Purdue University

Project Walker

500 Allison Road
West Lafayette, IN 47906

January 10th , 2019

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Summary of CDR 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

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1.2. Launch Vehicle Summary

1.2.1. Size and Mass

Our launch vehicle will be 120" tall when assembled and weigh an estimated 27.4 pounds when not loaded with propellant or 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

We are using an Aerotech Rocketry L1520 Blue Thunder as our means for propulsion. It is a 75mm diameter, 3 grain motor that produces a total impulse of 3,716 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 rocket 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

Our 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 PDR

2.1. Changes Made To Vehicle Criteria

There have been few changes to the criteria the launch vehicle is required to meet, and follows all requirements set forth by the 2019 NASA SL handbook since the Preliminary Design Review. The first change involved removing the switchbands the team intended to use in between some sections of the rocket. The reason they were removed was not an engineering decision, rather the company chosen to provide the team with the parts no longer manufactures and sells the 2” switchbands the team needs. While this is an unfortunate realization, the team maintains its drive to push forward nevertheless. Removing the switch bands lowered the total height of the rocket by about 6 inches. This altered our stability and center of pressure (CP) a little, but not enough to cause any serious issues.

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 Plan

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

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:

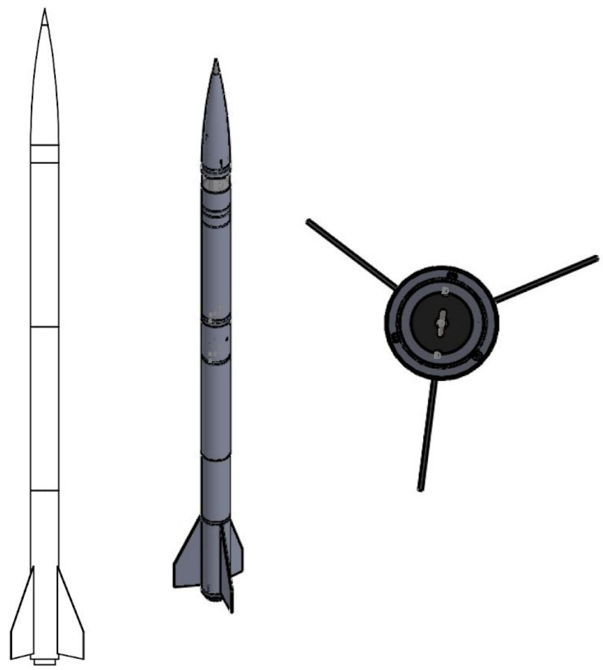
- The vehicle flight is stable during ascent
- The vehicle reaches the desired altitude of about 4950 feet AGL
- All recovery gear is successfully deployed at the appropriate altitudes
- The vehicle lands safely within the recovery zone boundaries
- The vehicle can be flown again without need for repairs 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 PDR

All of the design alternatives chosen during PDR have remained unchanged except for the components and sizing of the payload bay, the removal of switch bands from both the avionics bay and coupler connecting the mid and lower airframes, and the reduced size of the middle airframe. The chosen alternative payload bay will consist of two sealed sections separated by a small air chamber. One section would serve to house the rover payload, and the other would hold the deployment electronics and act as an attachment point for the recovery system. The larger section housing the rover would continue to be part of the nose cone and will still serve as an interface to the rest of the launch vehicle while the smaller section would be installed just aft of the larger section and would house deployment electronics and contain a u-bolt for the recovery system. Other than changes made to the payload bay and switch bands, the chosen design of the nose cone, upper airframe, avionics bay, and lower airframe are all the same as presented during PDR.

3.1.3. Dimensional Drawings Using SolidWorks

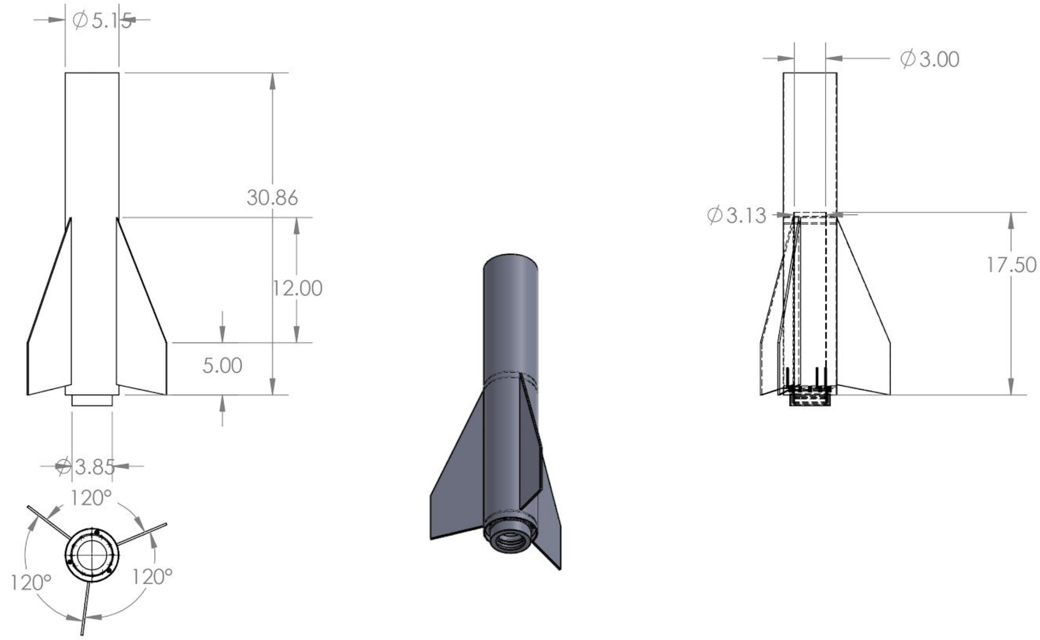
3.1.3.1. Assembled launch Vehicle



The image above and all following drawings were created in SolidWorks 2017.

The assembled launch vehicle, as shown above, includes all metal hardware and 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 is also not shown, but the motor retainer, thrust plate, and all appropriate fasteners are modeled in the drawing. 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. The team also chose to show the avionics bay and payload bay by making those body tube sections transparent to allow for a more detailed look at the rocket and its inner workings.

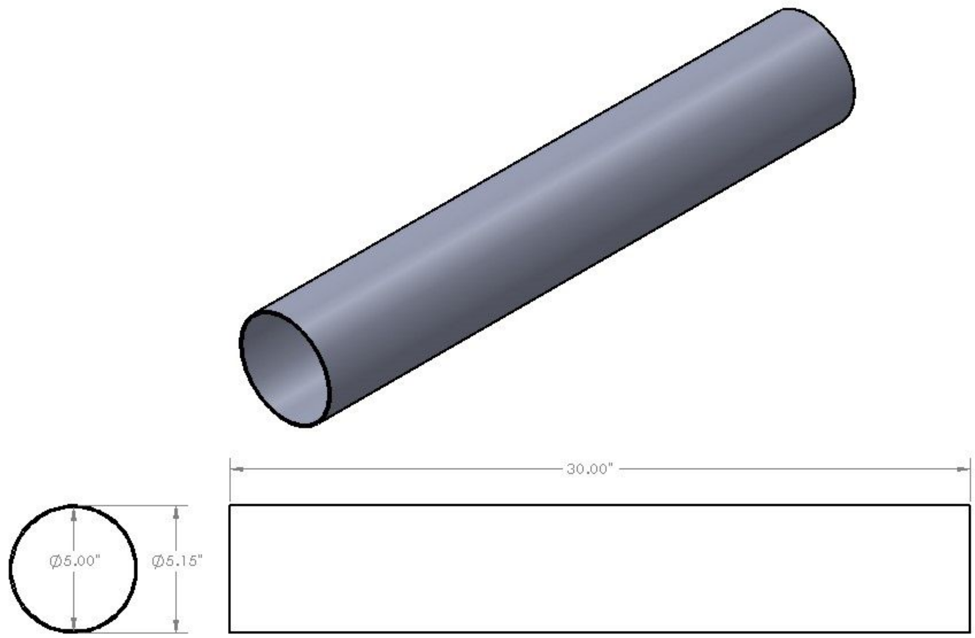
3.1.3.2. Lower Airframe Subsystem and Components



Our lower airframe section will have a 5.15” outer diameter, 5.00” inner diameter, be 30.86” 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

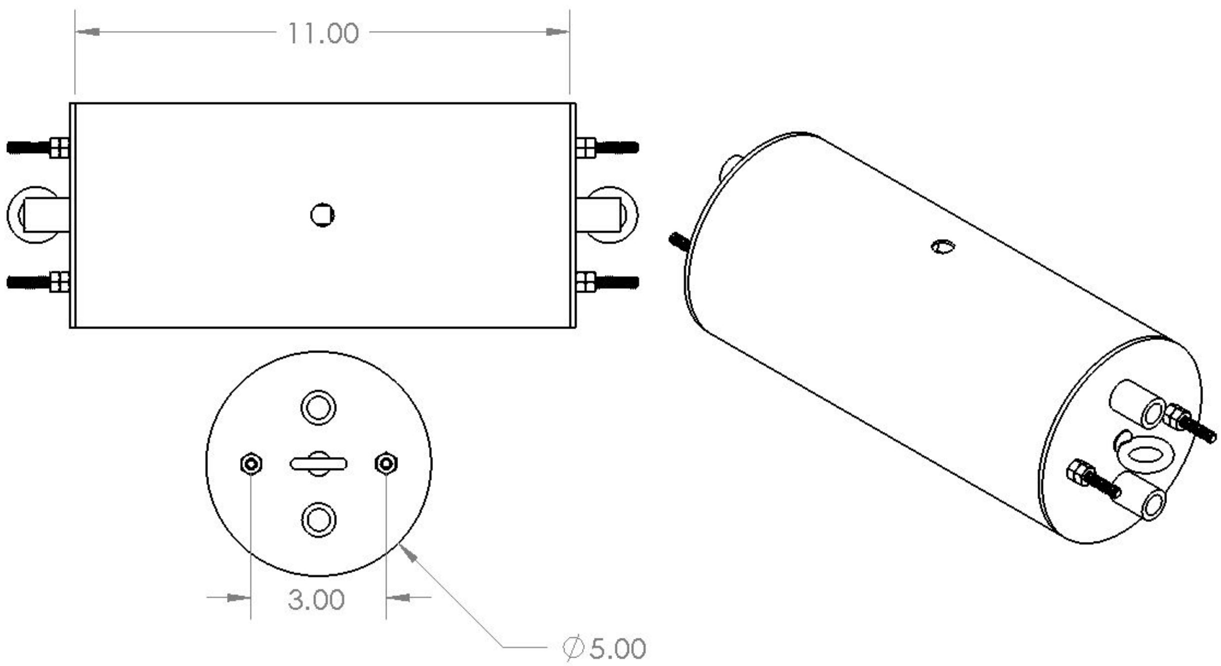


The mid airframe will have an outer diameter of 5.15”, and inner diameter of 5.00”, and will be 30” long. 5.00” of both ends of the tube will be used to interface with coupler tubes, leaving 20.00” of usable room for drogue recovery gear.

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

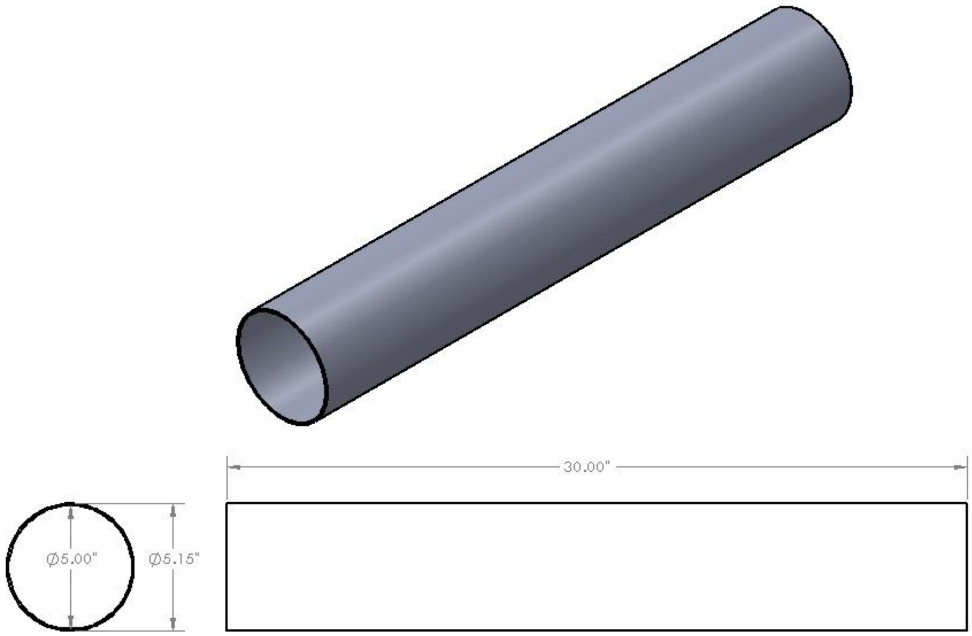
This tube will mate with the avionics bay coupler one one end, and the payload bay coupler one the other end. The mid airframe will be secured to the payload bay coupler using multiple removable metal rivets to hold the lower sections of the rocket together during flight. The avionics bay and upper sections 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

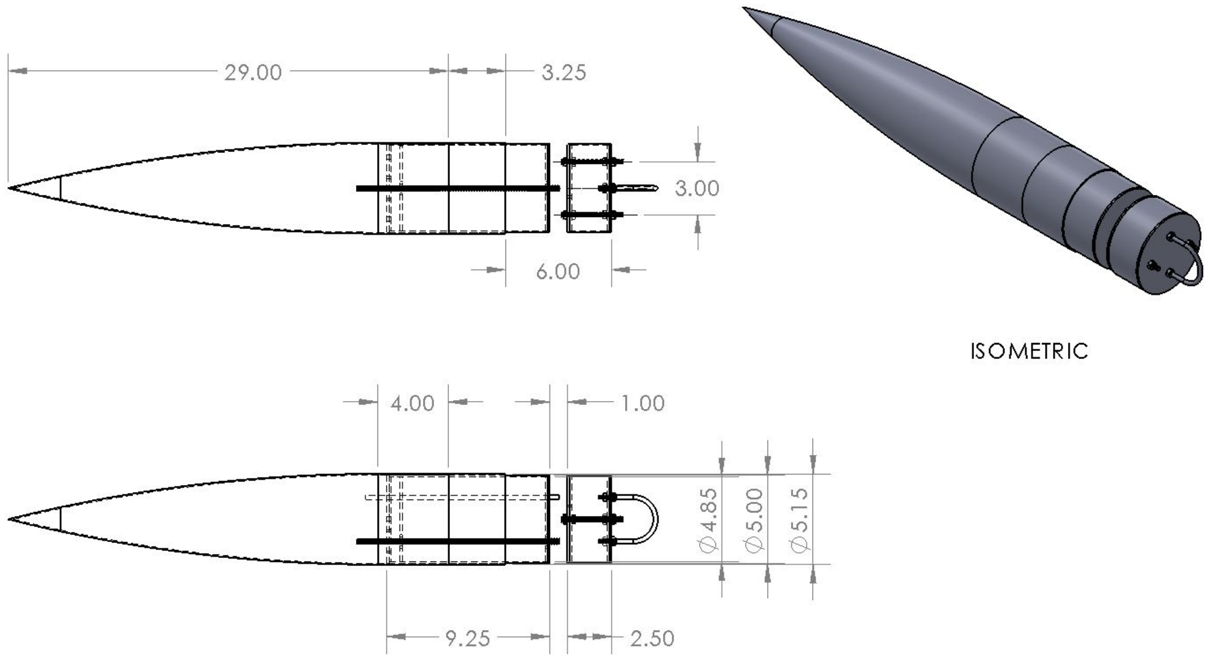


The upper airframe will have an outer diameter of 5.15”, and inner diameter of 5.00”, and will be 30” long. 5.00” of both ends of the tube will be used to interface with coupler tubes, leaving 20.00” of usable room for main recovery gear.

The team elected to use a standard 30” length of tubing. As a result, we do not need to pay an extra fee to have the tube recut to a custom length and the center of gravity remains as far from the aft of the rocket as possible. This also provides us with ample room to pack our 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 nose cone bay coupler one one end, and the avionics bay coupler one the other end. The upper airframe will be secured to the avionics bay coupler using multiple removable metal rivets to hold the sections of the rocket together during flight. The nose cone bay of the rocket will be shear pinned 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 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 nosecone will be riveted 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 a u-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. The switch band and nose cone will both be attached to the payload using rivets.

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. Overall, there is very little manufacturing that the team needs to perform in house outside of 3D printing.

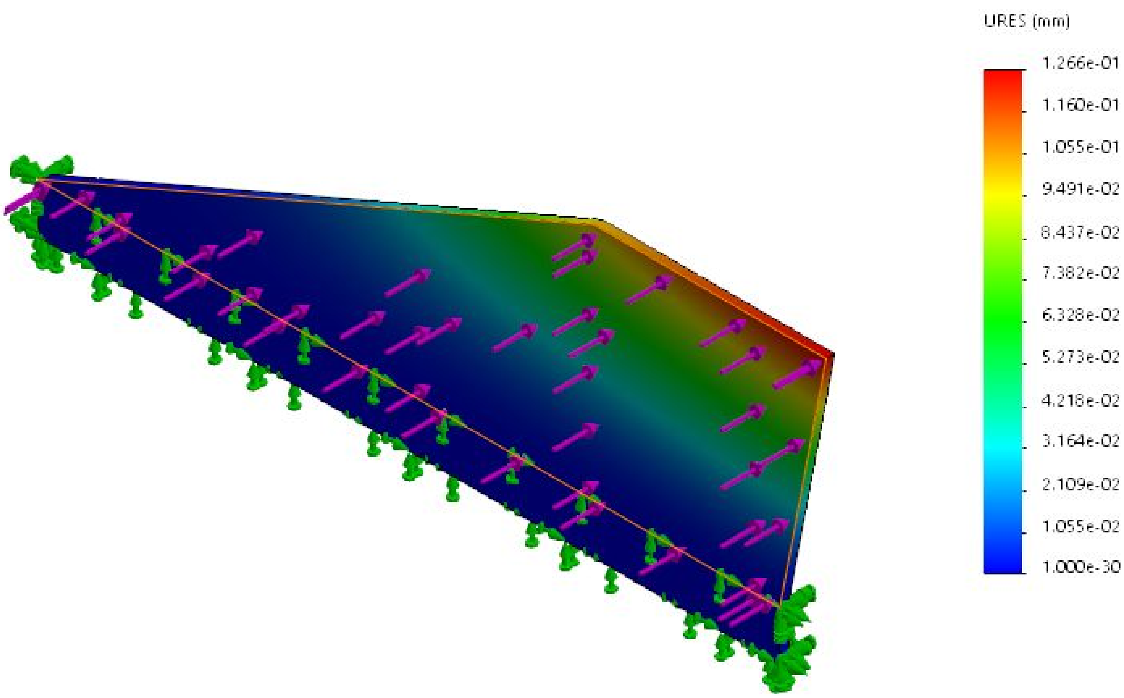
3.1.5. Design Integrity

3.1.5.1. Fin Shape and Style

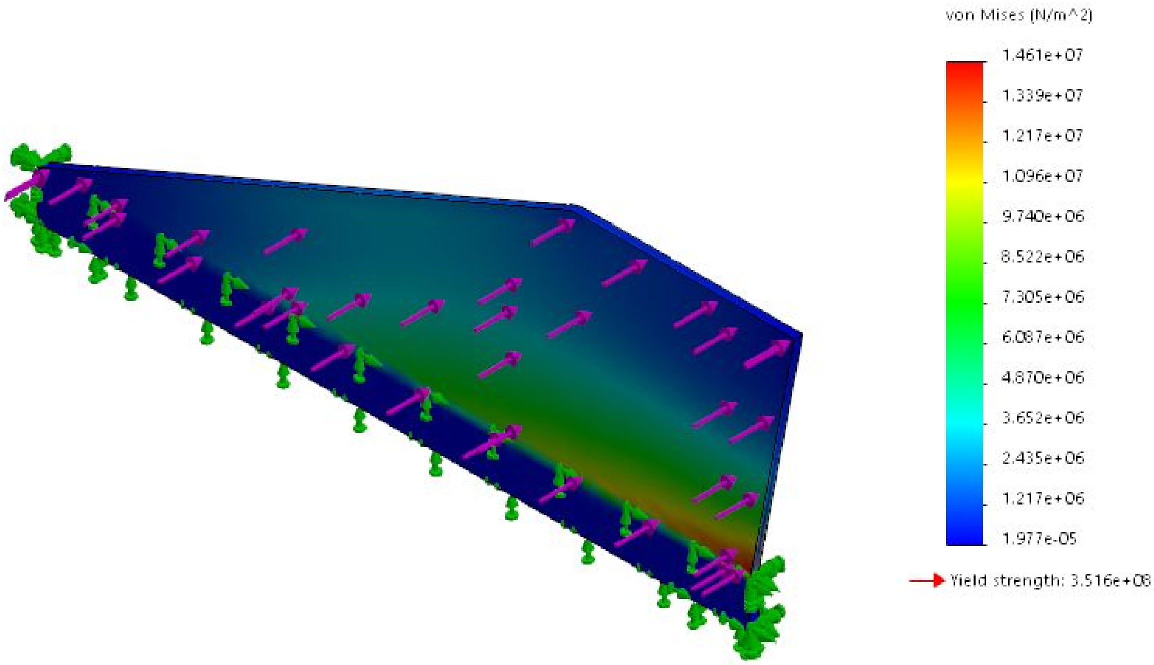
This year, we have decided to adopt the swept fin shape.The swept fin shape is an extremely common style in model rocketry, and is especially beneficial when stability is needed at higher speeds. The shape helps reduce drag by reducing the amount of acceleration over the wing. We combined this shape with a shallower sweep angle. This combination is 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. Material Use For Fins, Bulkheads, and Structural Members

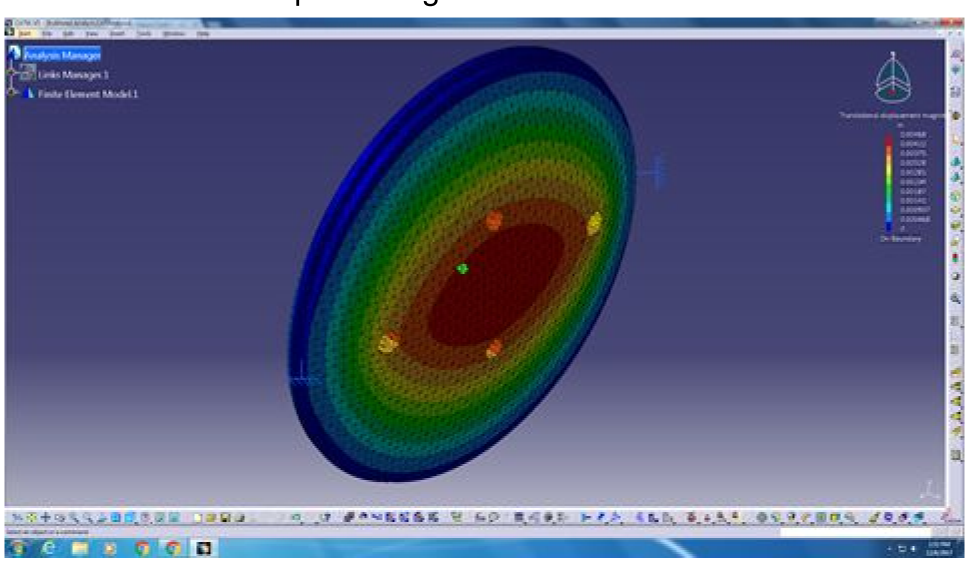
The validation of the shape and materials used for fins, bulkheads, and structural members of the rocket was completed using finite element analysis within SolidWorks 2017 and CATIA V5-6R2017. Each part was designed and given the appropriate material properties, such as Young's Modulus, Yield Strength, 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 2017, the material properties for the various fiberglasses is incomplete which causes the finite element analysis to run improperly. To mitigate this issue, the fins were done using 1020 steel, a material capable of being used as a backup and sufficient to test the effects of the force on the fins.



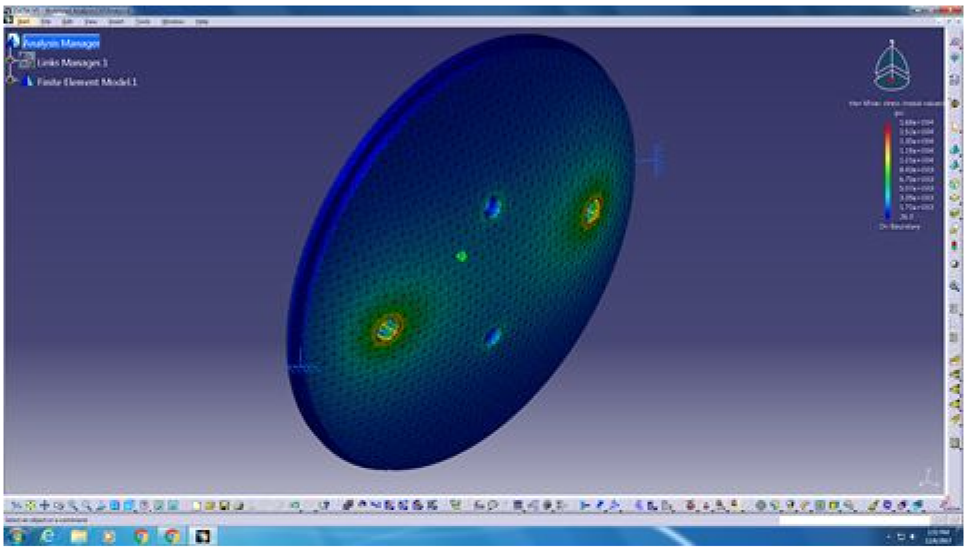
The figure above is a screen capture of the translational displacement of the rocket fin. The green arrows represent a fixed location on the part due to epoxy in this case. This mimics how the fin tab will be glued to the motor tube inside of the rocket, rendering it unable to move. At the top of the fin is a lateral distributed force of fifty foot 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 0.127 mm. This is shown by the area of red within the image, according the the color legend shown on the right.



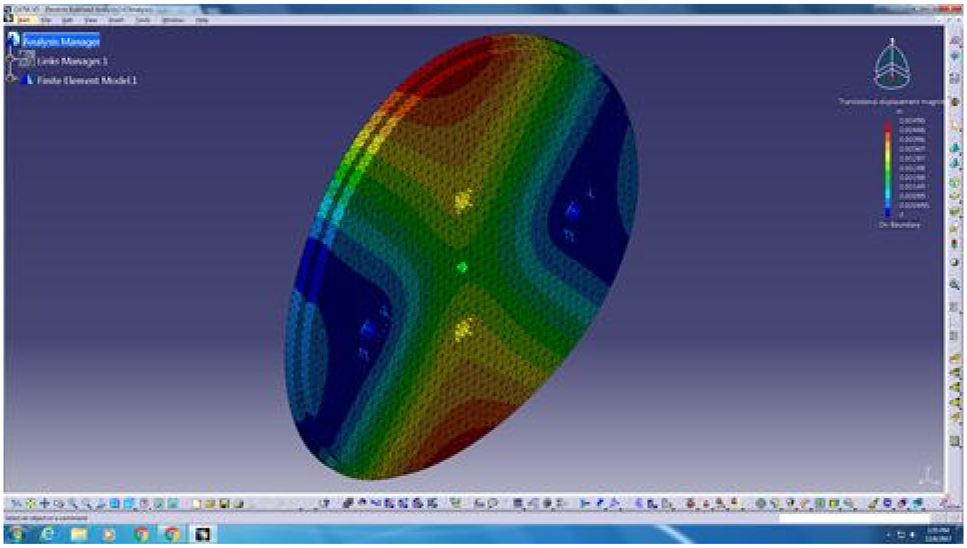
The image above is a screen capture of the Von Mises forces experienced by the vehicle's fin when exposed to the same clamping and displacement force as mentioned above. With these variables in place, the maximum expected stress within the component is simulated to be 14.61 MPa, located on the back edge 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 team has chosen the proper material and thickness for this component to withstand the expected flight forces.



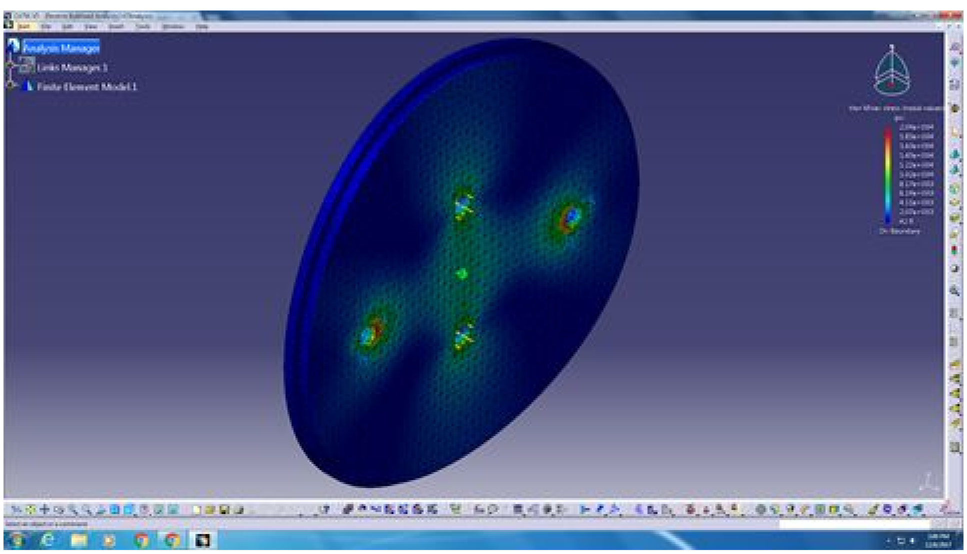
The figure above is a screen capture of the translational displacement of the rocket bulkhead when pulled against the coupling tube by the threaded rods that hold it in place within the rocket. On the perimeter of the bulkhead is a blue figure, representing a clamp on the part. A distributed force of five hundred 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 0.00468”. 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 1.68e+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 team has chosen the proper material and thickness for this component to withstand the expected flight forces.

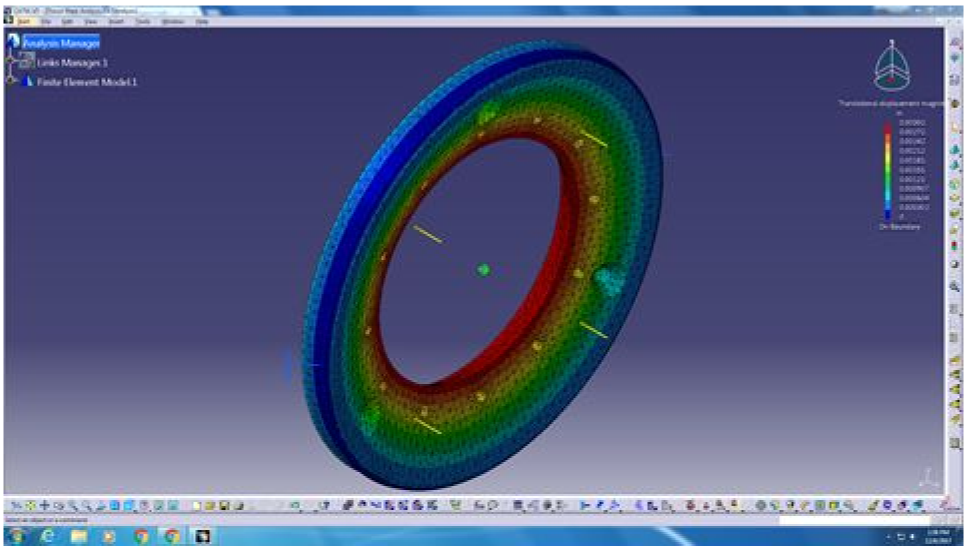


The figure above is a screen capture of the translational displacement of the rocket bulkhead when pulled on by the u-bolts that connect to the recovery harness. Within the holes that would accept threaded rods to hold the bulkhead in place is a blue figure, representing a clamp on the part. A distributed force of five hundred pounds was then applied to the holes that would accept the u-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 0.00495”. This is shown by the area of red within the image, according the the color legend shown on the right.

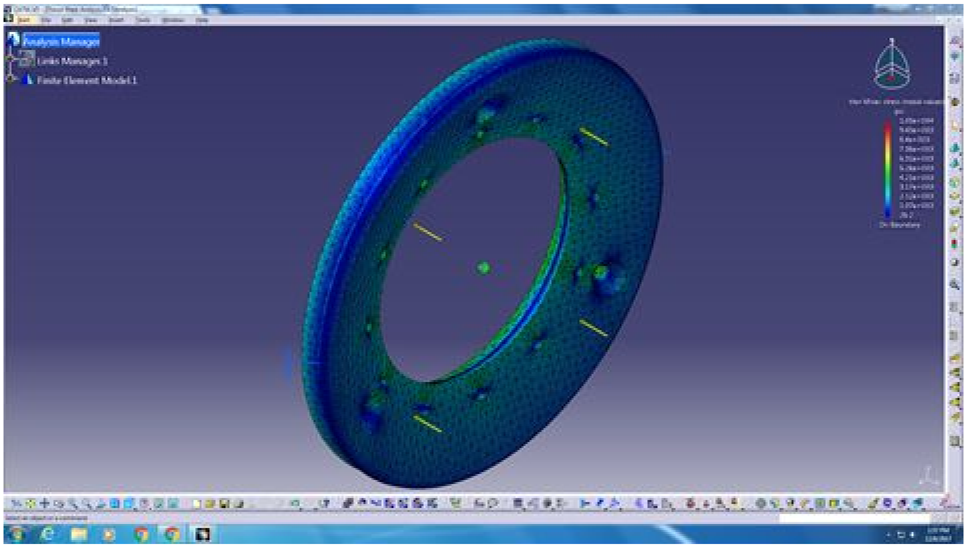


The image above is a screen capture of the Von Mises forces experienced by the vehicle’s bulkhead when exposed to the same clamping and displacement force as mentioned above. With these variables in place, the maximum expected stress within the component is simulated to be 2.04e+4 pounds per square inch, 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 team has chosen the proper material and thickness for this component to withstand the expected flight forces.

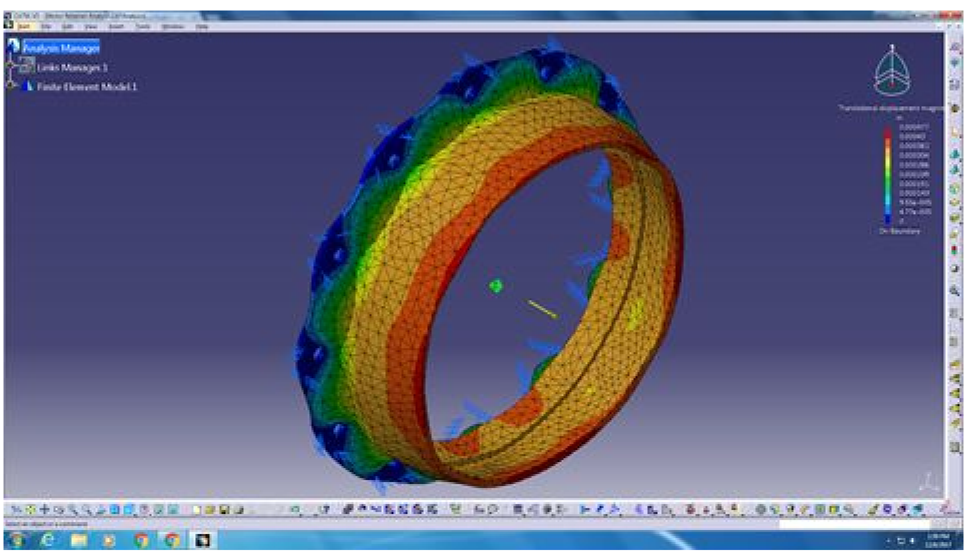
3.1.5.3. Motor Mounting and Retention



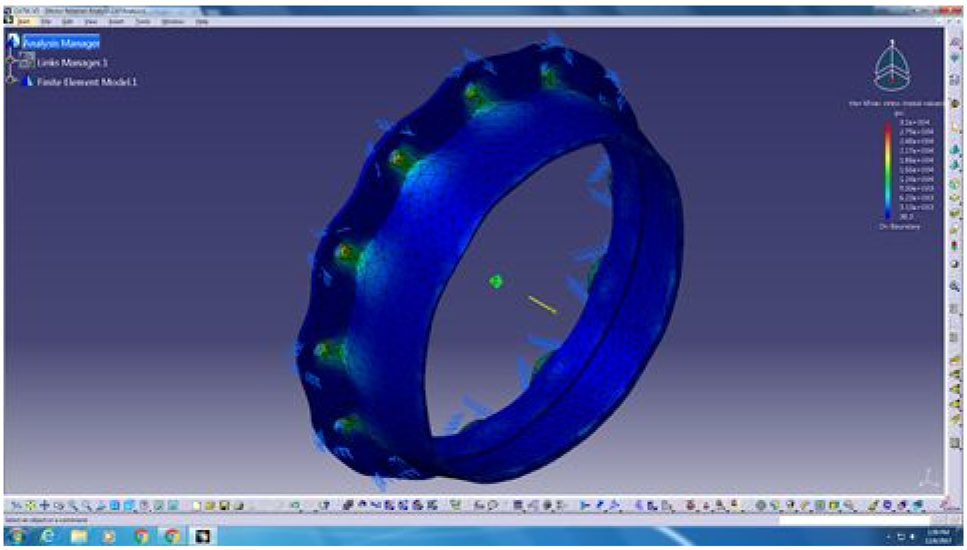
The figure above is a screen capture of the translational displacement of the rocket thrust plate when pushed against the airframe by the thrust of the motor that propels the rocket and held in place by three screws. On the perimeter of the thrust place is a blue figure, representing a clamp on the part. A distributed force of one thousand pounds was then applied to the face that would accept the motor retainer. With these settings, the maximum experienced translational displacement of the center of the plate is expected to be 0.00302”. 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 thrust plate 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 1.05e+4 pounds per square inch, located on the inner face of the plate and around the holes that accept studs to hold the motor retainer in place. This is below the yield strength of the material, meaning that the plate will not experience any deformation past the elastic range. This demonstrates that the team has chosen the proper material and thickness for this component to withstand the expected flight forces.



The figure above is a screen capture of the translational displacement of the rocket motor retainer when pulled on by the motor casing attempting to be removed from the motor tube by the force caused by parachute deployment. Within the holes that would accept studs to hold the retainer in place on the thrust plate is a blue figure, representing a clamp on the part. A distributed force of one thousand hundred pounds was then applied to the inner face that would contain the motor casing, mimicking the force pulling on the retainer against the studs. With these settings, the maximum experienced translational displacement of the center of the bulkhead is expected to be 0.000477”. 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 motor retainer 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 3.10e+4 pounds per square inch, located on the inside of the holes that accept the studs to hold the retainer in place. This is below the yield strength of the material, meaning that the plate will not experience any deformation past the elastic range. This demonstrates that the team has chosen the proper material and thickness for this component to withstand the expected flight forces.

3.1.5.4. Final Mass of Launch Vehicle and Subsystems

The final mass of the launch vehicle and subsystems, including the recovery gear, metal components, and structural members is expected to be approximately 27.5 pounds sans motor. The final flight ready mass of the launch vehicle, including ejection charges and the motor and motor hardware, is expected to be approximately 39.31 pounds. During descent, after all of the motor propellant has been expelled and ejection charges have been fired, the final descent mass of the launch vehicle is expected to be 35.23 pounds.

3.2. Subscale Flight Results

3.2.1. Recorded Flight Data

On our subscale flight, the Missile Works RRC3+ Sport was the primary altimeter and for redundancy the JollyLogic AltimeterOne. This allowed assurance that the team understood how the RRC3+ Sport operated and to verify that our 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 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 present 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

- A launch lug was used on the subscale which will not be used on the full-scale, as the full-scale will be using a launch rail and will have rail buttons

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 our 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 our 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 our launch, besides the wind. All of our data can be confirmed with WeatherUnderground.com, https://www.wunderground.com/history/daily/us/in/lafayette/KLAF/date/2018-12-5 and TimeAndDate.com, https://www.timeanddate.com/weather/usa/lafayette-in/historic.

3.2.4. Flight Analysis

3.2.4.1. Predicted Vs. Recorded Flight Data

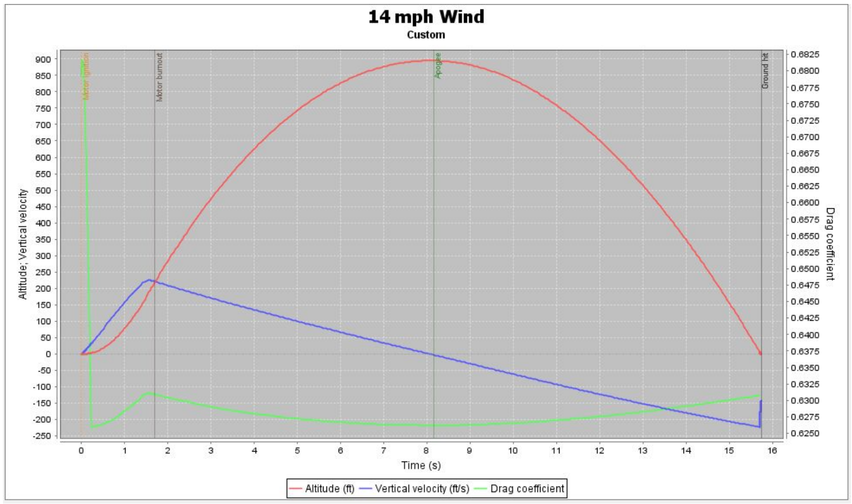
By creating a simulation of the subscale vehicle in OpenRocket, an estimated apogee of 950 feet was obtained. This is not far off from the data returned from the altimeters, which stated the rocket had ascended to an apogee of either 884 feet or 895 feet. It should also be mentioned that some initial 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 our rocket dealt with the fins. The fins were not completely straight and were not spaced out properly. Although this discontinuity did not fail our subscale launch, it was certainly something that needs to be addressed for our full scale rocket. Outside of our control was the wind. While we do have an idea of the average wind speed, the gusts at any given moment were hard to accurately measure. However, our 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, our 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. Recovery Subsystem

3.3.1. Chosen Design Alternatives From PDR

There were only minor changes that needed to be made from PDR. The first change made was two completely redundant systems (two external key switches, two altimeters, two batteries for each altimeter, and two sets of e-matches). The second change made from PDR was to increase the amount of 4Fg black powder in the redundant charge well by approximately 10-20%. The parachute, harnesses, bulkheads, and attachment hardware are all the same as presented during PDR.

3.3.2. Parachute, Harnesses, Fireproofing, Bulkheads, and Attachment Hardware

Our team has decided to use the Skyangle Cert 3 Drogue Parachute as a means of drogue recovery. Although it weighs more than some alternatives, occupies more volume, and has a lower drag coefficient, we chose it because it is cheaper and more robust. This choice of parachute is constructed of zero porosity, 1.9 ounce per square yard, silicone coated balloon cloth. Four shroud lines attach at the bottom to a 1,500 pound rated heavy duty, 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. Although it weighs more than some alternatives and occupies more volume, we chose it because it has a high drag coefficient and is cheaper and more robust than the Fruity Chute alternative from PDR. It is still sized to provide a slow enough landing so that that no section of the rocket touches down with more than 75 foot pounds of energy, as listed in the requirements. Furthermore, it adds more weight above the center of gravity than the Fruity Chute, increasing our margin of stability. The option our team chose is constructed of zero porosity, 1.9 ounce per square yard, silicone coated balloon cloth. Four shroud lines attach at the bottom to a 1,500 pound rated heavy duty, 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 2.59 and a surface area of 89.0 square feet. It will be attached to the tether via a ¼" stainless steel quick link that connects through the swivel and a loop in the shock cord. 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.

For the shock cords in our rocket our team has decided to use a 40' long section of ½" tubular kevlar. They are lightweight, fire resistant, volumetrically efficient, and have 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 our rocket. Each end will have a loop sewn into the fabric through which we can pass a quick link for easy attachment to the rocket. In addition, each individual tether, drogue and main, will have a loop sewn ⅓ of the length from the top. This will provide an attachment point for the parachute we will be using for recovery. The estimated mass of the tether, not including the mass of quick links that attach the shock cord to the rocket and parachute, is 0.5 pounds.

Our team decided to use the Nomex blankets 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 and attached directly to the parachute. As a result, we can tightly wrap the parachute inside of the material, as opposed to simply packing insulation around it, risking a gap in the fireproofing. Both the drogue and main parachute will be protected using this method, and both Nomex blankets will be 18” x 18” squares. We estimate that the total mass of both the drogue and main Nomex blankets is approximately 0.25 pounds.

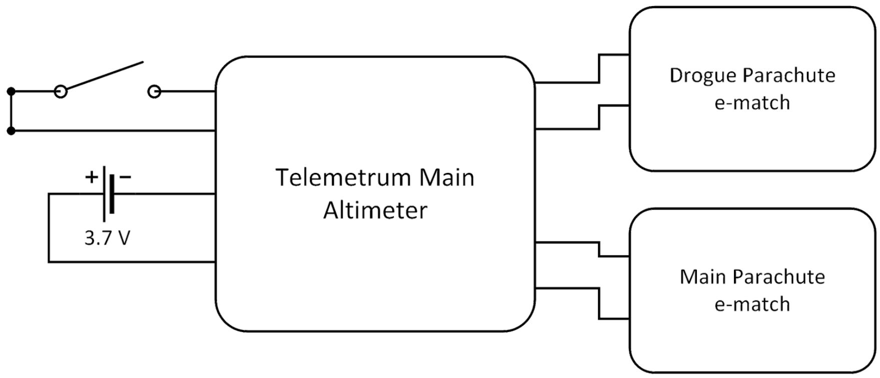
The bulkheads we will be using for the rocket will be constructed from 0.25”” thick G10 fiberglass, and contain five 0.25” holes. Two of these holes will be spaced 3.0” apart from center to center and will accept threaded rods that secure the bulkheads to the coupler tube. There will be one hole for an eye-bolt that attaches the rocket to the recovery tether. There will also be two holes for each charge well. These bulkheads will accept the shock of deployment and carry the weight of the rocket 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.

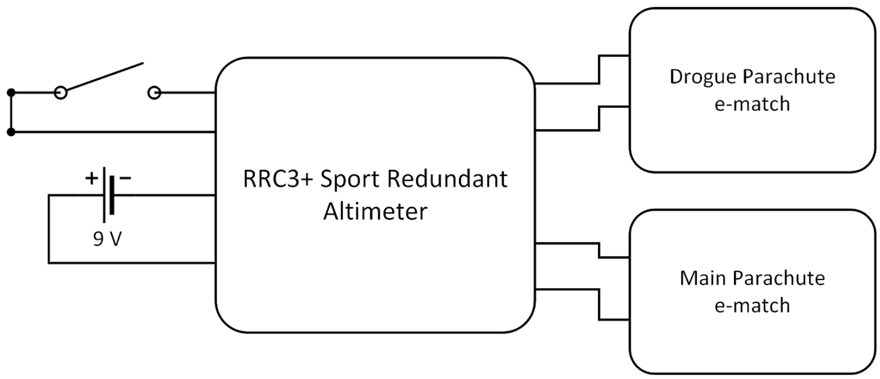
All attachment hardware, including nuts, bolts, washers, u-bolts, and quick links will be constructed from high strength stainless steel, either type 316 or 18-8 depending on availability and sourcing. These alloys were chosen for their exceptional strength, corrosion resistance, and general robustness. 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, and will be verified as the team procures components.

3.3.3. Avionics Components and Redundancy:

The avionics team decided on using the Telemetrum as our primary altimeter and GPS and the RRC3+ Sport as our secondary altimeter. To ensure the most redundant system, the two different altimeters operate using separate batteries. Telemetrum uses a 3.7V LiPo battery, while the RRC3+ Sport uses a 9V battery. To facilitate the separation of the launch vehicle in order to deploy the drogue and main parachutes, we decided on using black powder charges. The backup charge contains 15% more black powder than the primary charge.

3.3.4. Electrical Schematics





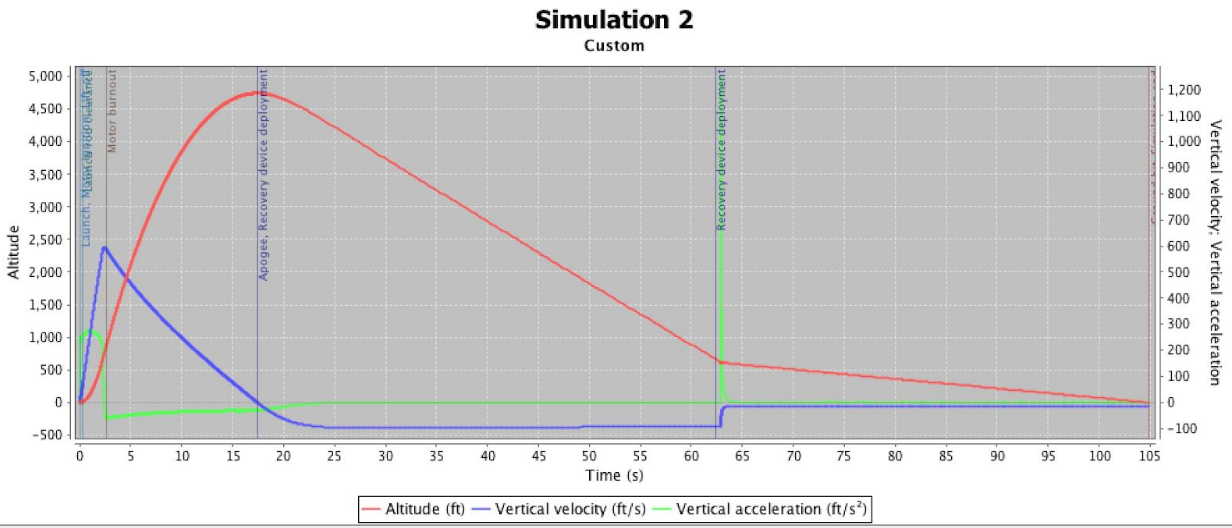
The two electrical schematics below show the electrical circuits for the Telemetrum main altimeter (top image) and the RRC3+ Sport redundant altimeter (bottom image). Each altimeter is powered by it’s own battery, and it turned on using its own switch. Each altimeter connects to e-matches for the drouge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

3.3.5. Locating Tracker Operating Frequency

The Telemetrum can be configured to communicate GPS data over a wide range of frequencies. It will be set to use the 434.550 MHz channel which is the frequency that is recommended on the Altus Metrum website. We are using the TeleBT in combination with the Arrow II Model 440-3 3 Element Yagi Beam antenna to communicate with the Telemetrum in flight.

3.4. Mission Performance Predictions

3.4.1. Altitude Predictions With Simulated Vehicle Data

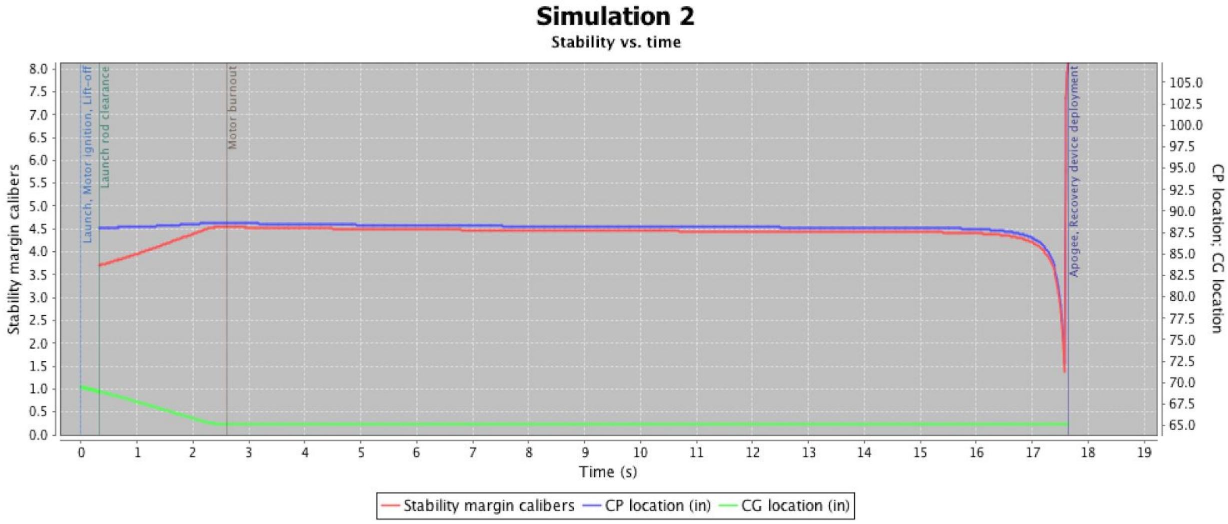


As can be seen from the graph above, our rocket is simulated to reach a maximum altitude of 4,853’ above ground level. This is under our target altitude of 4,950’ above ground level. Once our group has constructed our flight vehicle, we will have a more accurate weight measurement for the rocket that can then be entered into the simulation program. Because the rocket is anticipated to weigh more than the simulation shows, as weight is added into the computer model our ballast will decrease.

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

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

3.4.2. Stability Margins With CP/CG Relationships and Locations



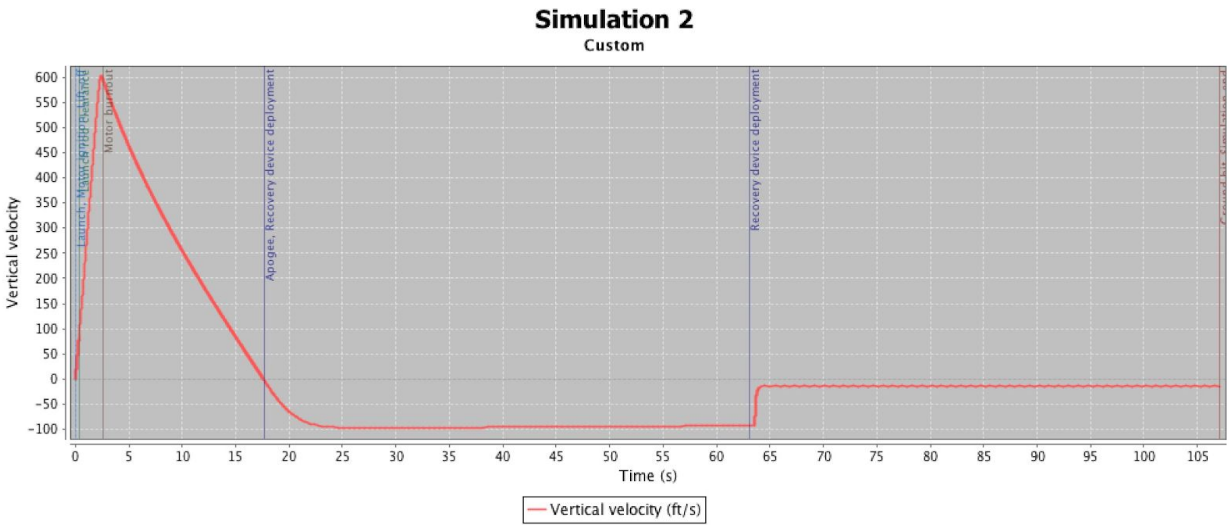
As seen from the graph above, the rocket exits the 144” long, 1.5” launch rail with a minimum stability margin of approximately 3.5 calibers, meeting the minimum requirement of 2 calibers. During the ascent phase, the rocket does not experience a significant drop in stability until it reaches a low enough 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.

3.4.3. Kinetic Energy At Landing

3.4.3.1. Graph Of Velocity Vs. Time



The figure above illustrates the vertical velocity of the rocket over time. The rocket accelerates quickly during boost and begins 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.

3.4.3.2. 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 14.3 pounds at touchdown. This will consist of the lower airframe and motor assembly, middle airframe, and drogue recovery gear. Assuming the landing velocity is still 10.3 mph, the landing energy for this section will be roughly 50.67 foot pounds.

3.4.3.3. 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 9.71 pounds at touchdown. This will consist of the avionics bay, upper airframe, and main recovery gear. Assuming the landing velocity is still 10.3 mph, the landing energy for this section will be approximately 32.3 foot pounds.

3.4.3.4. Nose Cone Kinetic Energy At Landing

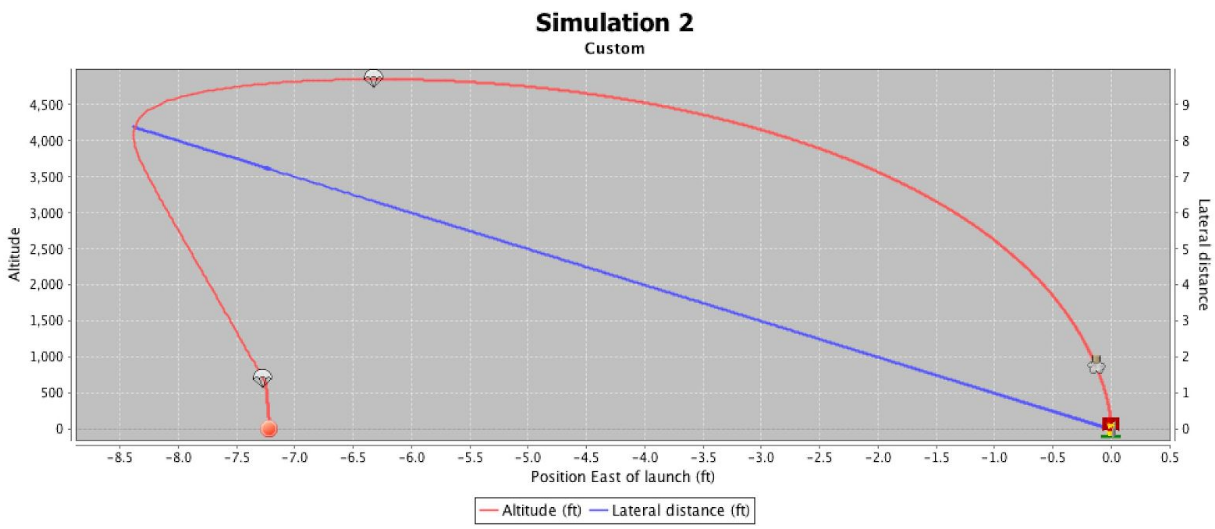
The nose section and payload section of the rocket that will be falling independently while remaining tethered to the remainder of the vehicle is expected to weigh 12.68 pounds at touchdown. This will consist of the nose cone, Multitronix Telemetry Pro, and nose coupler. Assuming the landing velocity is still eight and a half miles per hour, the landing energy for this section will be roughly 44.93 foot pounds.

3.4.4. Rocket Descent Time

The total descent time of the rocket is approximated to be 89.4 seconds in other words approximately a minute and a half. This calculation does not include time for ejecting of parachutes and reaction time.

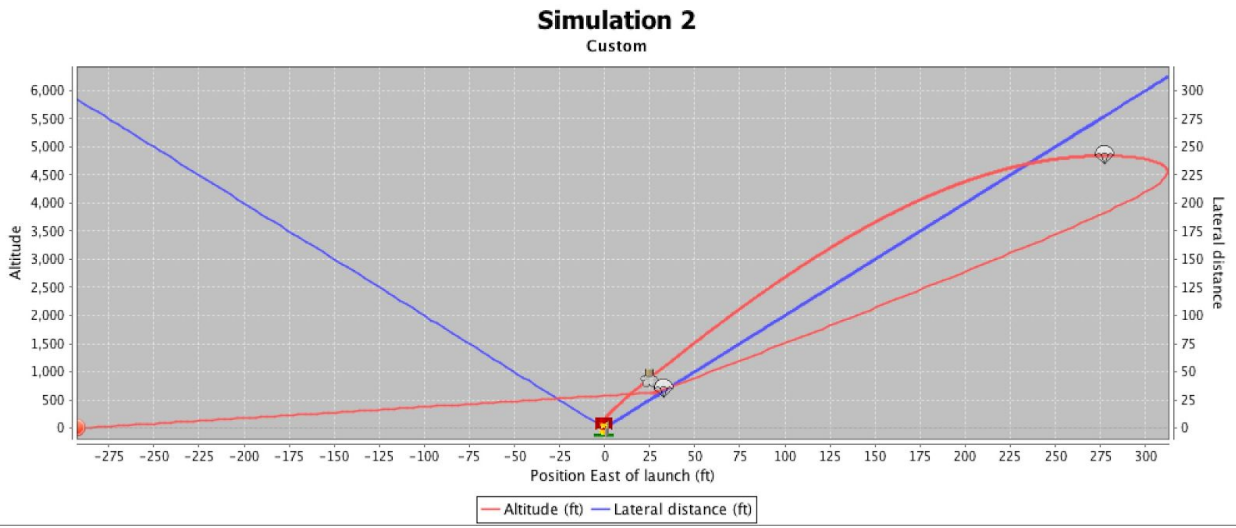
3.4.5. Drift Distance Calculations

3.4.5.1. 0 MPH Drift Distance Calculations



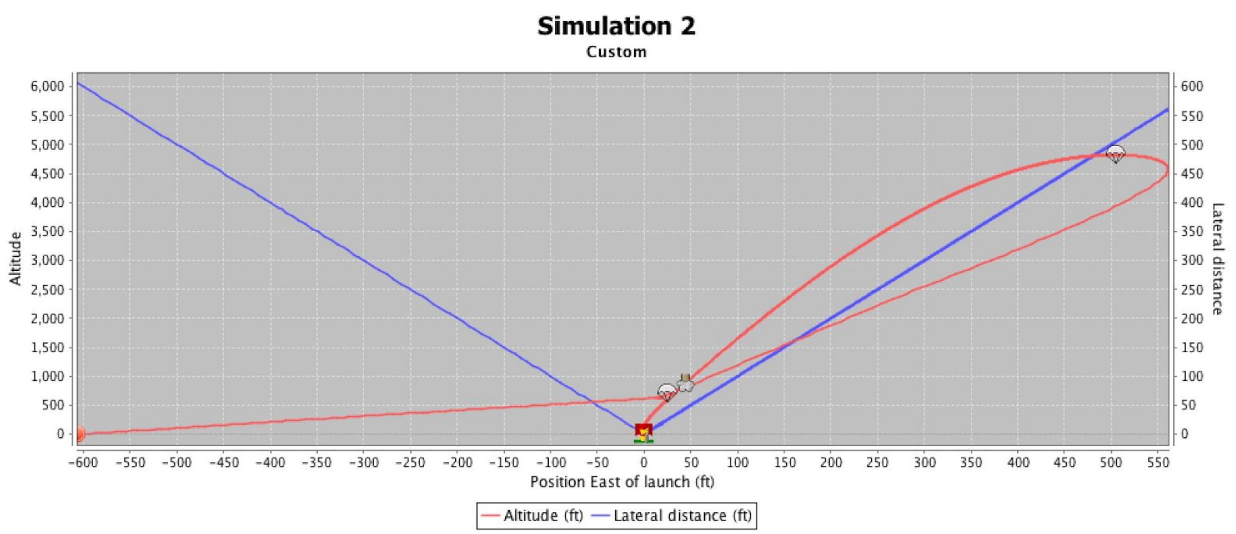
With an average wind speed of zero miles per hour with zero standard deviation and zero percent turbulence intensity, our simulated maximum drift distance during flight is nearly ten feet.

3.4.5.2. 5 MPH Drift Distance Calculations



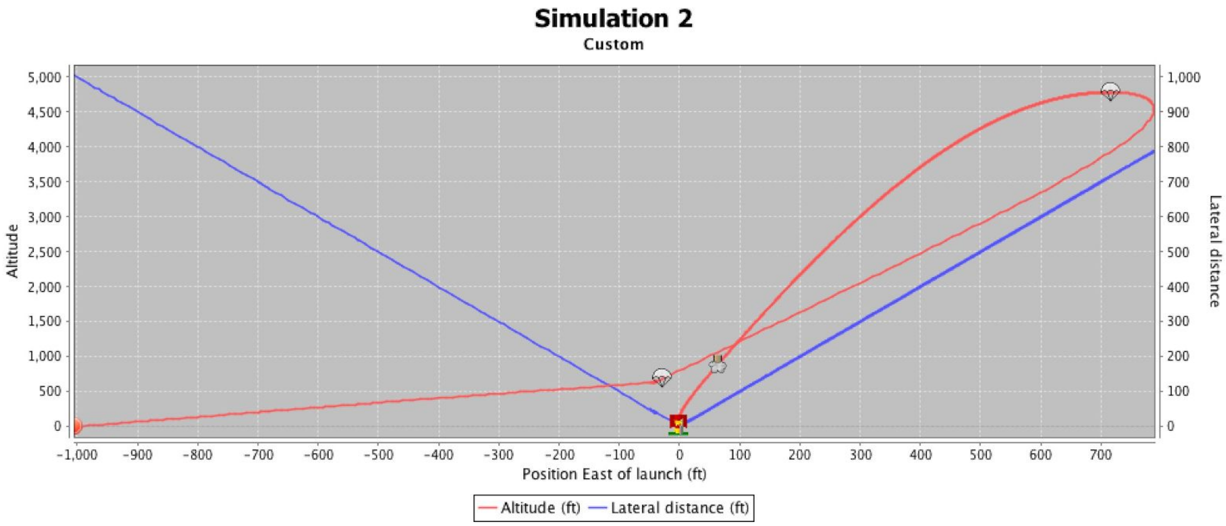
With an average wind speed of five miles per hour with 0.5 miles per hour standard deviation and ten percent turbulence intensity, our simulated maximum drift distance during flight is roughly 450’. The rocket travels nearly 225’ east of the launch site as it tilts into the wind, then drifts back over the launch site during recovery and continues heading west until touchdown 450’ west of the launch position.

3.4.5.3. 10 MPH Drift Distance Calculations



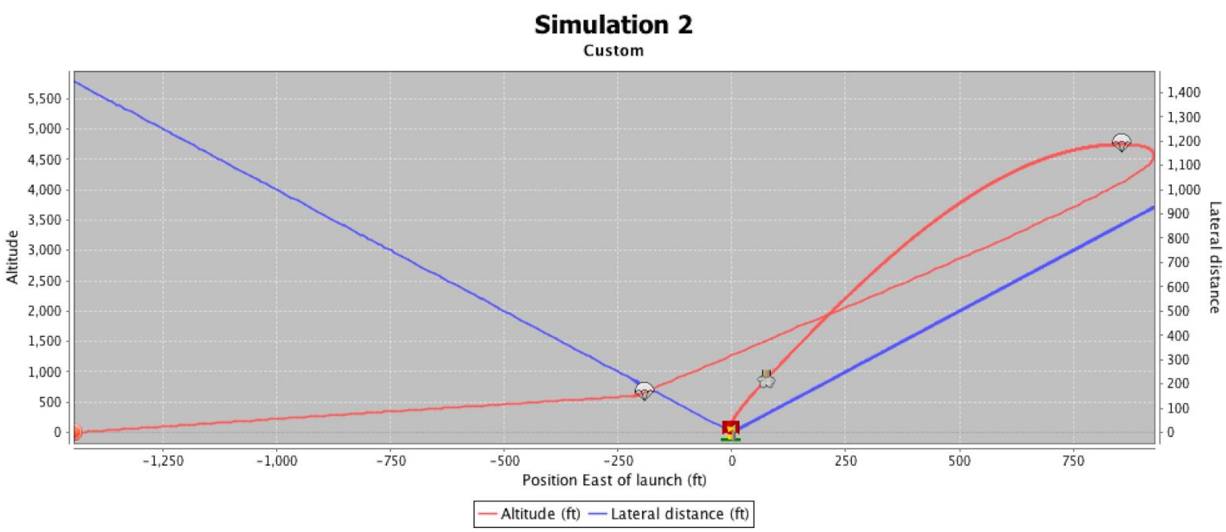
With an average wind speed of ten miles per hour with one mile per hour standard deviation and 10 percent turbulence intensity, our simulated maximum drift distance during flight is roughly 800’. The rocket travels nearly 575’ east of the launch site as it tilts into the wind, then drifts back over the launch site during recovery and continues heading west until touchdown 800’ west of the launch position.

3.4.5.4. 15 MPH Drift Distance Calculations



With an average wind speed of fifteen miles per hour with 1.5 mile per hour standard deviation and 10 percent turbulence intensity, our simulated maximum drift distance during flight is roughly 1,000'. The rocket travels nearly 800' east of the launch site as it tilts into the wind, then drifts back over the launch site during recovery and continues heading west until touchdown 1,000' west of the launch position.

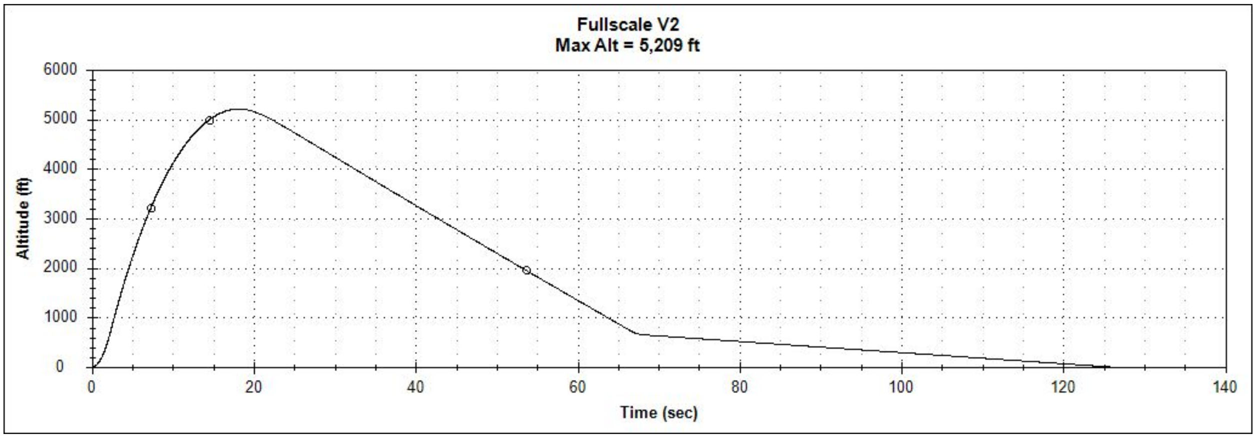
3.4.5.5. 20 MPH Drift Distance Calculations



With an average wind speed of twenty miles per hour with 2 mile per hour standard deviation and 10 percent turbulence intensity, our simulated maximum drift distance during flight is roughly 1,400'. The rocket travels nearly 950' east of the launch site as it tilts into the wind, then drifts back over the launch site during recovery and continues heading west until touchdown 1,400' west of the launch position.

3.4.6. RASAero Calculations

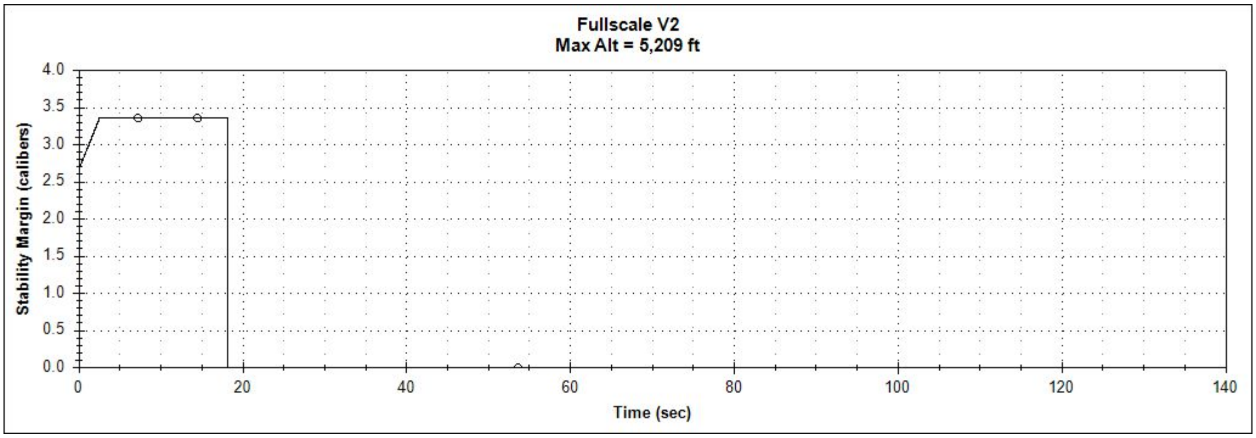
3.4.6.1. Altitude Predictions With Simulated Vehicle Data

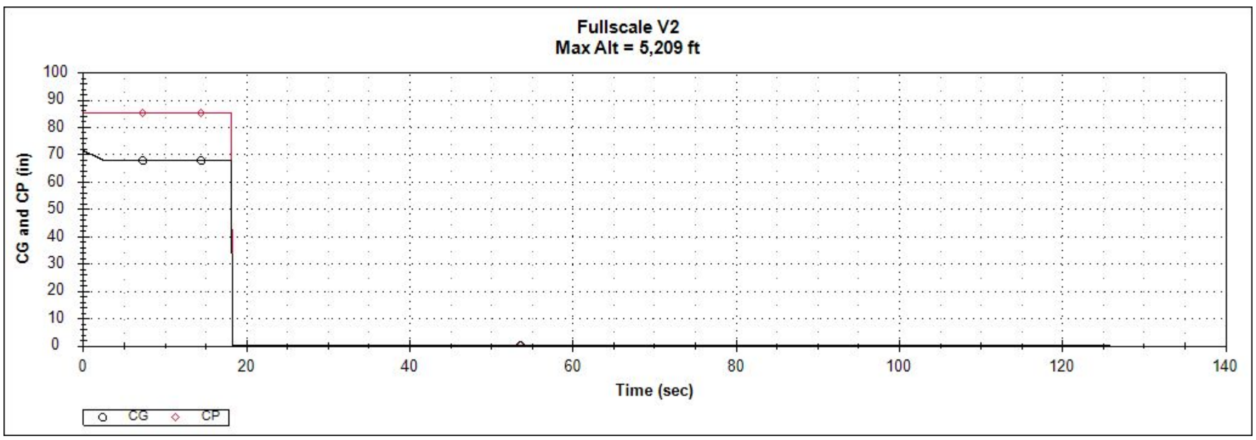


The graph above, which was produced using RAS Aero II, is a result of running an identical simulation as the team performed with OpenRocket 15.03. All simulation settings were the same, and the vehicle dimensions and metrics were input manually. As a result, the same rocket flying on the same motor is predicted to achieve a maximum altitude of 5,209 feet above ground level. This is an increase of 191' over the OpenRocket simulations, and a total of 259' over the target altitude of 4,950 ft. This is a significant difference, but the team believes that the chosen target is still valid and achievable.

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 in both programs as changes are made and weights are updated. In time, our group expects the difference in the models to decrease and approach the desired altitude of 4,950 feet.

3.4.6.2. Stability Margins With CP/CG Relationships and Locations

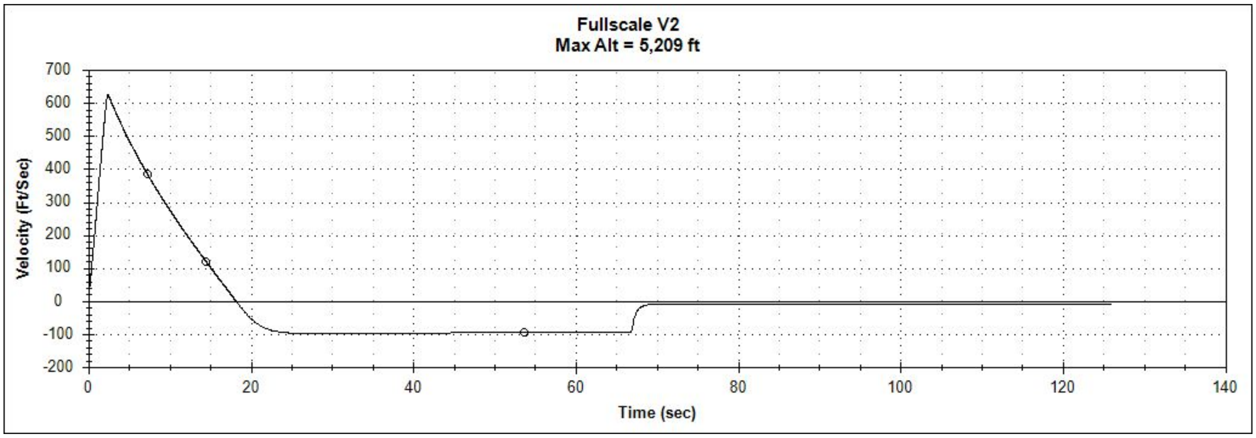




The stability margin graph shown above, produced using RASAero II, shows similar results to the stability curve produced in OpenRocket. The static stability is approximately 3.4 calibers, but is higher than the stability at the time of launch rail clearance which is estimated by OpenRocket to be around 2 calibers. OpenRocket does, however, calculate the static stability to be 3.38 calibers, so these estimates do in fact reinforce each other. Furthermore, RASAero predicts the stability during the coast phase to be approximately 4.5 calibers after expelling all of the propellant mass. This, again, is roughly equal to the stability predicted by OpenRocket.

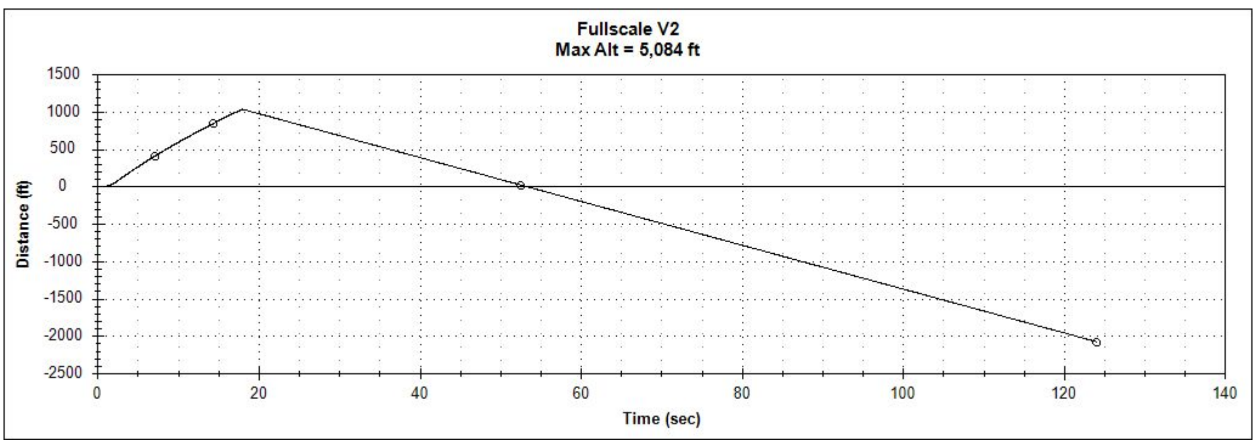
In addition, the location and change in both the center of pressure and center of gravity are approximately equal to those in OpenRocket 15.03. The center of gravity starts at 71” from the datum and moves nearly one full caliber forward. The center of pressure in OpenRocket started at around 81” from the tip of the nose cone and moved aft to approximately 90”, which is roughly equal to where RAS Aero II places the center of pressure during the flight simulation.

3.4.6.3. Kinetic Energy At Landing



The graph above was created using RASAero II and depicts the vertical velocity of our vehicle during the flight. Just as in OpenRocket, the terminal velocity during drogue descent is roughly 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.

3.4.6.4. Drift Distance Calculations



The image above shows the drift of our launch vehicle while flying in twenty mile per hour winds, similar to the drift model created in OpenRocket 15.03. The rocket originally drifts approximately 1,000’ 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 2,050’ past the point of origin. The total drift distance of 3,050’ is 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 RAS Aero 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 5,209’, but only reaches 5,084’ when factoring wind and tilting.

3.4.7. 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 we mature our computer simulations to match our real world 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.

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, and all inexperienced flyers will receive an additional briefing about basic launch safety (e.g., not standing immediately next to the launch pad as the launch control officer prepares to ignite the propellant situated on top of it).

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

Briefings will cover the following topics and more:

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

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 to maintain a reminder of potential threats or concerns. All lab equipment will be labeled with the basic safety protocols associated with its use, including any PPE required to operate it, and all hazardous materials will be stored in labeled containers.

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

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

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

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

4.4. Launch Concerns and Operation Procedures

4.4.1. Draft Of Final Assembly and Launch Procedures

4.4.1.1. 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 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
- Leave no trace during retrieval to minimize pollution from team members

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. 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. 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
- 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
- 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, 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 so unwary passerby do not get involved with them. Apply the same safety procedures to these parts one would with the rocket as a whole
- Do not forget to also check the launchpad for damage, nor to 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

4.4.1.2. 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 fight
- 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 suppliers instructions, general guidelines for motor preparation are as follows:

- Double check to ensure the motor is proper for the desired flight profile and certified by NAR, Tripoli, or CAR.
- 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, and 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.

4.4.1.3. Setup On The Launch Pad

General Information:

- 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 proper for launch before beginning setup. Check hazard analysis and contingency plans for all conditions which mean you should not 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 if one arises. Also 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 minimal threats from passerby, weather, wildlife, man-made structures, or dangerous terrain

During setup:

- Ensure the ground is stable 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
    - Check for additional abrasions or other damage as well 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) 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
- 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. 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, as any of these issues could 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

4.4.1.4. 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 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.

4.4.1.5. Troubleshooting

If any of these procedures/checklists should skip a step, numerous of the hazards provided in the analysis below may occur other than those mentioned.

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. Attempt to find a planned machine to use as a backup 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, store the rocket indoors, be aware that humidity might be the cause of the expansion
- Part failure, loss, or damage: Run simulations of the rocket’s flight as well as stability and load-bearing tests 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, ensure the rail itself was set up using instructions which came with the product

Aerodynamics:

- Adverse effects from drag: Ensure the appropriate amount of shear pins, fasteners, and vent holes are being used
- 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 physical center of gravity and compare it to the calculated center of pressure. Run simulated stability tests. Make changes as necessary to increase the stability margin by adding ballast or changing 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 between flight
- Arming system failure: Consult the manufacturer’s instruction manual, ensure the system is undamaged and communicating properly with the team before initiating the next flight
- Overheating of avionics or payload: Ensure the avionics bay and payload are properly thermally insulated. If they are not, take efforts to insulate them with putty. Ensure the avionics bay and payload are not overloaded with wiring, as this can cause overheating and even fire hazards
- Inappropriate or no 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 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, overly wet atmospheric conditions may have caused this. 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 spacing between the ejection charges and parachutes is proper, 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 holding the stages together is not excessive, and check for altimeter failure
- Shock cord issues: 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 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, attempt to help team members prevent their semester schedules from being too strenuous by giving them quality advice
- 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 a warm drink which does not have alcohol or caffeine in it. 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 you should not attempt to move the affected person
- Electrocution: Call medical personnel immediately. Separate the person from the electric source by turning its power off or standing on a non-conductive object and using another non-conductive object to remove the person from the source. Do not try to separate the person from current with a high-voltage source if you feel a tingling sensation in your legs and lower body. Hop on one foot to a safe place where you can wait for a power company or emergency personnel to disconnect the 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 swallowed, call the poison hotline immediately at (800) 222-1222. If a dangerous situation persists after washing the area with water, call 911.

4.4.1.6. 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

- Before beginning inspection, it may be necessary for competition officials to verify the results of the launch. Be aware of this
- 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 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
- 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:

- 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 or bending
- 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 or bending
- 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 it has accumulated. Ensure this waste is disposed of safely
- Once the launch pad has been checked for damage and cleaned properly, it may be taken down and prepared for safe transportation

4.5. 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:

4.5.1. 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.

4.5.2. Impact of Event

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

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

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

Category	**Negligible**	**Minor**	**Moderate**	**Major**	**Disastrous**
Remote	1	2	3	4	5
Unlikely	2	4	6	8	10
Possible	3	6	9	12	15
Likely	4	8	12	16	20
Very Likely	5	10	15	20	25

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

For all subsequent safety tables, the hazards, likelihood, severity, risk, mitigation, and verification will be considered, in addition to consideration of occurrence. Verification and mitigation will be different in that verification will to be to prove a control is in place while mitigation is the intended plan to control a situation. Final verifications will exist by showcasing design, analysis, testing, PPE/procedures, or another reference. These analyses shall help demonstrate the collective understanding of all components needed to complete the project and how risk/delays impact the project. Each verification will include strictly following the mitigation as a procedures/checklist in order to lower the risk. Verifications will use an 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 with different criteria whereas there is verification by testing, analysis, inspection, and demonstration. 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.

4.5.3. 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	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 location	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 before required; ensure after parts are received are in designated safe location from checklist	Low
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	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

				work		
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	3 (Loss of labor force, team members lose knowledge of what is	3, Low	Organize and budget for transportation early and keep track of dates on	Have list of team members going and have list of maximum transportation amounts; make sure permanent	Low

	project members to launch sites or workplace)	happening with the project, low attendance to the final launch)		which large amount of transportation are needed	funding exists for transportation; utilize an attendance roster well in advance before travel	
Design Flaw	2 (Program logic error, improper data entry, oversight)	5 (Inability to complete objectives or construct vehicle)	10, Medium	Collaborate and share design files for peer evaluation; 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, inability to construct vehicle)	10, Medium	Train all members to work in all areas necessary; have an organized group of subteams within the project and obtain updates from subteam leaders weekly	Utilization of work time table; 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
Low Availability of Personnel	2 (Classes become extremely involved, other extracurriculars have events which cannot be skipped)	2 (Labor shortages, low attendance, specific responsibilities of absent team members are overlooked)	4, Low	Determine who has time to complete tasks and declare those members responsible, ensure the schedule and deadlines are known by all team members so they	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

				can work around them, have team members prevent their semester schedules from being too strenuous		
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 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 in the designated area accessible only by team members	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	Low
Improper Transit Availability for Rocket	1 (No safe way to transport the subscale rockets or final rocket to the launch site)	5 (Failure to launch)	5, Low	Organize rocket transportation well in advance; ensure transportation can be sent to rocket location and capable of fitting rocket	Ensure transportation is set in advance and known to have transportation	Low
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 (Unreasonabl e expectations	1 (Slight delay in project progress)	1, Minimal	Do not expect a large amount of progress over breaks and	Purdue Academic Calendar known in advance; ensure team leads are active over	Minimal

	of team members)			holidays, as members will likely be busy and/or distanced from the designated workplace	break and have longer meeting once break is over to complete what must have been completed	
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

4.5.4. 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 assemblee 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	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	Medium

				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	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	
Burns From Motor Exhaust	2 (Close proximity to launch pad)	3 (Mild to moderate burns)	6, Low	Clean the launchpad before use, ensure all members are wearing proper PPE for launch, ensure all team members are an appropriate distance from the launch vehicle when launching and maintain minimum safe launch distances	Ensure 200 feet border 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	Low
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; 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 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
Dehydration	3 (Failure to drink adequate amounts of water)	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	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

				for at least 15 minutes and get emergency		
Dust or Chemical Inhalation	3 (Airborne particulate debris)	3 (Short to long-term respiratory damage)	9, Medium	Wear appropriate PPE or respirator; work in well ventilated 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 Matches Misuse	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	Ensure labelled and 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	Strictly follow the 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	Medium
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; 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	No contact allowed without call out before use to make sure PPE worn; make sure rules	Low

					followed as set forth by machining rules and checked by personnel supervising	
Epoxy Contact	3 (Resin spill, resin contact during application or while drying)	3 (Exposure to Irritant)	9, Medium	Wear appropriate PPE such as gloves or lab coats; wash with water and alert safety; work in well ventilated and visible but isolated area; have epoxy cleanser, soap, and water available with use	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
Eye Irritation	3 (Airborne particulate debris)	2 (Temporary eye irritation)	6, Low	Wear appropriate PPE or protective eyewear; such as 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	Team members must have adequate clothing, safety team will report violators to the project lead to decide if the violator should be dismissed to a colder area with enough space	Low

				appropriate PPE	predetermined for entire group; water will be provided	
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 anywhere in vicinity of workshop	PPE check must be done by a safety team member before conducting construction or explosive testing; stay behind cover to avoid shock waves from explosion testing; rules must be known before to use in addition to mandatory supervision to ensure proper use and safety	Low
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	Ensure people scheduled to attend have been mandatorily briefed on the temperature and rocket; ensure team members must have adequate clothing, safety team will report violators to the project lead to decide if the violator should be dismissed to a warmer area 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 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	Make sure area is evacuated and designated individuals are to recover components at a designated time when	Low

				procedures when handling batteries, e-matches, and other potentially combustible materials	determined to be safe; no contact allowed without call out and PPE; ensure PPE protocols are followed at all times;	
Injury from Ballistic Trajectory	3 (Recovery System Failure)	5 (Severe Injury, Death)	15, High	Keep all eyes on the launch vehicle and call “heads up” if needed	Make sure area is evacuated and individuals are 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	Medium
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	5 (Severe injury, death, cuts, burns,	15, High	Follow all launch safety procedures, stay out of rocket	PPE check must be done by a safety team member before	Low

	components, etc.)	etc)		safety circle, inspect rocket launch parts such as launch guide and motor casing, follow NAR/TRA safety code requirements, have first aid kit present	conducting launch; team members must guarantee someone is there to watch and ensure safety of each other; follow written procedures and checklists	
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 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 an appropriate distance from the launch vehicle when launching	Make sure area is evacuated and designated individuals are to recover components at a designated time when determined to be safe; no contact allowed without call out before use to make sure PPE worn; follow procedures to make sure launchpad clean and members past minimum distance	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	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	Low

				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; all MSDSs are available to the team at all times and are required to be understood before working with potentially hazardous materials	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 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 shoes that cover the toes / wear appropriate PPE; 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, wear shoes that cover the toes / wear appropriate PPE; 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	Medium

					designated by machining rules	
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 only occur on launch pad and otherwise avoid contact	Deemed unsafe to arm electronics until prior to ignition; allow no possibility of ignition until launch by keeping separately secured from team; no contact allowed without call out before use to make sure PPE worn	Low
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 (Carelessness)	4 (Possible Hospitalization)	12, Medium	Secure loose hair, clothing, and jewelry; wear appropriate PPE; 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-approved respiratory equipment must be worn in situations	No contact allowed without call out before use to make sure PPE worn; PPE check must be done by a safety	Medium

				where airborne particle debris will be present as the result of a construction or fabrication process with limited ventilation; work in well ventilated and visible but isolated area; have safety supervision or previous experience	team member for dust mask; area must be away from others and be ventilated; must have safety supervision or previous experience as instructed through 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, wear shoes that cover the toes / wear appropriate PPE; 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	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	Medium

				permit and is supervised by the safety lead	during handling by a safety team member before and during use	
Workplace Fire	2 (Unplanned ignition of flammable substance, through an overheated workplace, improper use or supervision of heating elements, or improper wiring)	5 (Severe burns, loss of workspace, irreversible damage to project)	10, Medium	Have fire suppression systems nearby, prohibit open flames, and store energetic devices in Type 4 magazines	Make sure workplace has updated fire safety protocol; in case of a fire, ensure that the workplace had updated fire suppression systems nearby	Medium

4.5.5. 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, make use of reliable building techniques, confirm analyses with test launches	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
Failure To Launch	2 (Lack of continuity)	1 (Recycle launch pad)	2, Minimal	Check for continuity prior to attempted launch	Ensure continuity checked by checklist
CATO	1 (Motor defect, assembly error)	5 (Partial or total destruction of vehicle)	5, Low	Inspect motor prior to assembly and closely follow assembly instructions	Ensure motor inspected by checklist during test runs and launch
Instability	1 (Stability	5 (Potentially	5, Low	Measure physical center of	Use a construction

	margin of less than 1.00)	dangerous flight path and loss of vehicle)		gravity and compare to calculated center of pressure	checklist which ensures the center of gravity has been measured and simulated and these measurements have been compared; these measurements should be made available to the entire team
Motor Expulsion	1 (Improper retention methods)	5 (Risk of recovery failure and low apogee)	5, Low	Use positive retention method to secure motor	Ensure motor secured by checklist during test runs and launch
Premature Ejection	1 (Altimeter programming, poor venting)	5 (Zippering)	5, Low	Check altimeter settings prior to flight and use appropriate vent holes	Ensure altimeter set by checklist during test runs and launch
Fin Loss or Damage	1 (Poor construction or improper materials used, faulty aerodynamic modeling, damage after landing from previous flights)	5 (Partial or total destruction of vehicle, ballistic trajectory)	5, Low	Use appropriate materials according to extensive mathematical and physical flight analyses, make use of reliable building techniques, run stability tests, confirm analyses with test launches, check to make sure the fins are still in good condition before launches - especially if launching the same rocket twice	Use a construction checklist which ensures mathematical analyses match physical analyses, if fins do not perform well in test launches perform another test launch with new fins before converting to full-scale, and use the launch checklists to ensure both before and after launch that the fins are in good condition
Loss of Nose Cone	1 (Poor construction or improper materials used)	5 (Partial or total destruction of vehicle)	5, Low	Use appropriate materials and high powered building techniques	Ensure that nose cone is secured well before ejection during test runs, otherwise alter
Loss of Parachute	3 (Poor construction or improper materials used)	5 (Partial or total destruction of vehicle)	15, Medium	Use appropriate materials and high powered building techniques	Ensure that parachute is secured well before ejection during test runs, otherwise alter to lower speed
Ejection 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	Test charge before final launch to ensure that charge does not fail
Altimeter	3 (Loss of	5 (Ballistic	15,	Secure all components to their	Ensure altimeter works

Failure	connection or improper programming)	trajectory, destruction of vehicle)	High	mounts and check settings	with prior tests
Payload Failure	3 (Electrical failure, program error, dead battery)	4 (Disqualified, objectives not met)	12, Medium	Test payload prior to flight, check batteries and connections	Ensure that payload is fully functioning prior to flight by conducting tests
Heat Damaged Recovery System	2 (Insufficient protection from ejection charge)	4 (Excessive landing velocity)	8, Medium	Use appropriate protection methods, such as Kevlar blankets	Ensure (prior to final launch) that proper materials are readily working and available in case heat damage occurs
Broken Fastener	1 (Excessive force)	5 (Ballistic trajectory)	5, Low	Use fasteners with a breaking strength safety factor of 2	Ensure by design and testing that secure
Joint Failure	1 (Excessive force, poor construction)	5 (Partial or total destruction of vehicle, ballistic trajectory)	5, Low	Use appropriate joint design according to extensive mathematical and physical flight analyses, make use of reliable building techniques, confirm analyses with test launches	Ensure by design and testing that secure
Centering Ring Failure	1 (Excessive force from motor, poor construction)	5 (Partial or total destruction of vehicle, ballistic trajectory)	5, Low	Use appropriate centering rings according to extensive mathematical and physical flight analyses, make use of reliable building techniques, confirm analyses with test launches	Ensure by design and testing that secure
Motor Mount Failure	1 (Faulty motor or motor mount preparation, poor construction, damage to motor mount)	5 (Partial or total destruction of vehicle, ballistic trajectory)	5, Low	Use mathematical and physical analyses to ensure the motor mount works as planned, test the motor mount with subscale flights, check the motor mount for damage before flight, team members who prepare the motor must be supervised by at least one other team member	Ensure by design and testing that secure
Destruction Due To Drag Forces	1 (Poor construction or improper materials used)	5 (Partial or total destruction of vehicle)	5, Low	Use appropriate materials and high powered building techniques	Ensure that proper materials are being used to construct the vehicle securely, so that destruction due to drag forces does not occur

Airframe Zipper	2 (Excessive deployment velocity)	5 (Partial destruction of vehicle)	10, Medium	Properly time ejection charges and use an appropriately long tether	Ensure by design, simulations, and testing that secure
GPS Lock Failure	2 (Interference or dead battery)	5 (Loss of vehicle)	10, Medium	Ensure proper GPS lock and battery charge before flight	Verify that GPS lock and battery charge are properly secured
Excessive Landing Speed	3 (Parachute damage or entanglement, improper load)	5 (Partial or complete destruction of vehicle)	15, High	Properly size, pack, and protect parachute	Ensure that parachute is well secured in on the aircraft and that it opens as planned; test the parachute before final launch
Battery Overcharge	3 (Unsupervised/undocumented charge)	3 (Destruction of battery)	9, Medium	Ensure batteries are documented and supervised if charging	Ensure alarms set and other individuals are aware batteries charging
Battery Puncture	2 (Landing damage)	5 (Partial or complete destruction of vehicle)	10, Medium	Ensure design has sufficient distance / protection from outside, and motor, charges, and batteries	Ensure by design and testing that secure from other systems or puncture
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	Ensure by design and testing that secure from other systems or puncture
Charge ignition close to motor	3 (Poor design location leads to damage)	5 (Partial or complete destruction of vehicle	15, High	Ensure design has sufficient distance / protection from motor, charges, and batteries	Independently ensure design is safe; ensure by isolated testing charge may work
Destruction of Bulkheads	1 (Poor construction or improper bulkheads chosen which cannot withstand launch forces, faulty stress modeling)	5 (Partial or total destruction of vehicle, ballistic trajectory)	5, Low	Use appropriate materials according to extensive high-stress mathematical and physical analyses, make use of reliable building techniques, run stability tests, confirm analyses with test launches	Ensure by design and testing that secure
Destruction of Nose Cone	1 (Poor construction, damage from previous flights, poor storage, or transportation)	3 (Lower rocket stability, possible deviations from flight path)	3, Low	Check the nose cone for damage before and after each launch, choose a nose cone which is strong enough to withstand launch forces according to mathematical and physical flight simulations,	Ensure by design and testing that secure

				confirm choice of nose cone with subscale launches	
Motor Tube Angled Incorrectly	1 (Poor construction, damage from previous flights, poor storage, or transportation)	3 (Lower rocket stability, rocket does not follow desired flight path well)	3, Low	Ensure proper measurements and alignments are made during construction, ensure there is no rush to attach the motor tube, double-check the alignment of the motor before each flight, test that the desired motor alignment is correct with subscale flights	Ensure by design and testing that secure
Motor Tube Comes Loose	1 (Poor construction, damage from previous flights, poor storage, or transportation, faulty motor preparation)	5 (Ballistic trajectory, catastrophic destruction of vehicle)	5, Low	Check the motor and motor tube for damage before each launch, run mathematical and physical flight simulations to ensure the tube performs as planned, confirm simulations with subscale launches	Ensure by design and testing that secure
Component Destruction Due To Drag Forces	1 (Poor construction or improper materials used)	5 (Partial or total destruction of vehicle, ballistic trajectory)	5, Low	Use appropriate materials according to mathematical and physical analyses, make use of reliable building techniques	Ensure by design and testing that secure
Premature Stage Separation	1 (Premature ejection, poor choice of shear pins or fasteners)	5 (Possible recovery failure and damage to or loss of vehicle, ballistic trajectory)	5, Low	Check altimeter settings prior to flight, use appropriate vent holes, and run thorough analyses to determine which types of shear pins and fasteners should be used	Ensure by design and testing that secure
Forgotten or Lost Component s	3 (Carelessness with rocket components, failure to take note of inventory before attempting to launch)	4 (Rocket does not launch at the desired launch time)	12, Medium	Have spares for components which are small and easy to lose, have an inventory of all rocket parts to be checked before moving the rocket to a launch site	Ensure components are secured and follow checklist
Poorly placed center of gravity	2 (Carelessness with rocket design, weight which was not considered in	3 (Lower rocket stability)	6, Low	Extensive, up-to-date, and detailed simulations and models of the rocket and its flight, adding and leaving room to add extra ballast as needed	Ensure by design and testing that secure

	mathematical or physical analyses)				
Poorly placed center of pressure	2 (Carelessness with rocket design, design aspects which were not considered in mathematical or physical analyses)	3 (Lower rocket stability)	6, Low	Extensive, up-to-date, and detailed simulations and models of the rocket and its flight, changing design aspects such as fin size as needed	Ensure by design and testing that secure
Premature Ejection	1 (Altimeter programming, poor venting)	5 (Zippering, possible recovery failure and damage to or loss of vehicle)	5, Low	Check altimeter settings prior to flight and use appropriate vent holes	Ensure by design and testing that secure
Ejection Charge Failure	4 (Not enough power, electrical failure)	5 (Ballistic trajectory, destruction of vehicle)	20, High	Ground test charge sizes at least once before flight	Ensure by design and testing that secure
Rocket Disconnects from the Launch Rail	2 (High wind speeds, failure to properly use the rail buttons, faulty rail buttons)	5 (Partial or total destruction of vehicle, ballistic trajectory which endangers personnel, onlookers, and property on the ground)	10, Medium	Use mathematical and physical analyses to ensure the rail buttons are properly aligned and working as planned, double check the rail buttons are properly attaching the rocket to the launch pad before launch, test rail buttons with subscale flights)	Ensure by design and testing that secure
Flightpath Interference	2 (Wildlife in the air, unforeseen obstacles such as a loose balloon)	4 (Minor to severe change in the vehicle's flightpath, possible ballistic trajectory)	8, Medium	Ensure there are clear skies above before launching, ensure an FAA waiver has been obtained for the designated launch area	Ensure launch site is designated and secure
Unplanned Amounts of Friction	2 (Faulty setup of launch rail, faulty installation of	2 (Rocket does not follow the	4, Low	Set up the rail using instructions which come with the product, use lubrication on	Ensure by design and testing that secure

Between Rocket and Launch Rail	rocket on launch rail, failure to properly lubricate launch rail as needed, weather conditions cause excess friction)	designated flight path well, lower maximum height)		the rail as needed according to weather and rail type, ensure the rocket is properly installed on the launch rail	
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
Propellant Fails to Burn for Desired Duration	1 (Faulty motor preparation, poor quality of propellant, damage to motor)	3 (Rocket does not follow the designated flight path well, lower maximum height, if drastic change in maximum height the ejection charges for recovery may not deploy)	3, Low	Purchase propellant and motors only from reliable sources, check the motor for damage prior to launching, team members who prepare the motor must be supervised by at least one other team member	Ensure by design and testing that secure
Propellant Burns Through Rocket Components	1 (Faulty motor preparation, poor quality of propellant, poor construction, damage to motor, damage to propellant casing)	5 (Ballistic trajectory, 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
Propellant Explosion	1 (Faulty motor preparation, poor quality of	5 (Ballistic trajectory, catastrophic	5, Low	Purchase propellant and motors only from reliable sources, check the motor for	Ensure by design and testing that secure

	propellant, damage to motor)	destruction of vehicle, possible harm to bystanders)		damage prior to launching, team members who prepare the motor must be supervised by at least one other team member	
Payload Computer Failure	3 (Electrical failure, program error, poor setup of wiring causes a connection to come undone, forgotten connection, battery failure)	5 (Disqualified, objectives not met, loss of electronic control)	15, High	Test payload prior to flight, check batteries and connections before flight	Ensure by design and testing that secure
Altimeter Failure	3 (Loss of connection, improper programming, altimeter comes dislodged, forgotten connection, battery failure)	5 (Ballistic trajectory, destruction of vehicle, improper timing for ejection of parachutes and stages)	15, High	Secure all components to their mounts and check settings, check batteries and connections before flight	Ensure by design and testing that secure
GPS Lock Failure	2 (Interference or dead battery)	5 (Loss of vehicle)	10, Medium	Ensure proper GPS lock and battery charge before flight	Ensure by design and testing that secure
Power Loss to Avionics Bay and/or Payload	3 (Faulty wiring, battery failure, poor setup of wiring causes a connection to come undone, forgotten connection)	5 (Disqualified, objectives not met, failure to correctly trigger ejection charges)	15, High	Test the reliability of the wiring and batteries through subscale flights, check batteries and connections before flight	Ensure by design and testing that secure
Improper Avionics and Payload Insulation	1 (Poor construction, damage to rocket body, avionics bay, or payload)	4 (Avionics bay and payload do not perform as planned, possible failure to trigger ejection charges at correct time, possible failure to meet mission objectives,	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	Ensure by design and testing that secure

		possible recovery failure, possible ballistic trajectory)			
Avionics Bay Fire	3 (Faulty wiring, battery failure, poor setup of wiring, adverse weather)	5 (May be disqualified if objectives are not met, possible failure to trigger ejection charges, damage to internal rocket components)	15, High	Thermal protection of avionics bay, do not overload avionics bay with wiring, only purchase avionics and payload equipment from reliable sources, check avionics bay and payload performance with test launches	Ensure by design and testing that secure
Human Error When Arming Avionics and Payload	3 (Forgotten connection, forgetting to activate avionics bay components or payload prior to launch)	5 (Disqualified, objectives not met, failure to correctly trigger ejection charges)	15, High	Leave reminders in multiple places to check that the avionics bay and payload are armed and ready before launch, follow launch checklists closely	Ensure follow safety checklist to ensure properly armed
Arming System Failure	3 (Faulty arming system, faulty wiring, battery failure, poor setup of 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	Ensure by design and testing that secure
Poor Spacing Between the Ejection Charge and the Parachute	2 (Failure to properly consider the requirements of the recovery system, poor budgeting of space in rocket, failure to read instructions that come with parachute and/or ejection charges)	5 (Partial or total damage to the parachute, parachute does not launch from the rocket, possible recovery failure)	10, Medium	Read all instructions which come with the parachute and ejection charges, establish clear requirements of the recovery system early in the design process, run mathematical and physical analyses on the design of the rocket, ensure the parachute is spaced properly with subscale test flights	Ensure by design and testing that secure

Airframe Zipper	2 (Excessive velocity when recovery system is deployed)	5 (Partial yet severe destruction of vehicle)	10, Medium	Properly time ejection charges and use an appropriately long tether	Ensure by design and testing that secure
Stage Fails to Separate	2 (Faulty ejection charge, excessive strength is used to hold stages together, altimeter failure)	4 (Rocket does not follow desired flight path, possible ballistic trajectory, lower maximum height, damage to the rocket)	8, Medium	Any team member who loads the ejection charges must be supervised by at least one other team member, examine ejection charges for damage before launch, ensure proper functionality of the altimeters, ejection charges, and interstage joints and fasteners through test flights and mathematical and physical analyses, have a secondary ejection charge for each stage separation	Ensure by design and testing that secure
Main Parachute Fails to Deploy	2 (Poor design of where parachute is in rocket, poor sealing of parachute chamber, poor loading of parachute, faulty parachute or ejection charge, altimeter failure)	5 (Main parachute does not slow down the rocket, recovery failure, ballistic trajectory)	10, Medium	Any team member who seals or packs the parachute chamber must be supervised by at least one other team member, examine parachute and ejection charges for damage before launch, run mathematical and physical analyses as well as subscale tests to ensure parachute is in the right position in the rocket, have a secondary ejection charge in case of emergency which is larger than the first	Ensure by design and testing that secure
Drogue Parachute Fails to Deploy	2 (Poor design of where parachute is in rocket, poor sealing of parachute chamber, poor loading of parachute, faulty parachute or ejection charge, altimeter failure)	5 (Drogue parachute does not slow down the rocket, recovery failure, ballistic trajectory)	10, Medium	Any team member who seals or packs the parachute chamber must be supervised by at least one other team member, examine parachute and ejection charges for damage before launch, run mathematical and physical analyses as well as subscale tests to ensure parachute is in the right position in the rocket, have a secondary ejection charge in case of emergency which is larger than the first	Ensure by design and testing that secure
Parachute Canopy Breaks or	1 (Poor canopy materials, improper ejection	4 (Possible recovery failure,	4, Low	Only buy parachutes from reliable sources, remove threats to parachute integrity	Ensure by design and testing that secure

Tears	of recovery system, damage from previous flights or transportation)	ballistic trajectory)		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	
Parachute Shroud Lines Break	1 (Poor shroud line materials, improper ejection of recovery system, damage from previous flights or transportation)	4 (Possible recovery failure, ballistic trajectory)	4, Low	Only buy parachutes from reliable sources, remove threats to parachute integrity from the parachute housing, test the recovery system through mathematical and physical analyses as well as subscale flights, check the recovery system for damage before launch	Ensure by design and testing that secure
Shock Cord Break or Disconnect	1 (Faulty shock cord, damage to shock cord, poor connection to the rocket)	5 (Parachute disconnect from the rocket, recovery failure, ballistic trajectory)	5, Low	Any team member who connects the shock cord to the rocket must be supervised by at least one other team member, check the shock cord for damage before and after flight, only buy shock cords from reliable sources, analyze the shock cord with test flights	Ensure by design and testing that secure
Tangled Parachute or Shock Cord	1 (Faulty or damaged shock cord or parachute, poor packing of shock cord and/or 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
Parachute Comes Loose from Rocket	1 (Failure of recovery system mount on the rocket body, poor shroud line materials, improper ejection of recovery system, damage	5 (Recovery failure, ballistic trajectory)	5, Low	Only buy parachutes from reliable sources, test the recovery system through mathematical and physical analyses as well as subscale flights, check the recovery system for damage before launch, double check that the recovery system is properly	Ensure by design and testing that secure

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

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

4.5.6. 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	Low
Collisions with Man-made Structures or with Humans	2 (Failure to properly predict trajectory, failure to choose an appropriate launch area)	5 (Damage to public property or private property not owned by the team, damage to team equipment, serious damage to	10, Medium	Do not launch under adverse conditions which may affect the course of the rocket, run a large number of tests which analyze the rocket's trajectory mathematically and physically, choose a launch area which is not close to civilization, follow launch	Run tests to analyze and estimate the rocket's trajectory so that the rocket's path is known to the team; do not launch rocket under adverse weather conditions and choose a launch location which allows for open space to avoid accidents	Low

		team personnel or passerby)		procedures closely		
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 rocket components and difficulty assembling the rocket because of this)	3, Low	Use as little metal as possible, apply rust prevention techniques, store the rocket indoors, choose a launch site with a desirable climate, choose not to launch if heat expansion makes assembly necessitate drastic adaptation	Ensure that launch site does not have any undesirable conditions; ensure that electronics are well protected and will not have contact with wet conditions; do not launch if there is rainfall	Minimal

Wet 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 irritation)	9, Medium	Ensure team is protected from the sun 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	Ensure team is notified of all weather on day of launch or manufacturing to wear proper clothing; ensure mitigation is strictly followed due to weather notification to prevent sunburn; with rocket and water,	Medium

				weather to bring sunglasses	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 Exhaust	5 (Combustion of APCP motors)	1 (Small amounts of greenhouse gases emitted)	5, Low	Carpool to events to reduce pollution from exhaust in another way	Ensure team members with only high attendance may go, and be carpooled, to save energy	Low
Chemical Pollution to Water	2 (Fuel leakages, battery fluid	4 (Danger of sickness to wildlife or	8, Medium	Do not launch if the launching area is within 750 meters of a	Use designated launch areas as designated to which must strictly	Low

Sources	leakages, launch too close to a water source)	humans which rely on the water sources)		water source, check the rocket for leakages before launch	follow this rule to be approved	
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

4.6. Checklists

4.6.1. Pre-Launch Checklist

General Safety:

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

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

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

Flight Check:

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

Pad Distance:

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

Pad Installation:

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

Flight Trajectory:

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

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

Beginning the Launch:

- ❏ Shortly before the countdown, give a loud announcement that the rocket will be launched; if applicable to the situation, use a PA system
- ❏ Ensure that all spectators are aware of the launch and that parents are in close contact with all children
- ❏ When launching, give at least a loud 5-second numerical countdown followed by shouting “launch”

4.6.2. Launch Checklist

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

- ❏ Communicate launch progress effectively to NASA officials, if needed

In the case of a misfire:

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

4.6.3. Post-Launch Checklist

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

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 potentially 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 for all potentially hazardous substances which will be used on the project and will ensure the use of proper PPE when handling hazardous materials. The MSDSs are to be referred to when a hazard occurs in order to execute the most effective mitigation and ensure all safety concerns are addressed. All MSDSs are available to the team at all times and are required to be understood before working with potentially hazardous materials as to help increase awareness to reduce the potential for a hazard or likelihood of failure.

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. Payload Criteria

5.1. Mission Statement and Mission Success Criteria

Mission Statement:

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

Mission Success Criteria:

- The payload bay 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

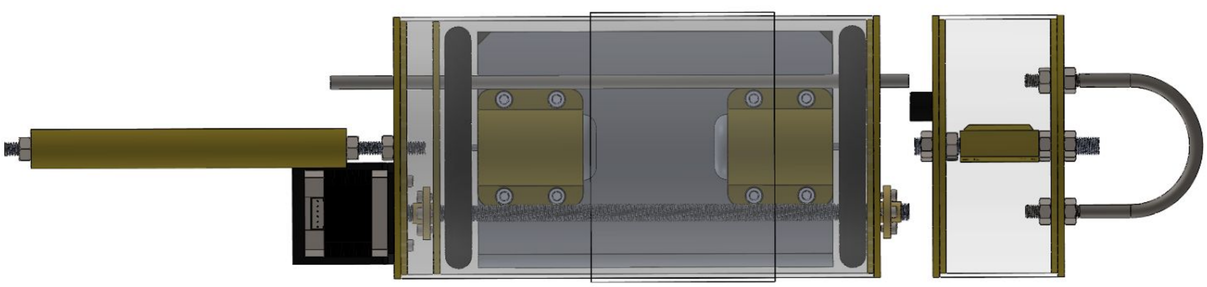
5.2. Selection, Design, and Rationale of Payload

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

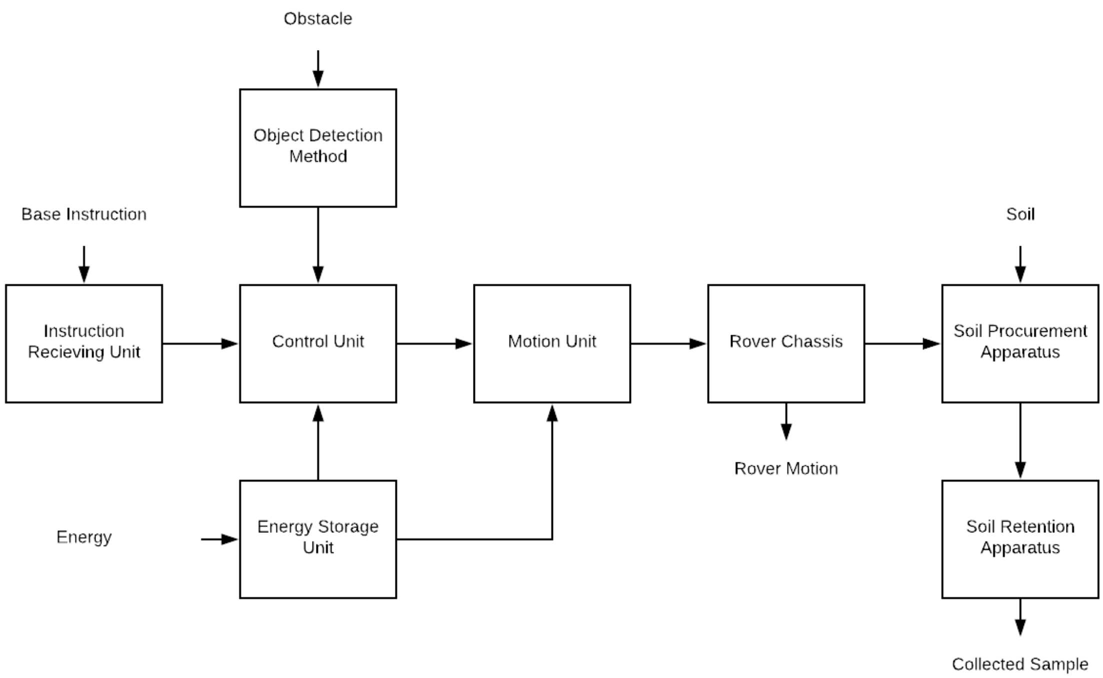
The rover will consist of two large wheels on either side of a chassis. The chassis will hold the control unit, power system, motion unit, as well as the object detection method needed for navigation. The soil collection apparatus will be deployable from the rear of the chassis.

The rover will be contained within a rover containment bay that will be attached to the nose cone and interfaced with the launch vehicle. A bay separate from the one that contains the rover will be required to eject the rover containment bay and nose cone assembly from the launch vehicle before the rover itself can be deployed and isolated. The rover containment bay will protect the rover from any harsh or atypical forces during flight or launch vehicle touchdown. It will also hold the final deployment electronics that will deploy the rover using linear actuator to push the rover out. The ejection bay will separate the rover containment bay from the rest of the launch vehicle using a black powder charge and work as an attachment point for the recovery system.

The following is a summary of how components of the payload will function and their order of operation. After successful launch and safe touch down, the rover will be deployed from the rocket after being instructed from a remote location. Once the payload bay receives a signal, a black powder charge will be ignited and launch the rover containment bay from the launch vehicle. If the rover containment bay and nose cone assembly are successfully ejected from the launch vehicle upper airframe, the rover will be deployed. Once in its starting configuration, the rover will switch from an idle state to an active state and start to navigate autonomously to an ending configuration fitting the success criteria. After finishing its autonomous navigation, the rover will deploy its soil sampling system and collect, store, then finally seal an adequate volume of soil. Seen below is the payload bay which includes the rover assembly, the rover containment bay, and the ejection bay.



5.2.1. Overall System Design



5.2.2. Control Subsystem

5.2.2.1. Control Unit

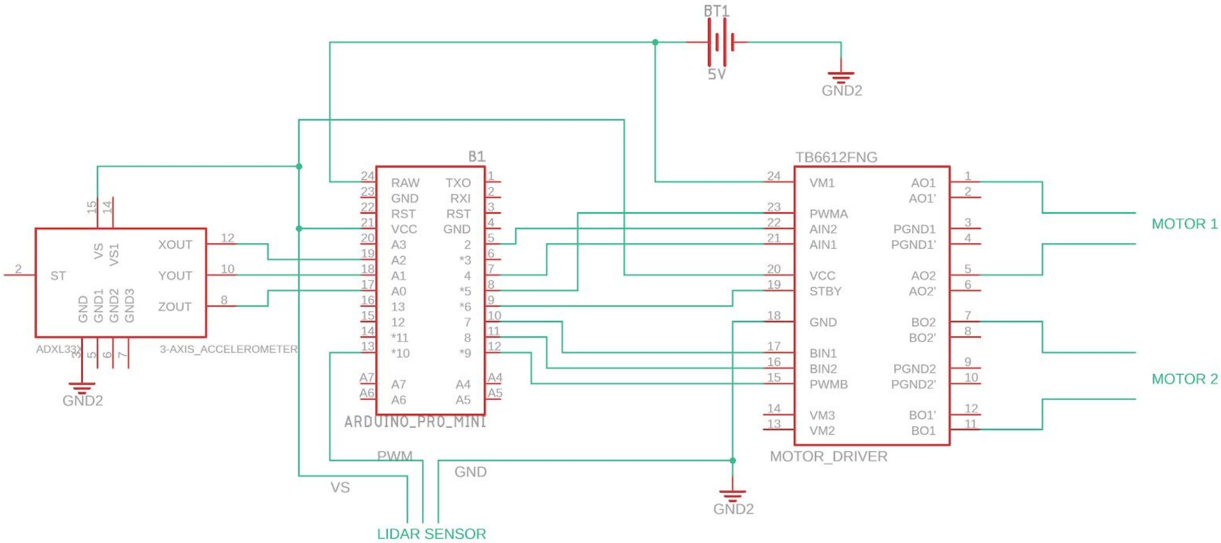
To fulfill the payload mission success criteria, the rover control unit must be able to access data from sensors, generate a set of instructions based on the sensor data, and finally execute those instructions continually until mission success. In order to accomplish all these tasks necessary for mission success, 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 finally the capacity to follow through on those decisions through control of the rover. 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 such 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

5.2.2.2. Electrical Design

The refinement of electronic component selection encompasses the largest change since PDR. Specific, off-the-shelf sensors and power electronics have been chosen to facilitate the larger goals of successful locomotion and sensing of the environment. These selections, as well as a brief description of the overall electrical design of the rover, are described below.

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 and 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. Second, 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 ADXL335 3-axis accelerometer, a 5V analog sensor that will allow for the estimation of the rover's position. Additionally, a LIDAR range-finding sensor is employed to provide high-resolution data regarding the rover's surroundings after deployment. Both of these aforementioned sensors will be critical to the rover's success after deployment from the rocket.

There were many power supply options considered 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. Although the list was not lengthy, it narrowed down the field of possibilities quite a bit. The requirements on this list are as follows:

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

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

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

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

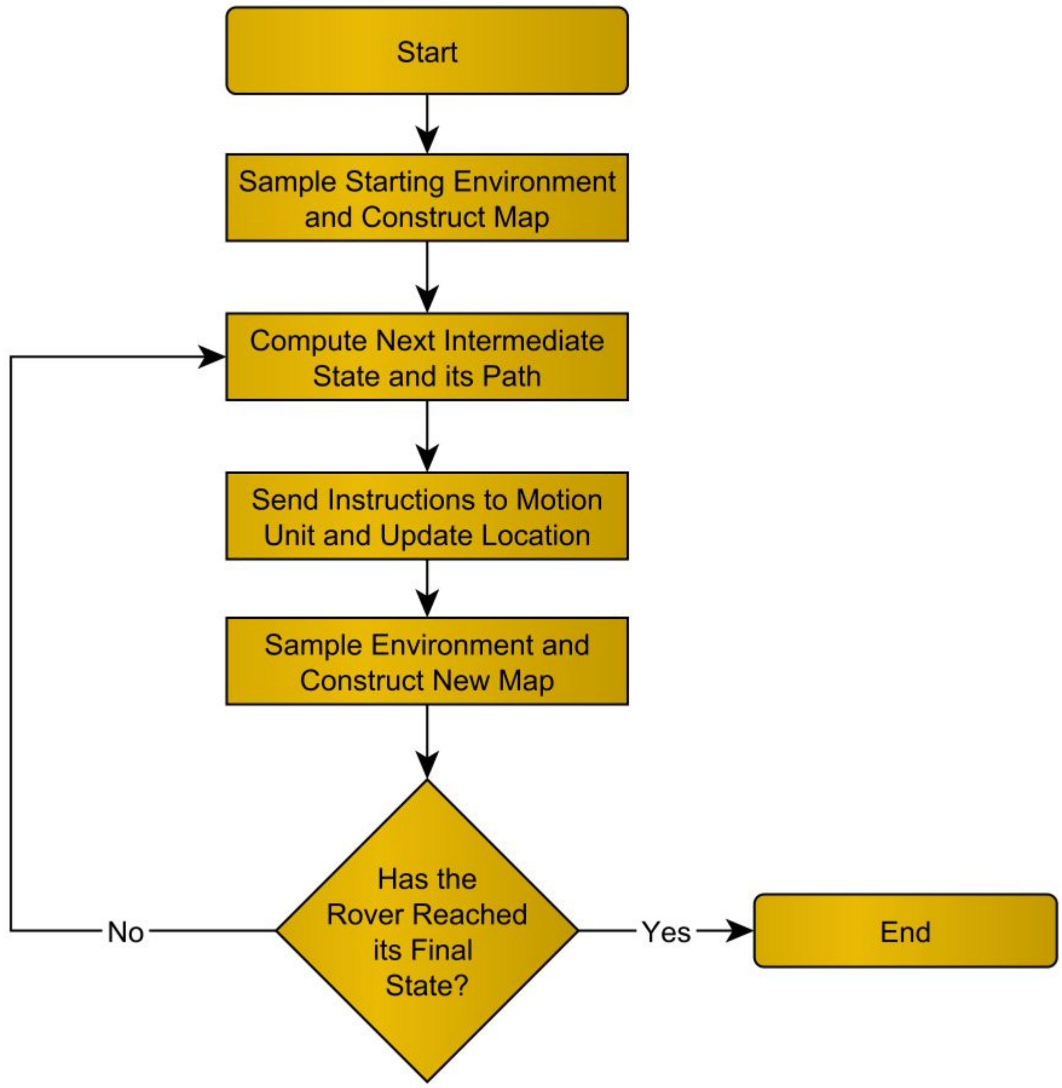
5.2.2.3. Autonomous Path-Planning Algorithm

The autonomous path-planning algorithm will have to solve the problem of determining the rover's pose and configuration relevant to rocket components and other environmental objects, distinguishing between objects that are rocket components or environmental objects, determining 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.

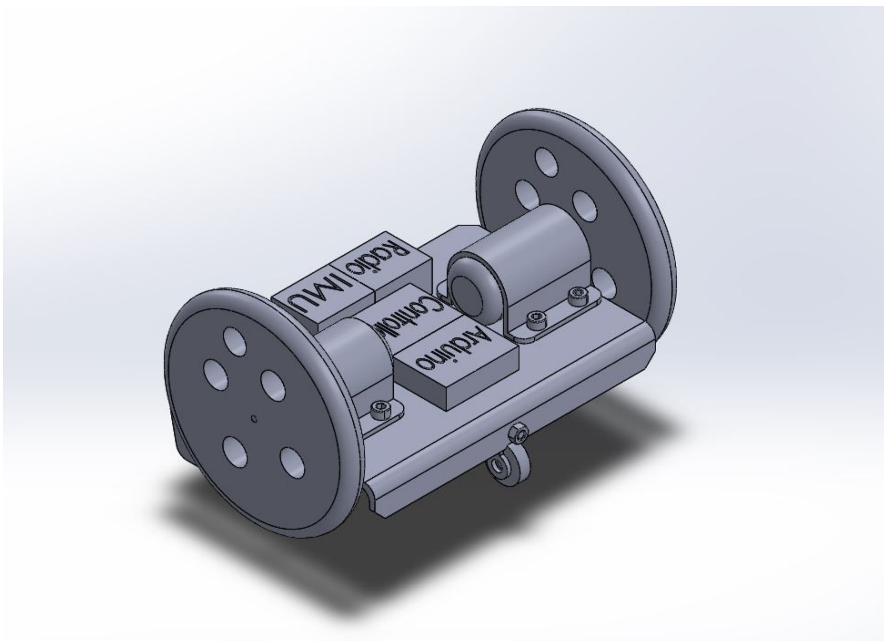
In order to determine the rover's pose and configuration, range-finding sensors are necessary to construct a local map that will be used to calculate an intermediate state before reaching a final configuration. In order to distinguish between rocket components and environmental objects, rocket component 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 inherent error is amplified by the non 2D terrain traversed by the rover, so precaution must be taken when assuming a final configuration meaning 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 and 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.

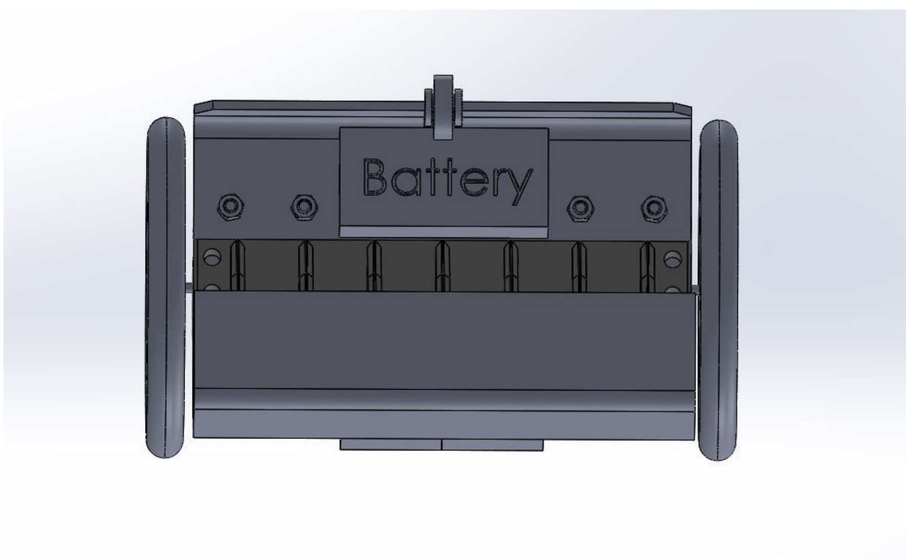

Start
Sample Starting Environment and Construct Map
Compute Next Intermediate State and its Path
Send Instructions to Motion Unit and Update Location
Sample Environment and Construct New Map
Has the Rover Reached its Final State?
No
Yes
End

5.2.3. Chassis Subsystem

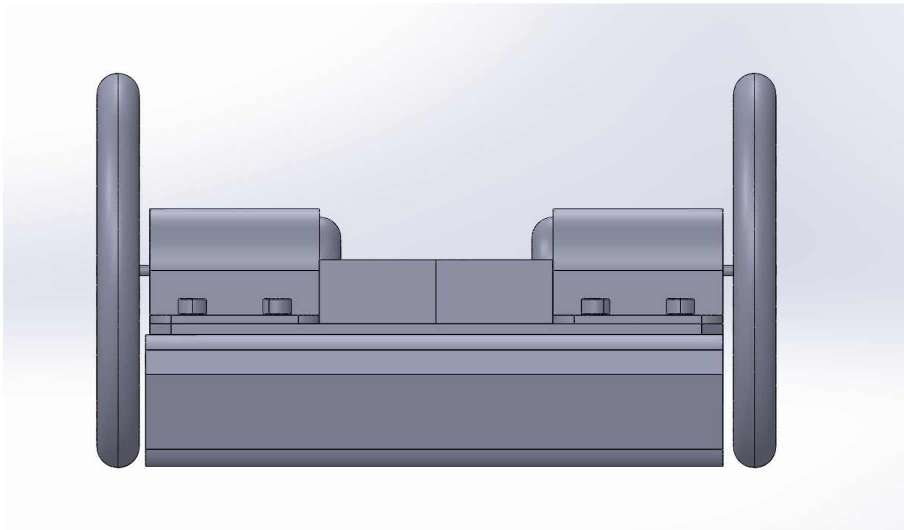


5.2.3.1. Rover Body

There have been very few changes made to the rover body since PDR. Aluminum 6061 has been selected to be used for the chassis. A ball bearing as a third wheel has been added to the front of the chassis as a support. A new deployment method has been developed that uses an additional motor placed on the top of the chassis. This motor works similar to a linear actuator by holding the payload inside the launch vehicle by a threaded rod and then pushing the payload out along the rod upon landing. Aluminum 6061 will be used for the main chassis of the rover as it is easy to work with and very durable. The chassis plate is 4.625 inches by 6.75 inches by ⅛ inch to have enough room for all components and to be durable while fitting within the launch vehicle. The motors are positioned such that all other components will rest underneath the axles connecting to the wheels. This ensures that the majority of the mass will be underneath the axis of rotation and the rover will naturally tend to be right side up. The electronics boards will rest on top of the chassis for ease of access. The soil collection system will be attached at the rear of the chassis so it can effectively collect soil and reduce unwanted chassis rotation caused by the motors. It will be stored within the chassis and unfolded out of and away from the rake once the rover has reached the correct orientation and is ready to collect soil. The motors are on either side of the chassis in the middle so that the rover can rotate 360 degrees and flip itself over in the event of landing upside down. The third smaller wheel will rest in the front center of the chassis next to the sensors and will act as a support to prevent unwanted flipping during driving. The sensors are positioned in the front by the third wheel so they have an unobstructed view of all potential obstacles in the driving path. The batteries are the most massive components and will be attached underneath the chassis to ensure all of their mass contributes to balancing the rover.



The picture above shows the bottom of the rover where the rake and the soil procurement system along with the battery are affixed.



5.2.3.2. Rover Motion

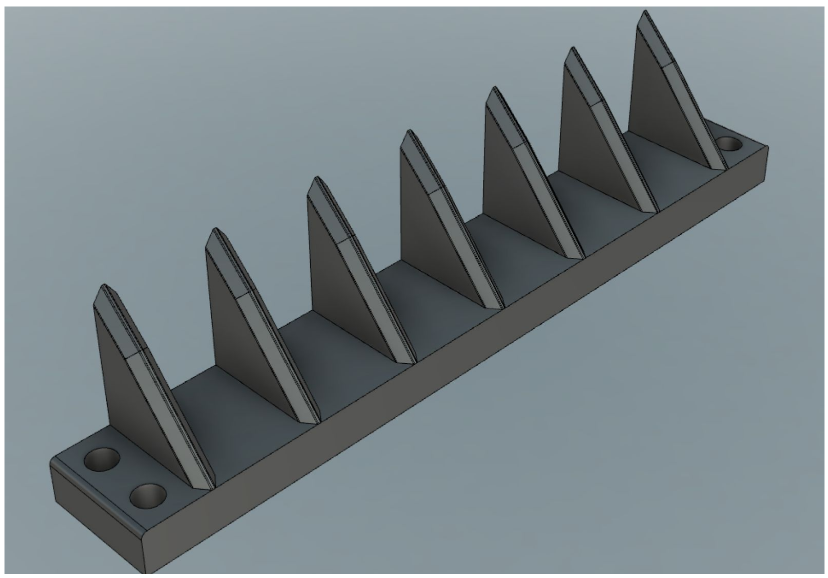
Since PDR a third wheel has been added to the front of the rover. This wheel acts only as a support and does not have a motor attached to it. The selected motors on the main drivetrain wheels were selected because they are effective at moving the rover by providing an adequate amount torque at a low amount of power. They are also cheap and easy to acquire or replace. The wheels were chosen for their durability and traction in top-soil based off of initial tests. While driving, the front wheel and soil collection system will prevent the rover from rotating about the axles.

5.2.4. Soil Sampling Subsystem

5.2.4.1. Soil Procurement

Since PDR, the soil procurement apparatus design system has advanced. The initial design had the rake extending out on a limb along with the hopper. Considering limited space, it was determined that condensing the design of the rake would be wise in order to stay within size regulations. Additionally, it was decided that the extending rake would be susceptible to many sources of damage while far from the center of the rover chassis. To solve this issue, the rake has been relocated underneath the chassis. The rake will consist of an additive manufactured flat plate of dimensions 6.75” by 1”. Projected from this plate will be seven rake teeth, angled in a way that gradually introduces incoming dirt to the tips of the rake 1.5” tall measured from the plane of attachment. Given the relative softness of soil and small overall scale of the rover, we expect that ABS plastic will be able to sustain continuous usage with negligible wear. The rake system was intended to be modular, being sized to the width of the rover chassis. Meanwhile, the rake can now be placed in a manner that does not require additional moving parts to deploy while still having a workable size to fit within the rover fairing.

In the end, the rake will still provide the same functions as discussed before. Being attached directly to the rear of the rover, the rake will help provide a counter-torque to oppose the backwards torque on the chassis created due to the forwards acceleration of the rover. This counter torque, itself, can be used to drive the rake into the soil underneath the rover, agitating the soil, making said soil more susceptible to sampling.



5.2.4.2. Soil Retention

In line with the changes made to the soil procurement apparatus, the soil retention apparatus has been condensed and refined to function while taking up less volume. In the previous design, there were increased concerns that a passive dragging apparatus would not only become damaged, but also presents an issue of a lack of control. Without a robust and deployable wiring/motorized setup and support unit attached to this dragging apparatus, there may not be a reasonable solution to trigger the sealing of the soil sample. In response to this issue, the soil retention apparatus has been relocated and attached to the rear of the rover, behind the soil procurement apparatus. This apparatus, now being directly attached to the rover chassis, is more accessible for electronic control. Upon completion of soil sampling, the retention system will be able to close via servo actuated changing of position.

5.2.4.2.1. Design Alternatives

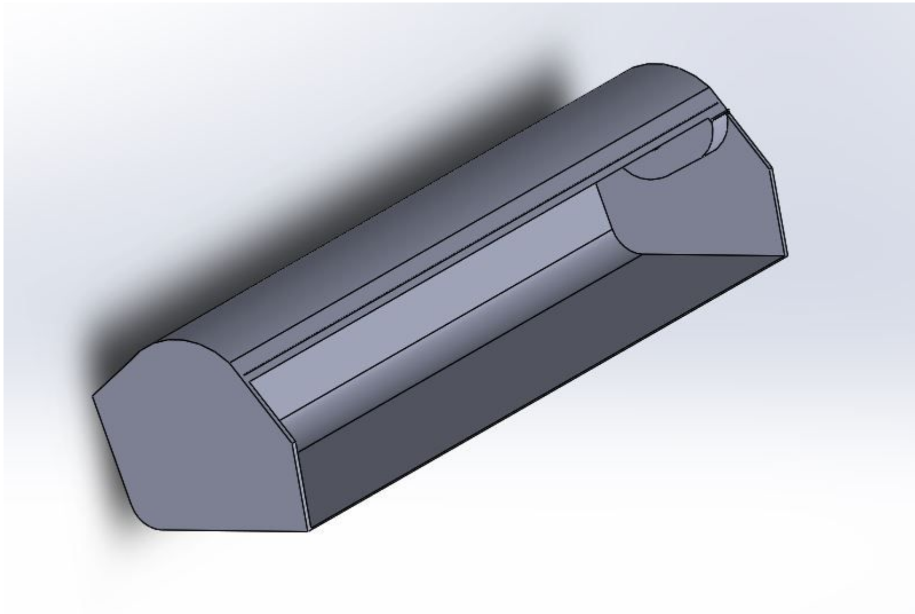
There have been numerous propositions for the specific design of the new attached version of the soil retention apparatus. Discussions concluded that the rover is incredibly small in scale (especially for those on the team used to robots with volumes over $18ft^3$) and therefore requires a mechanism 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.

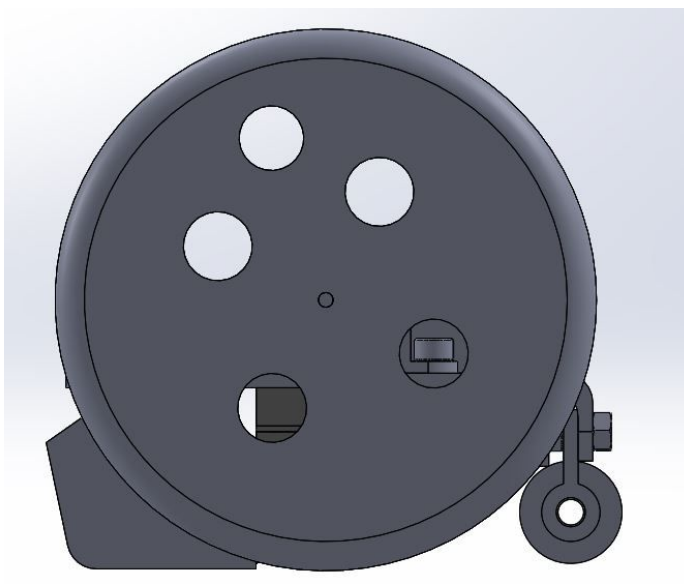
Design	**Description**	**Low Volume (Weight: 3)**	**Less Moving Parts (Weight: 5)**	**High Capacity (Weight: 2)**	**Simplicity (Weight: 5)**	**WEIGHTED SCORE**
Excavator	Half-cylinder design with a pivot point near the chassis plate. Collects soil and is rotated into both collection position and sealed position.	This setup requires an excavator along with an actuator mechanism capable of 90° rotation. **(Tier: 2)**	One piece must be movable. Requires actuation. **(Tier: 2)**	Full half cylinder of volume. When closed, will coincide with rake volume. **(Tier: 1)**	Simple design without too many unique shapes. Based on pre-existing excavator designs. Will require highly operational actuation. **(Tier: 2)**	**13**
Sliding Panel	Mostly similar to the excavator. The excavator will be sprung into place when deployed. A panel will be slid down from the top of the chassis to cover the excavator when sampling completes.	Similar to the excavator, but less volume required for excavator, but much more volume required to fit in sealing plate and required mechanisms. **(Tier: 1)**	Collector must be movable. A plate must also be slid into place. **(Tier: 1)**	Full half cylinder of volume. **(Tier: 2)**	Requires two systems with multiple moving parts and fittings to ensure proper opening, locking, and overall success. **(Tier: 1)**	**8**
Excavator /Rake Combo	This design would entirely scrap the current soil procurement apparatus in lieu of an excavator	Most compact of all designs, eliminating need for rake, combining into one	One piece must be movable. Requires actuation. **(Tier: 2)**	Intercut and wavy design limits capacity. **(Tier: 1)**	Similar to excavator design, but requires much more complex CAD work of retainment system. Also,	**11.5**

	with multiple defined "scoop teeth". This apparatus will be rotated into both collection position and sealed position.	apparatus. **(Tier: 3)**			complete scrap of rake counter-torque stability would be required. **(Tier: 1)**	

5.2.4.2.2. Final Design

As evidenced by the above decision matrix, the optimal design for the soil retention system was decided to be the "excavator". This design will include an approximately 6.75" wide "excavator" scoop, able to fit snugly over the soil procurement apparatus. As discussed previously, this scoop will be able to rotate about an axis near to the underside of the rover chassis. A servo-type motor will be used to rotate the soil retention apparatus about its pivot point, enabling both an open and closed state. During flight and prior to sampling subsystem activation, the apparatus will remain in its closed state. Once sampling begins, the apparatus will be opened 90° and held in place to begin accepting agitated soil. Finally, once sampling ends, the apparatus will be rotated back into place over the procurement apparatus. The soil procurement apparatus's teeth will be constructed in a manner that will allow collected sample to be pushed aside. The total volume of the inside of the scoop will be at least 5 times greater than the required 10ml sample and at least 2.5 times greater than the subsystem's target sample volume of 20ml. This provides a wide margin of error and flexibility in the quantity of soil the subsystem can collect.

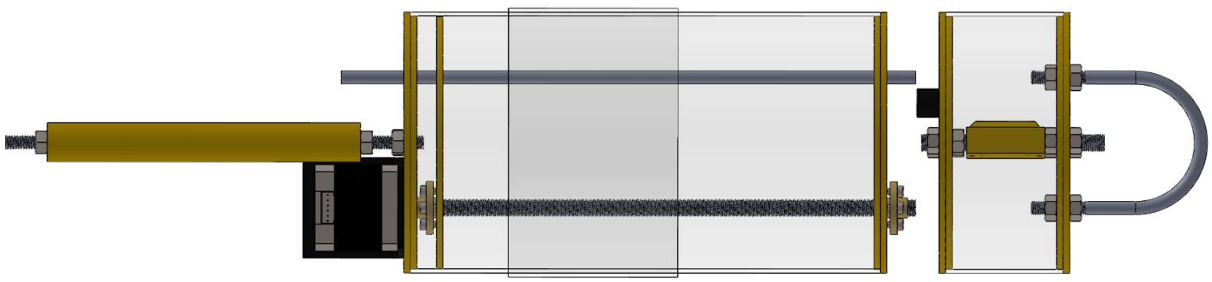




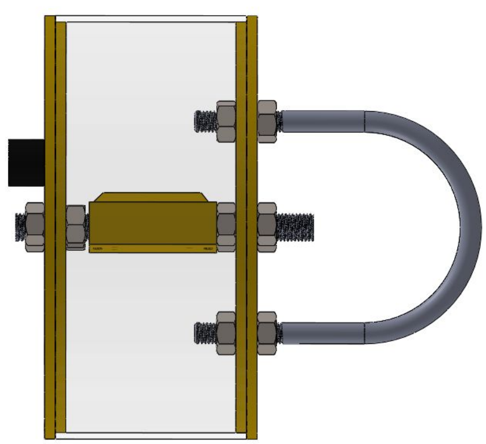
5.2.5. Retention and Deployment Subsystem

5.2.5.1. Payload Bay Retention and Deployment

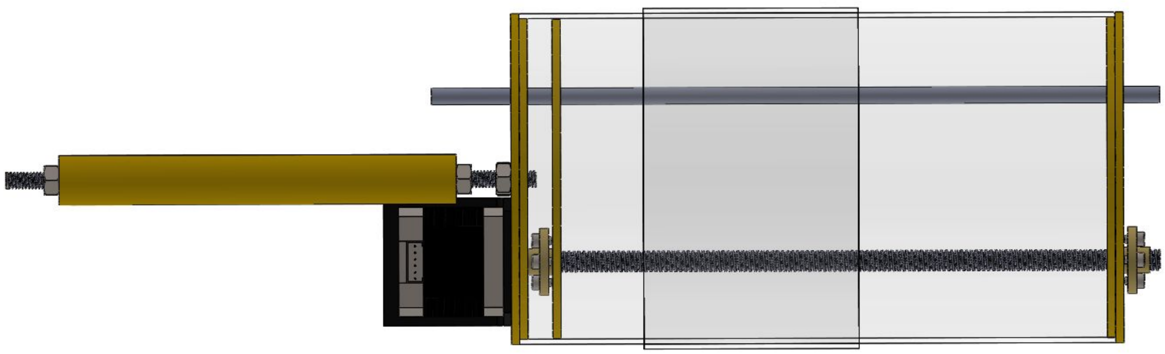
The retention and deployment subsystem of the payload will serve to protect the rover during launch vehicle ascent and descent and deploy the selected payload after rocket touchdown. The retention and deployment subsystem consists of a payload ejection bay and a rover containment bay. The payload ejection bay will separate the rover containment bay from the rocket using an ejection black powder charge and the rover containment bay will house a linear actuator that directly controls the bulkheads surrounding the rover that will deploy the rover. The ejection bay will be fastened to launch vehicle using rivets and will isolate the rover containment bay from the rest of the launch vehicle and recovery system. The rover containment bay will be temporarily fastened to the launch vehicle using shear pins that will break once the ejection charge is ignited by the ejection bay. Given that the rover containment bay is installed 5.00’’ into the 5.00’’ inner diameter upper airframe, a total of four 4-40 nylon shear pins to withstand any forces experienced during flight.



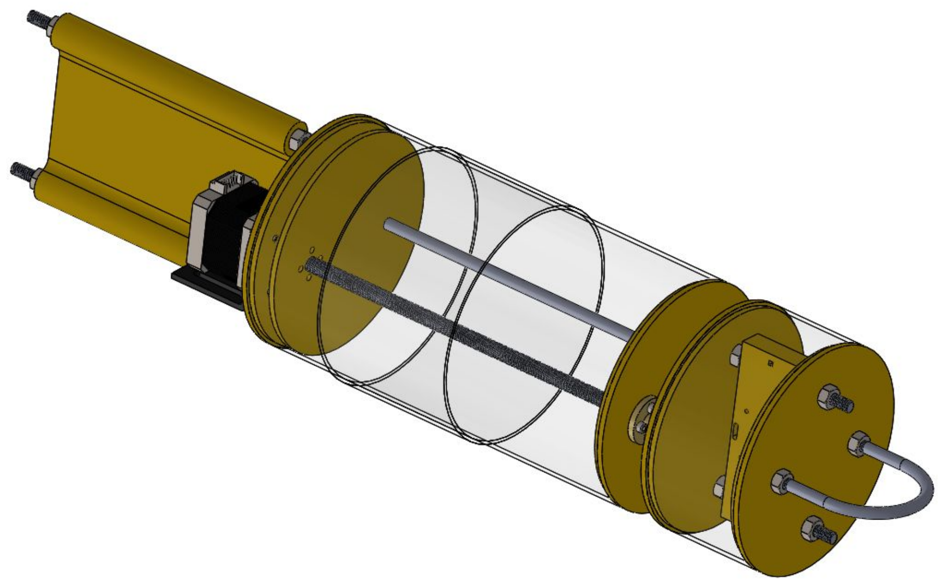
The payload ejection bay will eject the rover containment bay and its attached nose cone from the launch vehicle after it touches down using a black powder charge stored in an ejection canister. The ejection charge will be ignited using an e-match that will be lit by microcontroller. As detailed in the given payload deployment requirements, the ejection charge must be ignited remotely requiring the use of a radio unit to receive ejection instructions from the remote deployment base station. In order to avoid premature detonation of the black powder charge, an externally mounted slide switch will be used to activate the and power the ejection bay electronics. The payload ejection bay also serves as an attachment point for the recovery system and isolates the rover containment bay from the rest of the launch vehicle.



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 rover is to be deployed. 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 bay.

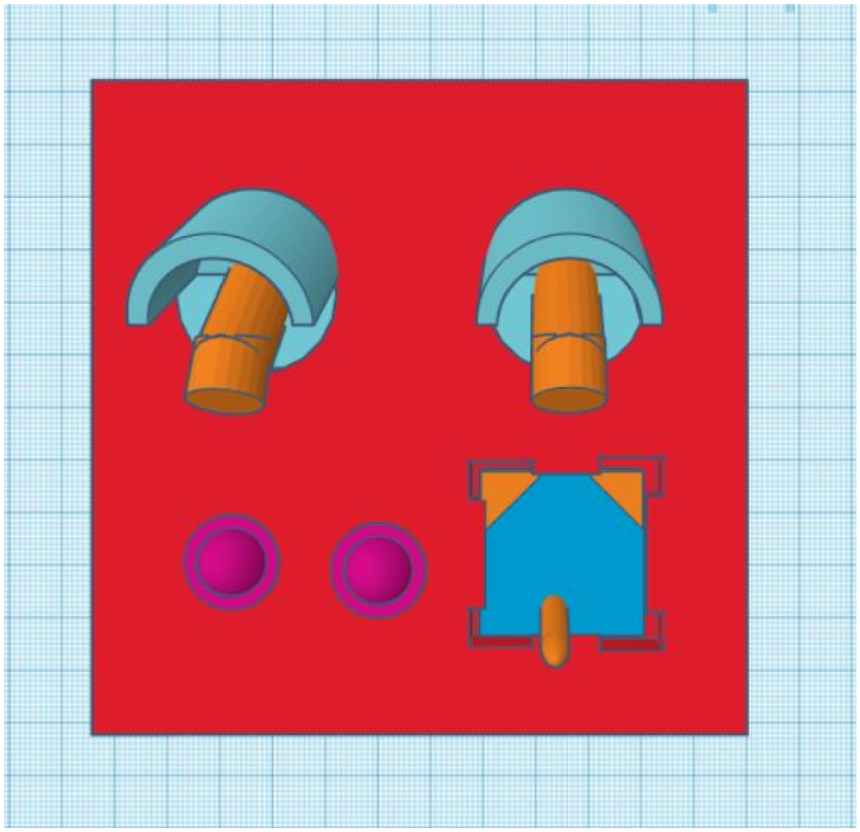


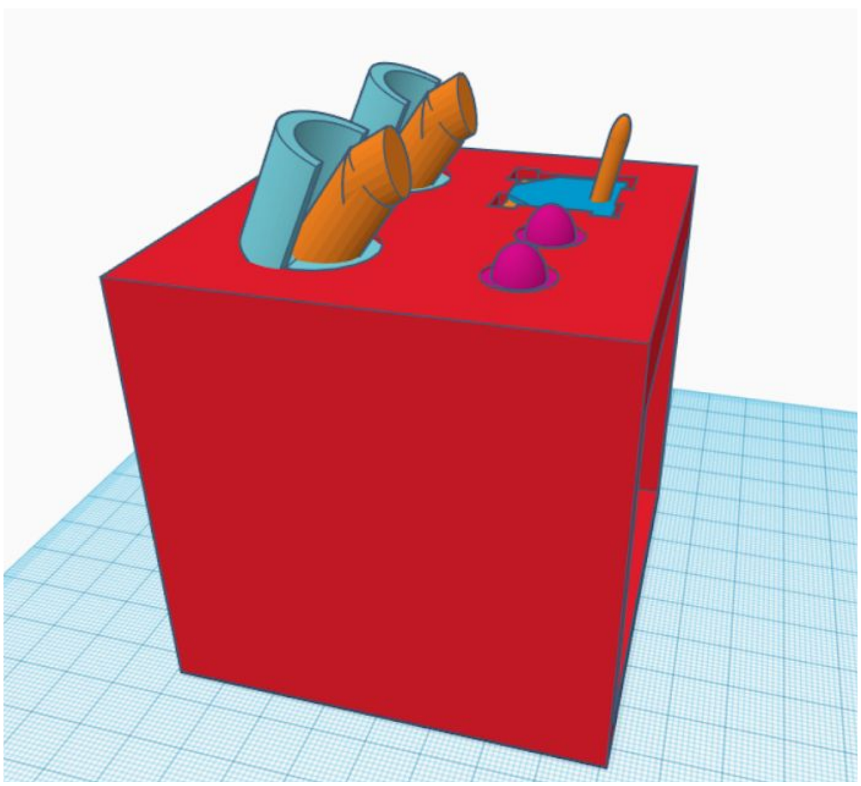
In order to contain the rover, two bulkheads are secured to a lead screw using lead screw nuts and surround the rover on both ends. The rover is held in place by the lead screw, the guide rod, and the two bulkheads that surround its wheels. Deploying the rover involves the translation of rotational motion from the stepper motor to linear motion and moves the bulkheads along the lead screw which moves the rover. When deploying, the lower bulkhead, the furthest bulkhead from the stepper motor, moves axially away from the stepper motor and is eventually pushed off, exposing the rover. The upper bulkhead, the bulkhead on the lead screw closest to the stepper motor, moves with the lower 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.

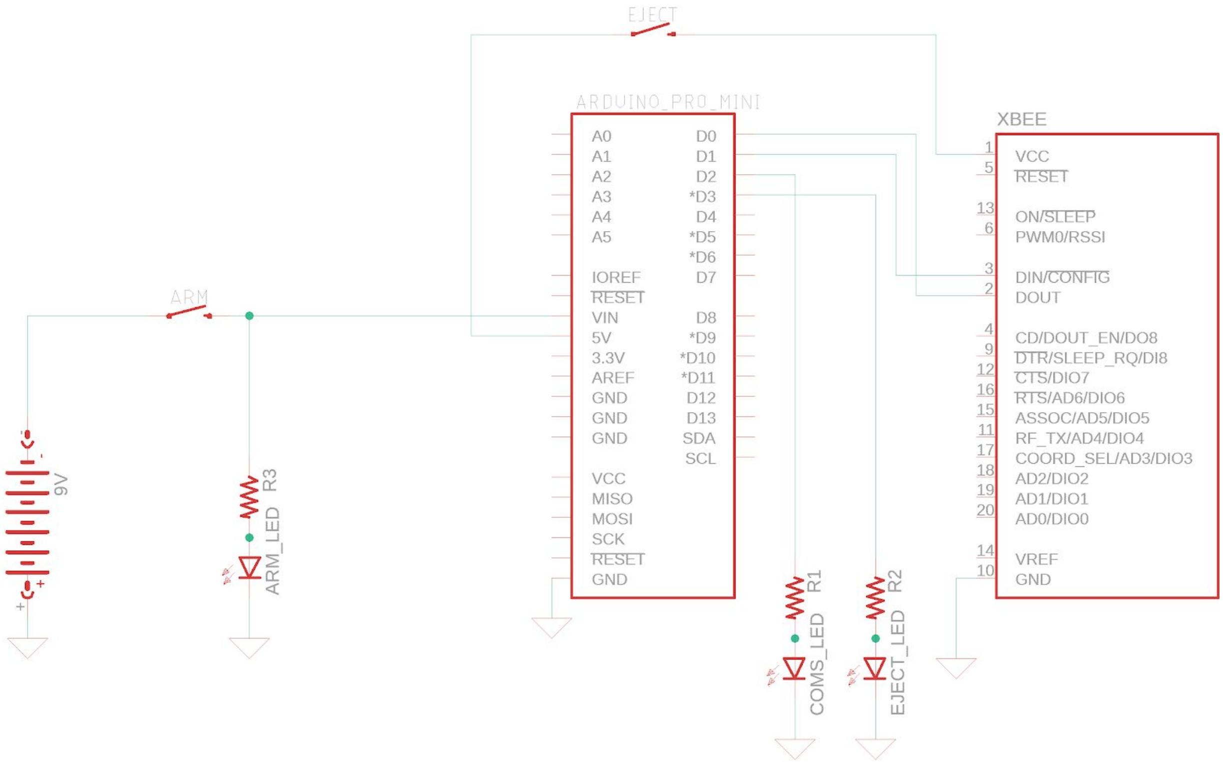


5.2.5.2. Remote Deployment Base Station

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 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. Project Plan

6.1. Testing

6.1.1. Tests Required To Prove Design Integrity

6.1.1.1. Avionics Continuity Testing

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 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.

Data:

Telemetrum

Trial	Number of Continuity Beeps
1	(X) beeps
2	(X) beeps
3	(X) beeps

RRC3+ Sport

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

Analysis:
The Telemetrum (passed/failed) the test.
The RRC3+ Sport **passed** the test.

Conclusion:
(This test has not been conducted yet.)
The RRC3+ Sport altimeter is very likely to consistently achieve continuity for a dual deploy configuration.

6.1.1.2. Avionics Battery Power Drain Calculations

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, we estimated that about 50 mAh were needed to power the entire system. Therefore, for the full scale launch, we will add a redundant 9V battery for the RRC3+ Sport and a redundant 3.7V LiPo battery for the Telemetrum.

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.)

6.1.1.3. Altimeter Ejection System Testing

Objective:

The objective of this test was to ensure that both the Telemetrum and RRC3+ Sport altimeters ignite the drogue ejection charge at apogee 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 data points in this test were qualitative (whether or not the e-matches ignited). Each altimeter passed this test if both their drogue and main e-matches ignited at the appropriate times (drogue at apogee and main at 700 ft) all three trials.

Procedure:
1) The extra materials that were collected to conduct this test included a glass bowl, an air needle, a wine bottle air remover pump and stopper, a small amount of putty, a thin wooden board, a tube of caulk, and a Jolly Logic Altimeter One.
2) The thin wooden board was prepared by drilling one large and one small hole into it. The wine stopper was placed into the large hole and glued into place, and the air needle was placed into the small hole and glued into place.
3) The glass bowl was prepared by placing it on top of the board and caulking around the edges to form a seal. Just before the caulk dried, though, the bowl was lifted out of place so the caulk ring could finish drying freestanding. This way, multiple tests could be conducted without having to form a new seal each time.
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 under the glass bowl. The putty was placed over the air needle to prevent air from returning to the bowl.
5) The wine bottle air remover pump was 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.
6) Finally, one edge of the putty was lifted up from the air needle to slowly allow air back inside the bowl, 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.

Data:

Telemetrum

Trial	Did the drogue e-match ignite at apogee?	Did the main e-match ignite at 700 ft?
1	(Yes/No)	(Yes/No)
2	(Yes/No)	(Yes/No)
3	(Yes/No)	(Yes/No)

RRC3+ Sport

Trial	Did the drogue e-match ignite at apogee?	Did the main e-match ignite at 700 ft?
1	(Yes/No)	(Yes/No)
2	(Yes/No)	(Yes/No)
3	(Yes/No)	(Yes/No)

Analysis:
The Telemetrum (passed/failed) the test.
The RRC3+ Sport (passed/failed) the test.

Conclusion:
(This test has not been conducted yet.)

6.1.1.4. Parachute Drop Testing

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.

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 30 lbs. Therefore, 30 lbs of weights were attached to the drogue (a 30” Recon from Wild Man Rocketry) and main (a 60” Skyangle Cert 2) parachutes separately.
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).
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:

Drogue

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

Main

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

Analysis:
Drogue - the range of times to open is 0.31 sec
The drogue parachute **passed** the test.

Main - the range of times to open is 0.60 sec
The main parachute **passed** the test.

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

6.1.2. Completed Tests and Results

6.2. NASA Handbook Requirements and Verification Plans

6.2.1. Handbook General Requirements and Verification Plans

- 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).
    - This requirement can be verified via 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.
- 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.
    - This requirement can be verified via demonstration.
    - Verification of this requirement occurs when providing each milestone report to NASA. Each delivered report should have these sections in it.
- The team will identify Foreign National (FN) team members by the Preliminary Design Review (PDR).
    - This requirement can be verified via demonstration.
    - Verification of this requirement occurs when the required information is delivered on time to the student launch team for review.
- The team will identify all members attending launch week activities by the Critical Design Review (CDR).
    - This requirement can be verified via demonstration.
    - Verification of this requirement occurs when the required information is delivered on time to the student launch team for review.
- 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, by the Flight Readiness Review (FRR), and will report these activities appropriately to the student launch team.
    - This requirement can be verified via demonstration.
    - Verification of this requirement occurs when the required information is delivered on time to the student launch team for review.

- The team will establish a social media presence to inform the public about team activities.
    - This requirement can be verified via 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.
- The team will email all deliverables to the NASA project management team by the deadline specified in the handbook for each milestone.
    - This requirement can be verified via demonstration.
    - Verification of this requirement occurs when the required information is delivered on time to the student launch team for review.
- All deliverables will be in PDF format.
    - This requirement can be verified via inspection.
    - Verification of this requirement occurs by double-checking that all attachments are in PDF format before emailing them to the student launch team.
- In every report, the team will provide a table of contents including major sections and their respective sub-sections.
    - This requirement can be verified via 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.
- In every report, the team will include the page number at the bottom of the page.
    - This requirement can be verified via 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.
- The team will provide any computer equipment necessary to perform a 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.
    - This requirement can be verified via testing.
    - Verification of this requirement will occur during the preparatory Q&A sessions and before presentations for each milestone to ensure the team can properly use the required technology.
- The team will use the launch pads provided by Student Launch's launch services provider.
    - This requirement can be verified via 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.

- 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.
  - This requirement can be verified via 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.

6.2.2. Handbook Vehicle Requirements and Verification Plans

- The vehicle will deliver the payload to an apogee altitude between 4,000 and 5,500 feet above ground level (AGL)
  - This requirement will be verified by redundant testing and analysis
  - Verification for this requirement includes constant retesting and analysis in simulation programs, including OpenRocket 15.03 and RASAero II.
- The team will identify its target altitude by the PDR milestone.
  - This requirement will be verified by testing and simulation
  - Verification for this requirement includes constant retesting and analysis in simulation programs, including OpenRocket 15.03 and RASAero II.
- 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.
  - This requirement can be verified via inspection.
  - Verification for this requirement includes inspecting rocket components before flight to ensure at least one altimeter is being used.
- 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.
  - This requirement will be verified by inspection and testing.

    - Verification for this requirement includes testing altimeter continuity and inspection of proper electrical connections.
- Each altimeter will have a dedicated power supply.
    - This requirement will be verified by inspection.
    - Verification for this requirement includes inspection of proper electrical connections and separate electrical systems.
- Each arming switch will be capable of being locked in the ON position for launch (i.e. cannot be disarmed due to flight forces).
- 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.
    - This requirement will be verified based on 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.
- 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.
    - This requirement will be verified by demonstration.
    - Verification for this requirement will be done by inspection prior to all launches.
- Coupler/airframe shoulders which are located at in-flight separation points will be at least 1 body diameter in length.
    - This requirement will be verified by demonstration.
    - Verification will be achieved by inspecting the rocket prior to all launches.
- Nosecone shoulders which are located at in-flight separation points will be at least ½ body diameter in length.
    - This requirement will be verified by demonstration.
    - Verification will be achieved by inspecting the rocket prior to all launches.
- The launch vehicle will be limited to a single stage.
    - This requirement will be verified by demonstration.
    - Verification will be achieved upon inspection prior to launches, proving that the rocket is only one stage.
- 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
    - This requirement will be verified by 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.

- 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.
- 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.
    - This requirement will be verified by 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.
- The launch vehicle will require no external circuitry or special ground support equipment to initiate launch (other than what is provided by the launch services provider).
    - This requirement will be verified by demonstration.
    - Verification will be done by inspection of the rocket in final flight configuration.
- 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).
    - This requirement will be verified by demonstration and testing.
    - Verification will include all launches which use these motors and demonstration during the official competition.
- Final motor choices will be declared by the Critical Design Review (CDR) milestone.
    - This requirement will be verified by demonstration.
    - Verification will be achieved by checking the CDR document and ensuring the motor choice does not change between CDR, FRR and PLAR.
- Any motor change after CDR will be approved by the NASA Range Safety Officer (RSO).
    - This requirement will be achieved by demonstration.
    - Verification will only be necessary in the event that the previous requirement is not met.
- All pressure vessels on the vehicle will be approved by the NASA RSO.
    - This requirement will be achieved by demonstration.
    - Verification will be demonstrated during the official competition.
- 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.
    - This requirement will be achieved by testing and analysis.

    - Verification will be met using simulation programs such as OpenRocket 15.03 and RASAero II.
- 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.
    - This requirement will be verified by demonstration.
    - Verification will be done by inspection of the rocket, seeing that the team has no pressure vessels.
- Full pedigree of any pressure vessel tanks used will be described, including the application for which the tank was designed, and the history of the tank, including the number of pressure cycles put on the tank, by whom, and when.
    - This requirement will be verified by demonstration.
    - Verification will be done by inspection of the rocket, seeing that the team has no pressure vessels.
- The total impulse provided by the launch vehicle will not exceed 5,120 Newton-seconds (L-class).
    - This requirement will be verified by testing and demonstration.
    - Verification will include all launches which use L-class or lower motors and demonstration during the official competition.
- 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.
    - This requirement will be verified by analysis and testing.
    - Verification will include using simulation programming, specifically OpenRocket 15.03 and RASAero II.
- The launch vehicle will accelerate to a minimum velocity of 52 fps at rail exit.
    - This requirement will be verified by analysis and testing.
    - Verification will include using simulation programming, specifically OpenRocket 15.03 and RASAero II.
- A subscale model of the final vehicle will be successfully launched and recovered prior to CDR.
    - This requirement will be verified by testing and demonstration.
    - Verification will include subscale results (listed earlier in this document) from a test launch and demonstration that the rocket has flown.
- 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.
    - This requirement will be verified by 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.

- The subscale model will carry an altimeter capable of recording the model's apogee altitude.
    - This requirement will be verified by testing and demonstration.
    - Verification will include subscale results (listed earlier in this document) from a test launch and demonstration that the rocket has flown.
- The subscale rocket will be a newly constructed rocket, designed and built specifically for this year's project.
    - This requirement will be verified by demonstration.
    - Verification will include demonstration that the rocket is unique to this year's competition.
- Proof of a successful subscale flight will be supplied in the CDR report.
    - This requirement will be verified by testing and demonstration.
    - Verification will include subscale results (listed earlier in this document) from a test launch and demonstration that the rocket has flown.
- 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 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.
    - This requirement will be verified by demonstration and testing.
    - Verification will be done by flying the rocket and demonstrating the rocket is the same. Flight results will be provided in the FRR document.
- 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 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.
    - This requirement will be verified by demonstration and testing.
    - Verification will be done by flying the rocket with the payload and demonstrating the rocket is the same as the final flight configuration.
- Any structural protuberance on the rocket will be located aft of the burnout center of gravity.
    - This requirement will be verified by demonstration.
    - Verification will be achieved by inspecting the rocket prior to all launches.

- 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.
    - This requirement will be verified by demonstration.
    - Verification will be done by inspection of the rocket prior to launch.
- 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.
    - This requirement will be verified by demonstration.
    - Verification will be done by inspection of the rocket.
- 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.
    - This requirement will be verified by demonstration.
    - Verification will be done by inspection of the rocket.
- The launch vehicle will not exceed Mach 1 at any point during flight.
    - This requirement will be verified by analysis and testing.
    - Verification will be done using software programs such as OpenRocket 15.03 and RASAero II.
- Vehicle ballast will not exceed 10% of the total unballasted weight of the rocket as it would sit on the pad.
    - This requirement will be verified by demonstration.
    - Verification will be achieved by inspecting the rocket prior to all launches.
- Transmissions from onboard transmitters will not exceed 250 mW of power.
    - This requirement will be verified by 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.
- 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.
    - This requirement will be verified by demonstration.
    - Verification will be done by inspection of the rocket.

6.2.3. Handbook Recovery Requirements and Verification Plans

- 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.
    - This requirement can be verified via demonstration
    - Verification for this requirement will be completed via ejection charge demonstration at simulated altitudes and via the subscale and full-scale flights.
- 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.
    - This requirement can be verified via demonstration
    - Verification for this requirement will be completed via successful deployment of drogue and main parachutes before first flight.
- At launch vehicle landing, each individual component of the launch vehicle must have a maximum kinetic energy of 75 ft-lb.
    - This requirement can be verified via analysis.
    - Verification for this requirement will be completed via OpenRocket simulation.
- The recovery system electrical circuits will be completely independent of any payload electrical circuits.
    - This requirement can be verified via inspection
    - Verification for this requirement will be completed via inspection of avionics bay.
- All recovery system electronics will be powered by commercially available batteries.
    - This requirement can be verified via inspection.
    - Verification for this requirement will be completed via inspection of avionics bay.
- The recovery system will contain redundant, commercially available altimeters.
    - This requirement can be verified via inspection.
    - Verification for this requirement will be completed via inspection of the avionics bay.
- Motor ejection will not be used as a form of primary or secondary deployment.
    - This requirement can be verified via inspection
    - Verification for this requirement will be completed via inspection of the flight vehicle.
- Removable shear pins will be used for both the main parachute compartment as well as the drogue parachute compartment.
    - This requirement can be verified via inspection

- Verification for this requirement will be completed via inspection of the flight vehicle.

- The launch vehicle recovery area will be limited to a 2,500 ft radius from the launch pads.
  - This requirement can be verified via analysis.
  - Verification for this requirement will be completed via OpenRocket simulation.
- Descent time, from apogee to touchdown, shall be limited to 90 seconds.
  - This requirement can be verified via analysis.
  - Verification for this requirement will be completed via OpenRocket simulation.
- 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 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.
  - This requirement can be verified via inspection.
  - Verification for this requirement will be completed via inspection of the flight vehicle.
- 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.
  - This requirement can be verified via inspection.
  - Verification for this requirement will be completed via inspection of the avionics bay.

6.2.4. Handbook Payload Requirements and Verification Plans

- The team will design a custom rover that will deploy from the internal structure of the launch vehicle.
    - This requirement can be verified via 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.
- 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.
    - This requirement can be verified via 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.
- 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.
    - This requirement can be verified via test.
    - Verification for this requirement will be achieved by placing the assembled launch vehicle in a touchdown configurations and remotely triggering rover deployment.
- 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.
    - This requirement can be verified via 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.
- The soil sample will be a minimum of 10 milliliters (mL).
    - This requirement can be verified via 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.
- 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.
    - This requirement can be verified via 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.
- The team will ensure that the rover's batteries are sufficiently protected from impact with the ground.
    - This requirement can be verified via 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.
- The batteries powering the rover will be brightly colored, clearly marked as a fire hazard, and easily distinguishable from other rover parts.
    - This requirement can be verified by 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.

6.2.5. Handbook Safety Requirements and Verification Plans

- 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.
    - This requirement can be verified by 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.
- 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
            - 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.
    - This requirement can be verified via inspection.
    - 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.
- 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.
    - This requirement can be verified by 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.
- The team will abide by all rules and regulations set forth by the FAA.
    - This requirement can be verified by 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.

6.3. PSP-SL Requirements and Verification Plans

6.3.1. Vehicle Team Derived Requirements

- The vehicle will deliver the payload to an apogee altitude of 4,950 +/- 100 feet above ground level (AGL).
    - This requirement will be verified by repeated testing and analysis.
    - Verification will be done through prior launches such as the full scale test flight and through software programs like OpenRocket 15.03 and RASAero II.

- The vehicle will feature an active retention system capable of maintaining the payload during flight so that it remains in good condition to be fully operational for the next flight.
    - This requirement will be verified by demonstration and testing.
    - Verification will be done by inspection of the rocket and through data collected from the full scale test flight.
- Upon reaching the ground, the vehicle will safely eject the upper airframe from the upper section of the launch vehicle, and the retention system will expel the rover such that it may operate autonomously without physical contact with the launch vehicle.
    - This requirement will be verified by demonstration and testing.
    - Verification will be done through the competition and through data of ground tests.
- The vehicle will carry at least two commercially available, barometric altimeters for recording the official altitude.
    - This requirement will be verified by demonstration.
    - Verification will be done by inspection of the rocket.
- The launch vehicle will not horizontally drift more than 2000 feet from its launch pad, or point of origin.
    - This requirement will be verified by demonstration, analysis, and testing.
    - Verification will be done through the competition and through software programs such as OpenRocket 15.03 and RASAero II as well as the data from the full scale test flight.
- The launch vehicle must be able to maintain full functionality when launched on a day with at least 20 mph wind speeds.
    - This requirement will be verified by demonstration, analysis and testing.
    - Verification will be done through the competition and through software programs such as OpenRocket 15.03 and RASAero II as well as the data from the full scale test flight.
- The launch vehicle will achieve its objective using three sections in a dual-deployment recovery configuration.
    - This requirement will be verified by demonstration.
    - Verification will be done by inspection of the rocket prior to launch.
- The fins on the rocket will be evenly spaced, as straight as possible, and secured tightly to provide the proper support to the vehicle without creating any additional hazards through poor construction.
    - This requirement will be verified by analysis and demonstration.

    - Verification will be done through analysis of the fins to ensure they are straight and evenly spaced and how tightly they are secured will be verified through demonstration.
- The construction and fully-successful operation of a 0.45x subscale model will occur by December 9, 2018.
    - This requirement will be verified by demonstration and testing.
    - Verification will be done by testing the subscale rocket and by checking that the deadline was kept through checking the date on the subscale launch (listed above).
- The full-scale rocket will be successfully launched and recovered in a test flight by March 3, 2019, configured in the same configuration that will be used on the final launch day.
    - This requirement will be verified by demonstration and testing.
    - Verification will be done by testing the full scale rocket and by checking that the deadline was kept through checking the date on the full scale launch (will be listed in the FRR document).

6.3.2. Recovery Team Derived Requirements

- 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.
    - This requirement can be verified via demonstration.
    - Verification for this requirement will be completed via ejection charge demonstration at simulated altitudes and via the subscale and full-scale test flights.
- If the drogue parachute does not immediately deploy at apogee, the secondary altimeter will detect this and eject the parachute at one second after reaching apogee.
    - This requirement can be verified via testing.
    - Verification for this requirement will be completed via ejection testing at simulated altitudes.
- 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.
    - This requirement can be verified via testing
    - Verification for this requirement will be completed via ejection testing at simulated altitudes.
- Each altimeter will have a separate and distinct power source and wiring system.
    - This requirement can be verified via inspection.

    - Verification for this requirement will be completed via inspection of the flight vehicle.
- The recovery system electronics will be properly shielded from any other onboard devices which may adversely affect their proper operation and will be at a suitable distance from any transmitting devices stored in the payload bay or any e-matches.
    - This requirement can be verified via demonstration.
    - Verification of this requirement will be accomplished if each electronic system to be used in the full-scale rocket is powered on and functional and recovery system communications remain uninterrupted.

The recovery system will be tested on the ground as well as in at least one full scale flight. The avionics will remain the same for all flights, and the team will ground test with them to ensure that they work as designed, ignite the ejection charges, properly pressurize the airframe sections enough to break the shear pins, and fully deploy the recovery gear. The gear will also be tested in flight, as we will be using the same recovery gear on the full scale test flight as in the competition flight. Furthermore, each parachute will be subjected to a drop test in order to verify consistent opening time.

6.3.3. Payload Team Derived Requirements

- After ejection of the payload bay from the air-frame of the launch vehicle, the separation between the payload bay and vehicle should be at least 10 feet.
    - This requirement can be verified via testing.
    - Verification of this requirement will be accomplished through separation testing of the payload bay from the full-scale vehicle in which the distance the payload bay is ejected to will be measured multiple times.
- The wireless communication system for transmitting the deployment signal to the rover should send, receive, and parse signals over distances up to 3000 feet.
    - This requirement can be verified via demonstration.
    - Verification for this requirement will be accomplished through multiple tests in which half the communication system remains stationary and the other half is transferred by car to a distance over 3000 feet away at which team members running the test will check for a signal.
- The rover shall be capable of reorienting itself from all predictable initial orientations after deployment.
    - This requirement can be verified via demonstration.
    - Verification for this requirement will be accomplished by placing the rover in a variety of initial deployment orientations and ensuring it is able to autonomously upright itself and begin moving to collect a sample.

- The rover shall be capable autonomously moving away from the rocket over varying terrain of types which are predicted to be at the launch field.
    - This requirement can be verified via demonstration
    - Verification for this requirement will be accomplished by checking that the rover can complete its mission on terrain which simulates a rutted field with cut corn stalks, red clay, and grassy dirt, at a minimum.
- The rover shall consistently acquire and contain 20 mL of soil upon execution of its soil collection routine.
    - This requirement can be verified via 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.
- The payload system's weight shall not exceed 8 lbs.
    - This requirement can be verified via inspection.
    - Verification for this requirement will be achieved by adding the weights of all payload parts and double-checking that the total weight of the payload system does not exceed the proposed limit.
- The battery, operating under typical mission conditions, shall provide power to the system for at least 6 hours.
    - This requirement can be verified by testing.
    - Verification for this requirement will be accomplished via battery drain testing of the battery to be used for payload. This testing will extrapolate data from a time period in which the battery is hooked up to the payload to determine how long it would take for the payload to completely drain its power.
- Range-finding measurements taken by the LIDAR sensor on-board the payload must be accurate to within an inch.
    - This requirement can be verified via testing.
    - Verification for this requirement will occur by mounting the LIDAR sensor then varying the distance of a flat plate which will be fixed in front of it. If the LIDAR sensor returns distance readings which are accurate to within an inch for each distance the plate is set at, this requirement is verified.

6.3.4. Payload Requirements Verification Plan

In order to verify the the payload design is ready for a successful mission, extensive testing will be done to ensure that the payload can meet the requirements derived by the payload team.

6.3.4.1. Ejection Separation Test

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 (Hodgon's 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), we attributed this 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.

6.3.4.2. Radio Communication Distance Test

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.

6.3.4.3. Rover Orientation Test

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.

6.3.4.4. Rover Mobility Test

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.

6.3.4.5. Soil Collection Test

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.

6.3.4.6. Rover Net Weight Test

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 our 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.

6.3.4.7. Battery Drain Test

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.

6.3.4.8. LIDAR Range Test

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

.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 .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 .5 feet up to a final distance of 30 feet and repeat step 3 for each plate movement.

6.3.5. Safety Team Derived Requirements and Verification Plans

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

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

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

If these five requirements are met fully by all project personnel, the safety team has efficiently served its purpose.

6.4. Budgeting and Timeline

6.4.1. Line Item Budget

6.4.1.1. Full Scale Budget

Rocket Parts	Unit Cost	Quantity	Total
5:1 5" Von Karman FWFG Nosecone	$108.95	1	$108.95
5" Stepped AL Avionics bay lids	$16	6	$96
5" FWFG Airframe, 30" long	$85	3	$255
Custom Airframe Slotting, 3/16" wide, 15" long	$6	3	$18
5" FWFG Switch Band, 2" long	$7	2	$14

5" FWFG Coupler, 12" long	$53	2	$106
3" FWFG Motor Tube, 30" long	$50	1	$50
1/8" G10 FG Centering Ring	$9	2	$18
1/2" Plywood Centering	$5	2	$10
3/16" G10 FG Fins 6" tall, 15" root, 4" tip, 10" sweep	$20	3	$60
Skyangle Cert 3 XL Parachute	$189	1	$189
Skyangle Cert 3 Drogue Parachute	$27.50	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	$450	1	$290
Aerotech 75mm 3G L1520-T Reload	$199	2	$380
			$1888.89

6.4.1.2. 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

6.4.1.3. Avionics Budget

Item	Unit Cost	Quantity	Total
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
			$701

6.4.1.4. Payload Budget

Item	Unit Cost	Quantity	Total
Arduino Pro Mini	$13.00	1	$13.00
Battery	$20.00	1	$20.00
LIDAR sensor	$130.00	1	$130.00
Motors	$25.00	2	$50.00
Soil Collection System Materials	$50.00	1	$50.00
Antennae	$30.00	2	$60.00
Wheels	$20.00	2	$40.00
Black Powder (1 lb)	$20.00	1	$20.00
3D Printed Material (Payload Bay and Chassis)	$20.00	1	$20.00
			$403

6.4.1.5. Branding Budget

Item	Unit Cost	Quantity	Total
Polos	$25	24	$600
			$600

6.4.1.6. Travel Budget

Item	Unit Cost	Quantity	Total
Hotel Room	$94	18	$1692

Gas	$40	18	$720
			$2412

Grant Total: $5800

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.
- **Avionics:** All items in the avionics section have also been purchased. The avionics line item budget should be nearly complete, if not complete at this point.
- **Payload:** Currently, items for the payload bay have not been purchased and no definite quantity is apparent for the total cost of items in the payload section. Individual items are there anticipated cost have been added to this section until a complete and definite parts list for the payload section has been created.
- **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 24 individuals will be attending the trip to Huntsville, and thus the amount on the line item budget it based on this quantity.
- **Travel:** Travel costs include hotel room reservations and gas costs (if traveling by car). With an estimated 24 individuals attending, 6 rooms will be necessary for 3 nights (quantity 18 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 we will be able to fund this option, although the amount is known in case it becomes a possibility.

6.4.2. Funding Plan

6.4.2.1. Sources Of Funding

Assuming that the team requires around $6000, there will be five primary ways funds will be made to support the NASA Student Launch project:

1. Skip-a-meals and Campus Fundraisers: Skip-a-meals are social events where individuals can mention the name of our organization at a designated food establishment and a percentage (usually half) of money they spend at the establishment will be given to the team. These events usually last for a whole afternoon.
2. INSGC Grant: We are in the process of receiving a grant for $4000 from the Indiana Space Grant Consortium, which results in grants paying more than we

had previously anticipated. We are still applying to grants in the event that we are unable to receive a company sponsorship.

3. Company Sponsorship: We have been unsuccessful as of so far in finding any company willing to provide a portion of our funds, but we are still making inquiries.
4. Crowdfunding: Our crowdfunding campaign will begin in the week of January 15th, and will continue with the anticipation of receiving roughly $1000 assuming adequate advertising and campaigning.
5. SEDS Treasury: Our parent organization is providing $700 towards funding the project.

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

Fund Source	**Funds Generated**
SEDS Treasury	$700
Restaurant Socials (3 throughout year)	$600 ($200 each)
INSGC Grant	$4000
Crowdfunding Campaign	$1000
TOTAL:	$6300 (~$300 margin)

Procurement of funds has changed slightly since preliminary design review. Below is a Gantt change identifying when funds will be generated from each of the methods above. Colored spaces indicate inbound funds. Notably, funds from the 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 be used to pay for largely 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. 15th	Jan. 22nd	Jan. 29th	Feb . 5th	Feb. 12th	Feb. 19th	Feb. 26th	Mar. 5th	Mar. 9th	Mar. 16th
Restaurant Fundraisers							Last Fundraiser Ends			

INSGC Grant						Funds in Pocket				
Crowdfunding Campaign							Campaign Ends			
Company Sponsorship							Ideal Date			

6.4.2.2. Allocation of Funds

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

Full Scale Rocket: The full scale rocket was almost entirely funded using parts from last year's rocket, thus no funds are directly allocated towards this area.

Subscale Rocket: The majority of parts for the subscale rocket have been provided to us by our 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 parts from the SEDS treasury and restaurant fundraisers. Certain parts in the avionics budget (specifically the altimeters) are also 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 have funds from the restaurant fundraisers, crowdfunding campaign, and potentially the SEDS treasury allocated to it. If additional funds are necessary, potential funds from company sponsorships can be used here.

Branding: Matching polos for our team 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, as previously mentioned, will be entirely funded by the INSGC grant, which we will receive confirmation on in mid-February.

6.4.2.3. Material Acquisition

Materials for the subscale rocket were all 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. Almost all, if not all materials for the avionics bay have already been purchased from various vendors. Most avionics purchases were completed by individuals team members, who have been reimbursed through the SEDS bank account.

6.5. Educational Engagement

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

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

6.5.1. 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

6.5.2. Outcome of Outreach

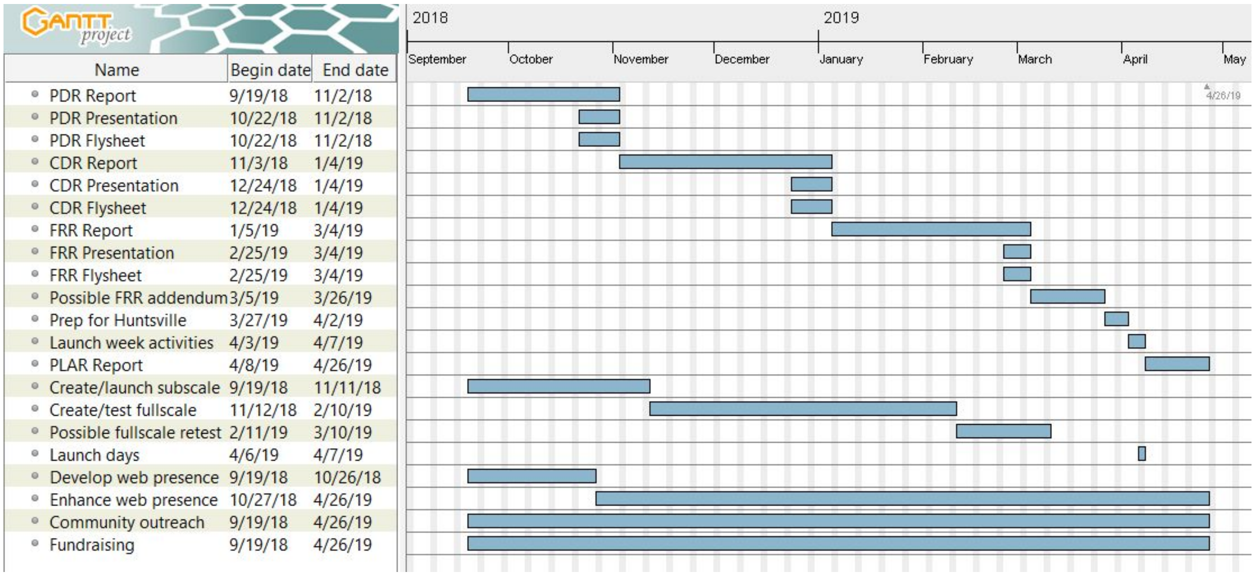
Team members which participated in Purdue Space Day were unable to see the evaluation reports the children gave to Space Day officials at the end of the day, but through word of mouth the team has heard that feedback was very positive in terms of both enjoyment and concepts learned. Team members also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

6.5.3. 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.

6.6. Timeline

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



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

Date	Event
08/31-09/03/2018	AIRFest 24 @ Argonia, Kansas Rocket Pasture
09/02/2018	Purdue SL general meeting
09/03/2018	LABOR DAY
09/09/2018	Indiana Rocketry Launch
09/09/2018	Purdue SL general meeting
09/16/2018	Purdue SL general meeting
09/19/2018	Proposal due to project office by 3PM CDT
09/23/2018	Purdue SL general meeting
09/29-09/30/2018	ROCI HPR Sport Launch @ AMA Aeromodeling Center in Muncie
09/30/2018	Purdue SL general meeting
10/04/2018	Awarded proposals announced
10/07/2018	Purdue SL general meeting
10/08-10/09/2018	OCTOBER BREAK
10/12/2018	Kickoff, PDR Q&A
10/13/2018	ROCI HPR Sport Launch @ Federal Rd. Field in Cedarville
10/14/2018	Purdue SL general meeting
10/14/2018	Indiana Rocketry Launch
10/20/2018	ROCI HPR Sport Launch @ AMA Aeromodeling Center in Muncie
10/21/2018	Purdue SL general meeting

10/26/2018	Web presence established, URLs sent to project office by 8AM CDT
10/27/2018	ROCI HPR Sport Launch @ Federal Rd. Field in Cedarville
10/28/2018	Purdue SL general meeting
11/01-11/03/2018	SEDS SpaceVision @ San Diego
11/02/2018	PDR reports, slides, and flysheet posted online by 8AM CDT
11/02-11/04/2018	Midwest Power Launch
11/04/2018	Purdue SL general meeting
11/05/2018	PDR video teleconferences start
11/10/2018	ROCI HPR Sport Launch @ Federal Rd. Field in Cedarville
11/11/2018	Purdue SL general meeting
11/11/2018	Indiana Rocketry Launch
11/18/2018	Purdue SL general meeting
11/19/2018	PDR video teleconferences end
11/21-11/24/2018	THANKSGIVING BREAK
11/24/2018	ROCI HPR Sport Launch @ Federal Rd. Field in Cedarville
11/25/2018	Purdue SL general meeting
11/27/2018	CDR Q&A
12/2/2018	Purdue SL general meeting
12/08/2018	Quad Cities Rocket Society (QCRS) Launch
12/09/2018	Purdue SL general meeting
12/09/2018	Indiana Rocketry Launch
12/15-01/06/2019	WINTER BREAK
01/03/2019	Final day for subscale launch
01/03/2019	Final motor choice made for launch
01/04/2019	CDR reports, slides, and flysheet posted online by 8AM CDT
01/06/2019	Possible Purdue SL general meeting
01/07/2019	CDR video teleconferences start
01/13/2019	Purdue SL general meeting
01/13/2018	Indiana Rocketry Launch (?)
01/20/2019	Purdue SL general meeting
01/21/2019	MLK JR. DAY
01/22/2019	CDR video teleconferences end
01/25/2019	FRR Q&A

01/27/2019	Purdue SL general meeting
02/03/2019	Purdue SL general meeting
02/10/2019	Purdue SL general meeting
02/10/2019	Indiana Rocketry Launch (?)
02/17/2019	Purdue SL general meeting
02/24/2019	Purdue SL general meeting
03/03/2019	Purdue SL general meeting
03/03/2019	Final day for full scale launch/Vehicle Demonstration Flight
03/04/2019	Vehicle Demonstration Flight data reported to NASA
03/04/2019	FRR reports, slides, and flysheet posted online by 8AM CDT
03/08/2019	FRR video teleconferences start
03/10/2019	Purdue SL general meeting
03/10/2019	Indiana Rocketry Launch (?)
03/11-03/16/2019	SPRING BREAK
03/17/2019	Possible Purdue SL general meeting
03/21/2019	FRR video teleconferences end
03/24/2019	Purdue SL general meeting
03/25/2019	Payload Demo Flight/Vehicle Demonstration Re-flight deadlines
03/25/2019	FRR Addendum submitted to NASA by 8:00 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

7. Appendix A

7.1. 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