute deployment. Secondly, the four 2-56 shear pins formerly securing the payload bay to the upper airframe will be replaced with four 4-40 shear pins. These nylon shear pins are capable of withstanding significantly more force than the the 2-56 shear pins, keeping the payload bay securely attached to the rocket throughout the flight. Finally, a shock cord will be added between the rover containment bay and the ejection bay. This will be an added safety measure to ensure that the payload bay will not undergo a ballistic descent in the event of shear pin failure.

The payload team is confident that these design changes will yield a more robust payload retention system capable of safely retaining the payload throughout the duration of the flight. A second payload demonstration flight will prove the capabilities of this new design and is currently scheduled for the week of March 17, 2019.

6.4. Selection, Design, and Rationale of Payload

6.4.1. Overall System Design





6.4.2. Control Subsystem

6.4.2.1. Control Unit

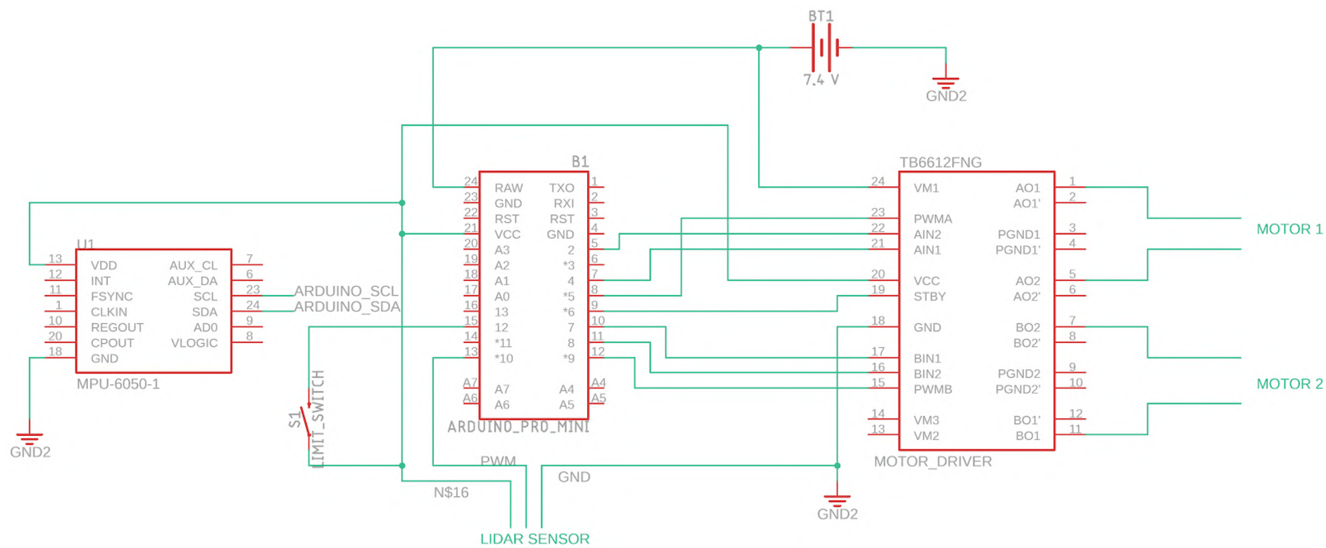
To fulfill the payload mission success criteria, the rover control unit must be able to access data from sensors, generate a set of instructions based on the sensor data, and execute those instructions continually until mission success. In order to accomplish all these tasks, the Arduino Pro Mini microcontroller was selected as the control unit because it offers simple integration of essential sensors, sufficient computational power for decision making, and the capacity to execute such decision making via its GPIO system. A key feature of the Arduino Pro Mini that elevated it above other potential control units is the device's variety of I/O pins packaged in a small footprint. With 14 digital pins (6 of which with pulse-width-modulation functionality) and I2C communication capability, this device would be able to handle all of the I/O required for mission success. Other microcontrollers with similar I/O capability were surveyed, but none had such functionality in such a small package. The table below shows a selection of other potential control units.

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

6.4.2.2. Electrical Design

The electrical design of the rover has changed little since CDR. The MPU-6050 accelerometer and gyroscope unit was selected as the IMU on-board the rover. This device was selected for two reasons. First, the the limited number of PWM-capable pins on the Arduino Pro Mini warranted a sensor that could interface with the microcontroller using an alternative serial-communication protocol. The MPU-6050 interfaces with the Arduino via I2C, meeting this need. Secondly, this device has both a 3-axis accelerometer and a 3-axis gyroscope. Other IMU sensors considered by the team were not capable of taking both of these types of measurements. In order to execute the dead-reckoning software algorithms designed to control the rover, a sensor capable of both linear and rotational acceleration measurements was needed. The MPU-6050 met this requirement, and was thus chosen as part of the electrical design.

The electrical system on-board the rover serves two primary purposes. First, it must function as the "brain" of the vehicle, obtaining and acting upon all inputs and outputs of the system. This means the electronics must be capable of processing input signals from a variety of sensors, such as an IMU and LIDAR, as well as making simple decisions based on this input data. A description of the selection and rationale for the Arduino Pro Mini that serves this purpose was described above. Secondly, the electronics on-board the rover must be capable of running the DC motors used to maneuver the vehicle. The schematic of the rover below shows the TB6612FNG motor controller used to interface the DC motors of the rover with the Arduino Pro Mini.



As indicated in the schematic above, the electronic design of the rover also includes a sensor package critical for mission success. Pictured on the left is the MPU-6050 3-axis accelerometer and gyroscope. Additionally, a LIDAR range-finding sensor is employed to provide high-resolution data regarding the rover's surroundings after deployment.

There were many power supply options, as the payload's overall design was being considered. In order to narrow down the possibilities between the variety of options available to the team, a list of basic requirements was created. 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

The leading choice for the power supply is GARTPOT 35C 2S LiPo Battery Pack with 1550 mAh for the battery. This option fulfills all of the requirements that the team had set. This selection is the same one in the preliminary design of the payload. A decision matrix illustrating why this choice was made is below:

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

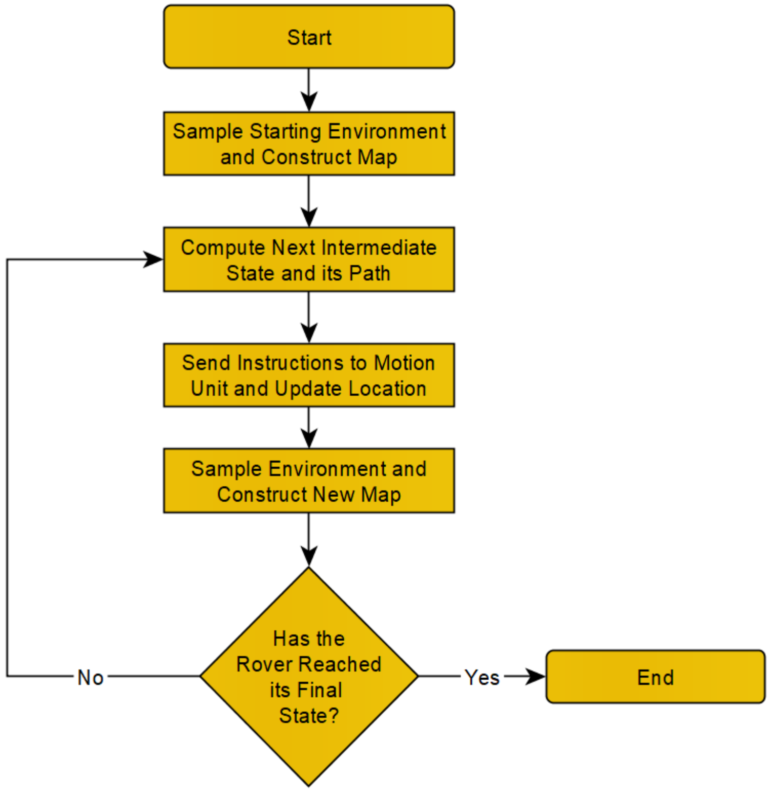
6.4.2.3. Software Design

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 an optimal path between an initial state and a calculated goal state, and finally estimating and measuring the rover's motion and final state in reference to the initial 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 graph, and that the odometer along with the range sensing unit have an inherent error.

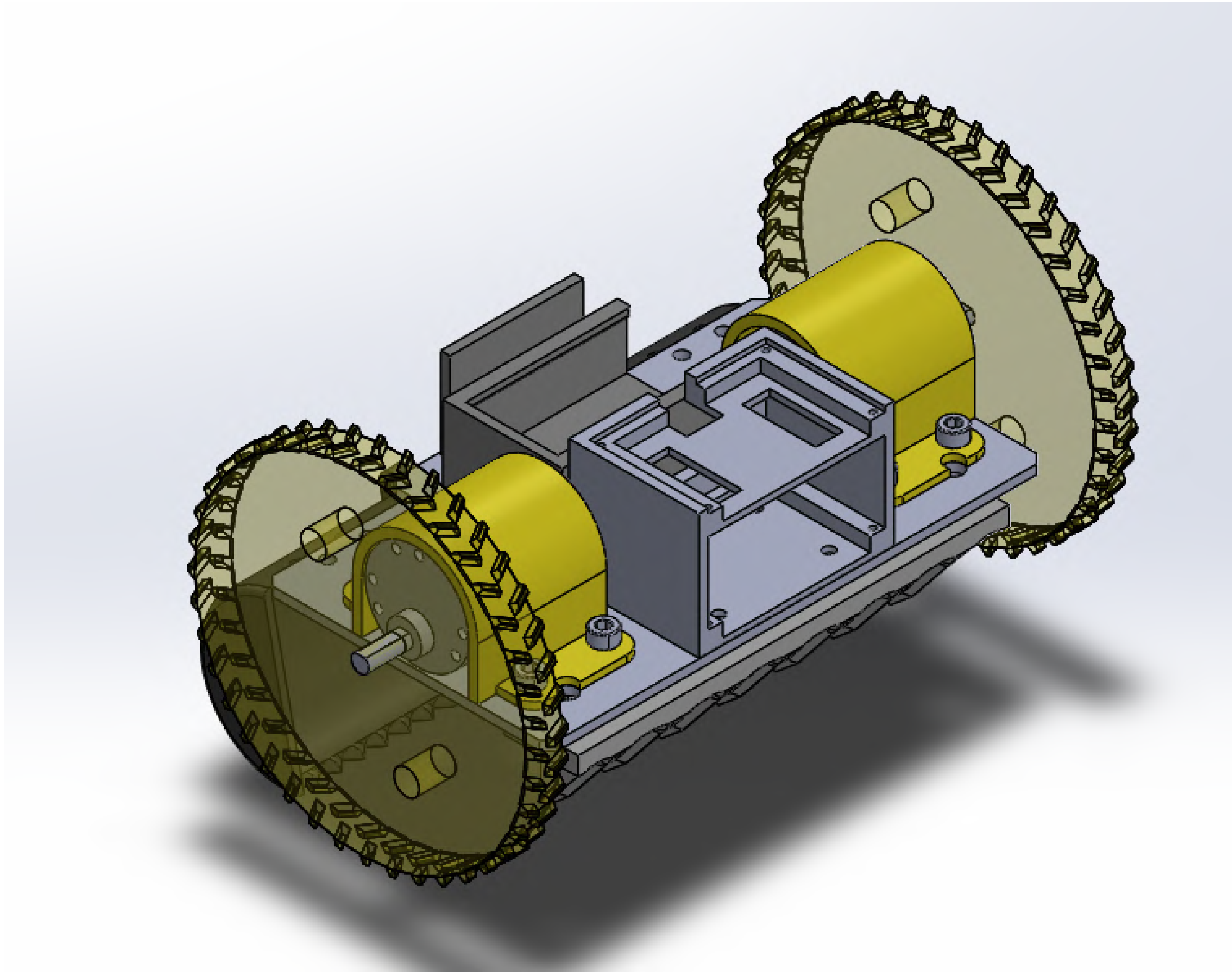
In order to determine the rover's pose and configuration, range-finding sensors are necessary to construct a local map that will be used to calculate an intermediate state before reaching a final configuration. In order to distinguish between rocket components and environmental objects, rocket component characteristics, such as length and diameter, will be stored and compared to specific objects in this constructed local map. This constructed local map will be used only once to compute the best intermediate state and the subsequent optimal path before discarding the map and sending instructions to the motion unit. Upon reaching the intermediate state a new map will be constructed and the steps described above will be repeated until it reaches a final state matching the payload mission success criteria.

Computing an optimal 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 2D layout of the terrain, the optimal path should be a line that connects the initial and end point that passes only through free space and farthest from any component of the rocket. Calculating the length traversed by the computed path is an inherently difficult task since the measurements taken from the inertial measurement unit (IMU) are inherently erroneous. This error is amplified by the non-2D terrain traversed by the rover, so caution must be taken when assuming a final configuration. This means that both the range finding sensor and IMU must be used to determine if the rover has found a configuration fitting the mission success criteria.

The rover's autonomous path-planning algorithm will involve constructing a single-use local map of its environment that will be used to compute an intermediate state and path, then send instructions to the motion unit to move to that intermediate path. The IMU will be used to create an estimate of the rover's position and update after each movement. The rover will continue to construct single-use maps at each new state after moving until it is determined to reach its final state. This algorithm was chosen instead of the previously proposed SLAM algorithm because the SLAM algorithm was determined to be too computationally expensive and would require design changes that exceed the constraints placed on the rover control unit and sensors. Below is the flowchart diagram describing the autonomous path-planning algorithm.


Start
Sample Starting Environment and Construct Map
Compute Next Intermediate State and its Path
Send Instructions to Motion Unit and Update Location
Sample Environment and Construct New Map
Has the Rover Reached its Final State?
No
Yes
End

6.4.3. Chassis Subsystem

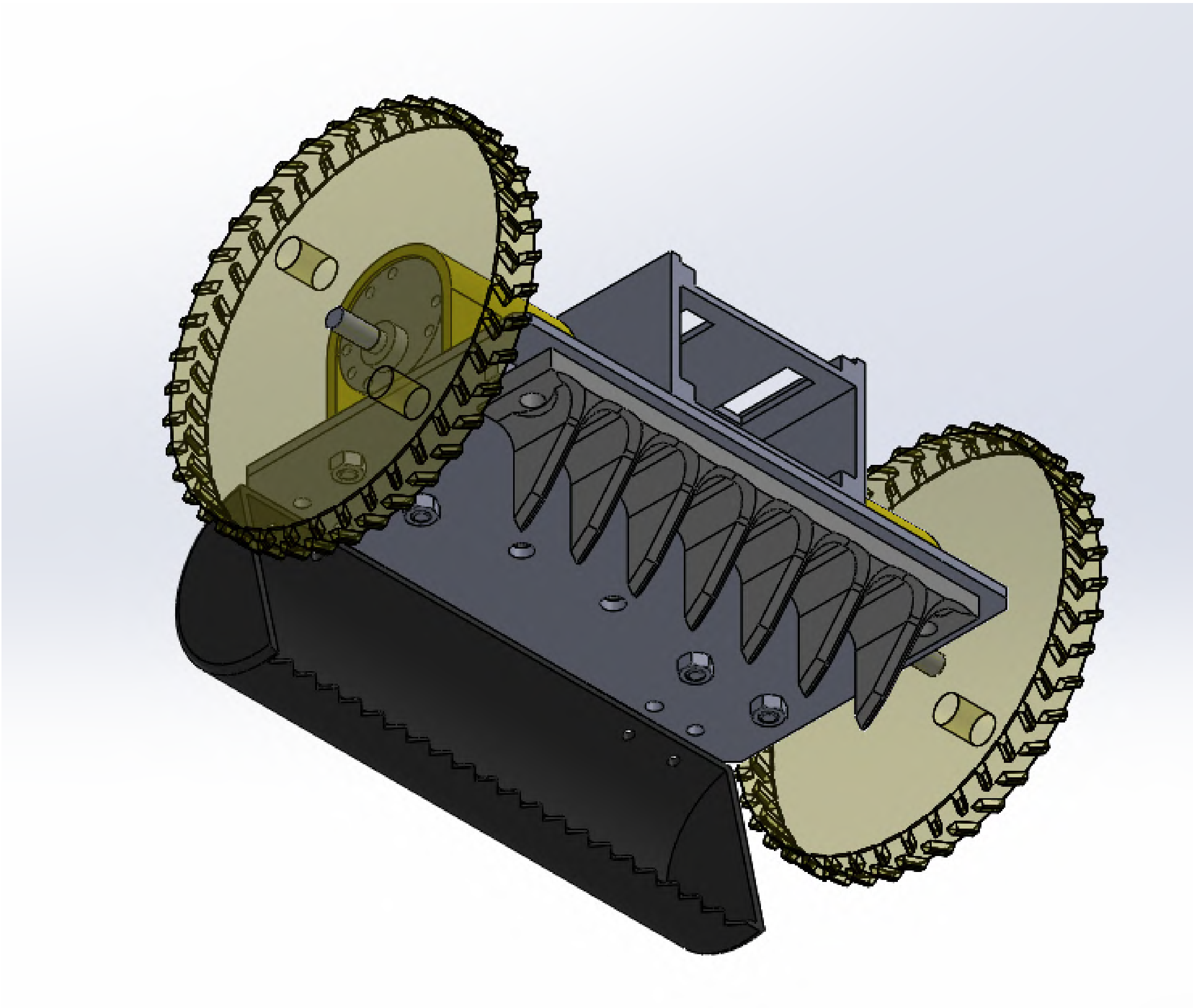


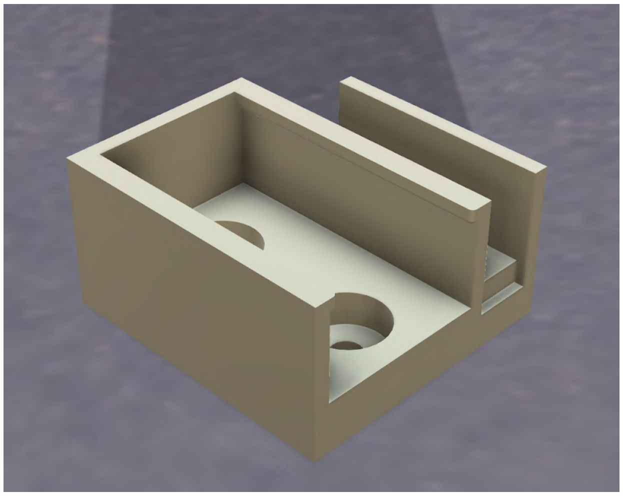
6.4.3.1. Rover Body

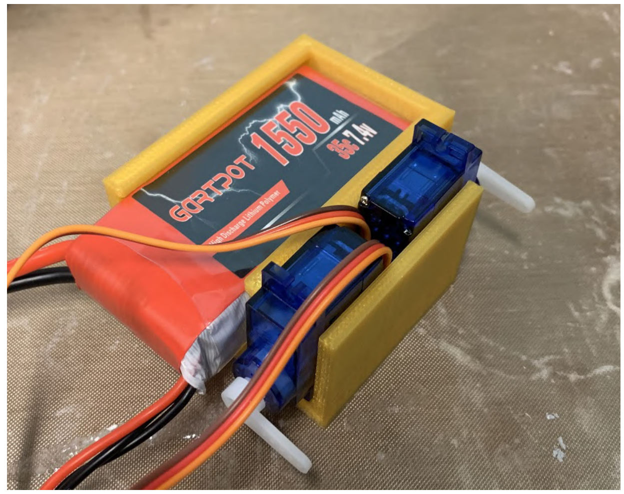
There have been very few changes made to the rover body since CDR. The chassis is now 4.1875 inches by 6.75 inches. This change in size was made to account for hinges on the rear of the rover that hold on the scoop. Numerous holes were added to attach all electronic components. The locations of the many static components have also either been changed or confirmed:

- The rake has been moved to the front of the chassis as it was too large for the scoop to rotate around it (Further discussion about this change can be found in the soil procurement section below).
- The scoop remains in the back of the chassis and still collects the soil loosened by the rake.
- The battery is now located on top of the chassis within a newly designed battery holder. This new location provides an additional downward force to the scoop so it can more effectively loosen soil.

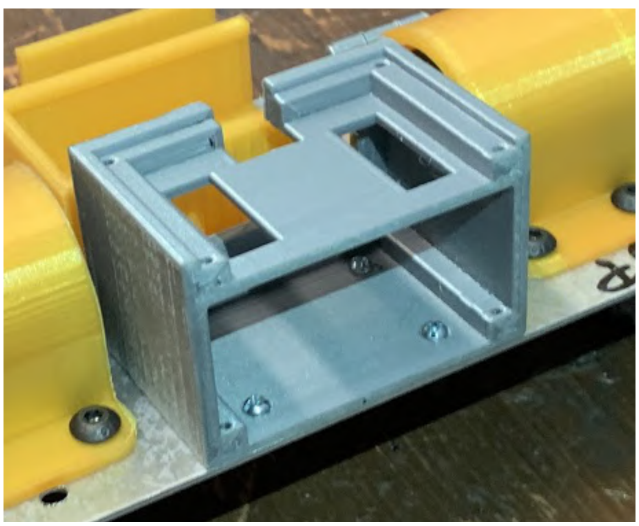
The servos intended to allow for the forced rotation of the soil retention system scoop are mounted on the battery holder as part of the same apparatus. The mount is slotted in such a manner that does not allow for rotation of the body of each servo in the direction of rotation.

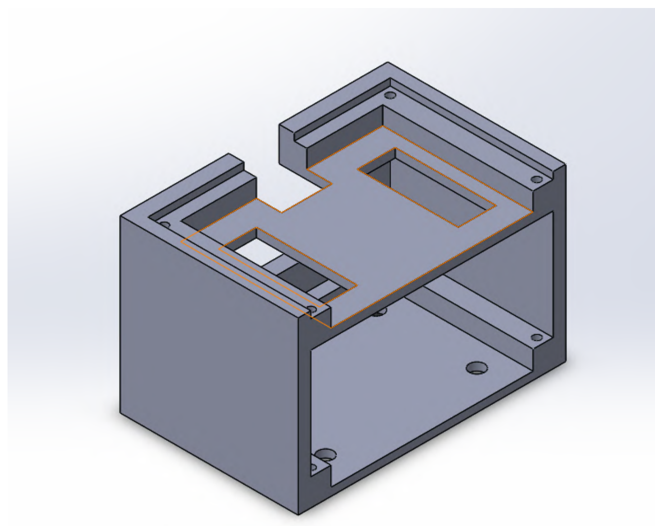




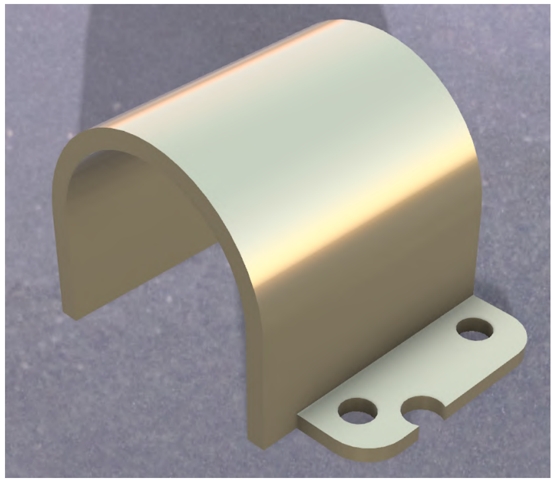


- The electronics boards are now located within a 3D printed support rack positioned at the front of the chassis. Its stacked design saves space and makes the electronics easy to access.





- The rover wheel motors are still positioned so all the components besides the electronic boards will rest underneath the axles, ensuring that the majority of the mass will be underneath the axis of rotation and the rover will naturally tend to be right side up. They are also still positioned on either side of the chassis in the middle. Each motor will be held in place by a motor mount.



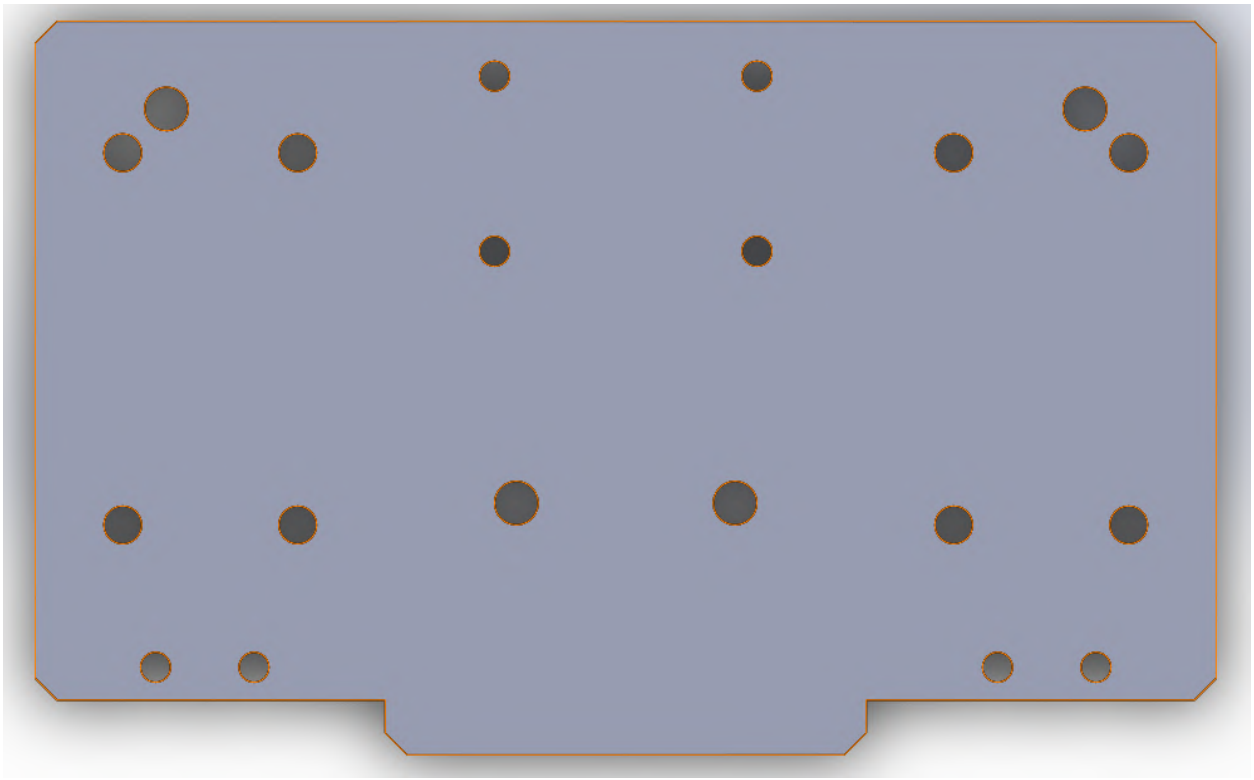
- The LIDAR sensor is still positioned in the front of the rover so they have an unobstructed view of all potential obstacles in the driving path.

6.4.3.2. Rover Motion

There have been multiple major changes to the rover-motion since CDR. The third wheel in the front of the rover has been removed and replaced by the rake. Additionally, the wheel motors have been changed to geared DC brushless motors, as the old ones provided too much velocity without an adequate amount of torque. They also have a low power requirement and are easily replaceable. The wheels have not been purchased as planned, but rather, they have been custom made by 3D printing. They were designed to be durable, have effective treads for driving in loose soil, and fit within the payload bay. When the rover is in motion, the rake in the front of the chassis will drag against the ground loosening soil. The rake's position also prevents the rover from rotating forward. The scoop in the rear of the chassis will be pushed downward by the rotational force of the motors and will collect the loosened soil. The scoop's position also prevents the rover from rotating backwards.

6.4.3.3. Chassis Construction

The rover was constructed using an aluminum 6061 sheet metal plate for the chassis. All components were fastened to the chassis. The first step in construction was the drilling of holes in the sheet metal via a drill press. Holes were drilled for the electronics boards, motor mounts, battery casings, and soil retention systems. All non-electronic parts were 3D printed. Initially, holes were drilled in the 3D printed parts, but after multiple failed assembly attempts, new parts were printed with holes already correctly placed. All components were fastened to the chassis using appropriately sized nuts and bolts (see image below). A pair of slots were cut into the aft section of the chassis in order to better facilitate the placement of the soil retention system so all the components stay within the confines of the payload bay.



6.4.4. Soil Sampling Subsystem

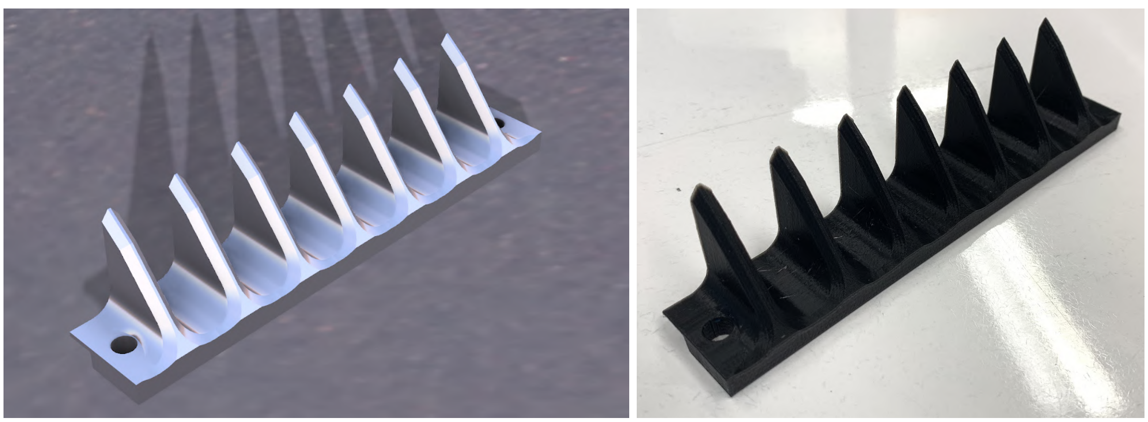
The finalization of the soil sampling design will be discussed in this section. The biggest update to the system is the method of integration which has influenced the design. Changes in component positions have been changed to stay within the confines of the payload bay.

6.4.4.1. Soil Procurement

As the physical prototypes of the rover began to be constructed, it became clear that a few constraints on the size and location of the rake were incompatible with the retention system's scoop. Though the sizes and dimensions of each of the respective parts were compatible with one another, it was determined that the overall size of the soil sampling system would not allow for proper fitting within the confines of the payload bay. Attempting to scale down the size of the soil sampling system as a whole was decided to not be viable, given current manufacturing techniques i.e. 3D printed part size, fastener size, and tool size.

Therefore, the rake's location was moved to be outside of the scoop. This would allow both parts to be sized independently of one another and would no longer require the same level of precision in fitting. The new location of the rake was decided to be flush with the ventral bow section of the rover. Given this new location, the soil procurement system could still perform its function of soil disruption, but would now not be dependent on the torque of the rover body to drive it downwards and into the soil. Instead, the rake will encounter soil and through its process of soil disruption, will provide further torque that will drive the soil retention scoop further into the soil for improved collection. In addition, this new location of the rake would provide similar forces that would have been applied by the proposed third wheel earlier in the design process.

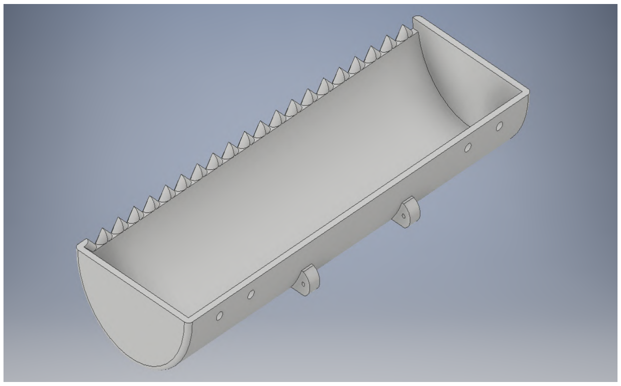
Otherwise, the basic design of the soil procurement system has changed little from CDR. Modifications were made to the rake simply to allow it to fit in the space underneath the chassis plate. The total height of each rake tooth from the rake base is now 1.378" (35mm). The total length of the rake has been shortened to 5.875" (150mm) with a width of 1" (25.4mm).



6.4.4.2. Soil Retention

Since CDR, the soil procurement system has undergone several changes. Initially, the design was a hollowed quarter cylinder. After bolting the hinges onto the scoop and rover chassis, it was discovered that the scoop was too wide, having a length greater than 6.75". The initial attempt to integrate the rover into the rocket payload bay was unsuccessful because the scoop jutted outside of the wheel diameter quite significantly, approximately by a quarter inch or more. This had been pure oversight and mostly not enough communication of constraints. This issue spurred further design. To make doubly sure that the scoop would fit, the scoop was redesigned into a semicircle that would fit entirely inside of the payload bay. With the rake moved to a different position on the underside of the rover chassis, this shape was able to be implemented without much issue.

The other major redesign to the scoop was the addition of serrated points (i.e. filleted teeth) to the leading edge of the scoop. The plausible fear the that chamfered edge would not gather the dirt prompted this design. The scoop weighs 75.6 grams.

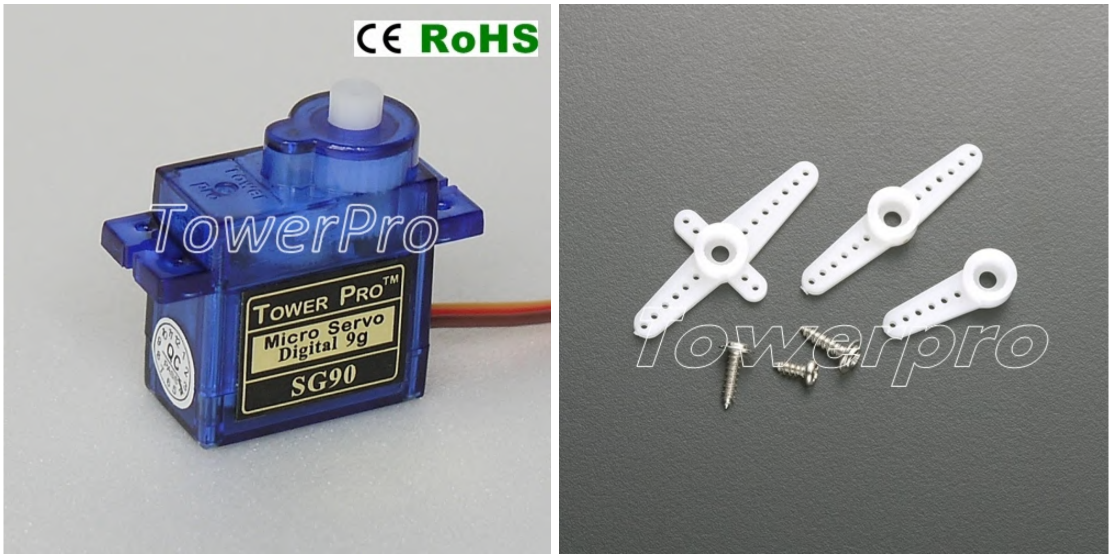


6.4.4.2.1. Actuation of the Soil Retention System

In order to comply with the regulation,

4.3.4. After deployment, the rover will autonomously move at least 10 ft. (in any direction) from the launch vehicle. Once the rover has reached its final destination, it will recover a soil sample.

The design needed to utilize a way that could actuate the scoop at the proper moment. Therefore, it was selected to use a set of two servos, *TowerPro Micro Servo Digital 9g SG90*, to rotate the scoop once the electronics had detected that the rover had driven a certain distance away from the landing sight. To connect the servo with the scoop, two tabs were added on the edge of the scoop with 1.5mm holes to allow for a structural connection which is currently in construction. The servos have a stall torque of 1.8kg/cm. Two of these servos will more than accommodate the actuation of the scoop which weighs 75.6 grams plus 10mL of soil. At the same time, a compartment for the servos and a flush mount for the servos were designed. Please refer to the rover body section above for pictures of the servo-mount interface.

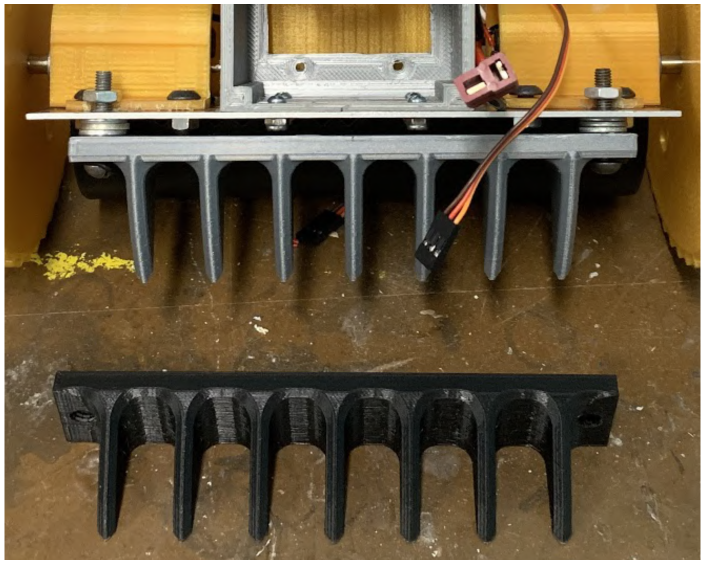


SG90 Micro Servo and Micro Servo Arms
http://www.towerpro.com.tw/product/sg90-7/

6.4.4.2.2. Design Alternatives

There have been numerous propositions for the specific design of the new attached version of the soil retention apparatus. Discussions concluded that the rover is incredibly small in scale (especially for those on the team used to robots with volumes over $18ft^3$) and therefore requires a mechanism that is simple enough to be reasonably constructed in the space allotted. A simple and effective design must be able to stay inside the confines of the fairing while in flight, deploy when the rover is ready to collect soil, and be able to seal the soil sample after sampling.

6.4.4.3. Final Design



The above image depicts the rake attached to the bottom of the chassis plate in its final location. In order to make room for the attachment fasteners of other components, the rake will be offset from the chassis plate using washers.

6.4.4.4. Soil Sampling System Construction

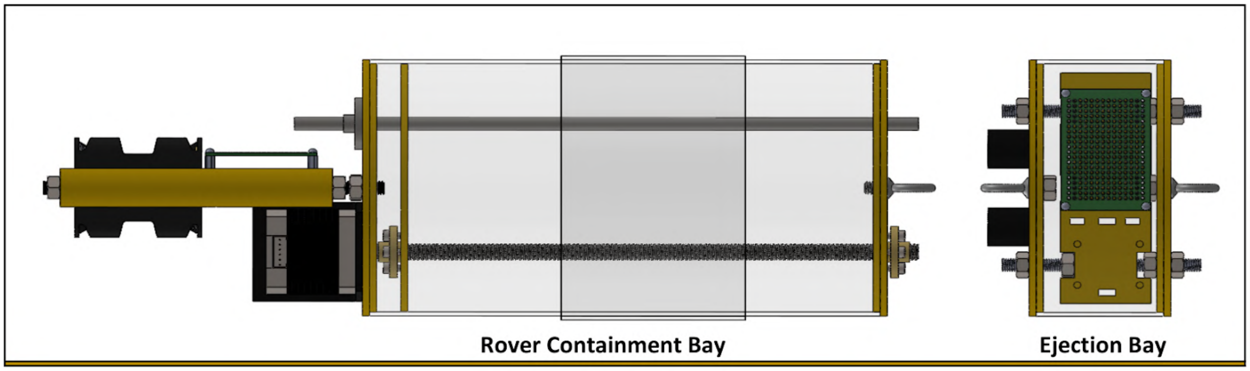
The basic construction of the soil sampling subsystem mostly includes parts that are 3D printed and only require fastening to the chassis plate. Before the planned days of construction, the 3D printed parts were printed at an on-campus location and then transported to the workshop. Parts like the fasteners and servos were ordered or procured from local hardware stores. Designs were provided to the chassis team about locations of holes and both the soil collection team and chassis team worked together to drill the required holes and fasten the components of the soil sampling system. The soil collection team proceeded to work with the control team to make sure that wired connections are correctly positioned. The design process of this caused several minor delays. Most of them were due to the reality that the designs do not work exactly like the expected ideal case. For example, the top of the chassis was initially desired to be bolted to the hinge, however, there was not enough space to rotate the scoop around the thickness of the chassis. The solution to this was to simply fasten the hinge under the chassis. Other delays included removing fastended parts to the chassis in order to drill other holes for the rake. By the time of the test flight, everything was secured to the chassis.

6.4.4.5. Testing

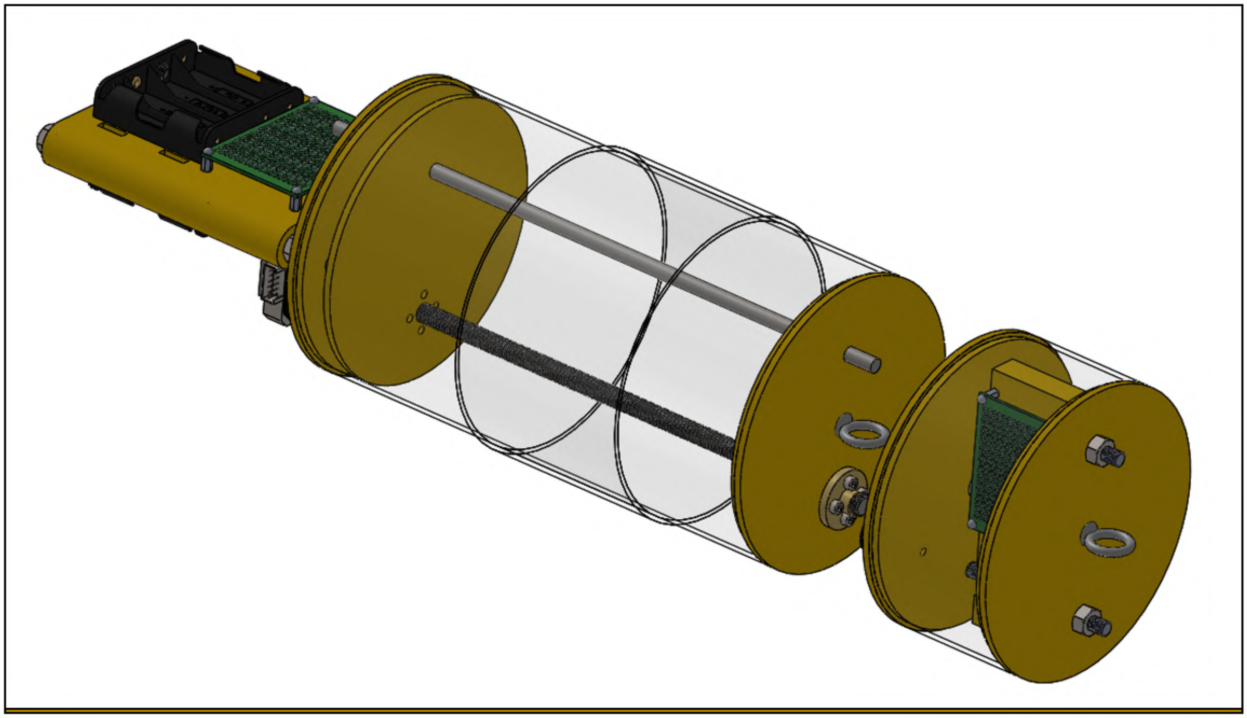
Testing the soil collection system has proven to be more challenging. Testing had been scheduled for the week of Feb 25th. With the unfortunate anomaly experienced during the Vehicle Demonstration Flight, this was cancelled until further notice. However, a new rover had to be built in order to persevere, much like the other subsystems that will be tested as soon as possible. Luckily, the vast majority of the parts are 3D printed, meaning that they will be able to hopefully come back quickly and finish off the vital testing that is still required to do.

6.4.5. Retention and Deployment Subsystem

6.4.5.1. Overall Subsystem Design

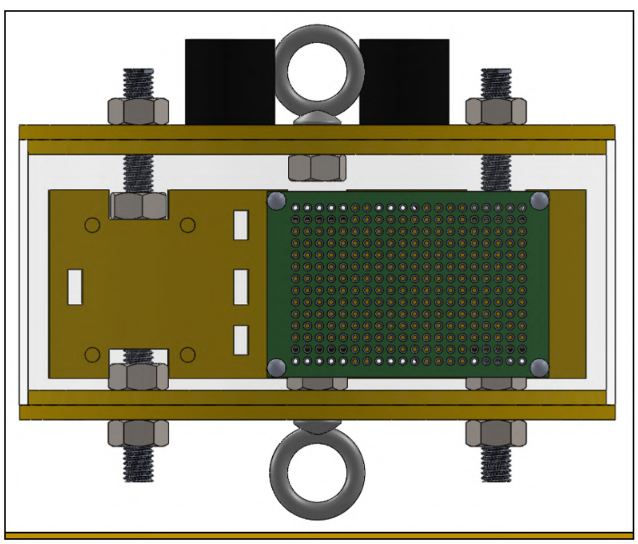


The retention and deployment subsystem of the payload will serve to contain the rover within the launch vehicle during flight and protect the rover payload from any atypical flight forces. The retention and deployment subsystem consists of two distinct components: the Ejection Bay and the Rover Containment Bay. The Ejection Bay will control the ignition of black powder charges that will separate the Rover Containment bay from the rocket body which will create an opening for the rover to deploy from. The Ejection Bay will be fixed inside the upper airframe, and separate the Rover Containment Bay from the rocket's recovery system. The Rover Containment Bay is the primary component of the retention and deployment subsystem which will hold and deploy the rover. The Rover Containment Bay will be partially installed within the noseconse and then temporarily fastened to the upper airframe using shear pins to withstand any forces experienced during flight. The Rover Containment Bay and the Ejection bay will be attached to each other with a shock cord that will keep all rocket components connected.



After a successful vehicle touchdown and upon receiving deployment instructions from the remote base station, the Ejection Bay will ignite its black powder charges and separate the Rover Containment Bay from the rocket body. Once separated from the rocket body, the Rover Containment Bay will have an opening that the rover will then be fully deployed from.

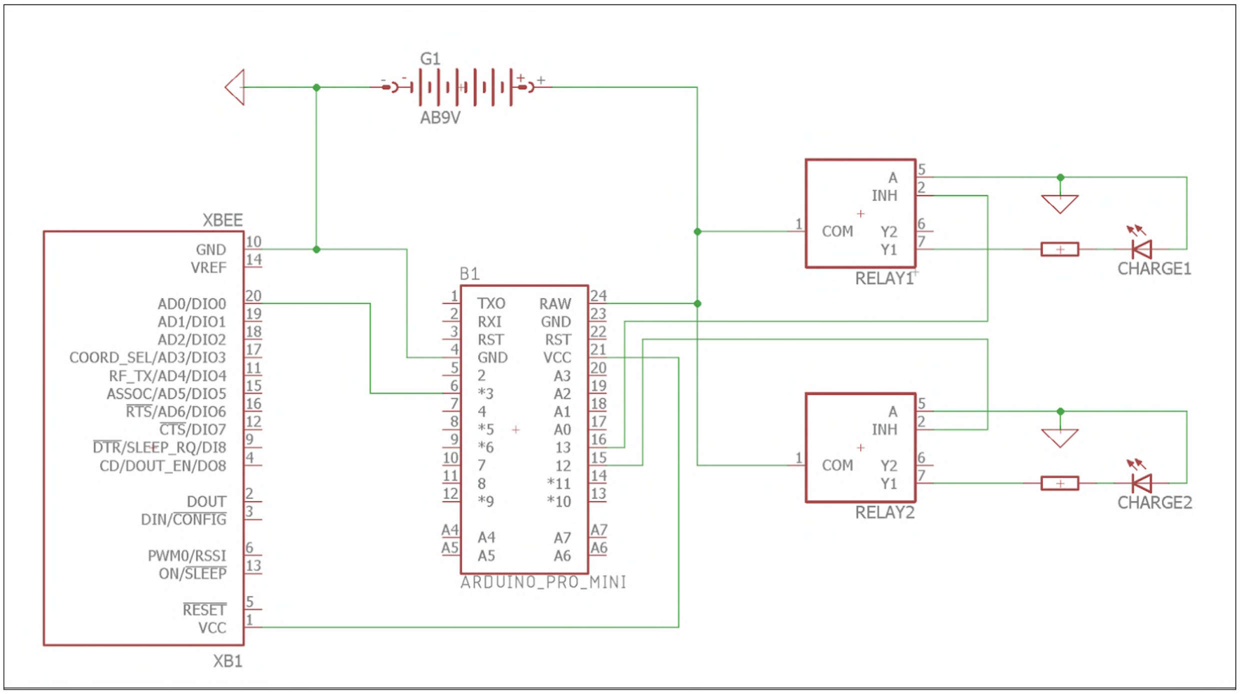
6.4.5.2. Ejection Bay



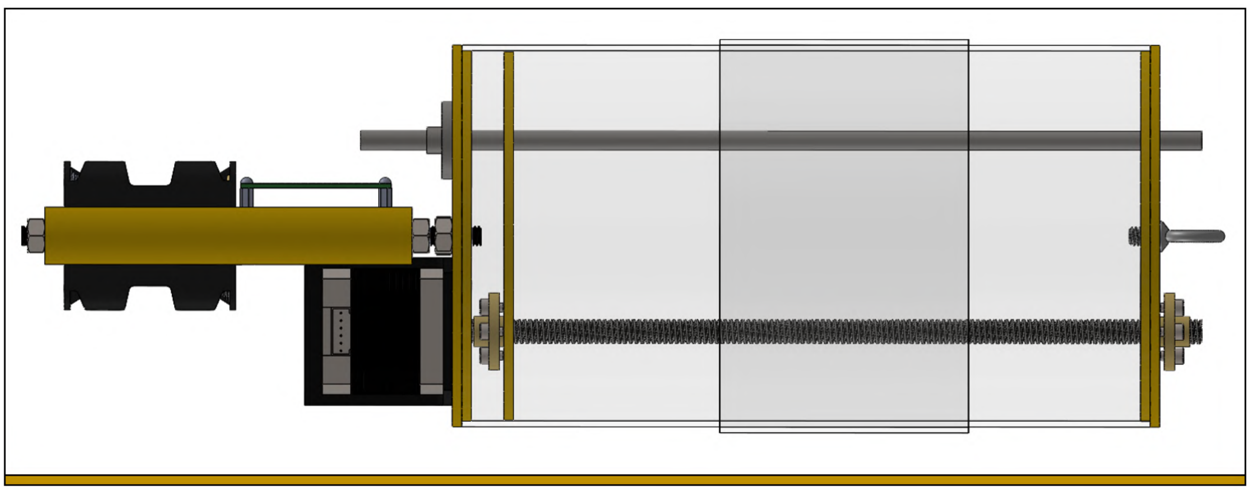
The Ejection Bay will eject the Rover Containment bay and its attached nose cone from the upper airframe of the launch vehicle after receiving a signal from the remote base station. Once a signal is received, the Ejection Bay will ignite a set of black powder charges stored in two separate charge canisters. The primary charge canister will hold 2 grams of black powder while the backup charge canister will hold 3 grams of black powder. In order to avoid premature detonation of the black powder charge, an externally mounted slide switch will be used to activate and power the ejection bay electronics. The Ejection Bay will also serve as an attachment point for the recovery system and isolates the Rover Containment Bay from the recovery system.

The Ejection Bay will be interfaced and permanently fixed during flight to the upper airframe of the rocket body using four rivets. The forward bulkplate of the Ejection Bay will be installed 4.5 inches into the top of the upper airframe leaving a 2 inch gap between the Rover Containment Bay and the Ejection Bay. The Ejection Bay, from the forward bulkplate to the aft bulkplate, is 2.5 inches in length and is held together using a pair of allthreads. Both of the bulkplates will have an eye bolt with the aft eye bolt attached to the recovery system and the forward eye bolt attached to the Rover Containment Bay.

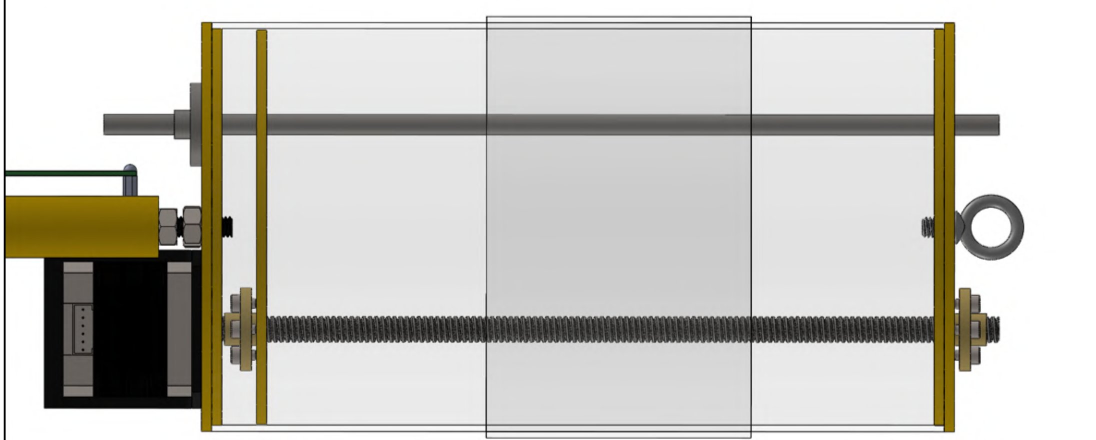
The electronics of the Ejection Bay must include a radio unit to receive the ejection signal, a microcontroller to handle the signal input, and two relays that are attached to the e-matches and are controlled by the microcontroller. The radio unit selected is the 2.4GHz XBee Pro since it has a relatively low power consumption and adequate range. The microcontroller selected is the Arduino Pro Mini due to its small size, common libraries, and low power consumption. The relays are a 5V DC single pole double throw (SPDT) relay as they are easy to control and interface easily with the Arduino.



6.4.5.3. Rover Containment Bay



The Rover Containment Bay serves to protect the rover during launch vehicle ascent and descent and will protect the rover from any atypical forces experienced during flight. The rover containment bay features a fail-safe active retention system that will keep the rover fixed in the bay until the rover deployment signal is received. The rover containment bay, once ejected from the launch vehicle, will deploy the rover using a stepper motor with a lead screw that linearly translates the rover outside of the bay. The stepper motor will be controlled using a microcontroller that will receive deployment instructions from the remote deployment base station. Since the deployment instruction must be triggered remotely, a radio unit must be interfaced with the microcontroller controlling the stepper motor. All of the deployment electronics are contained in the nose cone which is at the aft of the rover containment.

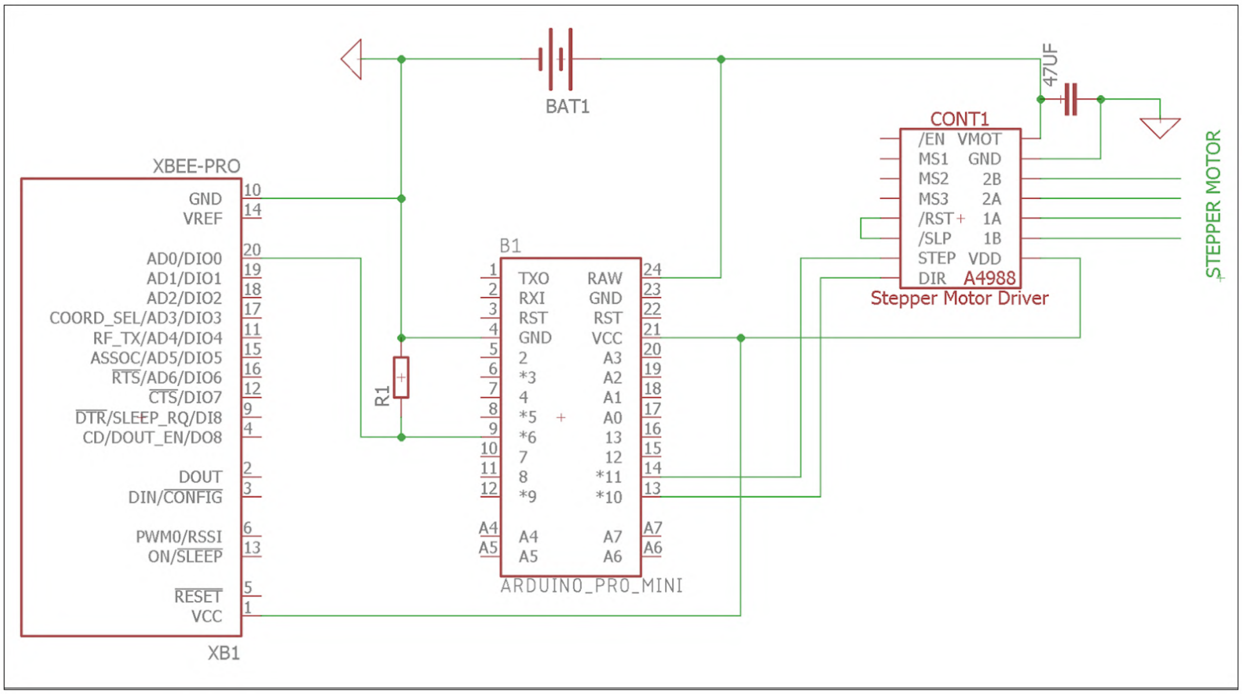


In order to contain the rover, two bulkplates are secured to a lead screw using lead screw nuts and surround the rover on both ends. The rover is held in place by the lead screw, the guide rod, and the two bulkplates that surround its wheels. Deploying the rover involves the translation of rotational motion from the stepper motor to linear motion and moves the bulkplates along the lead screw which moves the rover. When deploying, the retention bulkplate, the furthest bulkhead from the stepper motor, moves axially away from the stepper motor and is eventually pushed off, exposing the rover. The piston bulkplate, the backplate on the lead screw closest to the stepper motor, moves with the retention bulkhead and works as a piston to push the rover outside the bay. Once the upper bulkhead reaches the end of the lead screw and guide rod, the rover will be isolated and in its starting configuration.

The Rover Containment Bay will have 3.25 inches of its 9 inch coupler installed within the nosecone with 2.5 inches on the opposite end fitting inside of the upper airframe. The end being installed on the upper airframe will be fastened using four 4-40 shear pins while the end fitting inside the nosecone will be fastened using rivets. The rest of the coupler will be fitted with a 3.25 inch switch band that allows it to interface with the rocket body. The aft bookplate of Rover Containment bay will have an eye bolt that connects the Rover Containment Bay and nosecone assembly to the Ejection Bay.

The electronics of the Rover Containment Bay must include a radio unit to receive the ejection signal, stepper motor and stepper motor driver to operate the stepper motor, and a microcontroller to handle the signal input and control the stepper motor driver.

The radio unit selected is the 2.4GHz XBee Pro. The stepper motor is a NEMA 17 bipolar stepper motor with an operating current of 1.5A and holding torque of 57.1 ounce inches which was selected for its high holding torque. The selected stepper motor driver is the A4988 due to its wide voltage range and current selectivity. The microcontroller selected is the Arduino Pro Mini due to its low power consumption, access to common libraries, and small size.

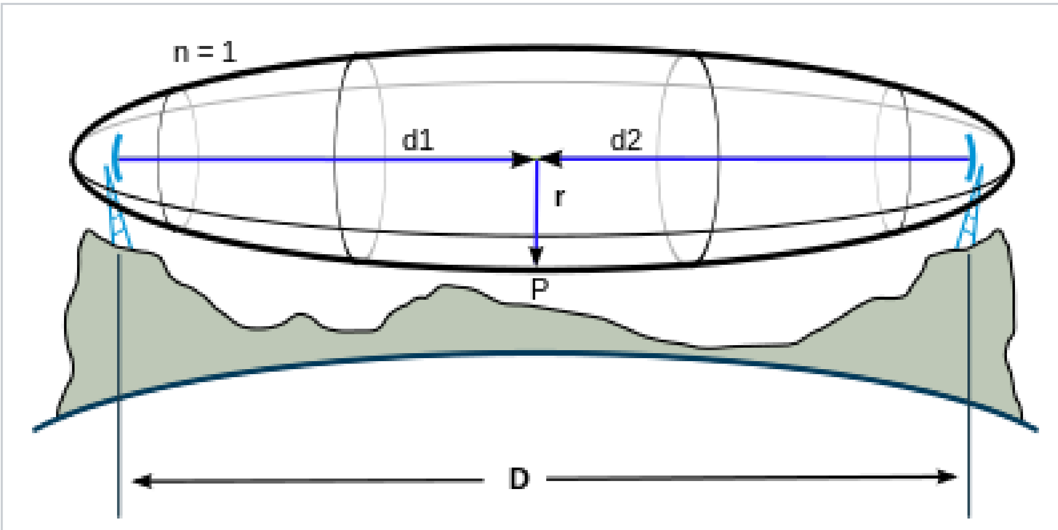


6.4.5.4. Remote Deployment Tower

Per the given payload requirements, the rover must be deployed from the rocket remotely, from an open-air distance of up to 2500 feet. This requirement informs the need for a portable control unit that can send and receive basic, secure communication signals over long distances. This unit must also be designed with safety in mind, utilizing hardware and electrical components that ensure the payload is deployed only when it is cleared to do so. The base station designed by the team meets these requirements. A CAD image and electrical schematic for the base station are pictured below.

The team tested the XBees initially, with both radios at the same height. The communications between the transmitters were only established at very close distances (no more than 50ft), despite the XBees specification stated that the radios had a range of 1 mile (5280 ft). This would not allow the team to establish the connection after landing in Huntsville, making it impossible to ignite the black-powder charge and deploy the rover.

After contacting the XBee company, and doing research on ways to improve the range, the team studied what is known as a Fresnel Zone. A Fresnel Zone, in few words, is a region of ellipsoidal regions regarding the strength of the signal between a transmitter and a receiver, and they are used to understand and maximize communications.
A Fresnel Zone looks like this:



Fresnel zone: *D* is the distance between the transmitter and the receiver; *r* is the radius of the first Fresnel zone (n=1) at point P. P is d1 away from the transmitter, and d2 away from the receiver.[1]

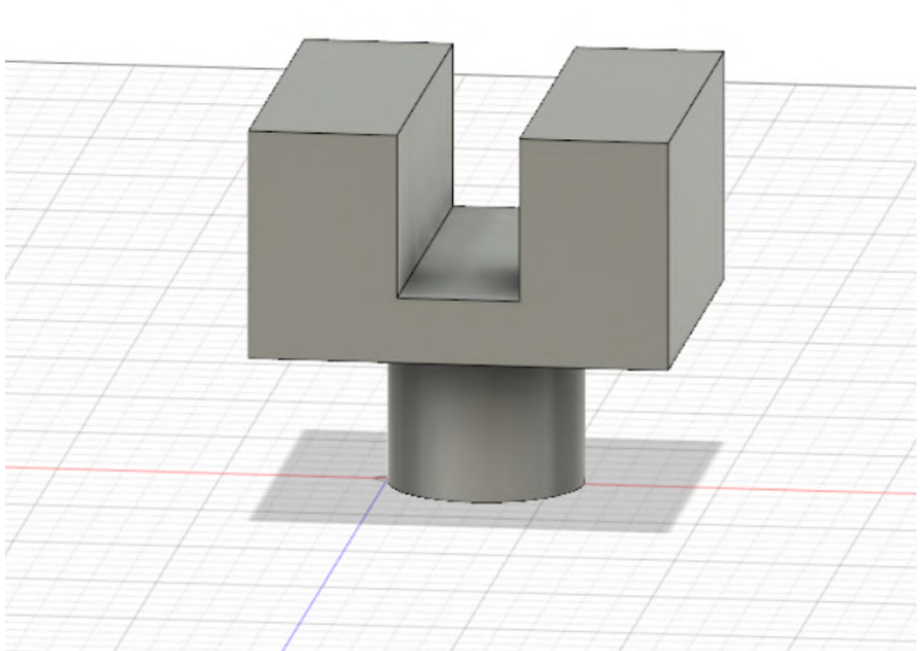
The equation for the height needed is the following:

$$Radius(ft) = 72.05 * \sqrt{(Distance(miles)/4 * f(GHz))}$$

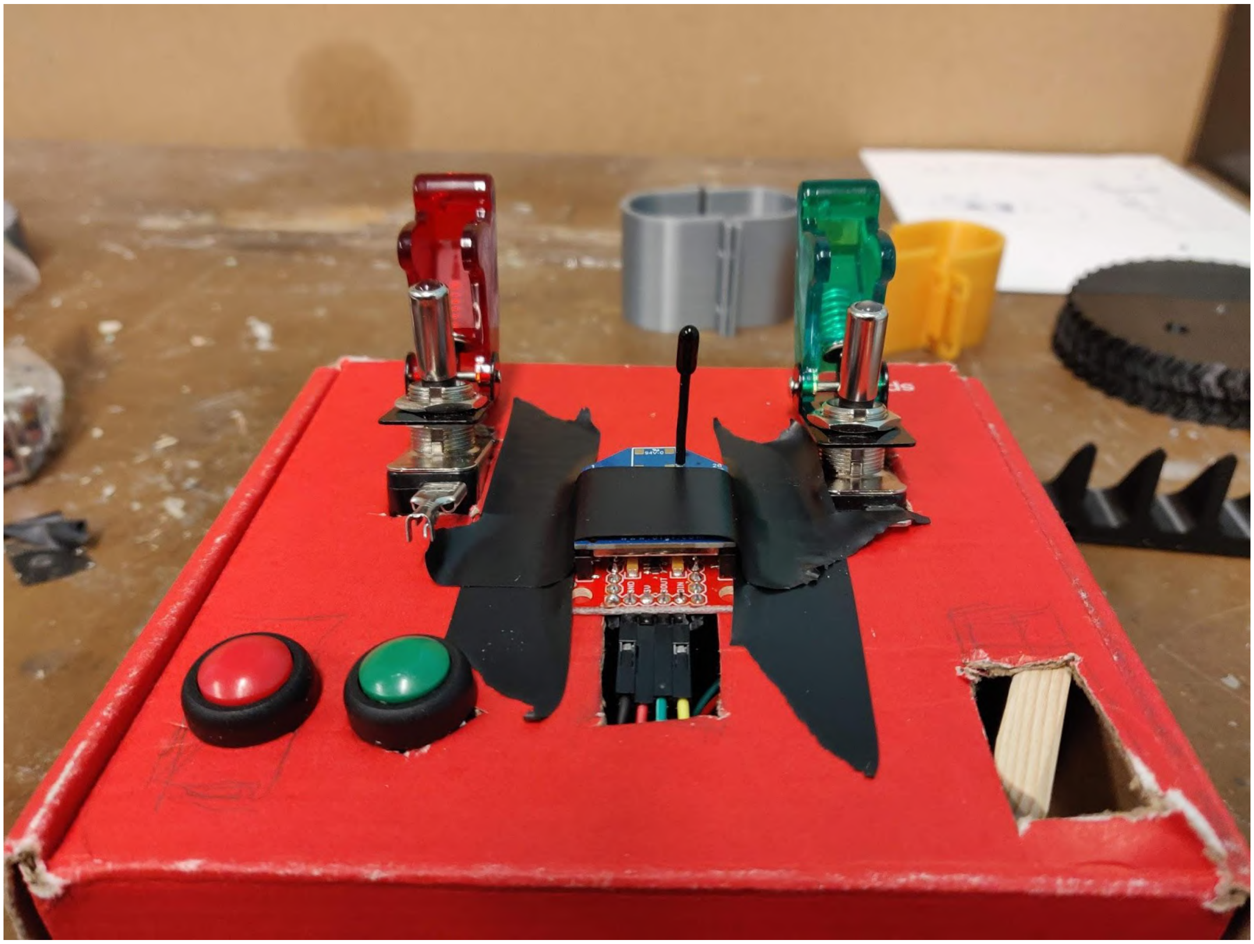
The team performed the calculation, using the maximum possible distance during the mission (2500 ft) and the frequency of the XBee (2.4GHz), and came to the conclusion that in order to increase the signal strength one of the radios needed to be at an altitude of 15.7ft. The team tested the hypothesis that height was needed by climbing up a hill with a 32.8 ft difference (roughly double the calculated height) from the ground and moving to approximately half the needed distance (1230ft). The test was successful as communications between the radios was correctly established and proved that increasing the height of one of the radios would result in a better signal.
Because of this, the team decided to build a tower on which to put the transmitter (the receiver will be on the ground after landing). The final design involves two parts. The first part involves a device that would raise the XBee 16ft in the air allowing for it to be able to communicate with its partner radio. The second part involves the base station

[1]Fresnel zone. (2019, February 19). Retrieved from https://en.wikipedia.org/wiki/Fresnel_zone

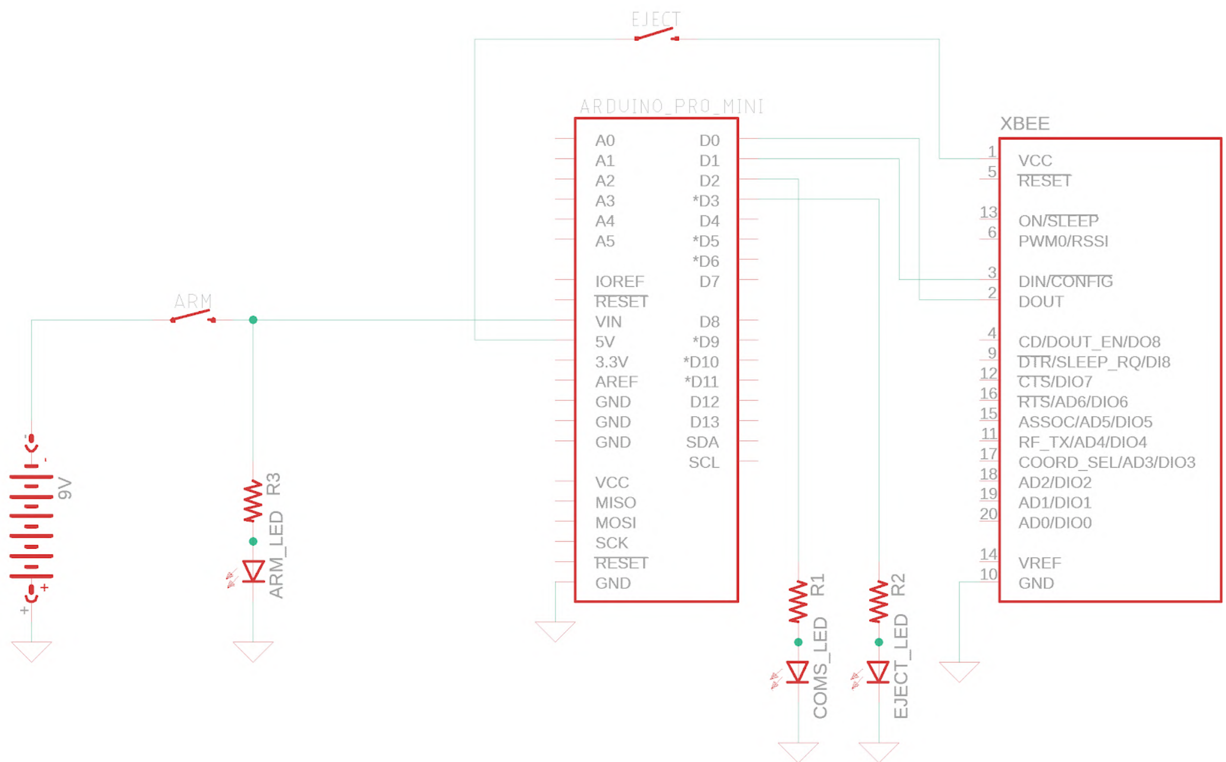
which will be on the ground allowing for the team to toggle the switches that will send the commands to the rover. The two parts are connected by a CAT5 ethernet cable. To raise the XBee in the air the team chose to use a 16ft telescoping pool pole. The telescoping pole was chosen for ease of carry, as well as lightness when it comes to weight. The XBee will be mounted on the top of the pole, fastened with a 3D printed part specifically designed for the radio to fit, while having enough space to fit the CAT5 cable, and will connect to the base station with a CAT5 cable. The base station is a box that holds an arduino with switches and lights necessary for communicating with the XBee. On the side of the box there will be a CAT5 coupler. This is where the cable connected to the XBee will be plugged into. The CAT5 cable was chosen because of its use in communications, the ability to connect and disconnect, and the multiple wires. The 3D printed part, which goes on top of the pole, is the following:



A prototype of the base station control box for sending the ejection and deployment signals can be seen below.



A schematic of the electrical design of this device is seen below.



The design centers around an Xbee Pro wireless radio configured in API mode, communicating via a serial communication protocol with an Arduino Pro Mini. The base station has two single-pole-single-throw (SPST) toggle switches. The first, featuring a safety cover over the switch when closed, is used to arm the system. As seen in the schematic above, this switch is placed between the 9V battery and VIN pin on the Arduino Pro Mini. When this switch is closed, no power is provided to the circuit, greatly mitigating accidental premature deployment of the rover. The second switch is connected to a digital input on the Arduino and is used to trigger the remote deployment. LED indicators have also been built into the device, providing clear indications that the circuit is on, that communication with the payload has been established, and that the deployment signal has been sent, respectively.

An additional layer of safety has also been implemented in the configuration of the Xbee radios. The slave Xbee, on-board the payload, has been configured to only receive and process communication sent from the Xbee with the unique serial number of the radio on the base station. This ensures that extraneous signals do not prematurely execute the payload deployment process.

The base station itself resides in a 3D-printed housing. The 9V battery powering the system, as well as the Arduino Pro Mini reside inside housing, while the LED's, switches, and Xbee radio sit on top of the device.

6.4.5.5. Retention and Deployment Construction

Construction of the Ejection Bay primarily began with cutting off a section from the lower airframe coupler that was a length of 2.5 inches. The two bulkplates surrounding the coupler then had their all thread holes cut along with holes for the forged eye bolt, terminal blocks, and charge wells. The sled for the ejection electronics was 3D printed and mounting accessories were epoxied to the sled. After the entirety of the bay was complete, mounting holes for rivets were drilled in the upper airframe with matching holes in the coupler. A switch hole was also drilled between the upper airframe and the coupler before a recessed switch was epoxied to the inner ring of the ejection bay coupler.

Construction of the Rover Ejection Bay firstly began with obtaining a switch band from the lower airframe of length 3.25 inches. The switch band was then epoxied to the midsection of the bay's coupler. Rivet holes were then screwed on the coupler just above the switch band along with corresponding holes in the nosecone. The three bulkplates used in the construction of the bay then had all necessary holes drilled into them. The forward bulkplate that would go deepest into the nosecone had holes drilled into it for all threads, the guide rod, the stepper motor, and all mounting accessories for the guide rod and the stepper motor. The piston bulkplate that within the coupler had holes drilled for the lead screw nut and the guide rod hole. The retention bulkplate on the end of the bay had holes drilled for the lead screw nut, forged eye bolt, and the guide rod. Once all holes were completed, the forward bulkplate had all threads installed for the electronics and was epoxied to the top of the coupler. The electronics sled was then 3D printed and had its mounting accessories epoxied to it. All lead screw nuts were then secured to the piston bulkplate and retention bulkplate using machine screws, and the stepper motor and guide rods were secured to the forward bulkplate in a similar fashion. Finally, the forged eye bolt was installed on the retention bulkplate completing the Rover Containment Bay construction.

6.5. Flight Reliability Confidence

The payload team is confident in the flight reliability of the newest iteration of the payload design. The first payload demonstration flight, described above, demonstrated a critical flaw in the design of the payload retention system. The 2-56 shear pins securing the payload bay to the upper airframe were not capable of withstanding the force exerted during the deployment of the main parachute. While the payload system clearly failed during this flight, post-flight analysis has led to a design with stronger flight reliability. To prove the reliability of this new system, the payload team will execute tests on the new retention design configuration leading up to a second payload demonstration flight.

The performance of the payload containment bay and active retention system during the payload demonstration flight warrants such flight reliability confidence as well. Despite the massive forces experienced upon impact with the ground, the payload bay's active retention system successfully kept the rover inside the payload bay. This gives the payload team confidence that, under normal flight conditions, this system would safely secure the rover until the system is ready for its deployment.

6.6. Full Payload Construction Documentation

Below is a general procedure for the construction of the payload. It should be noted that this procedure was followed for the first generation payload that was lost during the payload demonstration flight. These same procedures will be followed for the construction of the second generation rover.

1. Construction and fabrication of the rover chassis
    a. The aluminum plate, on which the rover is built, was obtained through an on-campus organization.
    b. The plate was cut to match the existing rover design.
        i. The plate was secured to a cutting surface with clamps.
        ii. A metal dremel was used to trim edges where necessary.
        iii. A metal file was used to soften sharp edges to prevent cutting injury.
    c. The motor mounts, support rack, battery holder, and wheels were 3D-printed with PLA plastic through an on-campus service.
    d. Mounting holes for motor mounts, the soil procurement apparatus, the soil retention apparatus, the support rack, and the battery holder were drilled into the plate.
        i. All holes were marked on the plate at their desired locations.
        ii. The required drill bit size was selected and inserted into the drill press chuck.
        iii. The plate was secured to the drill press with clamps.
        iv. All holes were drilled in order of increasing size.
    e. The motor mounts, support rack, and battery holder were secured to the rover using appropriately sized nuts and bolts.
        i. Utilizing a crescent wrench of required size and either another wrench or screwdriver, all bolts were secured into place.

    ii. Any location where a bolt or nut meets plastic, a metal or rubber washer was used to distribute locking force.
    iii. Locking nuts were used in locations that would be subject to high stress.
  f. Electrical tape was added to the exterior of each DC motor to increase the friction between the motors and their mounts. They then secured in place onto the chassis. Along with the fact that the motor shafts are off center from the axis of the motor mounts, it is highly unlikely that the motors should become dislodged from their position barring that the mounts are not broken.
2. Construction and fabrication of the soil sampling system
    a. The rake and scoop components of the soil sampling system were 3D printed with PLA plastic through an on-campus service.
    b. The rake was attached to the chassis of the rover with appropriately sized nuts and bolts.
        i. Utilizing a crescent wrench of required size and either another wrench or screwdriver, all bolts were secured into place.
        ii. Any location where a bolt or nut meets plastic, a metal or rubber washer was used to distribute locking force.
    c. Additional washers and nuts were used to offset the rake from the underside of the chassis by approximately 3/16”. This necessary so that the rake would not interfere with the fasteners of the motor mounts.
    d. Rectangular slots were cut into each back corner of the chassis. This occurred after it was observed that the scoop was protruding outside the bounds of the payload bay.
        i. The plate was secured to a cutting surface with clamps.
        ii. A metal dremel was used to create the two required slots.
        iii. A metal file was used to soften sharp edges to prevent cutting injury.
    e. Hinges to rotate the scoop were mounted on the back of the chassis at the location of the newly cut slots.
        i. Utilizing a small nut driver of required size and either a screwdriver or a pair of pliers, all bolts were secured into place.
    f. The scoop was mounted to the hinges.
        i. Utilizing a small nut driver of required size and either a screwdriver or a pair of pliers, all bolts were secured into place.
3. Construction and fabrication of the retention and deployment system
    a. Ejection Bay and Rover Containment Bay electronics were soldered to their protoboards.

b. Ejection Bay coupler section cut and obtained from lower airframe coupler.
c. Ejection Bay bulkplates had their all thread, forged eye bolt, terminal block, and charge well holes drilled.
d. Rivet holes were drilled in the upper airframe and the Ejection Bay coupler.
e. Terminal blocks, charge wells, forged eye bolts, and all threads were installed and epoxied into the Ejection Bay bulkplates.
f. A switch hole was drilled and a switch was internally mounted to the Ejection Bay coupler.
g. All screws, fastening accessories, and the 3D printed sled were installed in the Ejection Bay.
h. Rover Containment Bay switch band was cut from the lower airframe and epoxied to the bay's coupler.
i. Rivet holes were then cut for the coupler and the nosecone.
j. The three bulkplates used in the Rover Containment Bay then had all their holes drilled.
    i. The forward bulkplate had two all thread holes drilled, a hole for the stepper motor lead screw, a hole for guide rod, and 8 holes for machine screws that fastens the stepper motor and the guide rod to the bulkplate.
    ii. The piston bulkplate had holes drilled for the lead screw, the guide rod, and 4 holes for machine screws that fastens the lead screw nut to the bulkplate.
    iii. The retention bulkplate had holes drilled for the lead screw, the guide rod, the forged eye bolt, and the 4 holes for machine screws that fastens the lead screw nut to the bulkplate.
k. The forward bulkplate was then epoxied to the top of the Rover Containment Bay coupler.
l. All fasteners, the eye bolt, and the 3D printed sled were installed on the Rover Containment Bay.

4. Construction and fabrication of the rover electronics system
    a. The Arduino Pro Mini and TB6612FNG motor driver were soldered to a protoboard.
    b. Solid-core wire was cut to size and soldered to form connections between Arduino GPIO pins and input pins on the motor driver.
    c. A 3-input terminal block was soldered to the top of the protoboard.
    d. 5V and ground connections were soldered onto the protoboard.

e. The MPU-6050 IMU was soldered to a second protoboard. Solid-core wire was soldered between this chip and the Arduino's I2C pins, as well as 5V and ground.
f. "Bullet" connectors were soldered to each DC motor terminal, as well as to the end of the LiPO battery wires. Once connected to the terminal blocks and motor driver, these bullet connectors were wrapped in electrical tape to mitigate the risk of a short-circuit.
g. The protoboards were secured to the electronics support rack via nylon screws in each corner. Electrical tape was placed over the main electronics board for additional security.

7. Requirements, Verification Plans, & Project Tests

7.1. NASA Handbook Requirements & Verification Plans

Subteam	Requirement	Verification Method	Verification Process/Description
General	Students on the team will do 100% of the project, including design, construction, written reports, presentations, and flight preparation with the exception of assembling the motors and handling black powder or any variant of ejection charges, or preparing and installing electric matches (to be done by the team's mentor).	Inspection	Verification of this requirement occurs constantly throughout the project - if any team member sees another outsourcing work that should be done by the team, it should be reported to project management.
General	The team will provide and maintain a project plan to include, but not limited to the following items: project milestones, budget and community support, checklists, personnel assignments, STEM engagement events, and risks and mitigations.	Demonstration	Verification of this requirement occurs when providing each milestone report to NASA. Each delivered report should have these sections in it.
General	The team will identify Foreign National (FN) team members by the Preliminary Design Review (PDR).	Demonstration	Verification of this requirement occurs when the required information is delivered on time to the student launch team for review.
General	The team will identify all members attending launch week activities by the Critical Design Review (CDR).	Demonstration	Verification of this requirement occurs when the required information is delivered on time to the student launch team for review.
General	The team will engage a minimum of 200 participants in educational, hands-on science, technology, engineering, and mathematics (STEM) activities, as defined in the STEM Engagement Activity Report,	Demonstration	Verification of this requirement occurs when the required information is delivered on time to the student launch team for review.

	by the Flight Readiness Review (FRR), and will report these activities appropriately to the student launch team.		
General	The team will establish a social media presence to inform the public about team activities.	Demonstration	Verification of this requirement occurs constantly as team members check that the website contains up-to-date information in a professional and presentable manner.
General	The team will email all deliverables to the NASA project management team by the deadline specified in the handbook for each milestone.	Demonstration	Verification of this requirement occurs when the required information is delivered on time to the student launch team for review.
General	All deliverables will be in PDF format.	Demonstration	Verification of this requirement occurs by double-checking that all attachments are in PDF format before emailing them to the student launch team.
General	In every report, the team will provide a table of contents including major sections and their respective sub-sections.	Inspection	Verification of this requirement occurs when each report is given its final review, as the reviewer will be checking to ensure a table of contents is included.
General	In every report, the team will include the page number at the bottom of the page.	Inspection	Verification of this requirement occurs when each report is given its final review, as the reviewer will be checking to ensure page numbers are included and are at the bottom of the page.
General	The team will provide any computer equipment necessary to perform a	Testing	Verification of this requirement will occur

	video teleconference with the review panel. This includes, but is not limited to, a computer system, video camera, speaker telephone, and a sufficient Internet connection. Cellular phones should be used for speakerphone capability only as a last resort.		during the preparatory Q&A sessions and before presentations for each milestone to ensure the team can properly use the required technology.
General	The team will use the launch pads provided by Student Launch's launch services provider.	Inspection	Verification of this requirement occurs when the team observes the launch pad it uses in Huntsville and asks for confirmation that it has been provided by the launch services provider.
General	The team will identify a "mentor", defined as an adult who is included as a team member, who will be supporting the team (or multiple teams) throughout the project year, and may or may not be affiliated with the school, institution, or organization. The mentor will have maintained a current certification, And will be in good standing, through the National Association of Rocketry (NAR) or Tripoli Rocketry Association (TRA) for the motor impulse of the launch vehicle and will have flown and successfully recovered (using electronic, staged recovery) a minimum of 2 flights in this or a higher impulse class, prior to PDR. The mentor will be designated as the individual owner of the rocket for liability purposes and must travel with the team to launch week.	Inspection	Verification of this requirement occurs when the team double-checks that the mentor position has been filled and that the chosen mentor satisfies all requirements listed above.
Vehicle	The vehicle will deliver the payload to an apogee altitude between 4,000 and 5,500 feet above ground level (AGL).	Testing and Analysis	Verification for this requirement includes constant retesting and analysis in simulation programs, including

			OpenRocket 15.03 and RASAero II.
Vehicle	The team will identify its target altitude by the PDR milestone.	Testing and Simulation	Verification for this requirement includes constant retesting and analysis in simulation programs, including OpenRocket 15.03 and RASAero II.
Vehicle	The vehicle will carry one commercially available, barometric altimeter for recording its official altitude used by the student launch team to determine the altitude award winner.	Inspection	Verification for this requirement includes inspecting rocket components before flight to ensure at least one altimeter is being used.
Vehicle	Each altimeter will be armed by a dedicated mechanical arming switch that is accessible from the exterior of the rocket airframe when the rocket is in the launch configuration on the launch pad.	Inspection and Testing	Verification for this requirement includes testing altimeter continuity and inspection of proper electrical connections.
Vehicle	Each altimeter will have a dedicated power supply.	Inspection	Verification for this requirement includes inspection of proper electrical connections and separate electrical systems.
Vehicle	Each arming switch will be capable of being locked in the ON position for launch (i.e. cannot be disarmed due to flight forces).	Demonstration	Verification of this requirement includes designing the arming switch such that it can be locked in the ON position.
Vehicle	The launch vehicle will be designed to be recoverable and reusable. Reusable is defined as being able to launch again on the same day without repairs or modifications.	Inspection and Testing	Verification for this requirement will include the subscale and full scale test flights and inspection of all parts to ensure there is no critical damage, structural issues, or missing parts.

Vehicle	The launch vehicle will have a maximum of four (4) independent sections. An independent section is defined as a section that is either tethered to the main vehicle or is recovered separately from the main vehicle using its own parachute.	Demonstration	Verification for this requirement will be done by inspection prior to all launches.
Vehicle	Coupler/airframe shoulders which are located at in-flight separation points will be at least 1 body diameter in length.	Demonstration	Verification will be achieved by inspecting the rocket prior to all launches.
Vehicle	Nosecone shoulders which are located at in-flight separation points will be at least ½ body diameter in length.	Inspection	Verification will be achieved by inspecting the rocket prior to all launches.
Vehicle	The launch vehicle will be limited to a single stage.	Demonstration and Inspection	Verification will be achieved upon inspection prior to launches, proving that the rocket is only one stage.
Vehicle	The launch vehicle will be capable of being prepared for flight at the launch site within 2 hours of the time the Federal Aviation Administration flight waiver opens.	Testing and Demonstration	Verification will include testing the team's ability to prepare the rocket in time both in house and prior to all launches and by demonstrating during the official competition.
Vehicle	The launch vehicle will be capable of remaining in launch-ready configuration on the pad for a minimum of 2 hours without losing the functionality of any critical on-board components.	Testing	Verification will include designing and testing the rocket's capability to stay launch-ready on the pad.
Vehicle	The launch vehicle will be capable of being launched by a standard 12-volt direct current firing system. The firing system will be provided by the NASA-designated launch services provider.	Demonstration and Testing	Verification will be done by inspection of the rocket upon final flight configuration and through prior launches including subscale and full scale.
Vehicle	The launch vehicle will require no external circuitry or special ground	Demonstration	Verification will be done by inspection of the

	support equipment to initiate launch (other than what is provided by the launch services provider).		rocket in final flight configuration.
Vehicle	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).	Demonstration and Testing	Verification will include all launches which use these motors and demonstration during the official competition.
Vehicle	Final motor choices will be declared by the Critical Design Review (CDR) milestone.	Demonstration	Verification will be achieved by checking the CDR document and ensuring the motor choice does not change between CDR, FRR and PLAR.
Vehicle	Any motor change after CDR will be approved by the NASA Range Safety Officer (RSO).	Demonstration	Verification will only be necessary in the event that the previous requirement is not met.
Vehicle	All pressure vessels on the vehicle will be approved by the NASA RSO.	Demonstration	Verification will be demonstrated during the official competition.
Vehicle	The minimum factor of safety for any pressure vessels on the vehicle (Burst or Ultimate pressure versus Max Expected Operating Pressure) will be 4:1 with supporting design documentation included in all milestone reviews.	Testing and Analysis	Verification will be met using simulation programs such as OpenRocket 15.03 and RASAero II.
Vehicle	Each pressure vessel will include a pressure relief valve that sees the full pressure of the tank and is capable of withstanding the maximum pressure and flow rate of the tank.	Demonstration	Verification will be done by inspection of the rocket, seeing that the team has no pressure vessels.
Vehicle	Full pedigree of any pressure vessel tanks used will be described,	Demonstration	Verification will be done by inspection of the

	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.		rocket, seeing that the team has no pressure vessels.
Vehicle	The total impulse provided by the launch vehicle will not exceed 5,120 Newton-seconds (L-class).	Demonstration	Verification will include all launches which use L-class or lower motors and demonstration during the official competition.
Vehicle	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.	Analysis	Verification will include using simulation programming, specifically OpenRocket 15.03 and RASAero II.
Vehicle	The launch vehicle will accelerate to a minimum velocity of 52 fps at rail exit.	Analysis	Verification will include using simulation programming, specifically OpenRocket 15.03 and RASAero II.
Vehicle	A subscale model of the final vehicle will be successfully launched and recovered prior to CDR.	Testing and Demonstration	Verification will include subscale results (listed earlier in this document) from a test launch and demonstration that the rocket has flown.
Vehicle	The subscale model will resemble and perform as similarly as possible to the full-scale model, however, the full-scale will not be used as the subscale model.	Testing and Demonstration	Verification will include subscale results (listed earlier in this document, stating a 0.45:1 scale of subscale to full scale) from a test launch and demonstration that the rocket has flown.
Vehicle	The subscale model will carry an altimeter capable of recording the model's apogee altitude.	Testing and Demonstration	Verification will include subscale results (listed earlier in this document) from a test launch and demonstration that the rocket has flown.

Vehicle	The subscale rocket will be a newly constructed rocket, designed and built specifically for this year's project.	Demonstration	Verification will include demonstration that the rocket is unique to this year's competition.
Vehicle	Proof of a successful subscale flight will be supplied in the CDR report.	Testing and Demonstration	Verification will include subscale results (listed earlier in this document) from a test launch and demonstration that the rocket has flown.
Vehicle	The team will successfully launch and recover its full-scale rocket prior to FRR in its final flight configuration. The rocket flown will be the same rocket to be flown on launch day. A successful flight is defined as a launch in which all hardware is functioning properly. For this flight, the following must be true: ● The vehicle and recovery system will have functioned as designed. ● The full-scale rocket will be a newly constructed rocket, designed and built specifically for this year's project. ● If the payload is not flown, mass simulators will be used to simulate the payload mass. The mass simulators will be located in the same approximate location on the rocket as the missing payload mass. ● If the payload changes the external surfaces of the rocket (such as with camera housings or external probes) or manages the total energy of the vehicle, those systems will be active during the full-scale Vehicle Demonstration Flight. ● The team shall fly the launch day motor for the Vehicle Demonstration Flight. The RSO may approve use of an alternative motor if the home launch field cannot support the	Testing and Demonstration	Verification will be done by flying the rocket and demonstrating the rocket is the same. Flight results will be provided in the FRR document.

	full impulse of the launch day motor or in other extenuating circumstances. ● The vehicle will 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 will not be added without a re-flight of the full scale launch vehicle. ● 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). ● Proof of a successful flight shall be supplied in the FRR report using altimeter data. ● Vehicle Demonstration flights must be completed by the FRR submission deadline unless a Vehicle Demonstration Re-flight is deemed necessary. ● If completing a Vehicle Demonstration Re-flight, an FRR Addendum will be submitted by the FRR Addendum deadline.		
Vehicle	The team will successfully launch and recover their full-scale rocket containing the completed payload prior to the Payload Demonstration Flight deadline. The rocket flown must be the same rocket to be flown on launch day. A successful flight is defined as a launch in which the rocket experiences stable ascent, the payload is fully retained during ascent and descent, and the payload is safely deployed on the ground. For this flight, the following must be true: ● The payload must be fully retained throughout the entirety of the flight, all retention	Testing and Demonstration	Verification will be done by flying the rocket with the payload and demonstrating the rocket is the same as the final flight configuration.

	mechanisms must function as designed, and the retention mechanism must not sustain damage requiring repair. ● The payload flown must be the final, active version ● If the above criteria is met during the original Vehicle Demonstration Flight, occurring prior to the FRR deadline and the information is included in the FRR package, the additional flight and FRR Addendum are not required. ● Payload Demonstration Flights must be completed by the FRR Addendum deadline. No extensions will be granted.		
Vehicle	Any structural protuberance on the rocket will be located aft of the burnout center of gravity.	Demonstration	Verification will be achieved by inspecting the rocket prior to all launches.
Vehicle	The team's name and launch day contact information will be in or on the rocket airframe as well as in or on any section of the vehicle that separates during flight and is not tethered to the main airframe. This information will be included in a manner that allows the information to be retrieved without the need to open or separate the vehicle.	Demonstration	Verification will be done by inspection of the rocket prior to launch.
Vehicle	The launch vehicle will not utilize forward canards. Camera housings will be exempted, provided the team can show that the housing(s) causes minimal aerodynamic effect on the rocket's stability.	Demonstration	Verification will be done by inspection of the rocket.
Vehicle	The launch vehicle will not utilize forward firing motors, motors that expel titanium sponges, hybrid motors, a cluster of motors, or motors fitted using friction.	Demonstration	Verification will be done by inspection of the rocket.

Vehicle	The launch vehicle will not exceed Mach 1 at any point during flight.	Analysis and Demonstration	Verification will be done using software programs such as OpenRocket 15.03 and RASAero II.
Vehicle	Vehicle ballast will not exceed 10% of the total unballasted weight of the rocket as it would sit on the pad.	Demonstration	Verification will be achieved by inspecting the rocket prior to all launches.
Vehicle	Transmissions from onboard transmitters will not exceed 250 mW of power.	Demonstration and Testing	Verification will be achieved by inspecting the rocket prior to all launches and using results from previous launches using the same transmitters.
Vehicle	Excessive and/or dense metal will not be utilized in the construction of the vehicle. Use of lightweight metal will be permitted but limited to the amount necessary to ensure structural integrity of the airframe under the expected operating stresses.	Demonstration	Verification will be done by inspection of the rocket.
Recovery	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 a lower altitude. ● The main parachute shall be deployed no lower than 500 feet. ● The apogee event may contain a delay of no more than 2 seconds.	Demonstration	Verification for this requirement will be completed via ejection charge demonstration at simulated altitudes and via the subscale and full-scale flights.
Recovery	The team must perform a successful ground ejection test for both the drogue and main parachutes. This must be done prior to the initial subscale and full-scale launches.	Demonstration	Verification for this requirement will be completed via successful deployment of drogue and main parachutes before first flight.

Recovery	At launch vehicle landing, each individual component of the launch vehicle must have a maximum kinetic energy of 75 ft-lb.	Analysis	Verification for this requirement will be completed via OpenRocket simulation.
Recovery	The recovery system electrical circuits will be completely independent of any payload electrical circuits.	Inspection	Verification for this requirement will be completed via inspection of avionics bay.
Recovery	All recovery system electronics will be powered by commercially available batteries.	Inspection	Verification for this requirement will be completed via inspection of avionics bay.
Recovery	The recovery system will contain redundant, commercially available altimeters.	Inspection	Verification for this requirement will be completed via inspection of the avionics bay.
Recovery	Motor ejection will not be used as a form of primary or secondary deployment.	Inspection	Verification for this requirement will be completed via inspection of the flight vehicle.
Recovery	Removable shear pins will be used for both the main parachute compartment as well as the drogue parachute compartment.	Inspection	Verification for this requirement will be completed via inspection of the flight vehicle.
Recovery	The launch vehicle recovery area will be limited to a 2,500 ft radius from the launch pads.	Analysis	Verification for this requirement will be completed via OpenRocket simulation.
Recovery	Descent time, from apogee to touchdown, shall be limited to 90 seconds.	Analysis	Verification for this requirement will be completed via OpenRocket simulation.
Recovery	An electronics tracking device will be installed in the launch vehicle and will transmit the position of the tethered vehicle or any independent vehicle component to a ground receiver. ● Any rocket section or payload component, which lands	Inspection	Verification for this requirement will be completed via inspection of the flight vehicle.

	untethered to the launch vehicle, will contain an active electronic tracking device. • The electronic tracking devices will be fully functional during the official flight on launch day.		
Recovery	The recovery system electronics will not adversely affected by any other on-board electronic devices during flight. • The recovery system altimeters will be physically located in a separate compartment within the vehicle from any other radio frequency transmitting and/or magnetic wave producing device. • The recovery system electronics will be shielded from all onboard devices which may generate magnetic waves to avoid inadvertent excitation of the recovery system. • The recovery system electronics will be shielded from any other onboard devices that may adversely affect the proper operation of the recovery system.	Inspection	Verification for this requirement will be completed via inspection of the avionics bay.
Payload	The team will design a custom rover that will deploy from the internal structure of the launch vehicle.	Demonstration	Verification for this requirement will consist of a test which places the launch vehicle in a touchdown configuration and deploys the rover and of the full-scale launch test with the custom payload installed.
Payload	The rover will be retained within the vehicle utilizing a fail-safe active retention system. The retention system will be robust enough to retain the rover if atypical flight forces are experienced.	Testing	Verification of this requirement will consist of the full-scale launch test with the custom payload installed and possible drop testing with the retention system and

			payload installed in the launch vehicle.
Payload	At landing, and under the supervision of the Remote Deployment Officer, the team will remotely activate a trigger to deploy the rover from the rocket.	Testing	Verification for this requirement will be achieved by placing the assembled launch vehicle in a touchdown configurations and remotely triggering rover deployment.
Payload	After deployment, the rover will autonomously move at least 10 ft. (in any direction) from the launch vehicle. Once the rover has reached its final destination, it will recover a soil sample.	Demonstration	Verification for this requirement will be achieved by placing the launch vehicle in a touchdown configuration and deploying the rover to ensure it starts its autonomous navigation and collects the required soil sample.
Payload	The soil sample will be a minimum of 10 milliliters (mL).	Demonstration	Verification for this requirement will be achieved by doing a test run on the rover in a terrain similar to Alabama red clay, such as harvested farmland, in which the soil collection system collects and stores a sample fulfilling this requirement.
Payload	The soil sample will be contained in an onboard container or compartment. The container or compartment will be closed or sealed to protect the sample after collection.	Demonstration	Verification for this requirement can be accomplished by sealing soil in the soil compartment and ensuring that no soil, under its own weight, can exit the soil compartment at any rover orientation.

Payload	The team will ensure that the rover's batteries are sufficiently protected from impact with the ground.	Demonstration	Verification for this requirement can be accomplished by placing the rover in any configuration in the vehicle and driving the rover over various terrain and ensuring the battery does not make any unexpected contact and is sufficiently protected.
Payload	The batteries powering the rover will be brightly colored, clearly marked as a fire hazard, and easily distinguishable from other rover parts.	Inspection	Verification for this requirement can be accomplished by double-checking that the rover's batteries are in a clearly-marked and distinguishable location on the rover and stand out in coloration.
Safety	The team will use a launch and safety checklist. The final checklist will be included in the FRR report and used during the LRR and any launch day operations.	Inspection and Demonstration	Verification for this requirement can be accomplished by ensuring that the team safety officer, project manager, and assistant project manager have copies of checklists and are present on for launch days.
Safety	The team must identify a student safety officer who will be responsible for all of the following items: ● Monitor team activities with an emphasis on safety during: ○ Design of vehicle and payload ○ Construction of vehicle and payload ○ Assembly of vehicle and payload ○ Ground testing of vehicle and payload ○ Subscale launch tests ○ Full-scale launch tests	Inspection and Demonstration	Verification for this requirement will be completed with the team identifying a student safety officer who will be responsible for the above items that will be completed similarly by verification by inspection.

	○ Launch day ○ Recovery activities ○ STEM Engagement Activities ● Implement procedures developed by the team for construction, assembly, launch, and recovery activities. ● Manage and maintain current revision of the team's revision hazard analyses, failure mode analyses, and recovery activities. ● Assist in the writing and development of the team's hazard analyses, failure mode analyses, and procedures.		
Safety	During test flights, the team will abide by the rules and guidance of the local rocketry club's RSO. The allowance of certain vehicle configurations and/or payloads at the NASA Student Launch does not give explicit or implicit authority for the team to fly these vehicle configurations and/or payloads at other club launches. The team will communicate their intentions to the local club's President or Prefect and RSO before attending and NAR or TRA launch.	Demonstration and Inspection	Verification for this requirement will be that both safety officer and project manager will read local regulations prior to test flights, bring copies with them to test flights, and brief team members on those test flights.
Safety	The team will abide by all rules and regulations set forth by the FAA.	Demonstration	Verification for this requirement will be that both safety officer and project manager will read local and future FAA regulations prior to all flights, bring copies with them to flights, and brief team members on those test flights. As well as obtain proper clearance for flight.

The above requirements, as mentioned, will be strictly completed by following the safety section and verifications listed in general safety procedures.

7.2. PSP-SL Requirements / Verification Plans / Project Tests

Subteam	Requirement	Requirement Justification	Verification Method	Verification Process/Description
General	The team will meet at least once a week to discuss general matters and collaborate.	This requirement aids in overall team communication and effective team participation.	Demonstration	Mandatory attendance meeting shall be held each week on Sunday from noon to 2pm.
Vehicle	The vehicle will deliver the payload to an apogee altitude of 4,950 +/- 100 feet above ground level (AGL) as designated by the chosen design requirements.	This is a refinement of the NASA handbook requirement to go between 4000 and 5500 feet AGL. Such as estimate has been deemed appropriate based on the design choices and requirements.	Analysis and Demonstration	During test flight of the full scale rocket, flight apogee will be recorded utilizing redundant altimeters. The simulated apogee will be verified through RASAero II and OpenRocket.
Vehicle	The vehicle will feature an active retention system capable of maintaining the payload during flight.	Such a retention system shall reduce risk of failure and improve chances of system remaining in good and fully operational condition for future launches.	Demonstration and Testing	The team shall design and construct the rocket with an active retention system. Testing shall take place during the full scale rocket test flight to ensure successful functioning of the system.
Vehicle	The vehicle will carry at least two commercially available, barometric altimeters for recording the official altitude.	This system redundancy ensures successful recording of flight apogee in the event an altimeter fails.	Inspection	Two altimeters shall be constructed within the full scale rocket, inspection and observation of the altimeters shall confirm this.
Vehicle	The launch vehicle will not horizontally drift more than 2000 feet from its launch	Requirement ensures safety to those in the area surrounding the launch site.	Analysis and Demonstration	Drift distance calculations shall be obtained from RASAero II and OpenRocket such that

	pad, or point of origin.			the target drift distance is reached before launch is deemed appropriate. Test launch shall verify simulated results.
Vehicle	The launch vehicle must be able to maintain full functionality and target drift distances when launched on a day with at most 20 mph wind speeds.	Requirement ensures that rocket will be feasible to launch under most standard weather conditions normally feasible for high-power rocket launches.	Analysis and Demonstration	Simulation data available from RASAero II and OpenRocket shall confirm feasibility of launch with 20 mph wind speeds in any given direction, including feasible drift distances as stated previously. Test launch shall loosely verify rocket functionality, depending on wind speeds on the launch day.
Vehicle	The construction and fully-successful operation of a 0.45x subscale model will occur by December 9, 2018.	Setting an early deadline for completion of the subscale model gives us additional time in the event extenuating circumstances occur.	Demonstration	Successful launch by the aforementioned date.
Vehicle	The fins on the rocket will be evenly spaced, as straight as possible, and secured tightly.	This requirement makes sure the fins are provided proper support to the vehicle without potentially causing unforeseen errors due to poor construction.	Inspection and Demonstration	A fin mount will be carefully constructed to hold the fins in place while drying on the rocket in such a way that the fins can be easily fixed in place and secured tightly. Inspection after procedure has been followed shall confirm satisfactory fin placement.
Vehicle	The full-scale rocket will be successfully launched and recovered in a test	Setting an early deadline for completion of the full scale model gives us additional	Demonstration	Successful launch by the aforementioned date.

	flight by March 3, 2019, configured in the same configuration that will be used on the final launch day.	time in the event extenuating circumstances occur.		
Vehicle	Attach fins to the rocket and secure them to prevent them from moving.	Appropriate application of epoxy will ensure the fins are properly secured to the rocket airframe.	Demonstration	3 applications of epoxy will be used to attach and secure the fins. Enough epoxy will be used to attach and secure the fins in place, add an inner fillet of epoxy to prevent the fins from moving, and finally add an outer fillet of epoxy for redundancy.
Funding	With the exception of team clothing, team expenses will be completely funded by various endeavors of the Purdue NASA Student Launch team.	In accordance with the inherent job of the funding team, funding shall be the result of the efforts of the Purdue NASA Student Launch team and not from individual contributions.	Demonstration	All attempts will be made to fund the organization's expenses through various means. Completion of verification will conclude once the competition has ended.
Recovery	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.	Deployment at these heights provides sufficient response time for various actions to occur onboard the rocket, in addition for reasonable standards of convention and safety to be met.	Demonstration and Testing	Altimeter ejection charge testing at simulated altitudes will confirm proper ejection of the parachutes. Demonstration will occur through successful ejection during the test flight launch at the desired altitude.
Recovery	If the drogue parachute does not immediately deploy at apogee, the secondary altimeter will detect this and	In order to maintain an appropriate safety margin, the secondary altimeter will eject the parachute after	Testing and Demonstration	Secondary altimeter response shall be tested during ejection charge testing. The second altimeter may potentially eject the parachute in the event

	eject the parachute at one second after reaching apogee.	a delayed period of time.		the first altimeter fails during the test launch and competition launch.
Recovery	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.	Similar to the case with the drogue chute, this leaves an appropriate margin of safety.	Testing and Demonstration	Secondary altimeter response shall be tested during ejection charge testing. The second altimeter may potentially eject the parachute in the event the first altimeter fails during the test launch and competition launch.
Recovery	Each altimeter will have a separate and distinct power source and wiring system. The main altimeter (Telemetrum) shall be powered by a 3.7 V LiPo battery, the secondary altimeter (RRC3+ Sport) by a 9V battery.	Separate sources allow for failure of a single power source to not result in failure of both altimeters. Battery size complies with standard battery size requirement for altimeters	Demonstration	Avionics bay shall be constructed with each altimeter being powered by its own battery.
Recovery	The recovery system shall use 6g charge wells.	Charge wells of this size fit effectively such that sufficient fire-resistant cellulose insulation (“dog barf”) can be packed in.	Demonstration	6g charge wells shall be used in construction of the recovery system.
Recovery	Both parachutes need to be able to open within 1 second after being ejected.	Requirement ensures time for deployment is sufficiently low such that the the deployment time is not a hazard to a safe landing.	Testing	Parachute drop tests shall be conducted to ensure the parachutes consistently drop within the aimed time frame.
Recovery	Both altimeter power should be able to maintain power for up to 1 hour	Guarantees altimeters will have sufficient power, even in	Testing	Battery drain tests shall be conducted to ensure both batteries can last for at least an

		extenuating circumstances.		hour.
Payload	After ejection of the payload bay from the airframe of the launch vehicle, the separation between the payload bay and vehicle should be at least 10 feet.	Guarantees payload gets sufficient separation from the rocket airframe upon deployment such that deployment shall be unimpeded.	Demonstration	Ejection shall be designed such that separation distance reached the aforementioned measurement. Demonstration shall occur during the test launch.
Payload	The wireless communication system for transmitting the deployment signal to the rover should send, receive, and parse signals over distances up to 3000 feet.	Requirement ensures proper functioning of the wireless communication device up to and beyond the maximum drift distance as mentioned in the previous derived requirement on drift distance.	Testing	Half of the wireless communication device shall be moved up to 3000 feet away to test for signal.
Payload	The rover shall be capable of reorienting itself from all predictable initial orientations after deployment.	Requirement ensures proper functioning of rover in any orientation it is released in upon deployment.	Testing	Rover shall be placed in all predictable orientations in multiple tests to ensure functionality.
Payload	The rover shall be capable of autonomously moving away from the rocket over varying terrain.	Based on types of terrain on the launch field, the rover should be prepared to traverse the territory.	Testing	The rover shall be tested on terrain that simulates a rutted field with cut corn stalks, red clay, and grassy dirt, at a minimum.
Payload	The rover shall consistently acquire and contain 20 mL of soil upon execution of its soil collection routine.	Collection of additional soil ensures sufficient sample collection upon the launch site.	Testing	The rover shall be tested at retrieving 20 mL of soil in terrain conditions similar to that of the launch field.

Payload	The payload system's weight shall not exceed 8 lbs.	Requirement provides a standard to maintain such that an excess of rocket weight being invested in the payload is avoided.	Demonstration	Upon completion, the payload shall weigh in at no more than 8 lbs.
Payload	The battery, operating under typical mission conditions, shall provide power to the system for at least 6 hours.	Requirement ensures the battery will surely provide sufficient power in the event launch is delayed or kept on the launch platform for an unexpectedly long period of time.	Testing	The battery shall be tested in simulated conditions to maintain power for the aforementioned 6 hours.
Payload	Range-finding measurements taken by the LIDAR sensor on-board the payload must be accurate to within an inch.	This level of accuracy guarantees under normal circumstances that the rover will not improperly collide with objects.	Testing	LIDAR range tests shall be conducted, verifying the functionality of the equipment at detecting objects within 1 inch accuracy.
Safety	Provide each team member with the knowledge required to work safely with high-power rockets and any hazardous materials associated with these rockets.	Requirement ensures proper safety to all individuals involved with rocket construction, and promotes educated behavior amongst hazardous materials in the future.	Demonstration	Individuals on the team shall be asked to comply with and sign off on being familiar with the necessary precautionary measures associated with rocket construction.
Safety	Have an organized set of procedures which can be followed at all times to enforce safe construction and launch practices and	Requirement ensures a greater likelihood to appropriate response to emergency situations.	Demonstration	Safety-related procedures will be produced in a fashion that is easy to follow and informative to general team members.

	to be fully prepared for any emergency.			

7.2.1. Note on Payload Derived Requirements

Due to an in-flight anomaly that occurred during the payload demonstration flight on February 25, 2019, the majority of payload testing and requirements verification was unable to be completed. The payload team immediately began work constructing a new payload system after the first was lost, and plans to begin testing and verifying requirements shall be created once the new system is complete. The payload team intends to utilize this same testing framework to ensure the payload successfully meets all mission criteria before the second payload demonstration flight in mid-March. As a result, the current payload system derived requirements shall not be changed.

8. Recovery Team Verification Plans

8.1.1.1. Project Tests

8.1.1.1.1. Parachute Drop Test & Results

Objective:

The objective of this test was to ensure both the drogue and main parachutes opened within a consistent time frame after being ejected.

Derived Requirements:

Both parachutes need to be able to open within a consistent time frame after being ejected in order to fulfill the design requirements.

Verification:

After each trial the parachute was dropped, the amount of time it took for it to come to a fully opened state was measured. The parachute passed this test if the times measured in three trials were all within one second of each other.

Procedure:

1) It is expected that the completed launch vehicle will weigh 40 lbs. Therefore, 40 lbs of weights were attached to the drogue and main parachutes separately for an estimate.
2) Through prior testing, it was determined that approximately 40 ft was an ample distance range for the parachutes to open. Therefore, each parachute was

dropped from a height of four stories (from the top of of a nearby parking garage at about 40 ft).

3) Using a stopwatch, after each trial the parachute was dropped, the amount of time it took for it to come to a fully opened state was measured.

Data:

Test Parachutes

Drogue - Wildman Rocketry Recon (30")

Trial	Time to Open
1	1.21 sec
2	1.03 sec
3	0.90 sec

Main - SkyAngle Cert 2 (60")

Trial	Time to Open
1	1.11 sec
2	1.71 sec
3	1.33 sec

Flight Parachutes

Drogue - SkyAngle Cert 3 Drogue

Trial	Time to Open
1	1.05 sec
2	0.85 sec
3	1.22 sec

Main - SkyAngle Cert 3 XL

Trial	Time to Open
1	1.26 sec *to hit the ground* *Only opened about one-third of the way*

	Test Unproven*
2	Test Unproven*
3	Test Unproven*

Analysis:
Test Parachutes
Drogue - the range of times to open is 0.31 sec
The drogue parachute **passed** the test as it was within the threshold.
Main - the range of times to open is 0.60 sec
The main parachute **passed** the test as it was within the threshold.

Flight Parachutes
Drogue - the range of times to open is 0.37 sec
The drogue parachute **passed** the test as it was within the threshold.
Main - **test unproven***

Conclusion:
Test Parachutes
Both parachutes are very likely to open within a consistent time frame after being ejected.

Flight Parachutes
The drogue parachute is very likely to open within a consistent time frame after being ejected.
*Note: The tallest parking garage publicly available to us to perform this test was not tall enough to allow the main flight parachute to completely open during its descent (it is too large). Therefore, this test must be classified as unproven. However, the main test parachute passed this test, and the main flight parachute was observed to open about one-third of the way in 1.26 seconds. There is reasonable confidence with the additional approval and guidance of a Level 3 Certified mentor that the main flight parachute is likely to open within a consistent time frame after being ejected. Additionally, we know from our test flight data that the main parachute had fully opened 2.48 seconds after the ejection charge ignited.

8.1.1.1.2. Altimeter Ejection Vacuum Test & Results

Objective:

The objective of this test was to ensure that both the Telemetrum and RRC3+ Sport altimeters ignite the drogue ejection charge at apogee (or one second after apogee for the RRC3+ Sport) and the main ejection charge at the correct altitude during descent (700 ft).

Derived Requirements:

Both altimeters need to be able to consistently ignite both ejection charges at the appropriate times.

Verification:

The Telemetrum altimeter passed this test if the magnitude of the difference between the apogee altitude and the altitude the drogue e-match ignited at was less than 700 feet and the altitude the main e-match ignited at was between 650 and 750 feet (it was programmed to be 700 feet) for all three trials. The RRC3+ Sport altimeter passed this test if the drogue delay (the time between apogee and ignition of the drogue e-match) was between 0.75 and 1.75 seconds (it was programmed to be 1.00 seconds) and the altitude the main e-match ignited at was between 650 and 750 feet (it was programmed to be 700 feet) for all three trials.

Procedure:

1) The extra materials that were collected to conduct this test included a glass bowl, a sheet of plexiglass, a tube a silicone caulk, a wine bottle air remover pump and stopper, and a Jolly Logic Altimeter One.
2) The sheet of plexiglass was prepared by drilling one large hole into it. The wine stopper was placed into this hole.
3) A ring of caulk was placed around the rim of the bowl.
4) To test one altimeter, an e-match was connected to each the drogue and main outputs, and this system (along with the Altimeter One) was placed in the glass bowl. The ends of the e-matches were positioned outside of the bowl to prevent the ejection gases from interfering with the altitude measurements.
5) Before the caulk had a chance to dry, the plexiglass was placed onto the bowl, allowing the wet caulk to form a seal between it and the rim of the bowl.
6) The wine bottle air remover pump was then used to remove air through the stopper. Once the process of removing air was halted at the expected apogee altitude (the digital display of the Altimeter One indicated when this was), the drogue e-match was expected to ignite (or one second after apogee for the RRC3+ Sport).
7) Finally, the stopper was very slightly lifted away from the bowl to slowly allow air back inside it, causing the altitude to decrease according to the Altimeter One.

The main e-match was expected to ignite at pressures corresponding to an altitude of 700 ft.

8) The flight data was downloaded onto a laptop for analysis.

Data:

Telemetrum

Trial	Apogee Altitude	Drogue Ignition Altitude	Main Ignition Altitude
1	4751.31 feet	4265.26 feet	724.48 feet
2	4675.69 feet	3977.56 feet	688.68 feet
3	4995.34 feet	4643.21 feet	708.04 feet

RRC3+ Sport

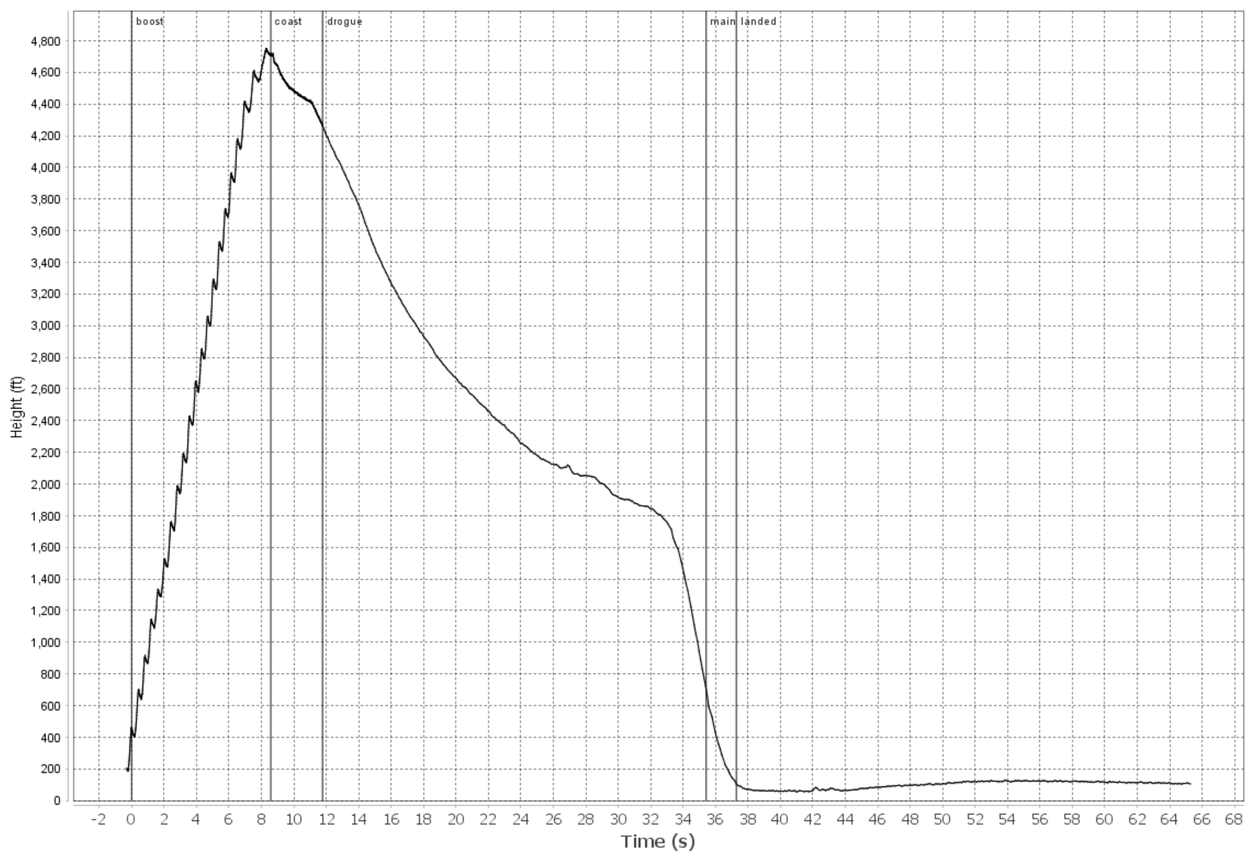
Trial	Apogee Altitude	Time Between Apogee and Drogue Ignition	Drogue Ignition Altitude	Main Ignition Altitude
1	5429.768 feet	1.05 sec	5215.006 feet	700.850 feet
2	5611.871 feet	1.65 sec	5339.104 feet	721.586 feet
3	5040.420 feet	1.60 sec	4835.574 feet	714.487 feet

Analysis:

Telemetrum

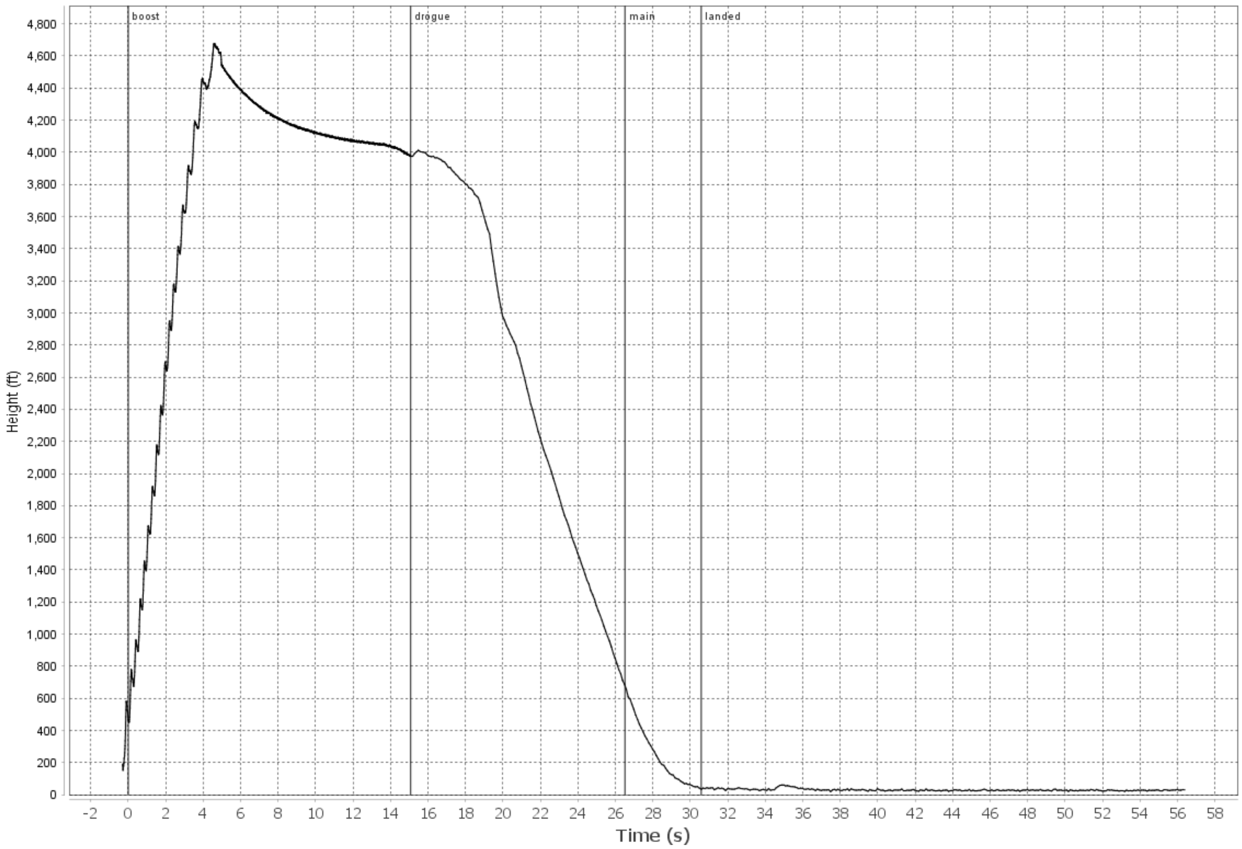
Trial 1

- The magnitude of the difference between apogee altitude and drogue ignition altitude is 486.05 feet
- The main e-match ignited between 650 and 750 feet



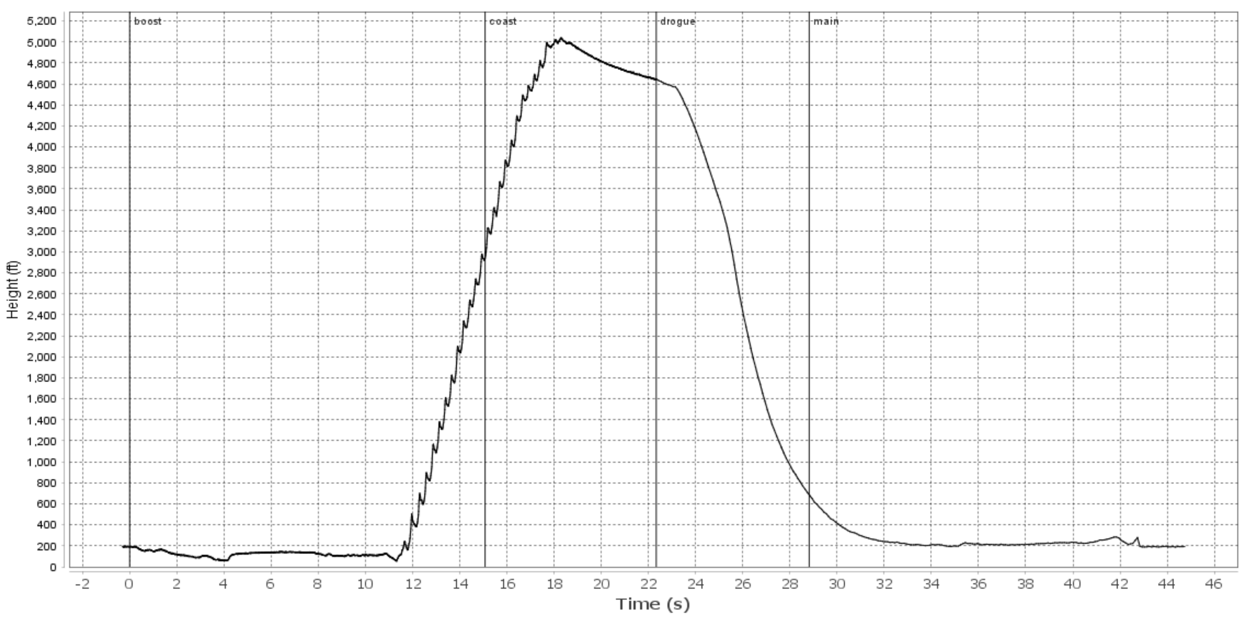
Trial 2

- The magnitude of the difference between apogee altitude and drogue ignition altitude is 698.13 feet
- The main e-match ignited between 650 and 750 feet



Trial 3

- The magnitude of the difference between apogee altitude and drogue ignition altitude is 352.13 feet
- The main e-match ignited between 650 and 750 feet

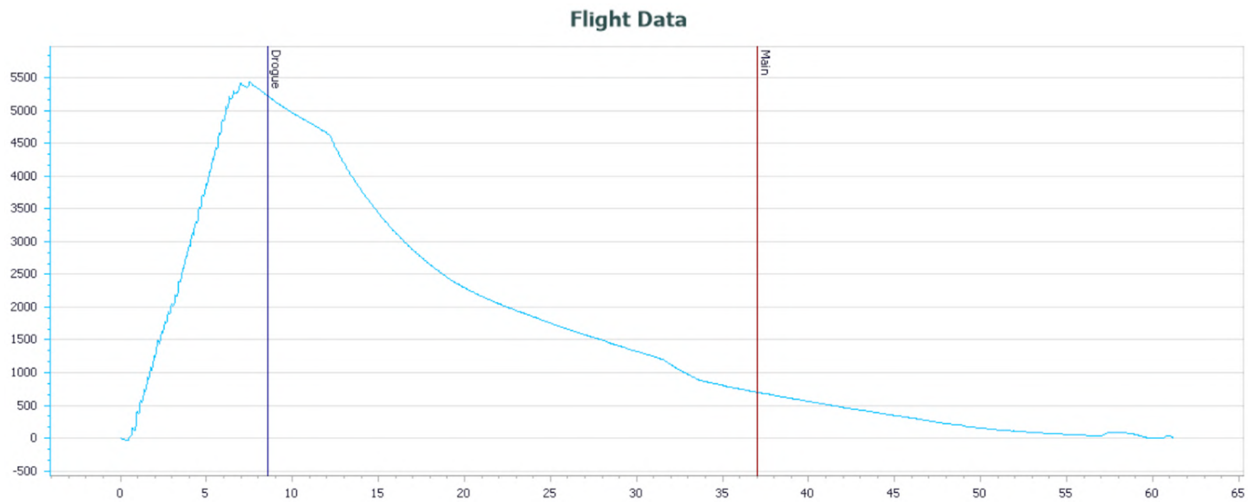


The Telemetrum **passed** the test.

RRC3+ Sport

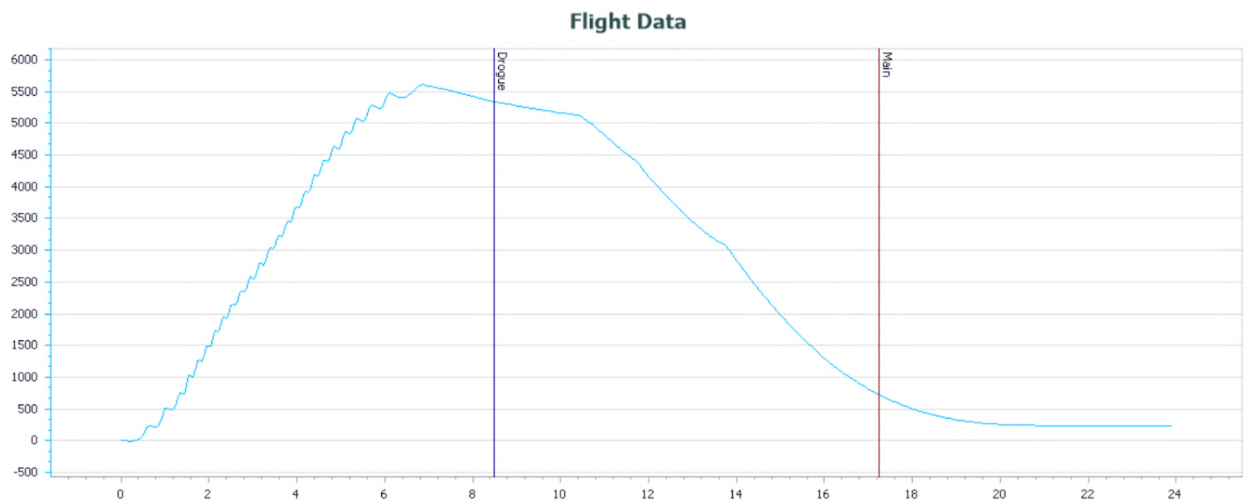
Trial 1

- The drogue delay was between 0.75 and 1.75 seconds
- The main e-match ignited between 650 and 750 feet



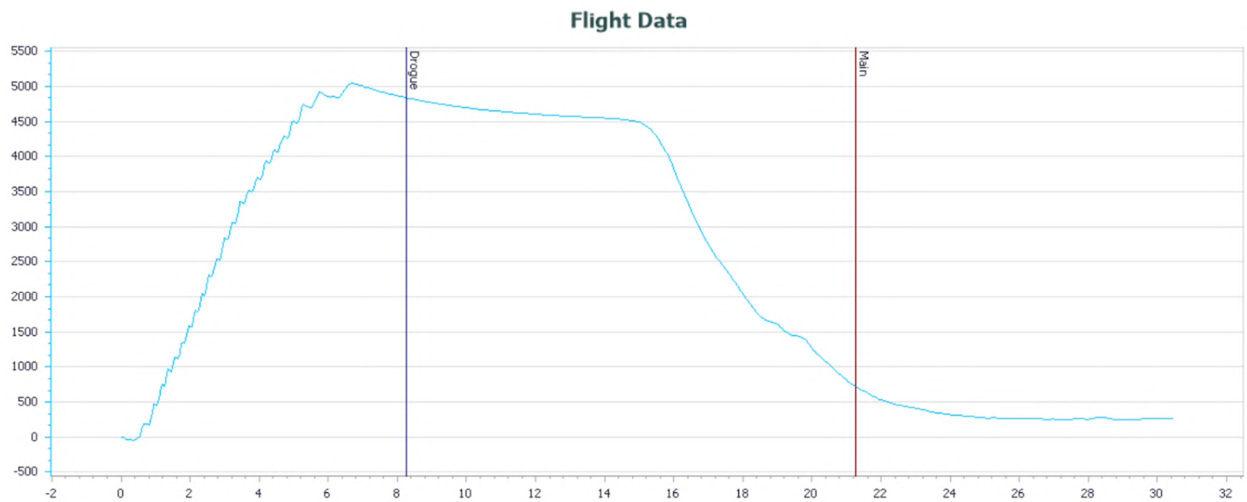
Trial 2

- The drogue delay was between 0.75 and 1.75 seconds
- The main e-match ignited between 650 and 750 feet



Trial 3

- The drogue delay was between 0.75 and 1.75 seconds
- The main e-match ignited between 650 and 750 feet



The RRC3+ Sport **passed** the test.

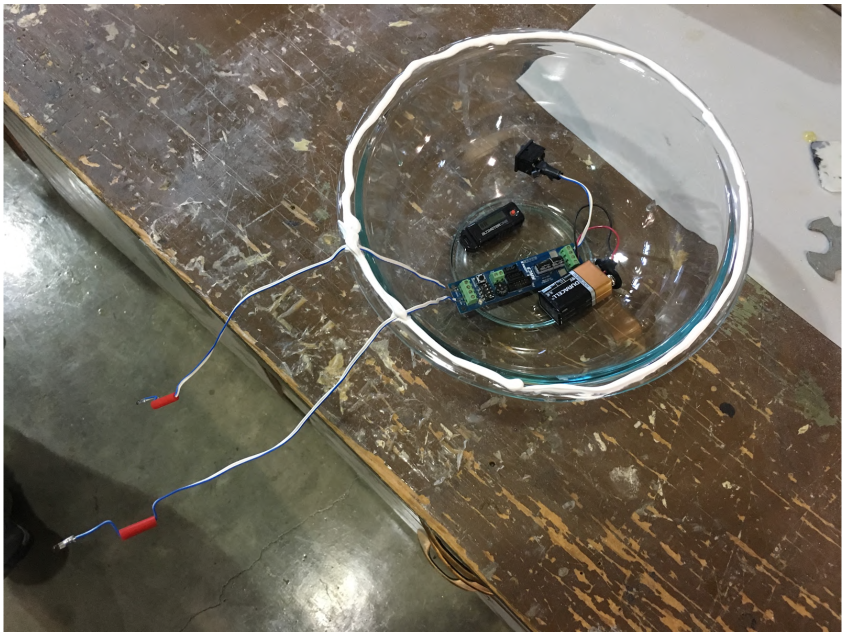
Conclusion:

Both altimeters are very likely to consistently ignite both ejection charges at the appropriate times.

Note: The reason why there was so much time and distance between apogee and drogue ignition altitude, especially for the more sensitive Telemetrum, was because it took some time to put down the pump and lift up the stopper from the bowl. The altitude was not decreasing quickly enough in this interim time to ignite the drogue e-match, but it did result in a significant drop in altitude. That is why the threshold to succeed for the magnitude of the difference between apogee altitude and drogue ignition altitude seems unusually high for the Telemetrum. This is one drawback of this test setup.

Pictures:

RRC3+ Sport



The setup before the plexiglass is placed onto the bowl.

Telemetrum

The completed setup.

8.1.1.1.3. Avionics Ejection Black Powder Test & Results

Objective:

The objective of this test was to ensure that the black power ejection system for the recovery components functions correctly.

Derived Requirements:
Both black powder canisters (one on either side of the avionics bay) need to be able to achieve successful separation of the avionics bay from the corresponding airframe, as well as full ejection of the corresponding parachute.

Verification:
Each black powder canister passed this test if its ignition resulted in at least six feet of separation of the avionics bay from the corresponding airframe, as well as full ejection of the corresponding parachute, for at least one amount of black powder equal to or greater than four grams for the upper airframe and three grams for the lower airframe.

Procedure:
1) The black powder canister on the upper airframe side of the avionics bay was filled with 4 grams of black powder.
2) An e-match connected to a 10-foot extension wire was inserted into the canister.
3) The avionics bay was reconnected to the upper airframe using shear pins.
4) The person conducting the test stood 10 feet away from the system and connected a 9V battery to the extension wire. The ejection charges were then expected to ignite and result in separation of the two components. If they did indeed separate, the distance between them was measured in feet.
5) If the above criteria in the Verification section were not met, the procedure was repeated using increasing amounts of black powder (in 1 gram increments) until six feet of separation and full ejection of the parachute were achieved. This last amount of black powder was then recorded as the ideal amount of black powder.
6) The procedure was also repeated for the black powder canister on the mid airframe side of the avionics bay, with 3 grams of black powder.

Data:

Upper Airframe Side Canister

Trial	Amount of Black Powder Used	Distance Between the Avionics Bay and the Upper Airframe	Did the main parachute eject completely?
1	4 grams	10 feet 8 inches	Yes

Mid Airframe Side Canister

Trial	Amount of Black Powder Used	Distance Between the Avionics Bay	Did the drogue parachute eject

		and the Mid Airframe	completely?
1	3 grams	16 feet 0 inches	Yes

Analysis:
The black powder canister on the upper airframe side of the avionics bay **passed** the test.
The ideal amount of black powder for this canister is 4 grams.

The black powder canister on the mid airframe side of the avionics bay **passed** the test.
The ideal amount of black powder for this canister is 3 grams.

Conclusion:
Both black powder canisters are very likely to achieve successful separation of the avionics bay from the corresponding airframe, as well as full ejection of the corresponding parachute.

8.1.1.1.4. Battery Drain Calculations, Test, & Results

<u>Calculations</u>
For the final full scale launch, the altimeters are required to run for at least one hour on the launch pad and for the duration of the flight. Due to this total time required for the altimeters to be running as well as the power needed to ignite the e-matches, it was estimated that about 50 mAh were needed to power the entire system. Therefore, for the full scale launch, one 9V battery for the RRC3+ Sport and one 3.7V LiPo battery for the Telemetrum will be used.

Power Requirements
- *3.5 VDC to 10.0 VDC / Optimized for 9V battery power*
- *6ma @ 9V quiesecent / 35ma @ 9V during piezo and LED operation*

Bridgewire Resistance	Maximum No-Fire Current	Minimum All-Fire Current	Recommended Minimum Firing Current	Recommended Nominal Firing Current	Maximum Test Current
1 ohm ± .2 ohms	.30 amp. (300milliamp.)	.60 amp (600 milliamp.)	.75 amp	1.00 amp	.04 amp (40 milliamp.)

<u>Test</u>

Objective:
The objective of this test was to ensure that the batteries could last for the duration of the launch.

Derived Requirements:
Each battery of both the 3.7V LiPo and 9V variety needs to be able to supply power to its corresponding altimeter (drawing about 50 mAh of power) for 0.5 hours more than the required amount of time (one hour).

Verification:
Each battery passed this test if, connected to its corresponding altimeter, the battery was able to keep it powered on for an hour and a half.

Procedure:
1) One 9V battery was connected to the RRC3+ Sport altimeter.
2) The altimeter was powered on, and the system was left for an hour.
3) At the end of the hour, it was checked if the altimeter was still powered on.
4) The procedure was repeated with the 3.7V LiPo battery and the TeleMetrum altimeter.

Data:

9V Battery

Trial	Was the RRC3+ Sport altimeter still powered on after an hour half?
1	Yes

3.7V LiPo Battery

Trial	Was the TeleMetrum altimeter still powered on after an hour?
1	Yes

Analysis:
The 9V battery **passed** the test.
The 3.7V LiPo battery **passed** the test.

Conclusion:

Both the 9V and 3.7V LiPo batteries are very likely to be able to supply power to their corresponding altimeters (drawing about 50 mAh of power) for the required amount of time (one hour).

8.1.1.1.5. Altimeter Continuity Test & Results

Objective:
The objective of this test was to ensure that continuity could be achieved when an e-match was connected to each the drogue and main outputs of both the Telemetrum and RRC3+ Sport altimeters.

Derived Requirements:
Both altimeters need to be able to consistently achieve continuity for a dual deploy configuration.

Verification:
Each altimeter passed this test if it emitted three beeps (or *dits* for the Telemetrum) every five seconds after the initialization routine for all three trials, indicating successful continuity for a dual deploy configuration.

Procedure:

1) A battery and a switch were connected to the RRC3+ Sport altimeter. An e-match was also connected to each the drogue and main outputs.
2) The altimeter was powered on and allowed to complete its initialization routine.
3) The number of continuity beeps that were subsequently emitted was then recorded for each of the three trials.
4) The same procedure was repeated with the Telemetrum altimeter (but listening for *dits* instead).

Data:

Telemetrum

Trial	Number of Continuity *Dits*
1	3 *dits*
2	3 *dits*
3	3 *dits*

RRC3+ Sport

Trial	Number of Continuity Beeps
1	3 beeps
2	3 beeps
3	3 beeps

Analysis:
The Telemetrum **passed** the test.
The RRC3+ Sport **passed** the test.

Conclusion:
Both altimeters are very likely to consistently achieve continuity for a dual deploy configuration.

8.1.2. Payload Team Verifications Plans

8.1.2.1. Project Tests

8.1.2.1.1. Ejection Separation Test & Results

Objective:
The objective of this test is that the payload bay containing the rover will be successfully ejected from the rocket after landing.

Verification:
In order to verify the objective is fulfilled, the separation between the payload bay and the main body separation must be at least 3 meters.

Procedure:
1. The rocket will be placed horizontally on the ground
2. The black powder charge will be activated, separating the nose cone from the main body
3. The distance will be measured to ensure it is at least 3 meters.
4. The procedure will be repeated 3 times

Previous testing has already been done, with a similar rocket and a mock weight to simulate the actual conditions. After testing, the team obtained the following results

	Test 1	Test 2	Test 3
Black powder (Hodgdon Pyrodex)	2.5 g	2.0 g	1.5 g
Forward displacement	67 in	75 in	57in
Backward displacement	102 in	108 in	82 in
Main body- nose cone separation	169 in	183 in	139 in

Weights	Value	Units
Weight (nose cone + simulated payload):	1930	g
Nose cone + 3d print	1045	g
nose cone	880	g
3d print	205	g
Mock weight	885	g

When analysing the data, the team realised that the second test (2.0g of Black Powder) displaced a further distance than the first one (2.5g), a difference attributed to how compact the black powder charge was set. The team came to the conclusion that tightly compacting the charge carries more value than the actual mass of black powder used. The minimal value needed for the test to be successful was of 10 inches of main body-nose cone separation (minimal distance for the payload bay to be ejected and fully deploy the rover). The target value was 3 ft, which the payload team found long enough to be sure it will work in any condition. All three test met the expectations.
Despite that the mission situation could not be perfectly simulated, the team decided that 1.5 grams of black powder were enough to fulfill the objective. Furthermore, the tests proved to be very useful due to two main reasons: first, the team learnt the importance of compactness when it comes to black powder charges and second, the 3D printed successfully withstanded all three of the impacts. The payload team is confident that smokeless black powder shall provide a sufficient means of separating the payload bay and nose cone from the rocket.

8.1.2.1.2. Radio Communication Distance Test & Results

Objective:

The communication system on-board the payload must be able to send and receive signals from an open-air distance of at least 3000 feet.

Verification:

Verification of the ability to successfully transmit and receive signals over this distance will be completed with extensive testing of the Xbee radios over varying distances and environments.

Procedure:

1. The two Xbee radios will be placed apart a known distance between 500 and 3000 feet.
2. The switch on the base XBee will be turned on, initializing the transmission of a signal to the slave XBee.
3. The slave XBee will be configured to pull one of its digital outputs, to which an LED is connected, HIGH if it receives a signal from the base XBee. Observation of the LED will indicate successful transmission of the signal.
4. The test will be repeated 10 times, varying the distance and/or location over which the test occurs each time.

8.1.2.1.3. Rover Orientation Test & Results

Objective:

The objective of this test is to make sure that the rover will be in the correct orientation after the rover has been deployed from the rocket.

Verification:

To pass this test, the rover must have been rotated less than 45 degrees from the rovers ideal orientation. To make sure the rover will consistently be deployed in the correct orientation, the rover must be deployed within the 45 degrees of the ideal orientation.

Procedure:

1. A white line perpendicular to the ground will be painted on the body of the rover in its ideal orientation.
2. The rover will then be ejected from the rocket.

3. After the rover has landed, the angle of the white to the ground will be measured.
4. The rover will be tested until it successfully ejects in the correct orientation three times.

8.1.2.1.4. Rover Mobility Test & Results

Objective:

The objective of the rover mobility test is to ensure that the rover can orient itself in any configuration to allow movement in any direction in 2-dimensions as well as ensure the rover can traverse any foreseeable environment. This will not limit path choice when the rover is autonomously navigating and will prevent the rover from getting stuck. The tested items that will be used in the verification test will be the entire rover assembly including the control unit and range sensing unit. The rover will be tested in a similar terrain to the Alabama red clay and will test mobility at different slopes and different entry angles.

Verification:

In order for the rover to pass this verification test, the rover will be put through a pass/fail test where it will be made to navigate over terrain of varying slope angles up to 45 degrees from horizontal. The entry angle, the angle the length of the rover makes with the direction of the slope, will be varied along with the slope angle. In order for the rover to pass a test, the entirety of the rover must be able to pass over the terrain without a greater than 5 degree change in entry angle. The rover must be able to pass every single test or else changes must be made to the rover wheels, motion unit or structure of the chassis.

Procedure:

1. A terrain similar to the Alabama red clay environment, such as harvested farmland, will be formed into slopes angled at 0 degrees to 45 degrees in increments of 5 degrees.
2. A rover will be driven straight at different entry angles varying from 0 degrees to 80 degrees in increments of 10 degrees.

8.1.2.1.5. Soil Collection Test & Results

Objective:

A soil collection system will be used which shall effectively loosen soil such that a collection apparatus mounted on the payload can collect and contain a minimum 20 mL soil sample. This total amount of 20 ml is a safely high target value since the 10 ml could be easily underestimated due to irregularities in the soil.

Verification:

In order to determine the ability of the soil sampling subsystem to collect a soil sample, the subsystem will be tested on a small test field. To pass the test, the soil sampling subsystem must be able to collect 20 ml of soil in a single trial.

Procedure:

1. The assembly will be mounted to the rover chassis and placed on a region of test top-soil. This region will be level, 4 cm deep, and flattened within 1 cm tolerance.
2. The rover will be instructed to drive forwards at operational speed after deploying the soil sampling system. The soil procurement apparatus will first loosen the soil by moving through an area of soil, then will collect it into a retention system, in which it can be permanently stored.
3. The system will pass this test once the final collected sample has surpassed the required 10 ml sample requirement, and as a matter of redundancy, collected an additional 10 ml of sample.
4. Three trials shall be conducted to collect multiple points of data. After each run, the surface will be filled and smoothened for the next. If the rover does not pass, redesign of soil collection system will be required.

8.1.2.1.6. Rover Net Weight Test & Results

Objective:

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.

Verification:

The weight of the payload and payload bay will be calculated by measuring the weight of each component. The dimensions of the payload bay will be measured and used to calculate the weight of the bay itself. All other components will be weighed using an imperial scale. To verify the calculations and ensure the net weight remains under 6 pounds, the payload bay and payload will be weighed on a scale upon assembly.

Procedure:

The components of the deployment system include the threaded rod, motor, support rod and all fasteners. The rover will also be broken up into individual components. These components are the following: two main driving motors, two main driving wheels, a small support wheel, a x by x sheet metal plate, the arduino electronics board, a LIDAR sensor, a gyro/accelerometer sensor, various fasteners and a LiPo battery pack.

8.1.2.1.7. LIDAR Range Test & Results

Objective:

The objective of this verification test is to verify that the 8th payload derived requirement is met in order to ensure that the onboard rover can identify objects and obstacles that the rover should avoid. The tested items that will be used in the final rover construction will be the LIDAR sensor and the rover control unit that will processing the LIDAR sensor data. The LIDAR sensor will be tested at known distances from objects between 0.5 feet to 30 feet in increments and the error of those measurements will be used to discover resolution.

Verification:

In order for the LIDAR sensor to pass this verification test, all measurements taken by the LIDAR sensor must be within 1 inch of the actual distance and must be able to meet the resolution requirement at a distance of at least 25 feet.

Procedure:

1. Set up the LIDAR sensor to a fixed point with its line of sight horizontal to the ground and connect to a microcontroller with a record on command button.
2. Place a flat plate a distance of 0.5 feet from the end of the LIDAR.
3. Record distance measured by LIDAR with the record on command button.
4. Move the flat plate in increments of 0.5 feet up to a final distance of 30 feet and repeat step 3 for each plate movement.

8.1.2.1.8. Battery Drain Test & Results

Objective:

The objective of this test was to ensure that the battery is able to be used effectively after deployment. Although the rocket will not be in the air for six hours, there are many factors that may influence the time between the rocket setup and the launch.

Verification:

The battery must be able to withstand the potentially long amount of time it may sit, untouched. The battery will pass this test if when run continuously it operates for a minimum of six hours and is able to move the rover correctly after it is deployed.

Procedure:

1. The battery will simulate the length of the launch and setup, by being run for as long as possible.
2. If the battery lasts longer than six hours then it is successful.

9. Budgeting and Timeline

9.1. Line Item Budget

9.1.1. Full Scale Budget

Rocket Parts	Unit Cost	Quantity	Total (including shipping)
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	$27.50	1	$27.50
18" x 18" Nomex Parachute Protector	$10.95	2	$21.90
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	$290	1	$290
Aerotech 75mm 3G L1520-T Reload	$199	2	$380
Aerotech 75mm 3G L1520-T Reload	$162	2	$324
0.187” x 24” x 24” Natural FR4 Epoxy/Glass	$87.35	1	$127.80

Laminate Sheet			
			$2340.69

9.1.2. Subscale Budget

Item	**Unit Cost**	**Quantity**	**Total**
Wildman Jr. Rocket Kit	$125.99	1	$125.99
Wildman Recon Recovery 30” Shute	$35.95	1	$35.95
H115-DM Motor	$35.99	1	$35.99
			$197.93

9.1.3. Avionics Budget

Item	**Unit Cost**	**Quantity**	**Total (including shipping)**
TeleMetrum - Altus Metrum Altimeter	$300.00	1	$300.00
TeleDongle - Altus Metrum	$100.00	1	$100.00
RRC3+ Sport - Missile Works Altimeter	$70.00	1	$70.00
Electronic Match	$1.00	25	$25.00
Jolly Logic AltimeterOne Altimeter	$58.19	1	$58.19
ALTIMETER MOUNTING POSTS	$3.68	2	$7.36
6g Charge Well	$8.50	2	$17.00
Missile 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

900mAh LiPo Battery Pack	$16.29	1	$16.29
Terminal Block	$7.10	2	$11.85
8g Charge Well	$8.95	4	$45.25
Solid Plywood Block (¼”X2’X4’)	$16.99	1	$16.99
Acrylic Sheet	$22.98	1	$22.98
Polyseamseal Sealant	$4.06	2	$8.12
			$823.48

9.1.4. Payload Budget

Item	Unit Cost	Quantity	Total
Arduino Pro Mini	$13.00	5	$65.00
7.4V 1550mAh 35C 2S LiPo Battery Pack	$12.99	1	$12.99
HOBBYMATE Imax B6 Clone Lipo Battery Balance Charger	$34.90	1	$34.90
LIDAR-Lite v3	$130.00	1	$130.00
Standard Gearmotor - 303 RPM (3-12V)	$24.95	2	$83.78
Servo Motor SG-90	$1.70	2	$3.40
Redrex Nema 17 Stepper Motor	$26.95	1	$26.95
XBee-PRO 60mW (802.15.4)	$37.95	3	$113.85
MPU 6050	$30.00	1	$30.00
Dual TB6612FNG	$4.95	1	$4.95
A4988 stepper motor driver	$5.95	1	$5.95
KY-019 5V DC Relay	$1.80	2	$3.60
Black Powder (1 lb)	$20.00	1	$20.00
3D Printed Material	$25.00	1	$25.00
			$560.37

9.1.5. Branding Budget

Item	Unit Cost	Quantity	Total
Polos	$25	22	$550

			$550

9.1.6. Travel Budget

Item	Unit Cost	Quantity	Total (plus tax)
Hotel Room (3 Nights)	$312	5	$1824
Gas (Rough Estimate)	$40	18	$720
			$2544

9.1.7. Budget Total

Budget Section	Total Cost	Discount	Final Total
Full Scale	$2340.69	$2071.34	$269.35
Subscale	$197.93	$0	$197.93
Avionics	$823.48	$470	$353.48
Payload	$560.37	$0	$560.37
Branding	$550	$550	$0
Travel	$2544	$0	$2544
	$7016.47	$3091.34	**$3925.13**

Budget Justification

- **Full Scale and Subscale:** Parts for both the full and subscale rocket have been purchased at this point, and all parts are fully detailed on the line item budget. A Wildman Junior kit was used for the subscale rocket, requiring for very few other parts to be purchased in order to construct the subscale rocket. A Wildman Junior case was used as it was provided by SEDS. An exception to this case is parts required for a future test launch, where certain purchases may be necessary to accommodate a new launch. A $2071.34 discount has been applied, this accounts for parts purchased in previous years, and a donation of one of the motors and the associated hardware.
- **Avionics:** All items in the avionics section have also been purchased. The avionics line item budget should be complete. Two of the altimeters purchased

for the team, in addition to the Teledongle, were purchased last year. As a result, a $470 discount has been applied.

- **Payload:** Although parts have been purchased for the payload section, due to the recent failure of payload tests, more parts for the payload section will likely be purchased. The budget currently reflects all necessary purchases without performing an additional test.
- **Branding:** The branding section includes now only polos required by members to wear during the competition in Huntsville, these polos will be purchased by the members of the team. An estimated 22 individuals will be attending the trip to Huntsville, and thus the amount on the line item budget it based on this quantity. A discount of the full cost has been applied due to members purchasing the polos with their own funds.
- **Travel:** Travel costs include hotel room reservations and gas costs (if traveling by car). With an estimated 22 individuals attending, 5 rooms will be necessary for 3 nights (quantity 15 total). Gas costs associated with driving over are estimated to be roughly $700. Alternatively, if funding permits, all individuals attending can fly to Huntsville, bringing the estimated cost in this section up to $6472. It is unlikely that this option will be able to be funded, although the amount is known in case it becomes a possibility.

9.1.8. Funding Plan

9.1.8.1. Sources Of Funding

Assuming that the team requires around $4000, there will be five (not including company sponsorship) primary ways funds will be raised to support the NASA Student Launch project:

1. Skip-a-meals (Restaurant Socials): Skip-a-meals are social events where individuals can mention the name of SEDS or Purdue’s NASA Student Launch at a designated food establishment and a percentage (usually a quarter) of money they spend at the establishment will be given to the team. These events usually last for a whole afternoon or the rest of the business day as collectively determined by the establishment and team.
2. Levy Restaurant Services Fundraising Program: Levy Restaurants, a service that hosts concession stands at Purdue, has agreed to let us volunteer at the stands in return for a portion of the funds they generate.
3. Company Sponsorship: The team has been unsuccessful as of so far in finding any company willing to provide a portion of the necessary funds, but is still making inquiries.
4. Crowdfunding: The crowdfunding campaign will begin in the week of January 15th, and will continue with the anticipation of receiving roughly $800 assuming

adequate advertising and campaigning. Currently, just over $600 has been generated from the crowdfunding campaign.

5. SEDS Treasury: The parent organization is providing $1000 towards funding the project.
6. AAE Travel Grant: The Aeronautical & Astronautical Engineering Department of Purdue has graciously agreed to give us $1600 to go towards travel costs associated with the competition.

Below is an updated chart with the anticipated funds from each of the sources.

Funding Source	Funds Generated
Restaurant Socials (3 throughout year)	$600 ($200 each)
Levy Restaurant Fundraiser	$300 (estimate)
Crowdfunding Campaign	$800
SEDS Treasury	$1000
AAE Travel Grant	$1600
TOTAL:	**$4300 ($300 margin)**

Procurement of funds has changed slightly since preliminary design review. Below is a Gantt chart identifying when funds will be generated from each of the methods above. Colored spaces indicate inbound funds. Notably, funds from the Indiana Space Grant Consortium (INSGC) Grants has specifically been allocated towards travel costs, which is a requirement by INSGC.

Both restaurant fundraisers and the crowdfunding campaign, as funding sources that will result in us receiving funds sooner, will be used to reimburse costs for the subscale rocket, and to pay for the full scale rocket. Funds from the INSGC grants will largely be used to pay for travel costs, but may also be allocated nominally to purchasing materials for the full scale rocket. Below is an ideal date to receive a company sponsorship, but no true date has been confirmed.

Week of:	Jan. 22nd	Jan. 29th	Feb. 5th	Feb. 12th	Feb. 19th	Feb. 26th	Mar. 5th	Mar. 9th	Mar. 16th
Restaurant Fundraisers									Last Fundraiser Ends
AAE Travel Grant					Funds in Pocket				

Crowdfunding Campaign							$600 Withdrawn		

9.1.8.2. Allocation of Funds

With changes from the preliminary design review in mind, a specific location to which all of the funds have been allocated has been devised.

Full Scale Rocket: The full scale rocket was almost entirely constructed using parts from last year's rocket, only a few additional purchases have taken place in this section.

Subscale Rocket: The majority of parts for the subscale rocket have been provided to us by the parent organization, SEDS. SEDS has provided us with a Wildman Jr. kit and motor to construct the subscale with, thus no funds are directly allocated towards this area.

Avionics: Parts for the avionics bay have been purchased mostly using funds from the SEDS treasury and restaurant fundraisers. Certain parts in the avionics (specifically the Telemetrum and RRC3+ Sport altimeters, as well as the Teledongle) were from last year's rocket, and thus no funds have been allocated specifically for these parts.

Payload: Parts required for the payload bay, including the payload itself, will be funded by the restaurant fundraisers, crowdfunding campaign, and potentially the SEDS treasury allocated to it. Due to the possibility of more parts to be purchased in this section in the future, additional funds may be required.

Branding: Team matching polos have been designed, and are purchased individually by members on the team itself, thus no funds are allocated to this category, which only includes the aforementioned polos.

Travel: Travel costs will be partially funded by the AAE travel grant. Additional costs shall be paid for by potential fundraisers, specifically the fundraiser with Levy Restaurants.

9.1.8.3. Material Acquisition

All materials for the subscale rocket were parts contained within the Wildman Junior kit, with the exception of the motor, which was purchased separately. Individuals who made purchases for the team will be reimbursed using funds from the SEDS Treasury, crowdfunding campaign, and restaurant fundraisers. All funds generated for the team are deposited into the SEDS bank account and are then used to purchase materials or reimburse students if they purchased materials individually. Materials for the full scale rocket in particular were all reused from Purdue's unlaunched NASA Student Launch rocket from last year. Most, if not all, materials for the avionics bay have already been purchased from various vendors. Most avionics purchases were completed by individual team members, who have been reimbursed through the SEDS bank account.

9.2. 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 randomly placed in teams in charge of various groups consisting of 10-90 students. The students created model rockets, astronaut arms, solar sails, and many other space-related projects with the help and supervision of team members. Team members showed the students the physics and reality of propulsion using systems such as dry ice rockets, and also showed the students the different organizations around Purdue that were involved in STEM related projects. This allowed for the students 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.

9.2.1. 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

9.2.2. Outcome of Outreach

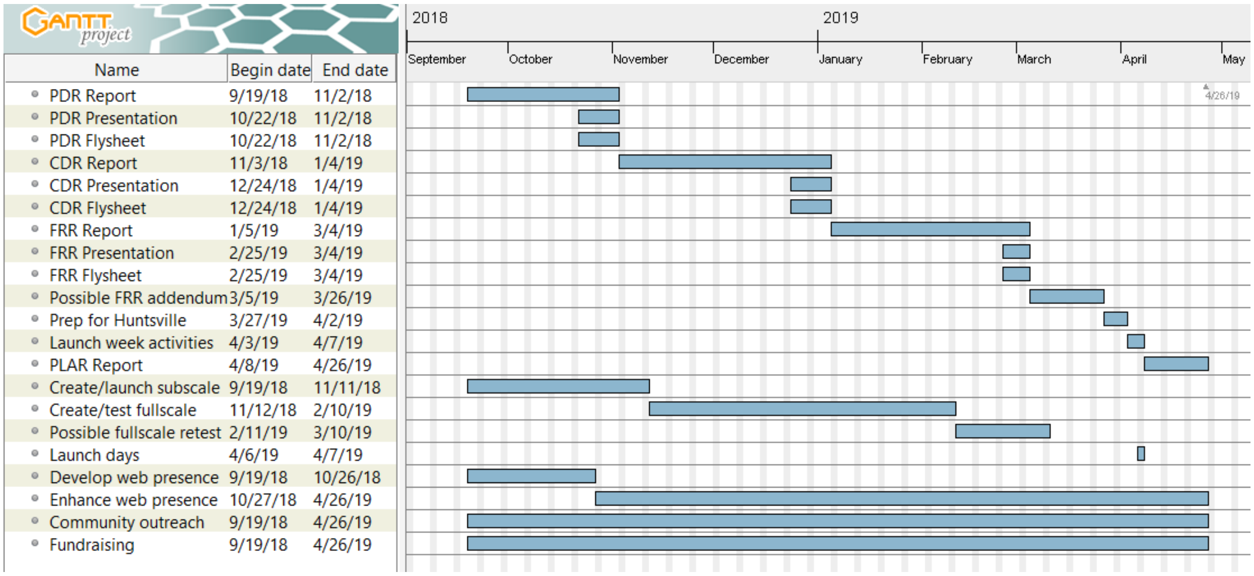
Team members who participated in Purdue Space Day were unable to see the evaluation reports the children gave to Space Day officials at the end of the day, but through word of mouth the team heard that feedback was very positive in terms of both enjoyment and concepts learned. Team members also report 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. The students used their initial experience from the dry ice rockets to make changes and learned that creating a higher internal pressure would allow the cap to pop off at a higher required force and therefore provide more thrust. The students overall were extremely excited by creating these rockets and shared their joy after learning from team members by pondering how they would similarly launch from home and if they were able to learn more on rocket science.

9.2.3. 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.

9.3. 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 color-coded timeline outlines events in these categories: 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
02/25/2019	Full Scale Demonstration Launch Day
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
03/07/2019	FRR video teleconferences start
03/09/2019	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
03/19/2019	Purdue University FRR Presentation
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 8:00 AM 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

10. Appendix A

10.1. NAR High Power Rocket Safety Code

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.
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.
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, nor heat sources within 25 feet of these motors.
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.
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.
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. 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.

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.
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.
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).
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.
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.
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