# The Pennsylvania State University

# LionTech Rocket Labs

2018 - 2019 Solium Project

# Critical Design Review Report

*046 Hammond Building, University Park, PA 16802*
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# List of Acronyms

| | |
|---|---|
| A&R | Avionics and Recovery |
| ABS | Acrylonitrile Butadiene Styrene |
| AV | Avionics |
| CFD | Computational Fluid Dynamics |
| EIT | Electronic and Information Technology |
| FAA | Federal Aviation Administration |
| FEA | Finite Element Analysis |
| EHS | Environmental Health and Safety |
| EUC | Engineering Undergraduate |
| GPS | Global Positioning System |
| HPCL | High Pressure Combustion Lab |
| LTRL | LionTech Rocket Labs |
| MDRA | Maryland Delaware Rocketry Association |
| MSDS | Material Safety Data Sheet |
| NAR | National Association of Rocketry |
| NASA | National Aeronautics and Space Administration |
| NFPA | National Fire Protection Association |
| PLA | Polylactic Acid |
| PPE | Personal Protective Equipment |
| PSC | Pittsburgh Space Command |
| PSU | The Pennsylvania State University |
| RSO | Range Safety Officer |
| SDS | Safety Datasheet |
| SLI | Student Launch Initiative |
| STEM | Science Technology Engineering and Mathematics |
| STTR | Small Business Technology Transfer |
| TRA | Tripoli Rocket Association |
| UPAC | University Park Allocation Committee |
| USD | United States Dollar |
| USLI | University Student Launch Initiative |

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# 1. Summary of Preliminary Design Report

## 1.1 Team Summary

### Team Name and Mailing Address

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### Adult Educator/Club Advisor

Dr. David Spencer – dbs9@psu.edu (814) 865-4537

### NAR Contact/Mentor

Justin Hess NAR L2 Certification - #102887 – jthess418@gmail.com

## 1.2 Launch Vehicle Summary

### Size and Mass

The flight vehicle is designed to carry a rover payload along with the necessary flight systems for telemetry acquisition and a successful recovery. The flight vehicle's target apogee is 5,280 feet. A diameter of 6 inches was chosen to give adequate space for the rover, its retention system, and its deployment system. The length of the flight vehicle is 120 inches to provide enough space for the payload and the necessary avionics and flight systems, and the flight vehicle's wet mass weight is 36.63 lbs. The center of pressure is located 94.34 inches aft of the tip of the nose cone, and the center of gravity is located 73.80 inches aft of the tip of the nose cone resulting in a static stability margin of 3.42 calibers. The rail size will be 10 ft tall and 15-15 gauge. The full flight vehicle with components can be seen below in Figure 1.

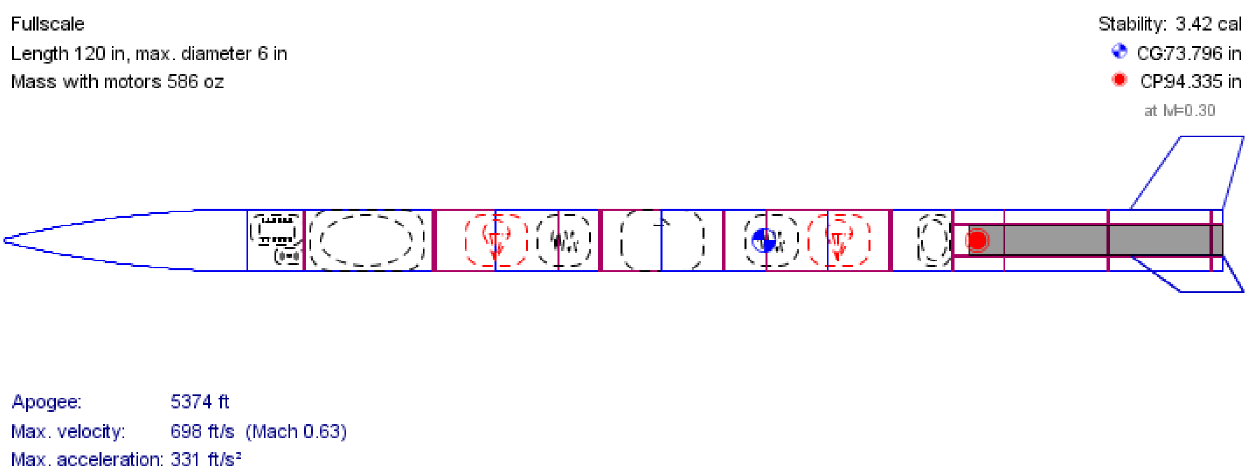


**Figure 1. Side View of the Fullscale Flight Vehicle**

### Final Motor Choice and Target Altitude

The motor selection is based on the mission performance criteria outlined in the NASA USLI 2018-19 Handbook and utilizes OpenRocket to simulate flight characteristics. Through this motor selection process, the Cesaroni L1355 was selected as the vehicle's motor and will take our launch vehicle to the target apogee of 5,280 feet.

### Recovery System

The rocket will have a dual-deployment parachute recovery system where the primary drogue parachute will deploy at apogee and the primary main parachute will deploy at 600 ft above ground level (AGL). The redundant altimeter will be at a two-second delay for drogue and deploy at 500ft AGL for main. The drogue parachute will be a 12" Fruity Chutes Classical Ultra and the main parachute will be an 84" Fruity Chutes Iris Ultra. The avionics bay will have a removable avionics board consisting of two independent Stratologger CF altimeters with corresponding independent power sources switches, initiators and black powder charges.

## 1.3 Payload Summary

### Payload Title

Deployable Rover/Soil Sample Recovery System

### Summary of Payload Experiment

The payload criteria section will outline the design decisions for the rover. The section is divided into 2 main parts, mechanical and software/hardware. The rover will be deployed from the launch vehicle's nose cone after landing and then autonomously move at least 10 feet away from all parts of the rocket. After the rover has reached its destination, it will collect a soil sample.

## Milestone Review Flysheet

# Milestone Review Flysheet 2018-2019

| Institution | LionTech Rocket Labs | Milestone | CDR |
|---|---|---|---|

| Vehicle Properties | |
|---|---|
| Total Length (in) | 120 |
| Diameter (in) | 6 |
| Gross Lift Off Weigh (lb) | 36.6 |
| Airframe Material(s) | Carbon Fiber, Fiberglass, Blue Tube |
| Fin Material and Thickness (in) | Fiberglass, 3/16" |
| Coupler Length/Shoulder Length (in) | 12 / 6 |

| Motor Properties | |
|---|---|
| Motor Brand/Designation | Cesaroni L1355 |
| Max/Average Thrust (lb) | 393 / 306 |
| Total Impulse (lbf-s) | 905 |
| Mass Before/After Burn (lb) | 10.9 / 4.2 |
| Liftoff Thrust (lb) | 360 |
| Motor Retention Method | Plywood centering rings, steel-infused epoxy |

| Stability Analysis | |
|---|---|
| Center of Pressure (in. from nose) | 94.3 |
| Center of Gravity (in. from nose) | 73.8 |
| Static Stability Margin (on pad) | 3.42 |
| Static Stability Margin (at rail exit) | 3.5 |
| Thrust-to-Weight Ratio | 7.77 |
| Rail Size/Type and Length (in) | 15-15 / 120 |
| Rail Exit Velocity (ft/s) | 75.7 |

| Ascent Analysis | |
|---|---|
| Maximum Velocity (ft/s) | 699 |
| Maximum Mach Number | 0.62 |
| Maximum Acceleration (ft/s^2) | 331 |
| Target Apogee (ft) | 5280 |
| Predicted Apogee (From Sim.) (ft) | 5374 |

| Recovery System Properties - Overall | |
|---|---|
| Total Descent Time (s) | 63.2 |
| Total Drift in 20 mph winds (ft) | 1857.77 |

| Recovery System Properties - Energetics | | |
|---|---|---|
| Ejection System Energetics (ex. Black Powder) | | 4F Black Powder |
| Energetics Mass - Drogue Chute (grams) | Primary | 1.5 |
| | Backup | 2 |
| Energetics Mass - Main Chute (grams) | Primary | 2 |
| | Backup | 3 |
| Energetics Mass - Other (grams) - If Applicable | Primary | |
| | Backup | |

| Recovery System Properties - Recovery Electronics | |
|---|---|
| Primary Altimeter Make/Model | Perfect Flight StrologgerCF |
| Secondary Altimeter Make/Model | Perfect Flight StrologgerCF |
| Other Altimeters (if applicable) | NA |
| Rocket Locator (Make/Model) | Americaloc GW300 |
| Additional Locators (if applicable) | NA |
| Transmitting Frequencies (all - vehicle and payload) | Something or other MHz |
| Describe Redundancy Plan (batteries, switches, etc.) | 9V battery, toggle switch |
| Pad Stay Time (Launch Configuration) | 2 hours |

| Recovery System Properties - Drogue Parachute | | | | |
|---|---|---|---|---|
| Manufacturer/Model | Fruity Chutes, Classical Ultra | | | |
| Size or Diameter (in or ft) | 12 in | | | |
| Main Altimeter Deployment Setting | Apogee | | | |
| Backup Altimeter Deployment Setting | Apogee + 2 seconds | | | |
| Velocity at Deployment (ft/s) | 74 | | | |
| Terminal Velocity (ft/s) | 140 | | | |
| Recovery Harness Material, Size, and Type (examples - 1/2 in. tubular Nylon or 1 in. flat Kevlar strap) | 1/4 in kevlar flat strap | | | |
| Recovery Harness Length (ft) | 24 | | | |
| Harness/Airframe Interfaces | 3/8 in steel U-Bolt | | | |
| Kinetic Energy of Each Section (ft-lbs) | Section 1 | Section 2 | Section 3 | Section 4 |
| | 2534.62 | 2706.01 | 1730.07 | NA |

| Recovery System Properties - Main Parachute | | | | |
|---|---|---|---|---|
| Manufacturer/Model | Fruity Chutes, Iris Ultra | | | |
| Size or Diameter (in) | 84 | | | |
| Main Altimeter Deployment Setting (ft) | 600 | | | |
| Backup Altimeter Deployment Setting (ft) | 500 | | | |
| Velocity at Deployment (ft/s) | 140 | | | |
| Terminal Velocity (ft/s) | 19.44 | | | |
| Recovery Harness Material, Size, and Type (examples - 1/2 in. tubular Nylon or 1 in. flat Kevlar strap) | 1/2 in kevlar flat strap | | | |
| Recovery Harness Length (ft) | 27 | | | |
| Harness/Airframe Interfaces | 3/8 in steel U-Bolt | | | |
| Kinetic Energy of Each Section (ft-lbs) | Section 1 | Section 2 | Section 3 | Section 4 |
| | 61.83 | 45.27 | 61.76 | NA |

# 2. Changes Made Since Proposal

## 2.1 Changes Made to Project Plan

Other than the revisions specified by the subsystems, no changes have been made to the project plan.

## 2.2 Changes Made to Vehicle Criteria

### Launch Vehicle

Many mass estimates of certain components have been refined since the last report. The mass of the fiberglass nose cone increased from 1.35 lbs to 4 lbs due to an incorrect listing on the manufacturer's website. The density estimates of the carbon fiber layup have increased slightly as well. Other minor changes among various components such as the camera and payload systems brings the new total mass of the rocket to 36.63 lbs which is a five pound increase from the PDR mass of 31.2 lbs. This increase in mass has resulted in a need for a larger motor to reach the target apogee. As a result, the team has selected the Cesaroni L1355 as the new primary motor choice.

### Recovery System

The team has decided to move forward with a longer drogue shock cord with a greater cross-sectional area. The drogue shock cord detailed in PDR was a half inch Kevlar cord that was 11 feet in length. Based on advice from the PDR review board and additional research, the team has decided to move forward with a half inch diameter, 24 foot shock cord made of Kevlar. This change was motivated by manufacturers' tendency to overstate the maximum load the cord can handle and a desire to increase the shock cords safety factor as a result. This larger shock cord will decrease the stress in the recovery harness as well as spread out the force on the rocket frame over a longer time during deployment.

The team has also decided to lower main deployment altitude from 700 feet to 600 feet above ground level. This was done to allow the team to use a larger main parachute without increasing the drift distance. The redundant altimeter will now deploy at 500 feet.

Additionally, a new mechanical switch system for altimeter arming has been designed after it was identified as an action item in the PDR score sheet. The new toggle switch system to arm both altimeters is further detailed in the avionics board section.

## 2.3 Changes Made to Payload Criteria

Table 1 shows the changes made to the payload design since PDR and the justifications for these changes. Table 1 does not include design decisions that were not finalized in PDR. Final design decisions and justifications will be outlined in the Payload Criteria Design section.

**Table 1. Justifications for Changes since PDR**

| Change | Justification |
|---|---|
| Motor mounts | The PDR models of the motor mounts were conceptual designs. The CDR models of the motor mounts include exact dimensions and include a flexible tab that allows the motor to snap into place. Allowing the motors to snap into place means that they are less likely to fall out due to vibrations during flight. |
| 3 radios for communication between the rover, rocket, and ground station | In PDR, the communication system was going to be attached to the rocket and not the rover. This made it difficult to have the rocket initiate the driving sequence, so the communication system will include a radio on the rover. Including an additional radio means that the ground station can control detonation through the rocket's communication system and then separately initiate the rover's driving sequence. This decreases the complexity of the wiring and minimizes the modes of failure. |
| Additional signal controls on the ground station GUI | Because the rocket is no longer initiating the driving sequence, additional controls were added to send the driving signal to the rover. |
| Implementation of safety features on ground station GUI | Check boxes were added to the ground station GUI so that none of the signals could be accidentally sent before the launch vehicle has landed. |
| Changed solenoid to a rotary solenoid | The solenoid was changed because the team determined that the linear solenoid was not an effective fail safe method of retainment. The rotary solenoid is fail safe and therefore closer aligns to the requirements. |
| External switch for disabling deployment on the launch stand | An external switch was implemented so that the deployment mechanism can be disabled from the launch pad by the safety officer if need be. This also allows the team to safe battery life on the communications system since it can now be turned on while on the launch pad instead of when assembling the rocket. |
| Scooping mechanism for soil sample recovery | The scooping mechanism was chosen for the soil sample recovery because of its simplicity for execution and implementation. The previous idea of a scooping wheel were too complicated and took up too much space to be feasible. |

# 3. Vehicle Criteria

## 3.1 Launch Vehicle Design and Justification

### Mission Statement and Success Criteria

The mission of the structures team of LTRL for the 2019 NASA Student Launch competition is to build a launch vehicle capable of safely and consistently flying to an altitude of 5,280 feet. This launch vehicle will also be able to hold and successfully deploy a rover payload.

The mission success criteria will be defined by the launch vehicle achieving an altitude within 5% of the target altitude and allowing the rover payload to exit the rocket after landing. This criteria also includes safety standards that require that no team members, launch officials, or spectators be in harm's way at any point during the launch process.

### Airframe

In the 2017-2018 competition year, the team built the launch vehicle using carbon fiber wrapped blue tube. For the 2018-2019 competition year, the team has decided to move forward with carbon fiber as the selected material to build the launch vehicle. This decision was made based on a weighted design selection matrix.

Four categories were considered for building the launch vehicle: creating carbon fiber tubes utilizing shrink tape and a heat source, creating carbon fiber tubes utilizing vacuum bagging, purchasing blue tube body tubes, and purchasing prefabricated, filament-wound glass fiber body tubes. Baking body tubes in an oven or autoclave was not considered due to a lack of necessary tools and sufficient working space.

There are six factors on the material selection matrix that were considered when determining which material would work best for the launch vehicle. A score of one to five was assigned to the different factors based on the material's performance in that criteria; a score of one is considered the worst and a score of five is considered the best. The six factors that were taken into account were strength, cost, workability, material weight, educational value, and safety. Strength was rated on the material's ability to withstand forces experienced during flight such as thrust forces, impact forces, compressive forces, potential zippering, and buckling. Materials with a higher tensile strength were given a higher score. Cost was determined by the price of the material per linear foot. If a material had a lower cost, it was given a higher score. Workability was scored based on how easily the material could be modified to satisfy the required dimensions. The more workable the material, the higher the score. Material weight is a measure of the materials density; a lower material density received a higher score. Educational value was graded based on how much club members could learn from utilizing the material with the more educational design options receiving a higher score. Finally, safety was scored based on the hazardousness of the material; a safer material received a higher score.

Each of the different criteria were weighted on a scale from zero-to-one; factors deemed more important were given a higher weight and the sum of their scores were equal to one. Strength received a weight of 0.15, despite its importance, because the team has not experienced flight conditions that have led to catastrophic failure for even the weakest materials. Cost was given a weight of 0.10 to account for the material's important impact on the team's budget. This weight accounts for the possibility that the team needs to rebuild the launch vehicle in the event of a catastrophic launch failure and, as a result, needs to replace the material. Workability was given a weight of 0.10 to reflect the importance of the material's ability to be constructed to the required dimensions. Material was given a weight of 0.15 due to its impact on apogee and stability of the launch vehicle. Educational value was given a weight of 0.25 because of the importance the team places on educating all the team's members. Safety was given a weight of 0.25 to account for the hazardousness of all the materials utilized. Safety risks can be limited if the correct steps are taken, but the utilization of composite materials provides a greater risk to the user.

The scores for the different materials can be found in Table 1 below.

**Table 2. Airframe Material Selection Matrix**

| | | Carbon Fiber (Shrink Tape) | | Carbon Fiber (Vacuum Bagging) | | Glass Fiber | | Blue Tube | |
|---|---|---|---|---|---|---|---|---|---|
| **Attributes** | **Weight** | Score | Weighted Score | Score | Weighted Score | Score | Weighted Score | Score | Weighted Score |
| **Strength** | 0.15 | 3 | 0.45 | 5 | 0.75 | 4 | 0.60 | 1 | 0.15 |
| **Cost** | 0.10 | 3 | 0.30 | 1 | 0.20 | 2 | 0.20 | 5 | 0.50 |
| **Workability** | 0.10 | 2 | 0.20 | 1 | 0.60 | 3 | 0.30 | 5 | 0.50 |
| **Material Weight** | 0.15 | 3 | 0.45 | 3 | 0.45 | 1 | 0.15 | 4 | 0.60 |
| **Educational Value** | 0.25 | 5 | 1.25 | 5 | 1.25 | 2 | 0.50 | 1 | 0.25 |
| **Safety** | 0.25 | 2 | 0.50 | 3 | 0.75 | 1 | 0.50 | 5 | 1.25 |
| **Total** | 1.00 | | **2.95** | | **3.40** | | **2.35** | | **3.25** |
| **Rank** | | | **3** | | **1** | | **4** | | **2** |

The tensile strength ratings given to the different materials can be found below in Table 2. Based on these values, glass fiber was awarded a score of four, and blue tube received a score of one. For carbon fiber, the team determined that there would be more voids between the matrix and fiber bond when shrink taping the carbon fiber rather than during the vacuum bagging process. The vacuum bagging process to create carbon fiber tubes received a score of five because the epoxy would be more evenly distributed throughout the laminate and any extra epoxy will be wicked out. Because of this, carbon fiber using shrink tape received a three and carbon fiber using vacuum bagging received a five.

**Table 3. Material Strength and Stiffness Comparison**

| Material | Tensile Strength [ksi] | Modulus [Msi] |
|---|---|---|
| Carbon Fiber | 610-635 | 33-38 |
| Glass Fiber | 500-650 | 10.5-12.4 |
| Blue Tube | 15-25 | 0.58 |

The cost for the materials measured by cost per linear foot can be found below in Table 3. The cost for carbon fiber price was calculated for six layers of 3K-Plain Weave variant. Six layers of 3K-Plain Weave variant was chosen based on calculations detailed in the testing plan section. Based on these values, carbon fiber using shrink tape was awarded a score of three, carbon using vacuum bagging received a score of one, glass fiber received a score of two, and blue tube received a score of five.

**Table 4. Material Cost Comparison**

| Material: | Cost/Foot [in $]: |
|---|---|
| Carbon Fiber (Shrink Tape) | 52.36 |
| Carbon Fiber Vacuum Bagging | 61.56 |
| Glass fiber | 55 |
| Blue Tube | 18 |

For the workability criteria, prefabricated glass fiber body tubes, carbon fiber created with a heat source and shrink tape, and carbon fiber created through vacuum bagging were given low scores of three, two, and one respectfully. Prefabricated glass fiber body tubes received a score of three because the tubes can be procured at the exact size needed for each section of the launch vehicle. Only small adjustments will be needed to correctly fit couplers and bulkheads into the body tubes. Carbon fiber tubes produced utilizing shrink tape and an external heat source received a score of two because the sections created would be difficult to cut, and may provide loose fittings between couplers and body tube. Carbon fiber tubes manufactured through the vacuum bagging process received a score of one due to the team's lack of experience utilizing this method. These sections will also be difficult to cut, and may provide loose fittings between couplers and body tube as well. Because it can easily be modified to meet the launch vehicle's specifications, blue tube received a score of five.

When scoring weight for the potential materials, it was discovered that there are some discrepancies between the density given from the supplier's website and the OpenRocket database. Table 4 details the differences in densities between OpenRocket's database and the supplier's information.

**Table 5. Density Discrepancy between OpenRocket and Supplier**

| | OpenRocket Density ($\frac{oz}{in^3}$) | Supplier Density ($\frac{oz}{in^3}$) |
|---|---|---|
| **Glass Fiber** | 1.07 | 1.18 |
| **Blue Tube** | 0.75 | 0.54 |
| **Carbon Fiber** | 1.03 | 0.919 |

For carbon fiber, the team believes that this discrepancy is caused by the specific fabric utilized. The process at which the tubes are cured will also have an effect on the density of carbon fiber. The supplier's density of carbon fiber assumes a fiber volume fraction of 0.60-0.65 while the team's fiber volume fraction for the launch vehicle may differ from this value. The team will have to take these discrepancies into account when building the launch vehicle and calculations will have to be done to determine the correct density of the carbon fiber. Using an average of the OpenRocket density and the manufacturer density, glass fiber, blue tube, and carbon fiber received a score of one, four, and three respectively.

Our team has decided to include an educational value category this year. One of the project's objectives is to involve students in engineering projects and to bestow upon them knowledge that will be valuable in their future careers. Since the aerospace industry is placing a greater emphasis on the utilizing of composite materials, the team has decided it would be beneficial to research new ways to incorporate them in our project. In this category, blue tube received a score of one. The team has utilized blue tube in past years and does not find any educational value in utilizing it again. Glass fiber was given a score of two because the prefabricated, filament-wound tubes would be bought and cut down to the correct dimensions. This provides some educational benefit because team members can learn about the different properties of glass fiber, but they are unable to see firsthand how the material is produced. Since carbon fiber is utilized heavily throughout the aerospace industry and only a few team members have experience with it, carbon fiber received a score of five.

For the safety criteria, blue tube received a score of five because it poses no significant safety hazards. Carbon fiber and glass fiber received scores of two and one respectfully because of the difficulties that come with modifying the laminate. Carbon fiber and glass fiber shards are dangerous when inhaled and can easily be embedded in the skin if proper caution is not taken. Vacuum bagged carbon fiber received a higher score than shrink taped carbon fiber because the shrink tape method involves the extended application of heat. This requires a heat source, such as an oven or a heat gun, which can be a safety hazard if the process is not carefully monitored and controlled.

After all the scores were assigned and weighted, vacuum bagged carbon fiber had the highest score and was selected as the team's airframe material for the 2018-2019 competition year as a result. The optimal amount of layers of carbon fiber will be determined by testing the structural integrity of test pieces composed of six and seven layers of carbon fiber. Calculations detailed in the testing plan section detail justification for either six or seven layers of carbon fiber that are necessary to withstand nominal flight forces. Several test pieces have been created to test the manufacturing process including the entire subscale vehicle. The team believes that the team's current carbon fiber manufacturing practices and procedures will be able to cope with fullscale production.

### Resin Decision

With the team moving forward with building the launch vehicle out of carbon fiber, the next step is to determine which composite matrix will work best. In high performance composites, fiber reinforcement is the backbone of the material. It provides the materials with stiffness and strength. The continuous matrix provides protection for the fibers, bonding, support, and a local stress transfer to occur throughout the fibers. Even though the matrix will not be taking the majority of the load, the type utilized is critical to the structural integrity of the composite laminate.

The three matrices considered were polyester, epoxy, and vinyl ester. Thermoplastics were not considered due to a lack of necessary equipment and budget.

Four factors on the material selection matrix were considered when determining which material would work best for the launch vehicle. The four factors that were taken into account were strength, cost, pot life, and cure time. A score of one to five was assigned to the different factors based on the material's performance in that criteria. A score of one is considered the worst and a score of five is considered the best. Strength was rated on the matrices' ability to withstand forces experienced during flight; a higher tensile strength resulted in a higher score. Cost was determined by analyzing the price of the material per gallon of the matrix. The score a material received was inversely proportional to its cost. Pot life was scored based on how long the matrix could remain at room temperature before curing. The longer the pot life, the higher the score it received. Having a longer pot life would allow the team to take their time while constructing the wet layup. Cure time was scored based on how long it would take for the matrix to cure. A larger time lapse received a lower score.

Each of the different criteria were weighted on a scale from zero to one. The factors that the team determined to be more important were given a higher weight and the sum of the scores is equal to one. Strength was given a weight of 0.50 to reflect its importance. Even though the laminate is dominated by the strength of the fiber utilized, the strength of the matrix is still essential to the overall strength of the layup. Cost was given a weight of 0.25 to account for the material's important impact on the team's budget. This weight accounts for the possibility that the team needs to rebuild the launch vehicle in the event of a catastrophic launch failure and would need to replace material as a result. Pot life was given a weight of 0.10 to reflect the ease of creating the laminate even with a shorter pot life. Cure time was given a weight of 0.15 due to its impact on the time it takes to construct the launch vehicle.

The scores for the different resins can be found in Table 5 below.

**Table 6. Resin Selection Matrix**

| | | Polyester | | Epoxy | | Vinyl Ester | |
|---|---|---|---|---|---|---|---|
| **Attributes** | **Weight** | Score | Weighted Score | Score | Weighted Score | Score | Weighted Score |
| **Strength** | 0.50 | 2 | 1.00 | 4 | 2.00 | 3 | 1.50 |
| **Cost** | 0.25 | 4 | 1.00 | 2 | 0.50 | 3 | 0.75 |
| **Pot Life** | 0.10 | 2 | 0.20 | 5 | 0.50 | 2 | 0.20 |
| **Cure Time** | 0.15 | 4 | 0.60 | 1 | 0.15 | 4 | 0.60 |
| **Total** | 1.00 | | **2.80** | | **3.15** | | **3.05** |
| **Rank** | | | **3** | | **1** | | **2** |

The tensile strength and flexural modulus of polyester, epoxy, and vinyl ester can be found in Table 6. From these values, polyester was awarded a score of two, epoxy received a score of four, and vinyl ester received a score of three.

**Table 7. Resin Strength and Stiffness Comparison**

| Matrix: | Tensile Strength [ksi]: | Modulus [Msi]: |
|---|---|---|
| Polyester | 5.8-13.0 | 0.46-0.51 |
| Epoxy | 13 | 0.54 |
| Vinyl Ester | 9.4-13.0 | 0.43-0.58 |

The cost of the three different resins can be found below in Table 7. This cost included the price for a gallon of the matrix and the hardener needed. From these values, polyester was awarded a score of four, epoxy received a score of two, and vinyl ester received a score of three.

**Table 8. Resin Cost Comparison**

| Matrix: | Cost / Gallon [in $]: |
|---|---|
| Polyester | 70 |
| Epoxy | 180 |
| Vinyl Ester | 105 |

Polyester and vinyl ester both have pot lives of approximately 20 minutes. Problems may occur if the team is not able to take their time when constructing the body tube. Because of this, both of the matrices received a score of two. Epoxy has a pot life of an hour after it has been mixed with the hardener which provides ample time for the team to construct the carbon fiber layup and make adjustments if necessary. As a result, epoxy received a score of five as a result.

Both polyester and vinyl ester received a score of four for cure time because both matrices cure within a matter of minutes and are sandable in approximately six hours. However, for a full cure, polyester and vinyl ester take 24 hours. Epoxy has a cure time of 24 hours, but it requires almost 48 hours for a full cure. For this reason, epoxy received a score of one.

After all of the scores were assigned and weighted, epoxy received the highest score and was selected as the team's matrix for this competition year as a result.

## Fin Retention

The team has decided to utilize 3D printed fin brackets to retain the fins during flight. This design feature was introduced two years ago and has been improved upon this year. The goal of the design is to easily remove and replace the fin brackets without replacing the fins. Because the fins are often the most common point of a structural failure on even nominal landings, this design specifically satisfies Requirement 2.10. No epoxy or permanent fastening methods are utilized with this fin retention system. The design can be seen in Figure 1.

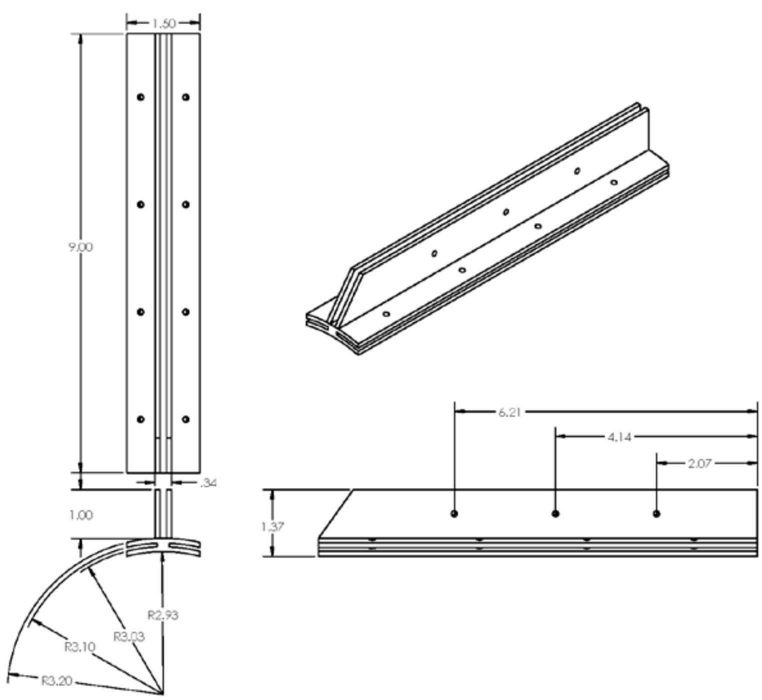


**Figure 2. SolidWorks Drawing of Fin Brackets**

There are holes to employ a screw and bolt retention system. This will allow team members to quickly replace a piece if it were to fail before or after launch. The fin brackets will lay on both the interior and the exterior of the body tube to provide extra structural support. The body tube will be cut from the aft edge to allow for the fin brackets to be inserted and laid flush with the aft end of the body tube. Eight screws will be placed in each fin bracket to keep them attached to the airframe during the entire flight. The fins will also be fastened with nuts and bolts through the top section of the brackets.

This design was chosen by utilizing a design selection matrix. Three designs were analyzed: the first design utilized a 3D printed bracket epoxied to the body tube, the second design involved epoxying the fins directly to the body tube, and the last design utilized a 3D printed bracket that was bolted to the airframe, pictured in Figure 1. The design in which the fins would be directly epoxied to the body tube was chosen to be the reference model due to its popularity in amateur rocketry.

The three designs were rated from one to five in several different categories. These categories were as follows: cost, strength, production time, and replaceability. The reference design was assigned a score of three for all attributes, then each alternative design was rated compared to the reference design. These scores were then multiplied by a weight value and summed. The total for the weight values added up to a sum of one. The design with the highest final score was chosen.

Cost was given a weight of 0.15 to account for the importance of staying within the project's budget. A lower cost would be considered more effective and provide it with a higher score, whereas a higher cost would be considered less effective granting it a lower score. Strength was given a weight of 0.20 to reflect the importance that a design will not fail in operation. A score of one or two states that the design is weaker than the reference design, while a score of four or five means that is stronger. Production time refers to the amount of time a design requires to be prepared. It was given a weight of 0.15 to help ensure that the selected design would not be overly time consuming. Since the launch vehicle needs to satisfy Requirement 2.10, replaceability was chosen to be the primary design requirement for the fin retention system. With this in mind, a weight of 0.50 was assigned to the replaceability attribute. A fin retention design that is easily removable and replaceable in case of damage would receive a score of four or five depending on how easily a piece can be replaced. If the design was harder to replace than the reference design, it would receive a score of one or two depending on how difficult it is to replace. Table 8 shows the fin retention selection matrix.

**Table 9. Fin Retention Selection Matrix**

| | | 3D Printed, Epoxied | | Epoxied (reference) | | 3D Printed, Bolted | |
|---|---|---|---|---|---|---|---|
| **Attributes** | **Weight** | Score | Weighted Score | Score | Weighted Score | Score | Weighted Score |
| **Cost** | 0.15 | 2 | 0.30 | 3 | 0.45 | 1 | 0.15 |
| **Strength** | 0.20 | 3 | 0.60 | 3 | 0.60 | 3 | 0.60 |
| **Production Time** | 0.15 | 2 | 0.30 | 3 | 0.45 | 2 | 0.30 |
| **Replaceability** | 0.50 | 4 | 2 | 3 | 1.50 | 5 | 2.50 |
| **Total** | 1.00 | | **3.20** | | **3.00** | | **3.55** |
| **Rank** | | | **3** | | **2** | | **1** |

The 3D printed-epoxied design scored a two for cost because both plastic filament and epoxy are required to implement this design. Since 3D printing takes extended time to complete, the design was assigned a score of two for production time. While epoxied fins are difficult to be removed, they scored a four since they do not require the motor tube to be replaced like fins epoxied to the motor tube does. 3D printed-epoxied brackets have been verified to withstand in flight forces in past years, but are not necessarily any stronger than epoxied fins to the motor tube and received a three as a result.

The 3D printed-bolted design scored a one because the plastic filament and screws costs more than the epoxy does for the reference design. It is also more expensive than the 3D printed-epoxied design due to needing additional filament and fasteners. This design is expected to be stronger than traditionally epoxied fins because it is fastened securely both on the interior and the exterior of the body tube. Since 3D printing of multiple hours is required to create the bracket, the design was assigned a score of two for production time. Because this design is entirely removable by simply removing a few bolts and then sliding the part out, this design received a score of five for replaceability.

After all the scores were assigned and weighted, the 3D Printed-Bolted design was chosen to be used for the fin retention system. This is the same design that the team moved forward with last year. However, the team has decided to test different materials this year for constructing the fin retention system. The three materials the team is considering are polylactic acid (PLA), acrylonitrile butadiene styrene (ABS), and polycarbonate.

The team used a weighted selection matrix to select the fin bracket material for the 2018-2019 competition year by comparing four important attributes: strength, cost, glass transition, and ease of use. A score of one to five was assigned to the different factors based on the material's performance in that criteria. A score of one was considered the worst, and a score of five was considered the best. Strength was rated on the material's ability to withstand forces experienced during flight and was measured by flexural modulus and tensile strength of the different filaments. Cost was determined by the price for a 0.118 inch diameter, 2.2 pound spool. If a material had a lower cost, it was given a higher score since this would allow the team to stay within budget. Glass transition was scored based on how high of a temperature the filament could encounter before converting into a liquid-like state. The higher the glass transition temperature, the higher the score it received. Ease of use was scored based on how easily the material is to print. The easier the material is to print, the higher the score it received.

Each of the different criteria were weighted on a scale from zero to one. The sum of the scores is equal to one. Strength was given a weight of 0.40 to reflect its importance. For the fin retention system to be effective it must be able to withstand multiple impacts. Cost was given a weight of 0.30 to account for the importance for the team to stay under budget. Since the team will be printing the fin brackets multiple times, cost was seen as one of the most important attributes. Glass transition was given a weight of 0.15 as it is pertinent for the material to be able to withstand heat for the structural integrity of launch vehicle. Since the launch vehicle will not encounter very high temperatures, it was not seen to be as important as cost or strength. Ease of use was given a weight of 0.15 to reflect the importance of the material's ability to be printed. Table 9 shows the fin retention material selection matrix.

**Table 10. Fin Retention Material Selection Matrix**

| | | PLA | | ABS | | Polycarbonate | |
|---|---|---|---|---|---|---|---|
| **Attributes** | **Weight** | Score | Weighted Score | Score | Weighted Score | Score | Weighted Score |
| **Strength** | 0.40 | 3 | 1.20 | 3.5 | 1.40 | 5 | 2.00 |
| **Cost** | 0.30 | 4 | 1.20 | 4 | 1.20 | 2 | 0.60 |
| **Glass Transition** | 0.15 | 2 | 0.30 | 3 | 0.45 | 5 | 0.75 |
| **Ease of Use** | 0.15 | 5 | 0.75 | 3 | 0.45 | 3 | 0.45 |
| **Total** | 1.00 | | **3.45** | | **3.50** | | **3.80** |
| **Rank** | | | **3** | | **2** | | **1** |

The tensile strength and the flexural modulus of PLA, ABS, and polycarbonate can be found below in Table 10. Based on these values, PLA was awarded a score of three, ABS received a score of 3.5, and polycarbonate received a score of five.

**Table 11. Filament Strength and Flexural Modulus Comparison**

| Filament: | Tensile Strength [ksi]: | Modulus [Msi]: |
|---|---|---|
| PLA | 5.37 | 5.8 |
| ABS | 3.92 | 11 |
| Polycarbonate | 7.98-10.88 | 7.25 |

The cost of each material can be found in Table 11. The team looked at filaments with a diameter of 0.118 inches in a 2.2 pound spool. Based on these values, PLA was awarded a score of four, ABS received a score of four, and polycarbonate received a score of two.

**Table 12. Filament Cost**

| Filament: | Cost [in $]: |
| --- | --- |
| PLA | 20 |
| ABS | 22 |
| Polycarbonate | 40 |

The glass transition temperatures for the different filaments can be found in Table 12. Based on these values, PLA was awarded a score of two, ABS received a score of three, and polycarbonate received a score of five.

**Table 13. Filament Glass Transition Temperature Comparison**

| Filament: | Glass Transition [in Fahrenheit]: |
| --- | --- |
| PLA | 140 |
| ABS | 221 |
| Polycarbonate | 297 |

For ease of use, PLA was seen as the easiest of the different filaments to print and received a score of five. Due to the poor central heating in the room where the team will be printing the fin brackets, the team would have to purchase or construct a housing unit to help retain heat for prints. Because of this, both ABS and polycarbonate received a score of three.

After the scores were assigned to each filament and totaled, Polycarbonate was decided to be the material for the fin brackets.

### Fins

The fins were designed to increase the stability of the launch vehicle by moving the center of pressure towards the aft end of the launch vehicle. The launch vehicle currently uses three fins. The fins will be made out of G10 Glass Fiber due to the materials high tensile strength and high flexural modulus. This is necessary to resist both fin flutter and ground impact. Since the fins are usually the first point of contact with the ground during the launch vehicle's descent, a material that has a higher tensile strength is required. Due to this, plywood was not chosen as the material for the fins as the fins would most likely fracture upon impact and would need to be replaced. A dimensioned drawing of the fin is located in Figure 2. The G10 Glass Fiber thickness will be 3/16 inches to improve the performance of the launch vehicle and to create safer stability margins. Simulations conducted using AeroFinSim confirm that plywood does not have the necessary tensile strength, but that G10 Glass Fiber can withstand the forces expected to be seen during flight. The fins will be placed and bolted into 3D printed fin brackets, which can be easily removed and interchanged.

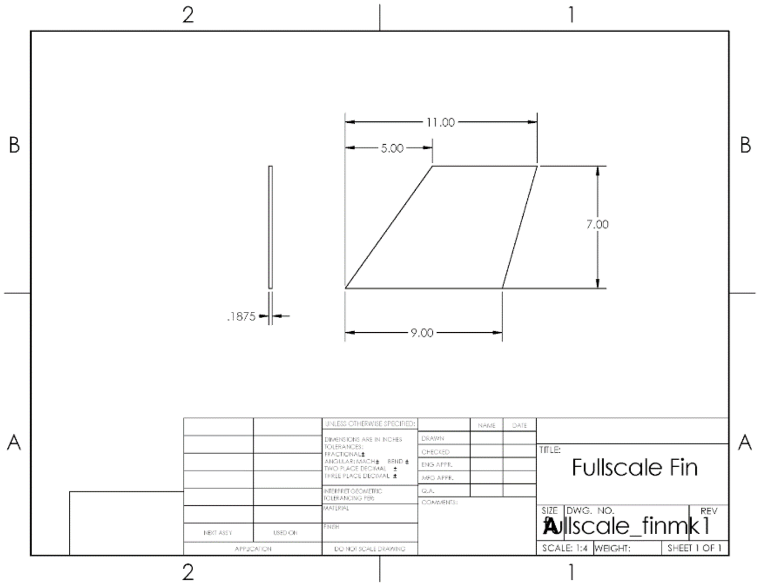


**Figure 3. Proposed Fin Shape**

## Camera System

As part of the team derived requirements, a down body camera has been included to supply visual data of flight performance and monitor fin flutter. The exterior portion of the camera is a Raspberry Pi Camera Module v2 with a width of 1 in and length of 1 in. The design has again been improved from last year's much bulkier design, largely due to using a different camera system. Figure 3 shows the more spatially efficient design for this year's competition.

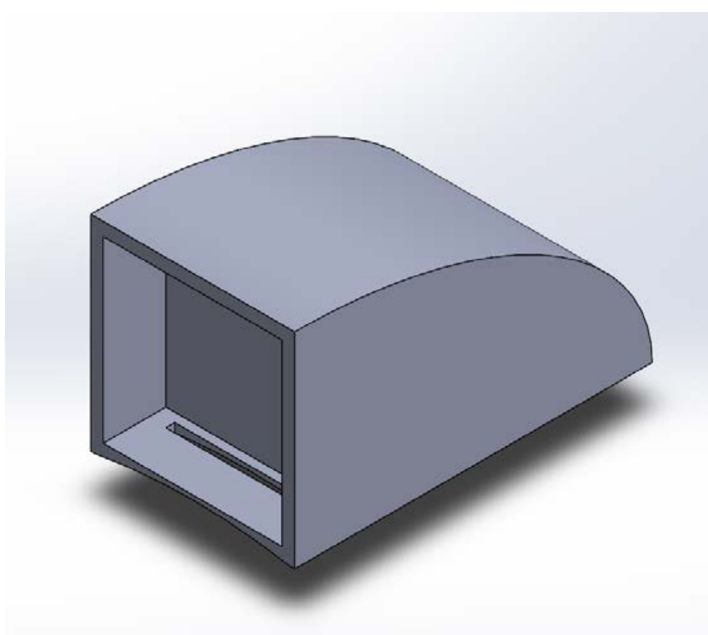

**Figure 4. 3D Render of the Camera Cover**

To securely seat the camera on the exterior of the rocket, a 3D printed cover was designed to tightly hold the camera to the body while also providing aerodynamic efficiency. This cover is to be printed in PLA material due to its lightweight characteristics.

### Separation Points

The current sectioning of the launch vehicle has been chosen so that each subsystem will have their own section to work on during launch day. This will allow the subsystems to operate independently of one another which will reduce the amount of time needed to assemble the launch vehicle.

The launch vehicle will house three separation points: two for parachute deployment and one for rover deployment. The separation point for the drogue parachute is located between the drogue body tube and the payload body tube. The separation point for the main parachute will be placed between the main parachute body tube and the booster body tube. The location of the two separations points for parachute deployment was chosen so that only one avionics bay will be needed for the launch vehicle. Additionally, in this configuration, the parachutes will be ejected out of their respective body tubes rather than ejected into the body tubes. Ejecting the parachutes into the body tube could cause the parachute to potentially become stuck in the body tube and not properly deploy and is being avoided because of this.

The separation point for rover deployment is located between the nose cone and the payload body tube. This separation point was chosen to ensure that the rover would not get caught in the parachute or part of the shock cord. The rover deployment will separate the entire nose cone from the body tube, so the team has decided upon doing a ground-separation to minimize in flight risk.

### Bulkheads

Bulkheads will be used on the ends of each coupler to help contain systems such as the avionics bay, and to act as attachment points for the parachutes. Each attachment point uses a coupler bulkhead and a body tube coupler attached together with an eye-bolt resulting in a combined thickness of 1⁄2 inch. This bulkhead design is shown below in Figure 4.

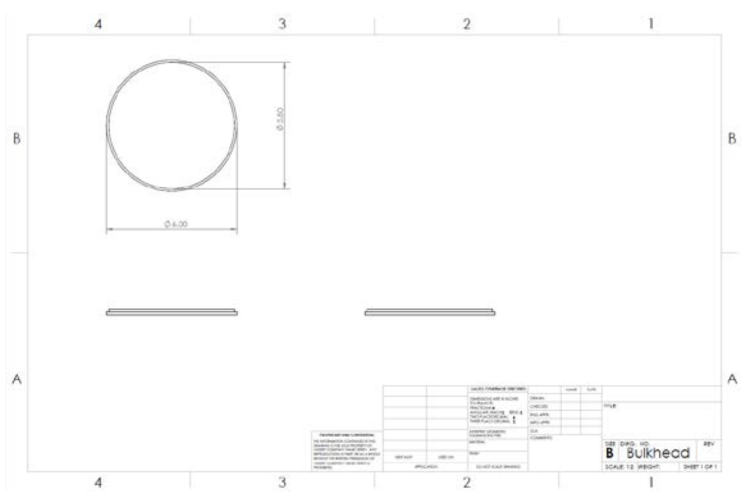


**Figure 5. Bulkhead Assembly**

To determine what material will be used for the bulkheads, a selection matrix was created. The three materials the team is considering utilizing are plywood, G10 glass fiber, and polylactic acid (PLA).

There were four factors utilized when determining which material would work best for the bulkheads. The four factors were strength, cost, mass, and workability. A score of one to five was assigned to each of the materials based on how it performed in each category. A score of five is considered the best, while a score of one is considered the worst. Strength was rated based on the material's tensile strength and flexural modulus. It was given a weight of 0.35 because it essential that a safety critical component such as the bulkhead does not fail structurally. Cost was rated based on how much the material costs for a ¼ inch thick piece. It was given a weight of 0.25 to account for the team to stay within its budget. Mass was rated based on how heavy the material is for a ¼ inch piece. It was given a weight of 0.25 to ensure that the bulkheads do not add too much weight to the launch vehicle. Workability was rated on how easy it is for the team to drill holes into the material and to sand it if necessary. Because of this, workability was given a weight of 0.15. Table 13 shows the bulkhead materials selection matrix.

**Table 14. Bulkhead Material Selection Matrix**

| | | **Plywood** | | **G10 Glass Fiber** | | **PLA** | |
|---|---|---|---|---|---|---|---|
| **Attributes** | **Weight** | Score | Weighted Score | Score | Weighted Score | Score | Weighted Score |
| **Strength** | 0.35 | 3 | 1.05 | 5 | 1.75 | 4 | 1.40 |
| **Cost** | 0.25 | 4 | 1.00 | 2 | 0.50 | 4 | 1.00 |
| **Mass** | 0.25 | 4 | 1.00 | 2 | 0.50 | 4 | 1.00 |
| **Workability** | 0.15 | 5 | 0.75 | 3 | 0.45 | 2 | 0.30 |
| **Total** | 1.00 | | **3.80** | | **3.20** | | **3.70** |
| **Rank** | | | **1** | | **3** | | **2** |

The tensile strength and the flexural modulus of plywood, G10 glass fiber, and PLA are shown in Table 14. Based on these values, plywood was awarded a score of three, G10 glass fiber received a score of five, and PLA received a score of four.

**Table 15. Bulkhead Material Tensile Strength and Flexural Modulus Comparison**

| Material: | Tensile Strength [ksi]: | Modulus [Msi]: |
|---|---|---|
| Plywood | 5 | 1.2-1.5 |
| G10 Glass Fiber | 42 | 2.4 |
| PLA | 5.37 | 5.8 |

Both plywood and PLA are a lot cheaper than G10 glass fiber, and were given scores of four compared to a score of two for G10 glass fiber as a result. The mass of PLA and plywood are a lot lower than glass fiber so they were given higher scores. The mass of PLA can vary with the amount of infill used during the print so it was given a score of four just like plywood. However, the workability of PLA is worse than plywood and glass fiber because it is harder to drill holes into the material without causing a structural deformity. Due to this reason, PLA was given a score of two. Glass fiber is more difficult and less safe to drill into and sand than plywood so it was given a score of three.

Based on the selection matrix presented above, the team has decided to move forward with utilizing plywood as the material for the bulkheads.

### Nose Cone

The nose cone of the flight vehicle is designed to minimize aerodynamic drag on the flight vehicle while being structurally stable and as light as possible. When choosing materials for the nose cone, choices were limited to already manufactured nose cones that fit the current dimensions of the flight vehicle. After researching many nose cone manufacturers such as Apogee Components and Madcow Rocketry, glass fiber nose cones were the only option that fit the diameter specifications for the launch vehicle.

For specific nose cone design, many different types of nose cone shape were considered. A selection matrix was created to determine the best nose cone shape for the flight vehicle. The selection matrix consisted of three different nose cone shapes found on Madcow Rocketry and Apogee Components: ogive 4:1, Von Karman 5.5:1, and conical 5:1. These shapes were rated on availability, cost, drag, and mass. For each attribute, each nose cone shape was given a score between one and five with one being the worst rating and five being the optimal rating.

The availability of each nose cone varied between each supplier, but currently Madcow Rocketry has all three nose cones readily available. For this reason each nose cone was given a score of five on availability. The cost of each nose cone was the same on Madcow Rocketry so each shape was given a score of three. The costs of nose cones on Apogee were cheaper for the ogive design, but the nose cone was out of stock. After research on the drag characteristics of the nose cone shapes, it was found that the conical shape would have the worst drag characteristics as it is the least streamlined shape out of the three. While the ogive and Von Karman shapes look very similar, Von Karman nose cones are designed to have minimum drag, whereas the ogive design is based only on geometric properties. For these reasons, the conical design was given a score of two, ogive a score of three, and Von Karman a score of five for drag. The mass of each nose cone shape was not given by Madcow Rocketry so an evaluation of mass from nose cones of previous years was performed. While the masses of the conical and ogive were similar, Von Karman nose cones from previous years were heavier than their ogive or conical counterparts. For these reasons the ogive and conical nose cones were given a score a four and the Von Karman nose cone was given a score of two.

The selection matrix table, Table 15, is shown below.

**Table 16. Nose Cone Selection Matrix**

| | | **Ogive 4:1** | | **Von Karman 5.5:1** | | **Conical 5:1** | |
|---|---|---|---|---|---|---|---|
| **Attributes** | **Weight** | Score | Weighted Score | Score | Weighted Score | Score | Weighted Score |
| **Availability** | 0.15 | 5 | 0.75 | 5 | 0.75 | 5 | 0.75 |
| **Cost** | 0.25 | 3 | 0.75 | 3 | 0.75 | 3 | 0.75 |
| **Drag** | 0.25 | 3 | 0.75 | 5 | 1.25 | 2 | 0.5 |
| **Mass** | 0.35 | 4 | 1.4 | 2 | 0.7 | 4 | 1.4 |
| **Total** | 1.00 | | **3.65** | | **3.45** | | **3.4** |
| **Rank** | | | **1** | | **2** | | **3** |

Based on the selection matrix presented above, the flight vehicle will use an ogive 4:1 nose cone.

### Motor Retention System

The motor retention system consists of multiple structures that keep the motor from separating from the flight vehicle. The motor retention consists of a motor tube that is epoxied to 3 centering rings with a bulkhead motor block. All centering rings and the motor block will be heavily epoxied to the booster body tube. The centering ring design is shown below in Figure 5.

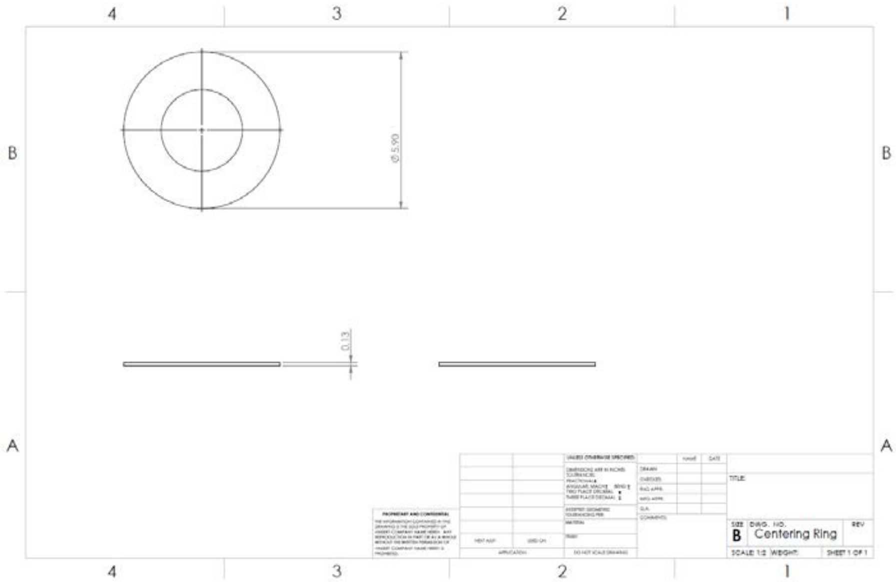


**Figure 6. Centering Ring Design**

The motor tube is made of glass fiber and is 26” long with in inner diameter of 3”. Each centering ring is ⅛” plywood and are placed at 1”, 11”, and 21” away from the aft end of the flight vehicle. The motor block is also ⅛” plywood and is placed at the end of the motor tube, 26” from the aft end of the flight vehicle. The motor retention system is shown in Figure 6.

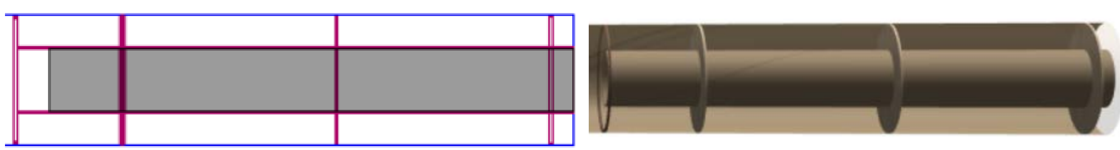

**Figure 7. Side View and 3D Image of the Motor Retention System**

This motor retention design has been used in every launch vehicle that LTRL has produced and has been verified by numerous previous test and competition flights. Previous testing on the structural strength of the bulkheads, centering rings, and epoxy show a greater combined strength in the current system than the given maximum thrust of the motor on the system.

## 3.2 Subscale Flight Results

The team successfully designed, constructed, launched, and recovered their 2018-2019 competition year subscale rocket on November 4th. Launch day conditions were very favorable with little cloud cover, light winds not exceeding 5 mph, and a temperature of 80 degrees°F.

### Structures and Propulsion Results

The predicted apogee and maximum velocity for these launch day conditions were 3239 ft and 484 ft/s respectively. Both of these values are plotted vs time in Figure 7.

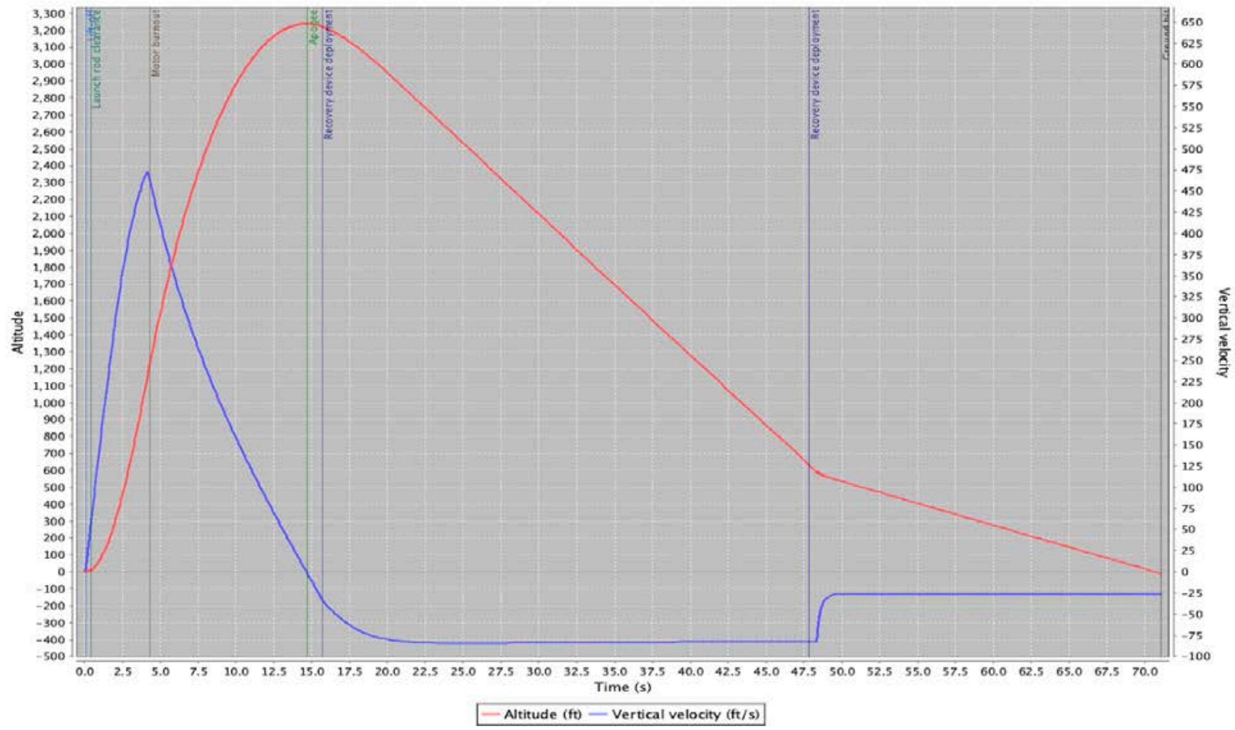


**Figure 8. Pre-Flight Simulation Plotting Both Altitude and Velocity vs. Time**

The rocket flew on a Cessaroni I120 motor. During ascent, there was an observed anomaly immediately after the rocket had cleared the launch rail. The rocket immediately began to oscillate back and forth as it ascended. The maximum angle of attack during these oscillations has been estimated at no more than 10 degrees. The significant amounts of energy lost during these oscillations, and the unexpected increased flight angle resulted in the launch vehicle only reaching an apogee of 1,877 ft instead of the predicted 3,034 ft. The altitude versus time and velocity versus time plots can be seen in Figure 8 and Figure 9 respectively.

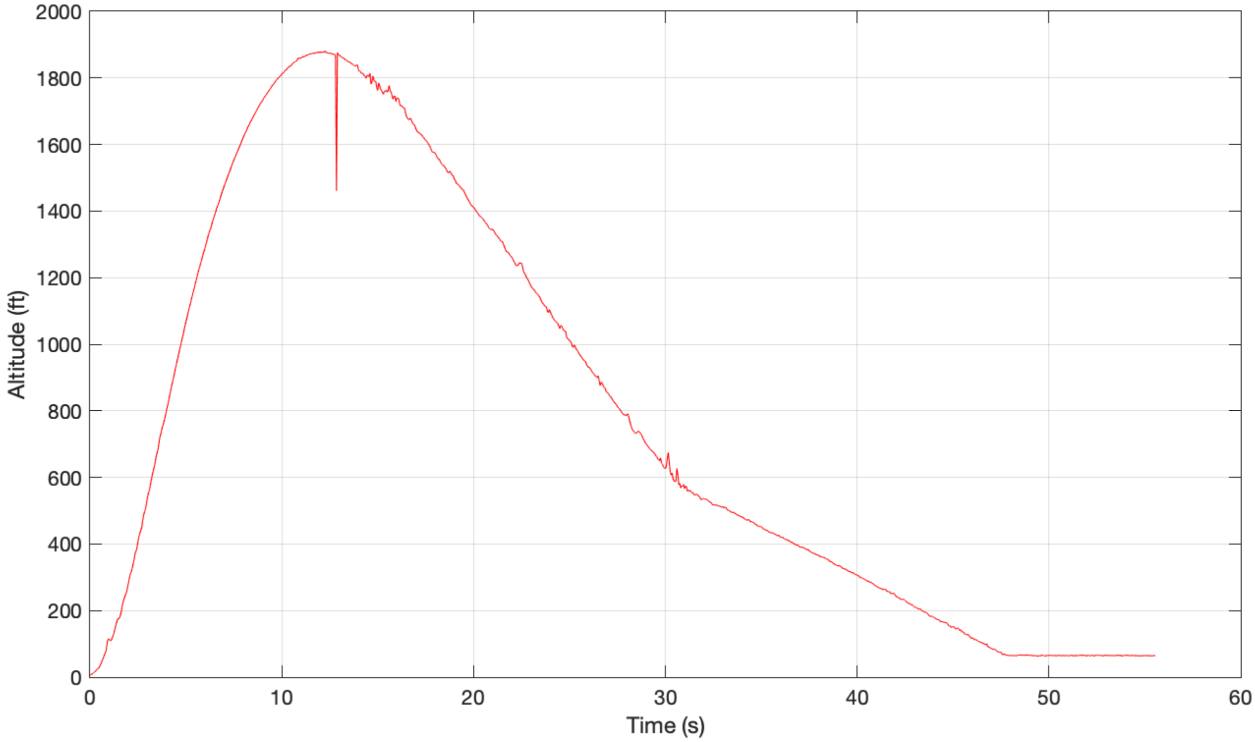


**Figure 9. Altitude vs. Time Plot of Subscale Flight**

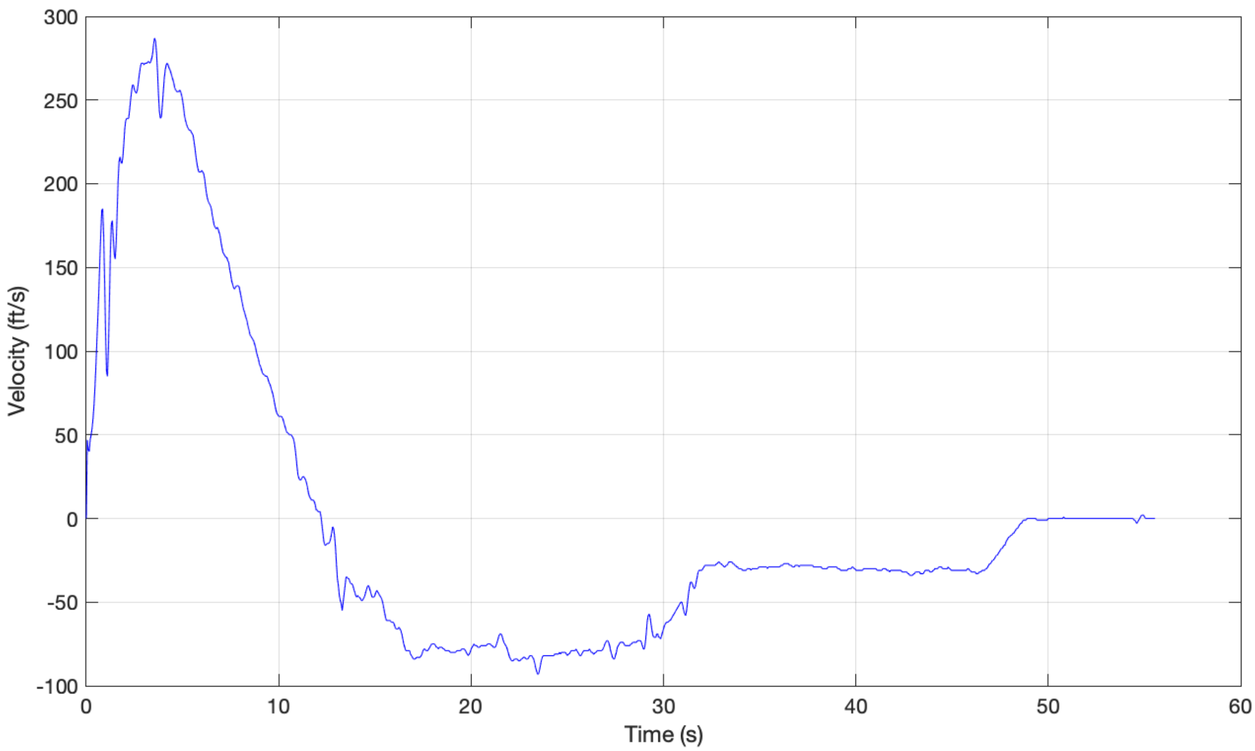


**Figure 10. Velocity vs. Time Plot of Subscale Flight**

From a structural standpoint, the subscale launch vehicle successfully fulfilled most derived and all non-derived requirements. However, the anomaly described above was likely due to a manufacturing tolerance discrepancy. The different sections of body tube were not sitting flush against each other when the rocket was fully assembled with all screws and shear pins in place. This meant that the flight vehicle exhibited a small amount of “flex” or “bend” while not evenly supported along its length. The club has noted this characteristic as a potential problem on previous flights but the manufacturing team did not exhibit enough attention to detail to notice the issue during subscale construction.

This manufacturing defect was likely the direct cause of the oscillation anomaly on ascent. However, this was the only structural discrepancy observed during the flight. Specially designed components of the vehicle such as fin brackets and the camera cover survived flight with no issues. The airframe of the rocket experienced no buckling, abrasion, or shearing during subscale launch. The manufacturing defect will be accounted for and mitigated during fullscale construction.

The subscale launch vehicle was exactly 50% of the full-scale rocket length. Subscale was designed to imitate the full-scale launch vehicle as close as possible to gather accurate aerodynamic data. The estimated drag coefficient of the fullscale rocket is approximately 0.58. This was done by taking the percentage error between subscale simulation apogee and subscale actual apogee, and then modifying the fullscale simulation coefficient of drag until the percent error in apogee’s matched.

The subscale flight was a success from a structures standpoint and brought up only minor issues in regard to the fullscale rocket design and fabrication. The only difference between the flight configurations of the subscale rocket and the fullscale rocket will be the inclusion of the camera system and the payload system. Since the flight was a success and no critical design errors were discovered, no structural design changes will be made as a result.

### Avionics and Recovery Results

The rocket was launched from a vertical launch rail within 100 feet of sea level. In these conditions the rocket was expected to take 55 seconds to descend from apogee with a trajectory shown in Figure 10. The rocket had an apogee of 1,877 feet and took 36 seconds to land from apogee. This would have been 2 seconds longer if the rocket did not land uphill of the launch site. The altitude data from subscale launch is shown in Figure 11.

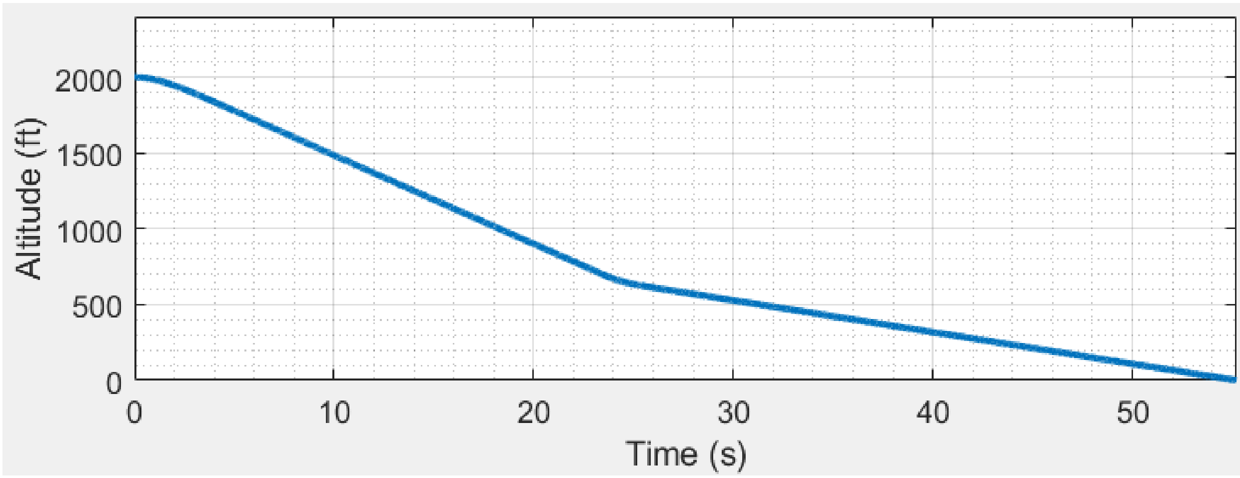


**Figure 11. Simulated Altitude vs. Time Graph**

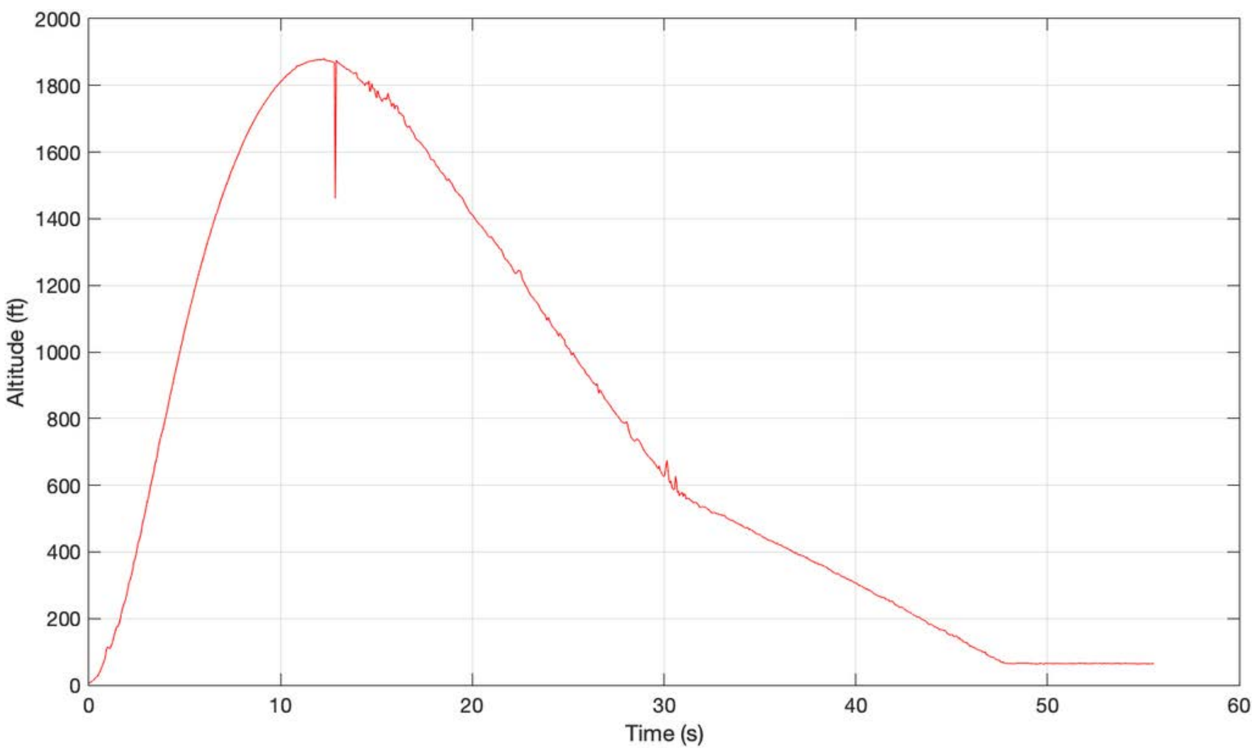


**Figure 12. Subscale Altitude vs. Time Graph**

The primary cause of the overestimation of descent time is due to the estimated descent speed. Figure 12 is the vertical velocity the rocket was predicted to experience. For descent under drogue, this was calculated to be approximately 60 ft/s. Shown in Figure 13 is the actual vertical velocity of the rocket. During descent under drogue, the rocket actually descended around 75 ft/s. This incorrect prediction of descent speed can be attributed to inaccurate calculation of the effective area of the tumbling body of the rocket. This value was overestimated at being twice the size of the outer radius. Another potential source of error is an overestimation of the coefficient of drag of both parachutes due to incorrect values given by the manufacturer's website.

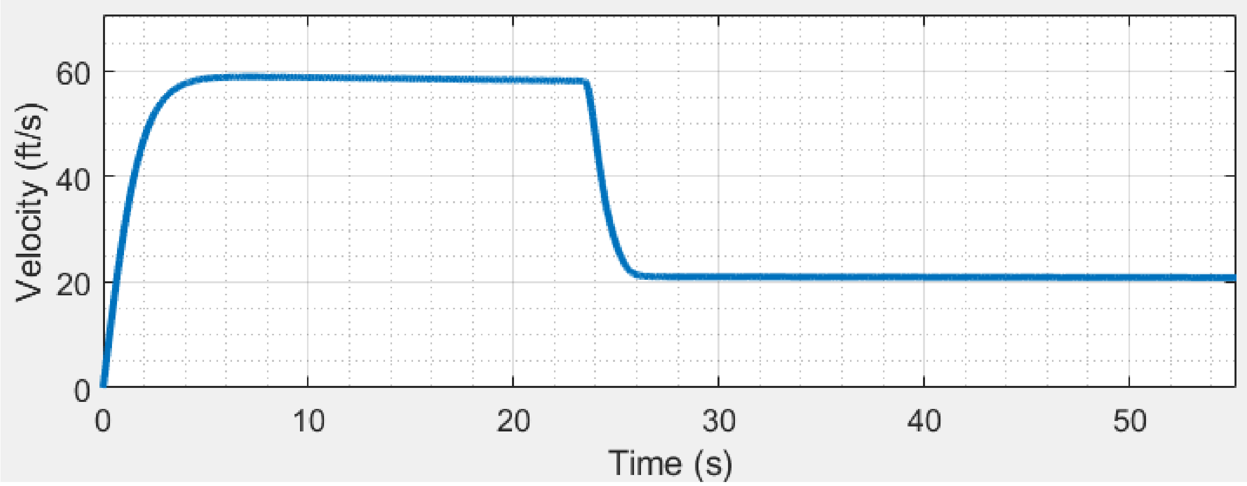


**Figure 13. Simulated Velocity vs. Time Graph**

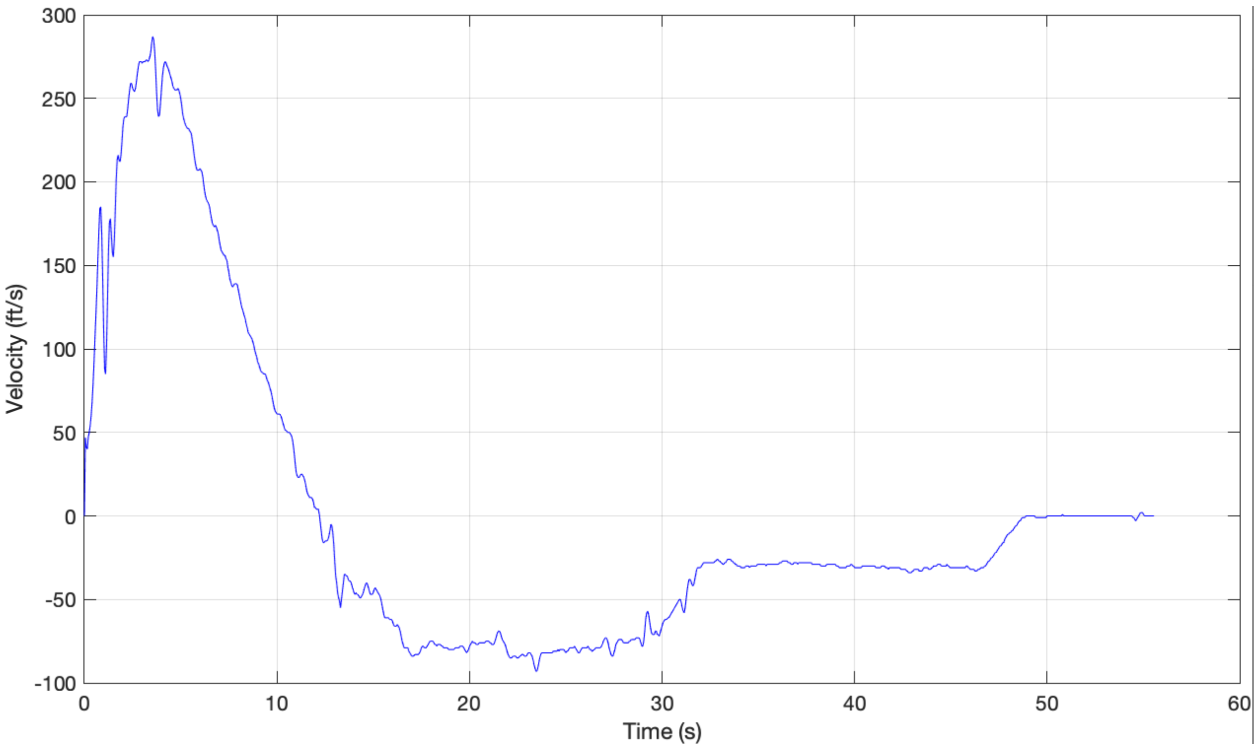


**Figure 14. Subscale Velocity vs. Time Graph**

Changes will be made to the coefficients of drag in the MATLAB script to give a more accurate estimate for future flights. For fullscale flight, the rocket is expected to descend faster than predicted under drogue descent which will place the rocket within the maximum drift distance in 20 mph winds. The new concern is landing velocity of fullscale sections to be faster than previously predicted. Comparing touchdown velocity from simulated descent velocity at 22 ft/s in Figure 12 with the actual velocity of 26 ft/s from Figure 13 yields an 18% increase in predicted speed**.** This 18% increase would cause the booster section to land with a kinetic energy about two lbf over specified kinetic energy requirements in fullscale flight. However, the team predicts an increase in body drag from the increased diameter of the fullscale body tubes, and expects this 18% error to be not be explicitly correlated to fullscale flight. Past fullscale flights did not yield an error margin as large as the one yielded in this year's subscale test flight. This can be explained by a lack of confidence in the coefficient of drag values given by the manufacturer for subscale's parachutes. Parachutes used on this year's fullscale rocket have been previously used, and their coefficient of drag values have been experimentally obtained by the team in previous years. This year's fullscale test flight will allow the team to further refine the team's descent model, and verify a slower descent time than predicted by subscale test flight.

## 3.3 Mission Performance Predictions

### Flight Profile Simulations

An OpenRocket model was created to simulate flight and vehicle characteristics. This model was used to calculate the static stability margin, the center of pressure (CP), and the center of gravity (CG). The CP is located 94.34 in. aft of the tip of the nose cone, and the CG is located 73.80 in. aft of the tip of the nose cone. The final flight vehicle has a diameter of 6", with a static stability margin of 3.42 calibers. The OpenRocket model is shown in Figure 14. The target apogee of exactly 1 mile will be achieved through altering the rocket's mass very slightly via incorporated ballast along with improving the model of drag calculation and thrust curve for more accurate apogee calculation. Improvements to modeling the rocket's flight will be made via static motor testing at Penn State's High Pressure Combustion Lab and experimental data from wind tunnel testing using a closed-circuit wind tunnel.

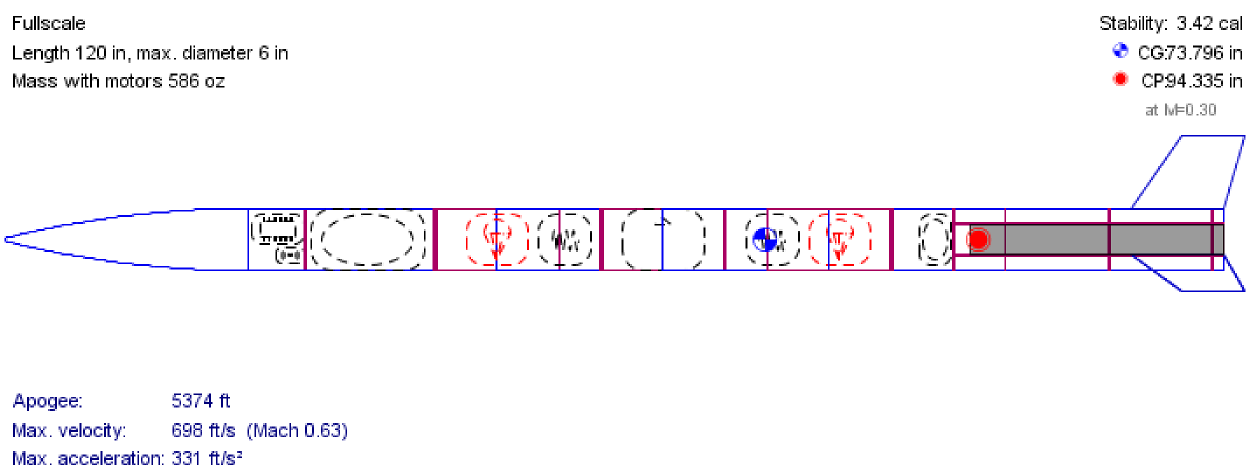


**Figure 15. OpenRocket Model of the Fullscale Flight Vehicle**

The subcomponent masses of the launch vehicle are shown in ounces in Table 17.

**Table 17. Subcomponent Masses of Flight Vehicle**

| Component | Weight (oz) |
|---|---|
| Nose cone | 84.6 |
| Payload Section | 74.3 |
| Payload-Drogue Coupler | 9.49 |
| Drogue Section | 18.6 |
| AV Bay | 87.4 |
| Main Section | 24.1 |
| Main-Booster Coupler | 13 |
| Booster Section | 99 |

It is shown in Figure 16 that a maximum velocity of 699 ft/s is reached just before motor burnout at 2.9 seconds and at an altitude of approximately 1,000 ft. This maximum velocity is well within the imposed limit of Mach 1 and occurs a safe distance from the launch pad. The rocket's velocity off a 10 ft rail is 75.7 ft/s which is well above the imposed minimum of 55 ft/s.

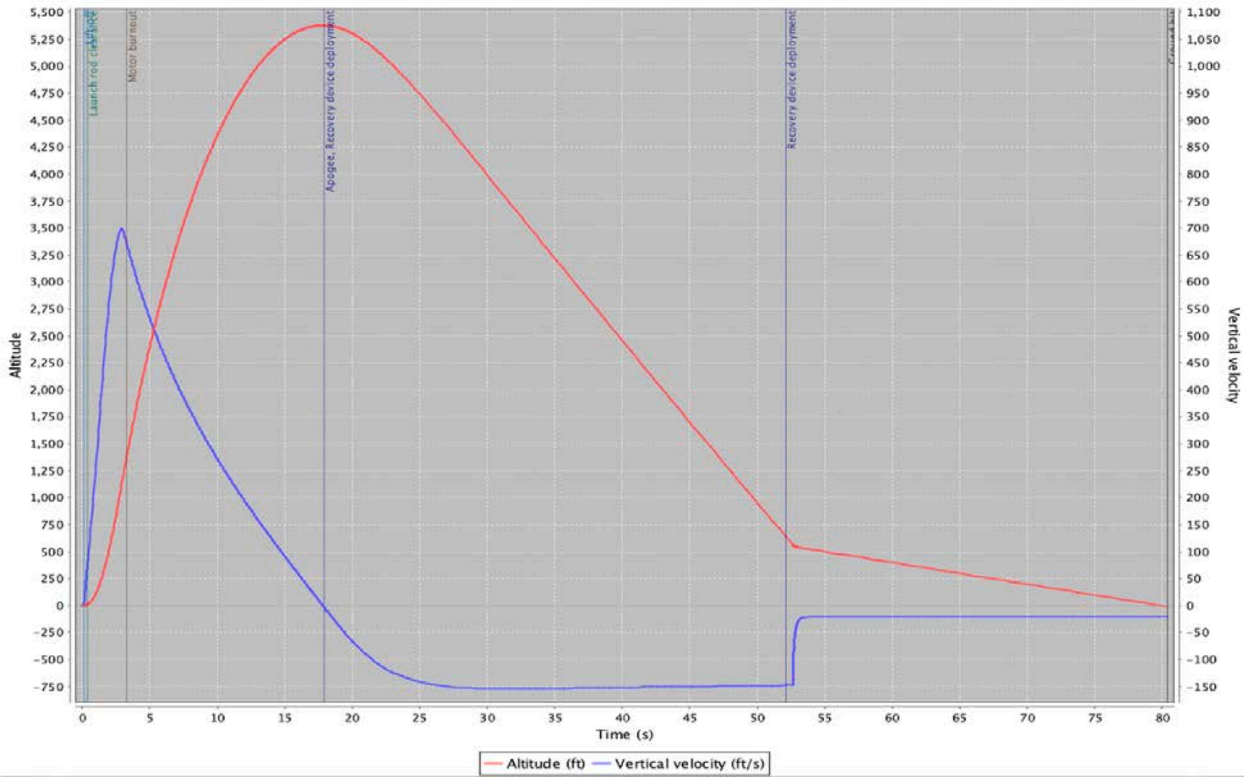


**Figure 16. Fullscale OpenRocket Flight Profile**

As in indicated in Figure 18, the stability off the launch rail is 3.50 calibers. This is above the team's mission success criteria and is indicative of a very stable flight even in the low velocity and low altitude regime. As propellant mass decreases, the stability increases to approximately 4.75 calibers before leveling off around 4.6 calibers during the coast to apogee.

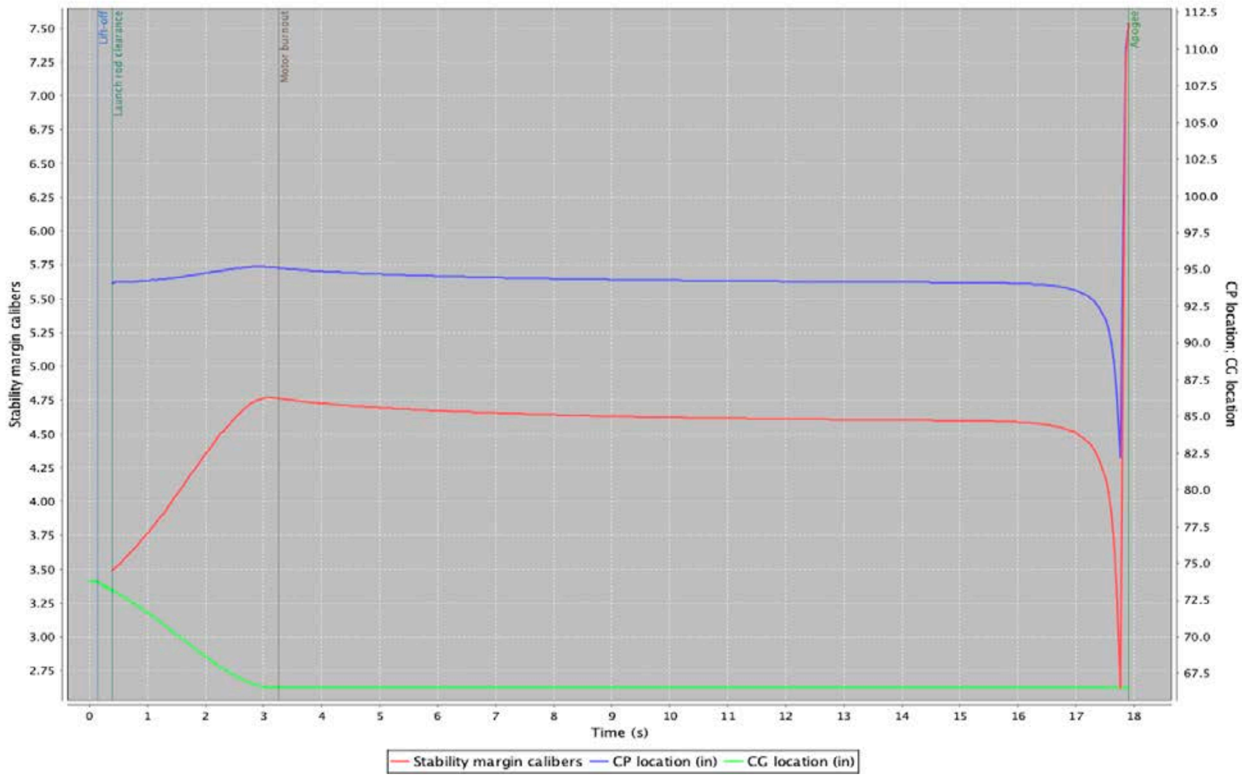


**Figure 17. Fullscale OpenRocket Stability Profile**

It is apparent that the thrust curve for the Cesaroni L1355 motor has the necessary characteristics to achieve the minimum rail velocity for stable flight as the rocket leaves the pad. The motor characteristics are shown in Table 18. To more accurately characterize the thrust of the motor, static testing will be performed at Penn State's High Pressure Combustion Lab.

**Table 18. Motor Characteristics**

| Motor | Apogee (ft) | Velocity off the Rail (fps) | Maximum Velocity (ft/s) | Thrust to Weight Ratio | Impulse (lbf*s) | Burn Time (s) | Mass (oz) |
|---|---|---|---|---|---|---|---|
| **Cesaroni L1355** | 5379 | 75.7 | 699 | 7.77 | 905 | 2.95 | 175 |

## Parachute and Kinetic Energy

The team used OpenRocket's flight predictions to determine the best parachute for this year's rocket. The team also used a MATLAB script as a second mode of verification to verify

OpenRocket's results. LTRL's MATLAB rocket descent simulation program runs a recovery model in which the force balance between gravity and drag is integrated over time with separate phases for drogue and main. The model assumes that the parachutes do not deploy and expand instantaneously, but rather assumes the parachutes expand in a linear fashion. In this MATLAB model, the parachute area increases linearly with respect to time until the deployment time is complete. The parameters of the parachute's coefficients of drag are based on experimentally derived values from previous launches. The 12" Fruity Chutes Classical Ultra drogue parachute is estimated to have a coefficient of drag of 1.5, and the 84" Fruity Chutes Iris Ultra main parachute is estimated to have a coefficient of drag of 1.6. These numbers are slightly lower than the manufacturer's estimate. Using OpenRocket and MATLAB, the team is able to confirm that these parachutes will land the rocket within the landing zone and with a safe amount of kinetic energy. The team's MATLAB model calculated that the rocket will take 63.6 seconds to descend from apogee to landing. The predicted descent profile from the MATLAB model can be seen in Figure 17. OpenRocket predicts the launch vehicle's descent time from apogee to be 63.2 seconds. This verifies the team's MATLAB model prediction that the launch vehicle will fulfill requirement 3.10.

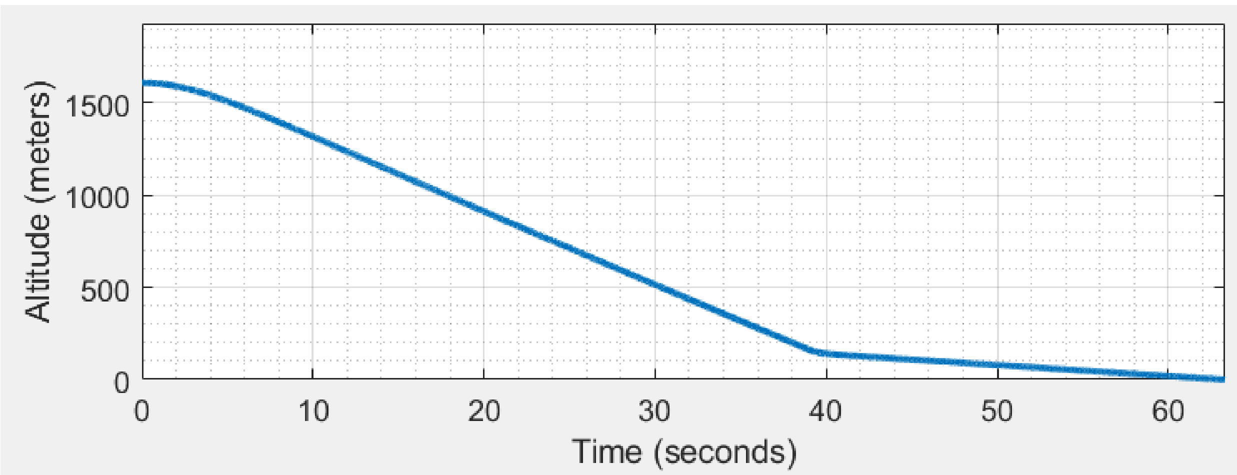


**Figure 18. MATLAB Descent Graph**

To ensure safe descent of the rocket within the landing zone, the team calculated drift distances for 5 mph, 10 mph, 15 mph, and 20 mph wind speeds. These calculations assumed there would be no launch angle and that the drogue parachute would deploy directly over the launch site. In Figure 18, the distance the rocket drifts from apogee is shown. OpenRocket drift distance show in Figure 19 that the maximum drift distance from apogee that the launch vehicle with experience is 1,600 feet at 20 mph winds. This means OpenRocket predicts a drift distance that is approximately 200 feet shorter than the MATLAB model in 20 mph wind. This is due to OpenRocket not accounting for body tube drag once the drogue parachute has deployed. If OpenRocket accounted for this extra body tube drag, the launch vehicle would drift further as well as descend slower. This problem explains OpenRocket's faster descent rate and shorter time to landing from apogee.

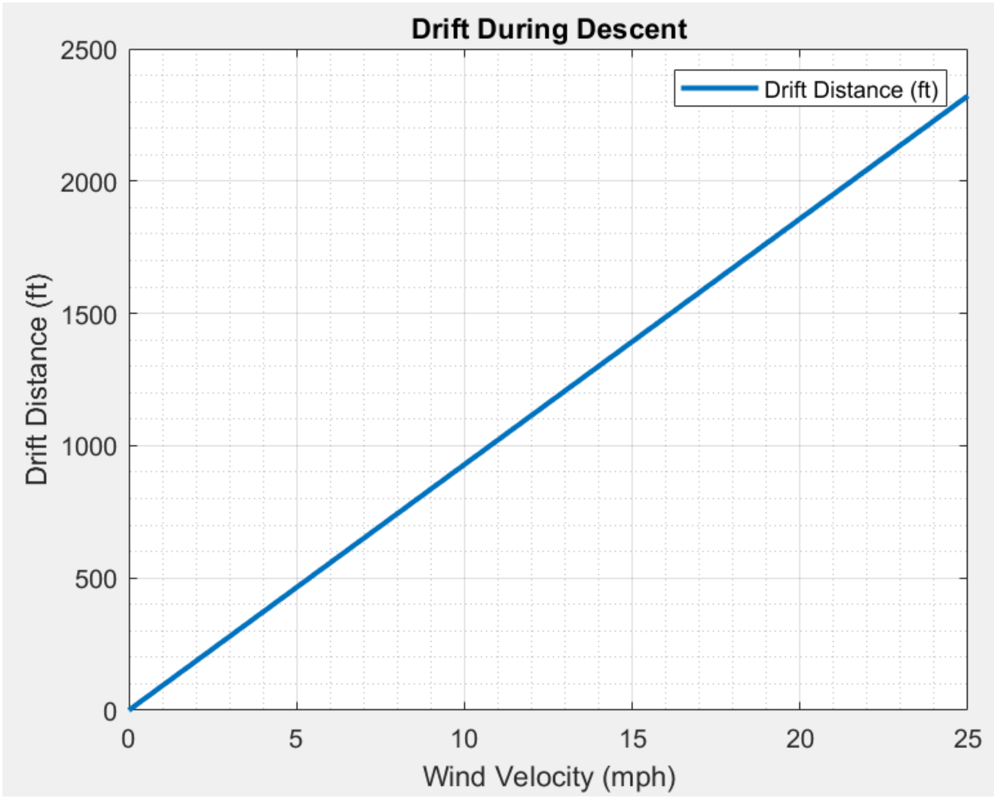


**Figure 19. MATLAB Drift during Descent**

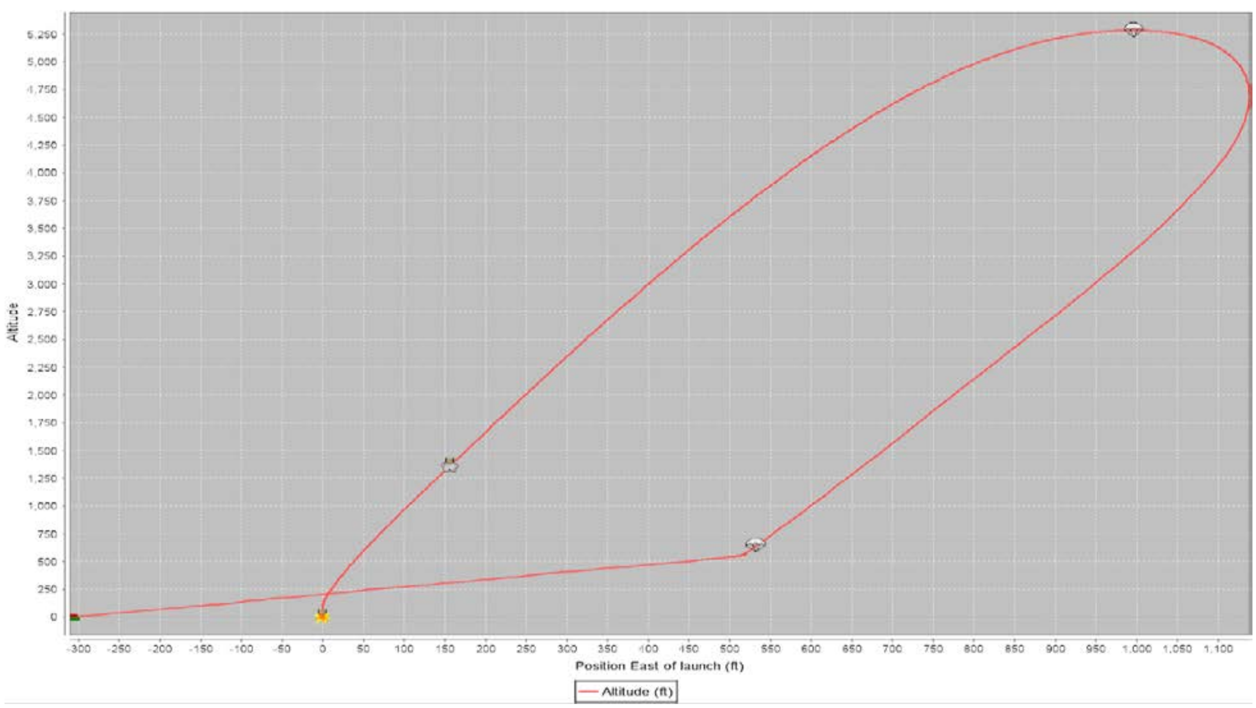


**Figure 20. OpenRocket Drift during Descent**

Exact drift distances by MATLAB from apogee to landing for wind velocity are given in Table 17.

**Table 19. MATLAB Drift Distance Calculations**

| Wind velocity | 5 mph | 10 mph | 15 mph | 20 mph |
|---|---|---|---|---|
| Drift distance | 464.44 ft | 928.88 ft | 1393.32 ft | 1857.77 ft |

The MATLAB simulations predicted that the landing velocity of the rocket is 19.44 ft/s. OpenRocket's predicted landing velocity of the rocket is 20.10 ft/s. Kinetic energy of each body tube section was calculated using Equation 1. The function of landing kinetic energy versus parachute size is given in Figure 20. The kinetic energy of each section of the rocket at landing is given in Table 18**.**

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

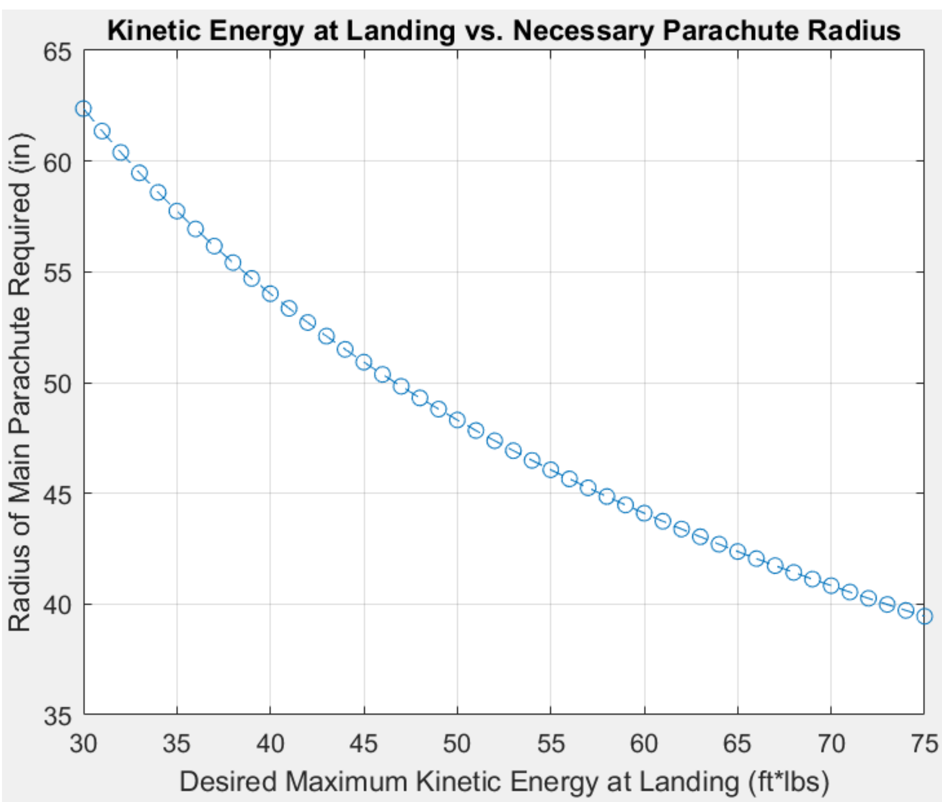


**Figure 21. Kinetic Energy at Landing vs. Necessary Parachute Radius**

**Table 20. Kinetic Energy by Section**

| Section | Mass | Kinetic Energy at landing (MATLAB) | Kinetic Energy at landing (OpenRocket) |
|---|---|---|---|
| Nose | 168.4 oz | 61.83 ft*lbs | 66.09 ft*lbs |
| Avionics | 123.3 oz | 45.27 ft*lbs | 48.39 ft*lbs |
| Booster | 168.2 oz | 61.76 ft*lbs | 66.02 ft*lbs |

The kinetic energy at landing based on OpenRocket calculations is higher than the MATLAB calculations. This is because OpenRocket does not model body drag, and kinetic energy values will be expected to be closer to MATLAB than OpenRocket as a result.

### Verification of OpenRocket

To verify the OpenRocket simulation results, the center of pressure, center of gravity, and flight apogee were calculated using LTRL's own MATLAB script.

To calculate the center of pressure, the following calculations were conducted. First, the center of pressure of the nosecone, $X_n$, was calculated using Equation 2.

$$X_n = 0.466 * L_n \tag{2}$$

$X_n$ is the location of the center of pressure for the fins as measured from the tip, $L_n$ is the length of the nose cone which is multiplied by a constant given for Ogive nose cones. The center of pressure of the fins was then calculated using Equation 3.

$$X_f = X_b + \frac{X_r * (C_r + 2 * C_t)}{3 * (C_r + C_t)} + \frac{1}{6} * \left(C_r + C_t - \frac{C_r * C_t}{C_r + C_t}\right) \tag{3}$$

$X_f$ is the location of the center of pressure of the fins as measured from the tip, $X_b$ is the length from the tip to the fin root chord, $X_r$ is the length from the fin root leading edge to the fin tip leading edge, $C_r$ is the fin root chord length, and $C_t$ is the fin tip chord length. The coefficient for the center of pressure of the fins, $C_{nf}$, was calculated using Equation 4.

$$C_{nf} = 1 + \frac{R}{S + R} * \frac{4N\left(\frac{S}{D}\right)^2}{1 + \sqrt{1 + \left(\frac{2 * Lf}{C_r + C_t}\right)^2}} \tag{4}$$

Where R is the radius of the rocket body, S is the semi span of the fins, N is the number of fins, and $L_f$ is the length of fin mid-chord line. The center of pressure as measured from the tip, X, was calculated using Equation 5.

$$X = \frac{C_{nn} * X_n + C_{nf} * X_f}{C_{nn} + C_{nf}} \tag{5}$$

Where $C_{nn}$ is the coefficient for the center of pressure for the nose cone. The center of pressure was calculated to be 93.54 inches aft of the tip.

To calculate the center of gravity, cg, Equation 6 was used.

$$cg = \frac{d_n * m_n + d_p * m_{payload} + d_m * m_m + d_d * m_d + d_b * m_b}{M} \tag{6}$$

Where $d_n$ is the distance from the center of mass of the nose cone to the tip, $m_n$ is the mass of the nose cone, $d_p$ is the distance of the center of mass of the payload section to the tip, $m_{payload}$ is the mass of the payload section, $d_m$ is the distance of the center of mass of the main parachute section to the tip, $m_m$ is the mass of the main parachute section, $d_d$ is the distance of the center of mass of the drogue section to the tip, $m_d$ is the mass of the drogue section, $d_b$ is the distance of the center of mass of the booster section to the tip, $m_b$ is the mass of the booster section, and M is the total mass of the rocket.

The center of gravity was calculated to be 75.89 in. aft of the tip.

To calculate the flight apogee, the altitude at which the motor burnout occurs must first be calculated. To calculate the burnout altitude, first the average mass, $m_a$, must be calculated. The average mass was calculated using Equation 7.

$$m_a = m_r + m_e - \frac{m_{prop}}{2} \tag{7}$$

Where $m_r$ is the mass of the rocket without a motor, $m_e$ is the mass of the motor, $m_{prop}$ is the mass of the propellant. The aerodynamic drag coefficient, k, was calculated using Equation 8.

$$k = \frac{1}{2} * \rho * C_d * A \tag{8}$$

Where ρ is the density of air, $C_d$ is the drag coefficient, and A is the cross-sectional area of the rocket. The burnout velocity, $q_1$, was calculated using Equation 9.

$$q_1 = \sqrt{\frac{T - (m_a * g)}{k}} \tag{9}$$

Where T is the average thrust of the motor, ma is the average mass of the rocket, and g is the gravitational constant. The burnout velocity decay coefficient, $x_1$, was calculated using Equation 10.

$$x_1 = \frac{2 * k * q_1}{m_a} \tag{10}$$

The burnout velocity, $v_1$, was calculated with Equation 11.

$$v_1 = q_1 * \frac{1 - \mathrm{e}^{-x_1 * t}}{1 + \mathrm{e}^{-x_1 * t}} \tag{11}$$

Where t is time at motor burnout. Finally, the altitude at which the motor burnout occurs, $y_1$ was calculated using Equation 12.

$$y_1 = -\frac{m_a}{2 * k} * \ln\left(\frac{T - (m_a * g) - (k * {v_1}^2)}{T - m_a * g}\right) \tag{12}$$

With the burnout altitude known the total altitude coasted can be calculated. To calculate the cost distance, the coast mass, $m_c$, must first be calculated. The coast mass was calculated using Equation 13.

$$m_c = m_r + m_e - m_{prop} \tag{13}$$

Where $m_r$ is the mass of the rocket, $m_e$ is the mass of the motor, and $m_{prop}$ is the mass of the propellant. Next, the coast velocity coefficient, $q_c$, was calculated using Equation 14.

$$q_c = \sqrt{\frac{T - m_c * g}{k}} \tag{14}$$

Where T is the average thrust of the motor, g is the gravitational constant, and k is the aerodynamic drag coefficient. The coast velocity decay coefficient, $x_c$, was calculated using Equation 15.

$$x_c = \left(\frac{2 * k * q_c}{m_c}\right) \tag{15}$$

The coast velocity, $v_c$, was calculated using Equation 16.

$$v_c = q_c * \frac{1 - \mathrm{e}^{-x_c * t}}{1 + e^{-x_c * t}} \tag{16}$$

The coast distance, $y_c$, was calculated using Equation 17.

$$y_c = \frac{m_c}{2 * k} * \ln\left(\frac{m_c * g + k * v_c^2}{T - m_c * g}\right) \quad (17)$$

Lastly, the flight apogee altitude, PA, was calculated using Equation 18.

$$PA = y_1 + y_c \quad (18)$$

The flight apogee altitude was calculated to be 5,694 ft. The code used to calculate these values can be seen in Appendix C: Verification of OpenRocket Flight Calculations.

With the results of both simulation techniques, the team compared the two sets of results. A comparison of the OpenRocket results and the MATLAB results is in Table 18 and the margin of error between the methods is in Table 19. All margins of error were below 5%.

**Table 21. OpenRocket and MATLAB Stability, Characteristics, and Apogee**

| | OpenRocket | MATLAB |
|---|---|---|
| **Center of Pressure (inches from tip)** | 94.34 | 93.54 |
| **Center of Gravity (inches from tip)** | 73.79 | 73.28 |
| **Static Stability (Calibers)** | 3.42 | 3.376 |
| **Altitude at Apogee (feet)** | 5373 | 5694 |

**Table 22. Percent Difference between MATLAB and OpenRocket Calculations**

| | Margin of Error |
|---|---|
| Center of Pressure | 0.85% |
| Center of Gravity | 0.89% |
| Static Stability | 0.68% |
| Altitude at Apogee | 5.97% |

The larger discrepancy in the predicted apogee altitudes is likely due to our MATLAB simulations simplistic calculation of altitude. The simulation does not account for any angle in the launch rail, winds horizontal to the flight path, turbulence in the air, or a changing coefficient of drag due to airspeed. However in the team’s experience, OpenRocket has proven to be very accurate in predicting apogee so the team is less concerned with that calculation. Regardless, the team will continue to improve the MATLAB simulation to account for the various factors listed previously.

## 3.4 Recovery Subsystem

The recovery system components include the avionics board, avionics bay structure, all-threads, parachutes and harnesses, GPS, charge wells, ejection charges, electromagnetic shielding and the shear pins at the separation points of the rocket. The avionics board will contain two independent sets of altimeters, charges, mechanical switches, initiators, and 9V batteries for power sources. By designing an avionics bay containing a secondary recovery system, the team ensures redundancy in their avionic systems that guarantee parachute deployment at the selected altitudes even with a failure of one system. The secondary redundant altimeter will be on a delay to ensure that both ejection charges do not detonate at the same time to avoid overpressurization of the body tubes. The team had three preliminary ideas for this year's design of the recovery system that are detailed below.

### Avionics Bay Design

The triangular avionics bay design was the first design considered by the team. This design was used two years ago and is pictured in Figure 21. This design features three all thread rods, and a bilaterally symmetric bulkhead.

**Figure 22. 2016-2017 Avionics Bay**

The avionics bay with door design is similar to the one used in the 2017- 2018 competition. This design is pictured in Figure 22 and features a fully enclosed avionics board, a faraday cage, and a door for quick launch pad access.

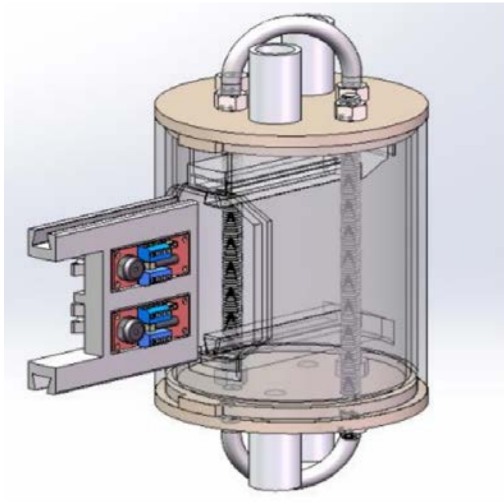

**Figure 23. 2017-2018 Avionics Bay**

The last design is a new consideration this year that is similar to last year's design with minor adjustments. This design is pictured in Figure 23 and improvements of the colonnaded avionics include weight reduction and easier faraday cage installation.

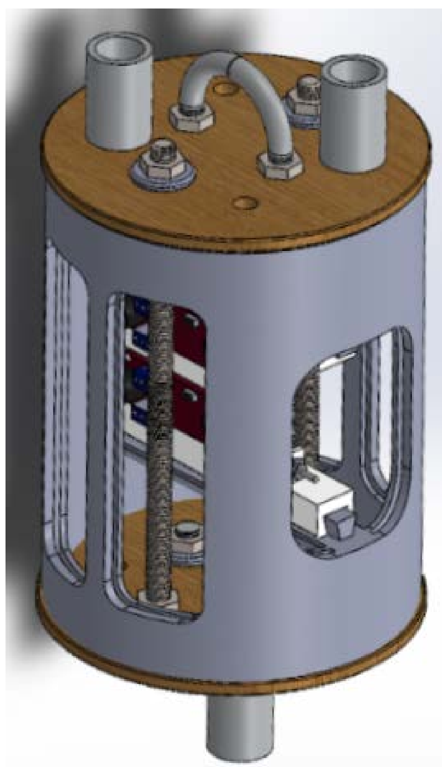

**Figure 24. Colonnaded Avionics Bay**

Five selection criteria of accessibility, ease of assembly, mass, precision, and cost were selected to adequately score and rank the three preliminary designs for the avionics bay.

The attribute for accessibility represents the difficulty for the team to access the altimeters and internals of the avionics bay after the rocket is fully constructed. It was given a weight of 0.4 since the ability of the internals of the avionics bay to be quickly and easily accessed on launch day is paramount to the success of the flight. A score of one means that the entire avionics bay has to be removed from the rocket by disassembling multiple separation points to access the avionics board wiring or initiator wiring. A score of three will be given if one section of the rocket must be disassembled to access the avionics board wiring or initiator wiring. A score of five is given if the entire wiring of the avionics bay can be accessed from the outside of the rocket without having to remove any components from the rocket frame.

The ease of assembly attribute represents how easy it is for the avionics bay to be built into the rocket during the designing and construction prior to launch day. This was given a weight of 0.1 because the team has sufficient time during the months leading up to the competition to assemble the rocket yet would still prefer a simple assembly. A score of five is given if the avionics bay requires no equipment other than hand tools, and if a team member can build the avionics bay without knowledge of the rest of the rocket. A score of three will be given to a design that does not require any tools not present in the teams lab but requires knowledge of integration of other systems within the rocket. A score of one is given if the avionics bay requires multiple tools the team does not have in the lab as well as specialized knowledge of other systems within the rocket.

The precision attribute for the avionics bay represents tolerance that the avionics bay can be built and flown in. This includes the ability of the avionics bay to fly on multiple launches without any of the wiring coming loose or components moving. This was given a weight of 0.3 because it is vital that the avionics board containing the electronics is kept stable during flight, and can be assembled in the exact same location after multiple flights. A score of five will be given if the design can be easily manufactured to required tolerances of .03 in, and can be launched multiple times without having to adjust or tighten any of the non-replaceable components. A score of three will be given to an avionics bay that few components can be manufactured with difficulty to the required tolerance, and that several parts in between flights may need replaced. A score of one is given to the design that will not be able to be manufactured to a tolerance of .03in, and has to be completely disassembled and then reassembled in between launches.

The mass of the avionics bay was given a weight of 0.1 because it is a very important component that is acceptable to be massive if it can complete its goal, but the team would still like to keep total mass as low as possible. Additionally, the required motor can be picked out after the launch vehicle design is finalized and can be correctly chosen as long as the avionics bay's mass is known. A score of five means the mass of the avionics bay and avionics board without the bulkheads are less than 10 ounces. A score of four to two will be given on a linear scale between 10 and 20 ounces. A score of one will be given to a design where the avionics bay and avionics board without the bulkheads weigh more than 20 ounces.

The cost attribute is the amount of time and money that would be required to build the selected design. Cost was given a weight of 0.1 due to all the options having a relatively similar and low cost. Time is considered to be a cost since all the designs are 3D printed and the printer cannot be used to create other parts while the avionics bay is being printed. Overnight printing for the printer is considered less than a 12 hour print. A score of one will be given to a design that takes longer than overnight to print or the cost is more than $20. A score of three will be given to a design that can be printed overnight. A score of five will be given to a design that can be printed in less than 5 hours and costs less than $5 in PLA.

The three preliminary design options were scored in Table 20 below.

**Table 23. Avionics Bay Design Selection Matrix**

| Selection Criteria | Weight | 2017 AV Bay | | 2018 AV Bay | | Colonnaded AV Bay | |
|---|---|---|---|---|---|---|---|
| | | Score | Weighted Score | Score | Weighted Score | Score | Weighted Score |
| Accessibility | 0.4 | 2 | 0.8 | 4 | 2 | 4 | 2 |
| Ease of Assembly | 0.1 | 3 | 0.3 | 2 | 0.2 | 3 | 0.3 |
| Precision | 0.3 | 3 | 0.9 | 4 | 1.2 | 4 | 1.2 |
| Mass | 0.1 | 5 | 0.5 | 1 | 0.1 | 2 | 0.2 |
| Cost | 0.1 | 5 | 0.5 | 1 | 0.1 | 2 | 0.2 |
| **Total** | 1.0 | | **3.0** | | **3.6** | | **3.9** |

The 2016-2017 avionics bay design from Table 20 was given a score of two for accessibility because the only way to access the components on launch day is to take out the avionics board by removing one of the end bulkheads. This requires a member to reach into the body tube after unscrewing the bolts on the all-thread rods. This proves to be an inefficient use of time, and may prevent the team from launching the rocket within the two hour window if any continuity issues occur. Additionally, it may be difficult to relaunch the vehicle within the two hour time limit using this avionics bay design. Its ease of assembly was scored at a three due to the difficulty in accessing components and the inability to reach both the batteries and the altimeters at the same time when reaching down the body tube. The second difficulty is that the wiring has to be wrapped from top to bottom and can become tangled easily. However, this can be mitigated with wiring labeling and attaching the wires to points on the avionics board. The triangular avionics bay was given a three for precision as it requires three all-thread rods which can be difficult to line up, and can create issues when positioning the avionics board on the all threads. The mass of this design was given a score of five because it is estimated to weigh 9.35 ounces. Finally, the cost for this design was given a five because it is estimated to cost $5.12 in materials and can be printed in five hours.

The 2017-2018 avionics bay was scored a four for accessibility because the design allows the team to access the altimeters and batteries easily by opening the door on the outside of the rocket while it is completely assembled. The ease of assembly scored a two as well because of the difficulty in incorporating the slider and creating a hole in the body tube and coupler of the rocket. This requires structural changes to the body tube as well as the combination of several 3D printed parts for the avionics bay. The precision of the avionics bay with a door scored a four since the slider fits tightly on the rail in the avionics bay and can be easily removed and reinserted at any time. The design of the avionics bay walls are meant to attach to the avionics coupler and will not move in between flights. The mass of this concept is expected to be 20.67 ounces and was given a one. The cost for building this design was given a one because it is estimated to be $11.36 and cannot be printed overnight.

The colonnaded avionics bay design scored of four in accessibility since the team can access the altimeters and batteries by unscrewing the door on the outside of the rocket and sliding out the avionics board. Ease of assembly scored a three since this design is built the same way as the 2018 model except that there are columns on the side instead of a solid enclosure which allows for easier access inside of the avionics bay and easier assembly as a result. The precision of this design was given a four since the slider fits tightly on the rail and the avionics bay walls are meant to attach to the avionics coupler and will not move in between flights. The mass is estimated to be 17.3 ounces and received a score of two. The cost for building this design was given a two because it is estimated to be $9.85 and cannot be printed overnight.

The colonnaded avionics bay design received the highest score and will be used in this year's competition rocket. The final design of the 2017-2018 recovery system is shown below in Figure 24.

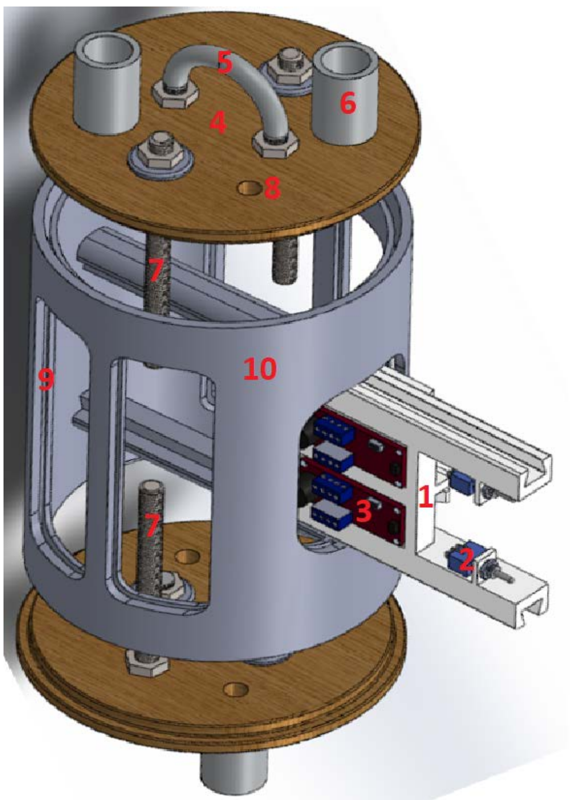


**Figure 25. Recovery System; Exploded View**

The following list refers to the numbering schema in Figure 24.

1. Avionics Board
2. Mechanical Switch
3. StratologgerCF Altimeter
4. Avionics Bulkhead
5. U-Bolt
6. Charger Well
7. Allthread Rod
8. Initiator wire pass through hole
9. Faraday Cage Channel
10. Avionics Bay

## Avionics Board

The avionics board is the component that the altimeters, batteries, and wiring are attached to. The avionics board contains the two completely independent altimeter systems, pictured in Figure 25. Each Stratologger CF altimeter is wired to a 9 volt battery. The batteries are located on the reverse side of the avionics board, and held in place with clips printed into the avionics board. All components are wired together using standard 16 gauge electrical wire. The wiring diagram for the avionics system is pictured in Figure 26. This avionics board is a completely removable section of the avionics bay. The benefit to this design is the ease of accessibility of the main components. The altimeters can be wired, adjusted, and inserted into the rocket just before launch without deconstructing any part of the rocket itself. The altimeter is also separately connected to two initiators which will ignite the ejection charge for both the main and drogue parachutes. The ejection charges are located in the charge wells on the outside of the two bulkheads on either end of the avionics bay. The switch connected to each altimeter is a toggle switch which is located internally and accessed through the door. These are mechanical switches that will be engaged before launch and will not be disengaged in flight.

The avionics board and avionics bay structure will be made of PLA, printed on the team’s 3D printer. This material is one the strongest and most resilient 3D printing filaments. The club has successfully used this material for avionic structures on numerous previous flights.

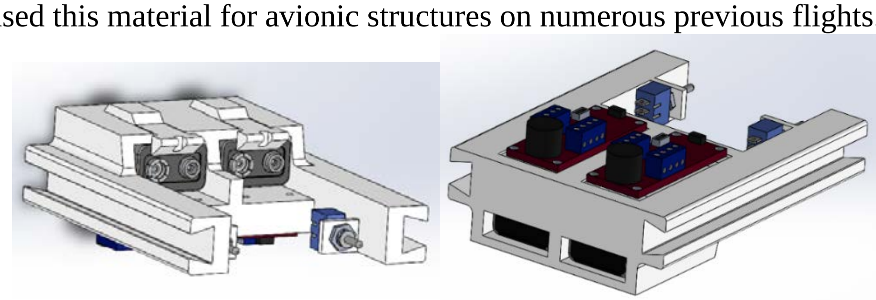

**Figure 26. Avionics Board**

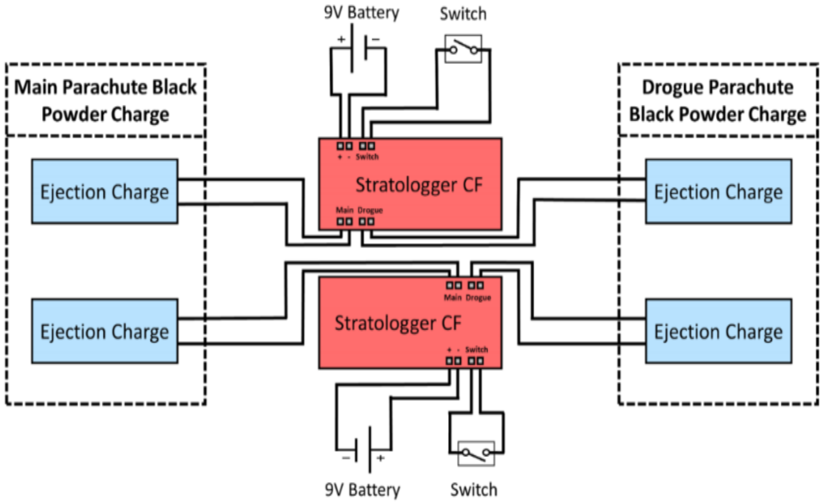


**Figure 27. Wiring Schematic**

## Avionics Bay Door

The avionics bay design has been chosen to include access through an external door seen in Figure 27. This door will allow the avionics and recovery team to assemble the avionics bay more easily and give access to the altimeters in case of emergency on the launch pad. The door contains a hole to allow the pressure inside to equal with the atmospheric pressure, and is secured by four corner screws that can easily be secured just before launch. The team will be able to access the internal toggle switch and connect loose wires without any major issues before launch.

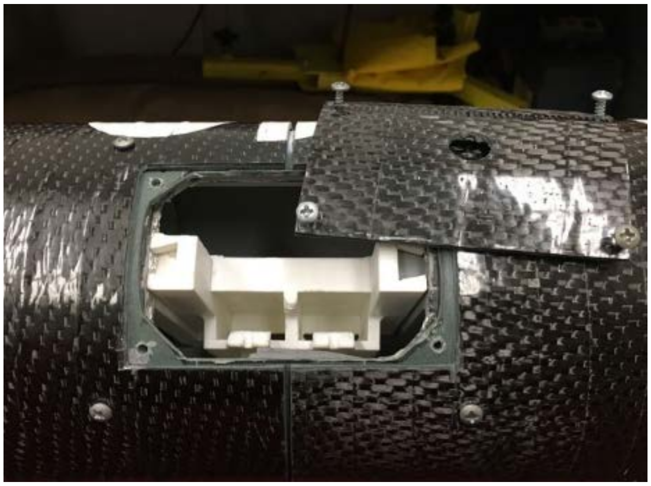

**Figure 28. Avionics Bay Door**

## Electronic Shielding

The avionics bay will contain electromagnetic shielding to prevent interference with the altimeters. The electronic shielding, also known as the faraday cage, is employed in order to shield the internal electrical components of the avionics bay from potential electronic interference. This prevents any potential accidental ignition of the separation charges. In past years, LTRL has constructed a wire mesh cage around the avionics bay. However, this made it difficult for hands to reach in and access the inside of the avionics bay before launch. This mesh was a safety hazard as it caused cuts on members' hands, and was difficult to install or adjust. This year's faraday cage was developed to combat many of the issues that the wire mesh had created. By utilizing an aluminum foil wrap around the inside of the avionics bay to act as a faraday cage, inadvertent electronic excitation will be prevented. The aluminum foil wrap is a lightweight option that is easier to install, doesn't restrict access to the avionics bay, and isn't a safety concern. In Figure 28, a close up on the slit between the inner and outer wall of the avionics bay is shown. This is where the aluminum foil faraday cage will reside.

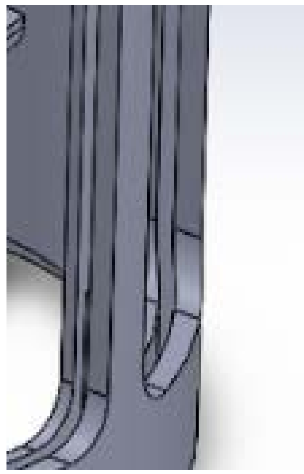

**Figure 29. Avionics Bay Close-Up**

## Altimeters

LTRL must use an altimeter which is able to measure and report peak altitude as well as maximum velocity during flight. The altimeter must be able record at least ten samples per second and must store information on altitude, temperature, and battery voltage. This data must be able to be transferred to a computer after recovery for calculations. It is important for the altimeter to store data even without power in case of an unforeseen loss of power after landing or during flight in case of a brownout. The altimeter needs to be able to deploy drogue and main parachutes by sending a signal to two initiators at independent events. The altimeter must also allow for programming of various altitudes for main parachute deployment.

The team used a weighted selection matrix to select an altimeter for the 2018-2019 competition year by comparing five important attributes: cost, size, reliability, accuracy, and programmability.

The cost attribute is the asking price of the altimeter in USD from the manufacturer's website. This attribute is assigned a weight of 0.1 because any altimeter purchased will be used by the team for years to come on subscale launches and certification flights. An altimeter will receive a five in the cost category if the team already owns the altimeter, resulting in zero dollars out of pocket. Scores of four to two are linearly spaced from $30 to $90. A score of one will be given, if the altimeter costs more than $120.

Size is given a score of 0.1 since the team would prefer the chosen altimeter to be as small as possible to allow for a smaller AV bay. This would allowed for reduced print times and reduced filament costs. A five in the size category will be given to an altimeter that has a footprint of 1 inches cubed or smaller. Scores of four to two are linearly spaced from 1.2 inches cubed to 1.8 inches cubed. A score of one will be given to an altimeter that has a footprint of 2 inches cubed or larger.

Reliability is one of the most important attributes for an altimeter as it needs to be able to survive the stresses and pressure differentials experienced during flight. The reliability attribute was given a weight of 0.3 since this is a mission critical component that must perform its assigned functions. An altimeter will be given a five in reliability if the altimeter is guaranteed by the manufacturer to operate through all the conditions that the flight vehicle will face. A score of three will be given to an altimeter that will operate at its suggested limit. A score of one will be given to an altimeter that is not operating within warranty period or not guaranteed to survive in flight forces. The team will also require the altimeter’s data to be reliable as well. This is measured by its ability to prevent data corruption from fluctuations in power supply during a two second brownout. The initial score will be increased by one if the altimeter contains at least a two second brownout protection. Reliability will also be based off of user reviews and by word of mouth recommendations. This may add or subtract one point from the score.

Accuracy is imperative so that all altimeters properly deploy the parachutes and accurately record apogee as well as other in-flight variables. This attribute was given a weight of 0.2 as the team needs to be able to relay accurate data about the launch. The altimeter will receive a score of five if it can record values above 5,000 feet to within 0.1% for altitude and velocity measurements. A score of three will be given to an altimeter that is accurate past 5,000 feet and accurate to within 0.5% for altitude and velocity measurements. An altimeter will receive a score of one if it is not accurate past 5,000 feet or only accurate to within 1% for altitude and velocity measurements.

The final attribute that the team is considering when choosing altimeters is ease of programmability. This factor was given a weight of 0.3 as it is one of the most important factors. It is important that both experienced and inexperienced team members can effectively interpret data and program the accompanying software. A score of five was given for programmability if inexperienced team members without any training other than reading the user manual can operate the software and program the altimeter. A score of four will be given to an altimeter that is easy to program with help from experienced team members. A score of two will be given to an altimeter that takes excessive amounts of time to program and pull data from. A score of one would be given to an altimeter with software and data that the experienced team members cannot operate after reading the user manual.

The weighted scores for each preliminary design option are shown below in Table 21.

**Table 24. Altimeters Selection Matrix**

| Selection Criteria | Weight | StratoLoggerCF | | StratoLogger SL100 | | Jolly Logic AltimeterThree | |
|---|---|---|---|---|---|---|---|
| | | **Score** | **Weighted Score** | **Score** | **Weighted Score** | **Score** | **Weighted Score** |
| Cost | 0.1 | 5 | 0.5 | 5 | 0.5 | 2 | 0.5 |
| Size | 0.1 | 5 | 0.5 | 3 | 0.3 | 5 | 0.5 |
| Reliability | 0.3 | 4 | 1.2 | 3 | 0.9 | 3 | 0.9 |
| Accuracy | 0.2 | 5 | 1 | 5 | 1 | 3 | 0.6 |
| Programmability | 0.3 | 4 | 1.5 | 4 | 1.5 | 5 | 1.2 |
| **Total** | **1** | | **4.40** | | **3.90** | | **4.00** |

The StratoLoggerCF and the StratoLogger SL100 both scored a five in the cost category as the club currently has both of these altimeters while the Jolly Logic AltimeterThree scored a 2 in the cost category as it is priced at around $110 on the manufacturer's website.

For the StratoLoggerCF, the footprint is only 2.0”x0.84”x0.5” in length, width, and height respectfully, while the StratoLogger SL100 has a footprint of 2.75”x0.9”x0.5” in length, width, and height. The total area of the StratoLoggerCF is 0.84 inches cubed, and the total area of the StratoLogger SL100’s area is 1.2375 inches cubed. The Jolly Logic AltimeterThree has a smaller size of 1.93”x.71”x.57” resulting in a footprint of only .74 inches cubed. These footprints resulted in the CF and AltimeterThree models achieving a five in the size category due to their very small size while the SL100 achieved a three due to its larger size.

All models of altimeter are rated to be able to exceed in flight forces and are roughly of the same reliability. Since all of these altimeters are guaranteed for three years, the club initially ranked all three of these altimeters as a two. The StratoLoggerCF model only has a two second brownout protection period compared to the Stratologger SL100’s three seconds of protection. However, the StratoLoggerCF is able to store more flight data if the power were to be lost during flight. Each altimeters score was incremented by one due to this protection. Comparing both to the AltimeterThree, the Jolly Logic version has an integrated rechargeable battery, resulting in much more reliability if the rocket were to lose power in flight. However, the Jolly Logic altimeter can store only one flight. The StratoLoggerCF model is the leading competitor in terms of memory storage as it has the advantage of being able to store multiple flights which prevents the possibility of accidental overwriting of previous flights whose data was not transferred. The StratoLoggerCF was given an extra one point for this ability to not lose previous flights data. This resulted in the StratoLoggerCF receiving the highest score of four while the StratoLogger SL100 and the Jolly Logic received a three.

The accuracy of both the StratoLoggerCF and Stratologger SL100 are rated for within 0.1% pressure fluctuations and up to 100,000 feet. However, the AltimeterThree is only rated for up to 29,500 feet reliability and there is no data known for pressure sensitivity. As a result, the AltimeterThree scored a three for accuracy and both Stratologger models scored a five.

Both StratoLogger altimeters use the same software which the team has experience using in the past and were given a score of four for programmability as a result. The AltimeterThree variant allows the data to be sent to a smartphone or other smart device, such as a tablet or a laptop. This prevents issues stemming from software which allows for anybody to use this altimeter and transfer and graph data effectively. As a result, the AltimeterThree was given a score of five for programmability.

The StratoLoggerCF altimeter received the highest weighted score, and was chosen to be the altimeter of choice for the 2018-2019 competition year. This altimeter shows a few advantages over the StratoLogger SL100 model such as smaller size, smaller footprint, and ease of accessibility. This allows the team to be much more conservative in the use of materials. The Jolly Flight altimeter might be smaller and easier to use, but it is more expensive and less accurate.

### Avionics Bay Bulkheads

The two avionics bay coupler bulkheads on either end of the avionics bay support the majority of the in-flight forces from the rocket frame and the recovery harness. The final design for the bulkheads and their attached components is pictured in Figure 32 and the integration of them into the entire avionics assembly was previously shown in Figure 24. The bulkheads are attached to each other by two steel all-thread rods that run on either side of the AV Board inside of the avionics bay. The bulkheads are attached to the recovery harness quick link by a 3/8th inch steel U-bolt. The bulkheads each have two charge wells that contain drogue and main, primary and secondary deployment charges mounted to the surface exterior to the avionics bay as well.

As determined by the design of the rocket, holes for the all-thread rods and U-bolt must align with the avionics board and be centered for maximum structural integrity. The initial arrangement of the bulkhead is shown in Figure 29.The holes for the initiator wires have no constraints for their location. In order to maximize the strength of the bulkhead plate, SolidWorks finite element analysis (FEA) was utilized to determine the optimum location of these two wire holes.

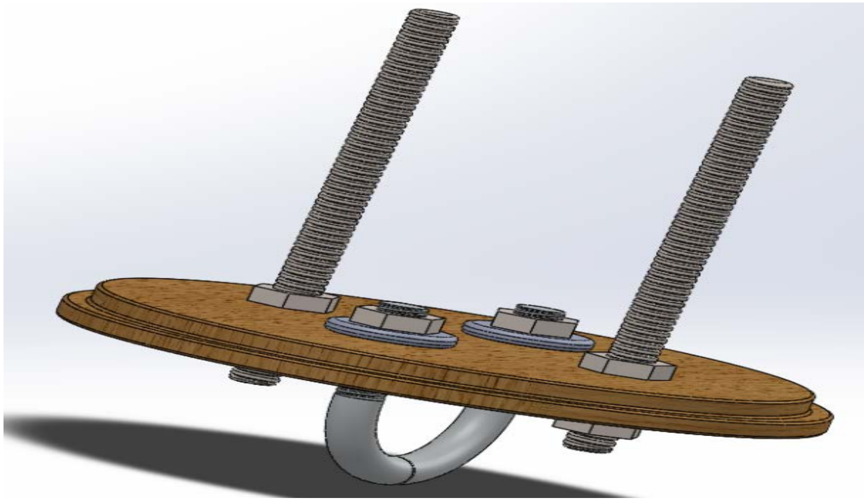

**Figure 30. Initial Avionics Bulkhead Arrangement**

To determine the location of the two wire holes, the bulkhead and its components were modeled and assembled in SolidWorks. Components include the all-thread rods, U-bolt, nuts, and washers. The model was then simulated under a load. The maximum load the bulkheads will experience was determined to be during main parachute deployment. Therefore, it can be concluded that the maximum forces will be where the recovery harness would transfer the force from the parachute to the bulkhead. In Figure 30, the simulated G force the rocket will experience is shown.

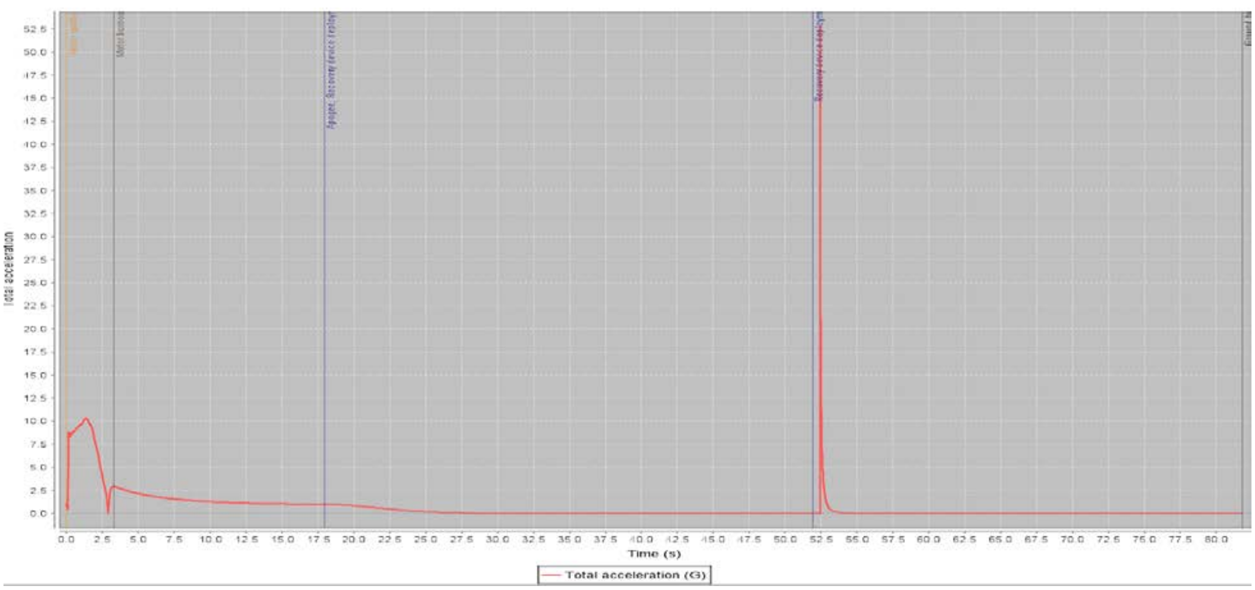


**Figure 31. Acceleration Profile**

The resulting stress test and factor of safety plot pictured in Figure 31 was then analyzed to determine where the bulkhead had the higher factor of safety to drill the initiator and charge well holes. The test will be successful when the optimal location of the holes are determined. If the best location for the placement of the wire holes is discovered to be in a location unable to connect to the charge wells, then the next optimal location will be assessed until a viable location is determined.

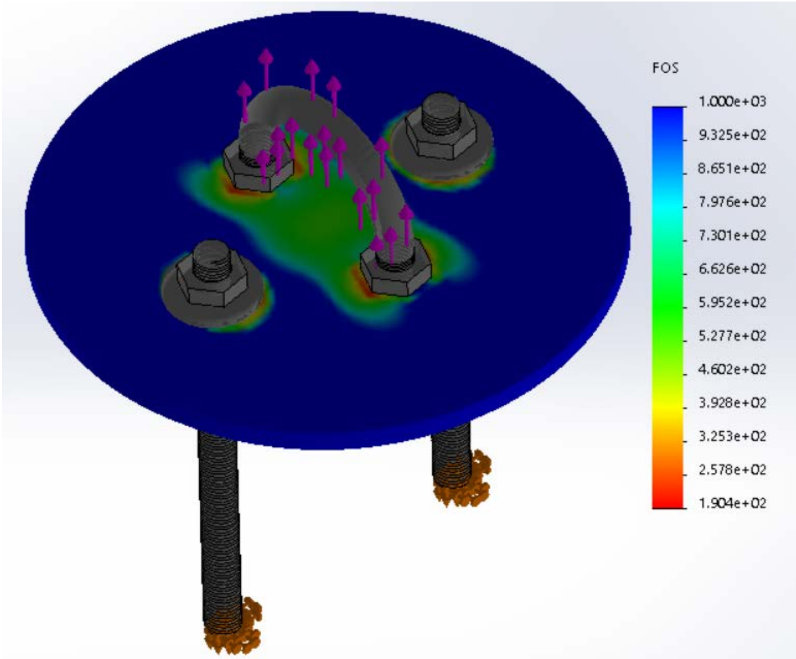


**Figure 32. Avionics Bulkhead FOS Simulation**

The final design for the avionics bulkheads is shown in **Figure XX3.** This design minimizes the maximum stresses that the bulkheads will endure during flight.

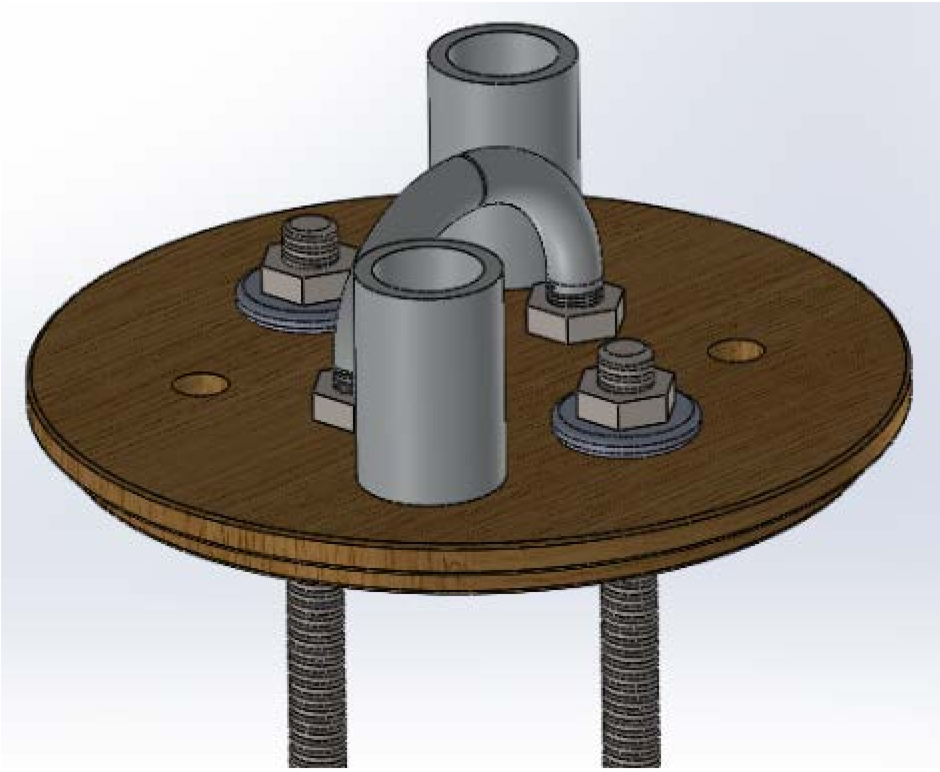

**Figure 33. Avionics Bulkhead**

## Separation Charges

The team must select an ejection charge which is compact and able to fit inside the rocket's main and drogue chambers. The ejection charge also needs to be reliably ignited when in contact with the initiator that receives a signal from the altimeter. The ejection charge must produce a reliable force that can be calculated in order to ensure that the charge detonation will break the shear pins and allow the rocket to separate. The three potential options for ejection charge material are black powder, $CO_2$, and Pyrodex. These potential ejection methods were scored in a weighted design matrix based on the following selection criteria: volume, cost, ease of use, tolerance, and safety.

The volume criteria is a measure of how much space inside the rocket the ejection system will require. The ejection charge well is limited in space and would prefer to use at little space as possible so this attribute was given a weight of 0.3. A score of five in this category will be given to a charge that requires 5 cubic centimeters of space or less. Scores of two to four are linearly spaced from 16 cubic centimeters to 9 cubic centimeters. A score of one will be given if the charge requires more than 20 cubic centimeters of space.

The cost of all explosives charges is relatively small and can be purchased in bulk so this attribute was given a weight of 0.1. A score of five will be given to a charge with a per-launch cost of 10 ¢ or less. Scores of four to two are linearly spaced from 7 ¢ to 3 ¢ per launch. A score of one will be given to a charge that costs more than 50 ¢ per launch.

Ease of use is a measure of how easy it is to get the explosive charge installed in the rocket on launch day. This attribute was given a weight of 0.2 as it important that potentially explosive charges can be easily quickly without spillage. A score of five for this attribute will be given to a charge that can installed by one person within two minutes. Scores of four to two are linearly spaced from 4 minutes to 8 minutes for setup. A score of one will be given if it takes one person more than ten minutes to set it up in the rocket.

Ease of modelling is how well the team can model the behavior of the explosion. This was given a weight of 0.1 since the team can use a factor of safety to ensure proper separation if modelling is inaccurate. A charge will be given a score of one if the team cannot model the event without using multiple correction factors. A score of four will be given if the charge requires one correction factor A score of three and two will be given for two or three corrections factors respectively. A score of five will be given to the charge if it can be modelled without using any correction factor.

The last attribute used to judge the potential ejection systems charge is safety. This attribute is the most important to the team and was given 0.3 weight. This is a measure of how many precautions the team must take when handling the explosives charge. A score a five in this attribute is given to a charge that only requires one extra safety measure. A score of one will be given to a charge that requires many safety measures as well as specialized training for members of the team in handling the material due to its hazardousness nature and potential danger to team members.

The weighted scores for each preliminary design option are shown below in Table 22.

**Table 25. Separation Charges and Design Selection Matrix**

| Selection Criteria | Weight | Black Powder | | CO2 | | Pyrodex | |
|---|---|---|---|---|---|---|---|
| | | Score | Weighted Score | Score | Weighted Score | Score | Weighted Score |
| Volume | 0.3 | 5 | 1.5 | 1 | 0.3 | 4 | 1.2 |
| Cost | 0.1 | 5 | 0.5 | 1 | 0.4 | 5 | 0.5 |
| Ease of Use | 0.2 | 5 | 1 | 2 | 0.4 | 3 | 0.6 |
| Ease of Modelling | 0.1 | 4 | 0.1 | 2 | 0.2 | 4 | 0.4 |
| Safety | 0.3 | 1 | 0.3 | 5 | 1.5 | 2 | 0.6 |
| **Total** | | | **3.4** | | **2.8** | | **3.3** |

Black powder and Pyrodex are similar in density and in many applications can be substituted in a 1:1 ratio. Pyrodex, which is closely compared to 3F black powder, has grains that range in size from .021”-.034” (.05334-.08636 centimeters) in diameter while the grains of 4F powder are only .009”-.020” (.02286-.0508 centimeters) in diameter. Black powder received a five in volume since it has will take up 1.5 cubic centimeters for drogue and 2.5 cubic centimeters for the main charge. Pyrodex has the same volume requirement for the powder but it received a score of four due to the extra packing material that would be required to keep it tightly compressed during launch. The $CO_2$ charge requires 14 cubic centimeters of space for one 12 gram charge which is the smallest size that can be purchased. With the additional hardware required to hold the $CO_2$ container, this ejection system will take up more than 20 cubic centimeters and received a one as a result.

For cost, both black powder and Pyrodex scored a five as each material only costs less than 10 cents per charge per flight. The $CO_2$ cartridge scored a one in this category as well since containers have to be purchased in sets, and cost around 70 cents per charge per flight.

For the ease of use attribute, black powder received a five due to it easily being measured and poured into the charge wells within 2 minutes. This has been tested by the team in previous years. Pyrodex received a three because it requires the same amount of time to pour in the charge wells but also requires extra packing afterwards. The $CO_2$ option was given a two because the $CO_2$ container has to be screwed in place and then armed which takes almost 10 minutes.

For ease of modelling, black powder and Pyrodex were both given scores of four because their explosion characteristics can be easily modeled using known laws of physics and a simple idealization of the body tube. The only correction factor the team has to estimate is the gas leakage during the pressurization event. There are also many online calculators for amateur rocketry black powder charge sizes to verify the team's calculations. Additionally, Range Safety Officers have greater experience with black powder charges, and can also additionally verify that the team is using the correct size charges. The $CO_2$ cartridges were given a two since it is harder to model the pressure distribution from ejection due to the uneven and slow pressure release of the $CO_2$ cartridge when they are popped.

The MSDS sheets for both black powder and Pyrodex are listed in Appendix C**.** Based on this, the team will give black powder a safety score of one and Pyrodex a two. CO2 cartridges only safety precaution is if the cartridge is prematurely punctured which can be greatly mitigated using proper safety procedures. Additionally, the $CO_2$ tanks contains no handling hazards and received a five as a result.

Black powder received the highest weighted scored, and was chosen to be the separation charge of choice for the 2018-2019 competition rocket. This material showed exceptional performance in volume required, cost, ease of use, and tolerance, despite being an unsafe material. The team will employ extensive safety precautions to ensure safe handling of the black powder at all times.

### Separation Charge Wells

The black powder used to separate the rocket for drogue and main parachute deployment will be contained within a charge well. There are four charge wells located on the exterior side of the avionics bay bulkhead. The purpose of these wells is to contain the explosive charge during launch, and to direct the flow of hot gases away from the avionics bay and towards the separation point. These charge wells will be approximately 1" long and 1" in diameter. The wells will be epoxied to the bulkheads next to the U-bolt that connects to the recovery harness. The three preliminary ejection well designs considered were PVC pipe, steel pipe, and 3D printed. These designs were evaluated in a weighted selection matrix based on the following selection criteria: ease of manufacturing, cost, strength, and weight.

Ease of manufacturing represents the amount of knowledge, and equipment required to create each black powder well. A score of one means that manufacturing the charge well requires special equipment and specialized knowledge from a team lead. A score of three means that either a team lead's specialized knowledge or special equipment is required to create this well. A score of five means that team members with no knowledge of the rocket or access to equipment past hand tools could build this component. This attribute was given a weight of 0.4 since the charge wells are simple components that should not require excessive time to manufacture.

Cost represents the amount money and time that will need to be allocated to produce these parts. A score of one means that the component costs more than $10 and will take more than one hour to produce. A score of five is given to a component that costs less than $1 and takes less than ten minutes to produce. Scores of two to four are linearly spaced between $7 and $3 as well as linearly spaced between 45 minutes of production time and 25 minutes. This attribute was assigned a weight of 0.1 due to the team preferring the charge wells to be built quickly and cheaply but it is not a necessity.

Strength represents the amount of stress the charge wells can undergo without failing. A score of one means that the material has a Young's modulus of less than 1 GPa. Scores two to four are linearly spaced between 25 GPA and 75 GPa. A score of five is given if the material has a GPa greater than 100 GPa. This attribute was assigned a weight of 0.3 since the team does not want to over design these simple components, but it is vital they hold up under pressure.

Weight represents the amount of mass added to the rocket by the charge wells. A score of one is given to a material that will weigh more than 10 grams per milliliter. A score of five is given to materials with a weight less than 1 gram per ml. Scores of two to four are linearly spaced between 7 grams per milliliter and 3 gram per milliliter. This attribute was assigned a weight of 0.2 since keeping the mass low in the avionics bay is important but these are light components.

The weighted scores for each preliminary design option are shown below in Table 23.

**Table 26. Separation Charge Wells Design Selection Matrix**

| Selection Criteria | Attribute Weight | PVC Pipe | | Steel Pipe | | 3D printed | |
|---|---|---|---|---|---|---|---|
| | | Score | Weighted Score | Score | Weighted Score | Score | Weighted Score |
| Ease of Manufacturing | 0.4 | 5 | 2 | 1 | 0.4 | 2 | 0.8 |
| Cost | 0.1 | 5 | .5 | 4 | 0.4 | 3 | 0.3 |
| Strength | 0.3 | 3 | 0.9 | 5 | 1.5 | 1 | 0.3 |
| Weight | 0.2 | 4 | 0.8 | 1 | 0.2 | 4 | .8 |
| **Total** | | | **4.2** | | **2.5** | | **2.2** |

The PVC pipe option scored a perfect five in ease of manufacture because the material requires only a hand saw and no specialized knowledge. The PVC pipe option scored a five in cost since it can be purchased in three foot sections for between $2.99 and $1.99. It is estimated to take 10 minutes to build these. The material was given a three in strength, because it only has an average Young's modulus of 58 MPa. With a relatively low weight, at 1.08 grams per milliliter, PVC pipe earned a score of four in weight.

The metal pipe option was given a four for ease of manufacturing because it would require a metal machine shop and members with experience in machining. The metal pipe also scored a four for cost because it is $2 per foot and can be purchased from multiple online vendors. It is estimated to take 15 minutes to construct these. This option received a five in strength because it has a Young's modulus of 200 GPa. Due to its relatively high weight at 8 grams per milliliter, the metal pipe charge well was given a score of one.

The 3D printed option earned a score of two for ease of manufacturing because members must be familiar with modeling software and it can only be printed by a team lead on the team's 3D printer. This option was given a three for the cost criteria since the amount of PLA filament will cost $2 and take an hour on the 3D printer. This material scored a one in strength due to the inherent flaws in 3D printing, and because PLA filament has a Young's modulus of approximately 40 MPa. The weight of a plastic 3D printed part is comparable to PVC plastic, at 1.3 grams per milliliter, and received a score of four.

PVC pipe received the highest weighted score and the charge wells will be made from PVC pipe as a result. It is low cost, light weight, and all team members have the knowledge on how to create ejection wells from PVC pipe without additional training. LTRL has used this design in the past, and is confident that PVC pipe will hold up to the stresses experienced during black powder ejection and will perform exceptionally.

### Black Powder Calculation

After selecting an ejection charge and a containment method for the ejection charge, the team was able to calculate the required black powder charge. Table 24 lists the masses of black powder the team will use for drogue and main parachute ejections. These amounts were chosen based on previous year's knowledge of what amount of black powder is able to reliably and safely separate the rocket.

**Table 27. Black Powder Calculation**

| | Fullscale Drogue | Fullscale Main | Fullscale Drogue Redundant | Fullscale Main Redundant |
|---|---|---|---|---|
| 4F Black Powder (grams) | 1.5 | 2 | 2 | 3 |
| Body tube diameter | 6” | 6” | 6” | 6” |
| Body tube length | 16” | 16” | 16” | 16” |

Using the dimensions of the drogue parachute bay and main parachute bay the team is able to calculate the number of shear pins that a given mass of black powder will break. The calculation for the volume of the chamber that is pressurized by the explosion is shown in the equation 18.

$$V = \frac{\pi D^2 L}{4} \qquad (18)$$

The volume is then substituted into Equation 18 for V where N is the mass of black powder in grams from Table 24. D is the body tube diameter from Table 24 and L is the body tube length from Table 24. P is the pressure in psi that will result from the black powder detonation in the chamber. Equation 19 assumes that the pressure inside will have equalized with the atmosphere prior to detonation and also contains the conversions from pounds to grams and the gas constant.

$$P = \frac{(N * \left(\frac{1lbf}{454grams}\right) * 266 \, ^{in\ lbf}/_{lbm} * 3370^0R)}{V} \tag{19}$$

Equation 20 solves for the force required to break the shear pins in lbs. P is the chamber pressure calculated from Equation 19 and D is the chamber diameter.

$$F = \frac{\pi}{4} P D^2 \tag{20}$$

The team uses brand 2-56 shear pins for all separation points on the flight vehicle. These shear pins fail at an average shear force of 25 lbs which has been confirmed in past flights, ground tests, and is listed on the shear pins manufacturer's site. Once the total force is known, it is divided by 25 and then rounded down for the maximum number of shear pins that amount of black powder will break. The number of 2-56 shear pins the team calculated is listed in the second row of Table 25. A factor of safety listed in row two of Table 25 was then applied to each of the results to account for any unknown factors. The last row in Table 25 has listed the number of shear pins the team plans on using on the flight vehicle for drogue and main separation point. The redundant charges fire into the same chamber as the main charges so they must have the same number of shear pins.

**Table 28. Shear Pin Calculations**

| | Fullscale Drogue | Fullscale Main | Fullscale Drogue Redundant | Fullscale Main Redundant |
|---|---|---|---|---|
| Calculated number of 2-56 shear pins | 5 | 6 | 6 | 10 |
| Factor of Safety | 1.5 | 1.25 | 2 | 2 |
| Actual number of 2-56 shear pins | 3 | 5 | 3 | 5 |

### GPS Unit

The team needs to have a GPS unit contained within the rocket to ensure it will be located after launch. The GPS needs to be able to be tracked remotely from a phone or laptop to within an accuracy of 25 ft. The GPS needs to able to maintain power for at least one day in case the team is not able to locate the rocket right away. It will be mounted securely inside the nose cone of the rocket so the GPS needs to be small enough to fit within that space. This location for the GPS mounting was chosen because it is far away from the payload section, avionics bay, and the motor. The team used a weighted selection matrix shown below in Table 26 to select a GPS for the 2018-2019 competition year by comparing five important attributes: cost, ease of use, size, reliability, and range.

Cost is the price in US dollars of the GPS unit being implemented. Cost was given a weighting of 0.2 because a GPS unit is a large upfront cost. However, it is a reusable piece of equipment that will be used in future years. A GPS will be given a score of five if the team already owns the GPS or cost less than $50.00. Scores of four to two are linearly distributed from $100.00 to $300.00. A GPS will be given a score of one if it costs more than $400.00.

Ease of use is a measure of how easy it is for the team to integrate the GPS into the rocket, and is also a measure of how easy it is for a team member to operate and track the GPS. Ease of use was given a weight of 0.4 because it is vital that the team is able to track the rocket and only has a short window on launch day to correctly set up the GPS. A GPS unit will be given a score of five if it can be set up by one unskilled team member in less than five minutes. A score of three will be given if it takes one skilled team member such as a team lead to operate and setup the GPS on launch day within 10 minutes. A score of three will also be given if the GPS instead takes multiple general body members to setup and operate the GPS on launch day within 10 minutes. A GPS unit will be given a score of one if it takes more than one skilled team member with training in the operation of the GPS to mount and correctly turn on the GPS system in more than 10 minutes.

Size is based on the volume the GPS takes up in the rocket. This attribute was given a weight of 0.1 since there is extra space inside the rocket for a small device the size of a few cubic inches. A GPS will be given a score of one if it has a volume greater than 10 cubic inches, and a score of five if it has a volume smaller than 1 cubic inch.  Scores of four to two are linearly distributed from 1 cubic inch to 5 cubic inches.

Reliability is based on the GPS's battery life, and the warranty that comes with the GPS. A GPS will be given a score of one if it has a battery life of less than one day or if it does not come with any warranty. A score of three will be given if either the GPS has a warranty longer than a year or a battery life greater than one day. A GPS will be given a score of five if it has a battery life of one week and provides a warranty longer than one year. This attribute was given a score of 0.2 because the team plans on using this GPS in future years.

Range is the distance that the GPS will be able to be tracked from the launch site. A GPS will be given a score of one if the GPS has a range of under one mile. A score of two will be given if the GPS has a range of miles in the single digits. A score of three will be given if the GPS has a range of miles in the double digits. A score of four will be given if the GPS has a range of miles in the triple digits. The GPS will be given a score of five if the range is anywhere on earth.

The weighted scores for each preliminary design option are shown below in Table 26.

**Table 29. GPS Selection Matrix**

| Selection Criteria | Attribute Weight | Americaloc GL300W | | Spy TEC STI GL300 | | BRB900Tx/Rx | |
|---|---|---|---|---|---|---|---|
| | | **Score** | **Weighted Score** | **Score** | **Weighted Score** | **Score** | **Weighted Score** |
| Cost | 0.2 | 5 | 1 | 4 | 0.8 | 2 | 0.4 |
| Ease of Use | 0.4 | 5 | 2 | 4 | 2 | 2 | 0.8 |
| Size | 0.1 | 1 | 0.2 | 5 | 1 | 5 | 0.5 |
| Reliability | 0.2 | 5 | 1 | 4 | 0.8 | 2 | 0.4 |
| Range | 0.1 | 5 | 0.5 | 5 | 0.5 | 3 | 0.3 |
| **Total** | | | **4.7** | | **4.7** | | **2.4** |

The Americaloc GPS costs $109.90 and was given a score of four for the cost attribute. The SKY TEC costs $49.90 and was given a score of five. The BRB 9000 costs $309 and so was given a score of two.

For ease of us, the Americaloc GPS was given a score of five since it can be accessed using any tablet or phone with an app without having a wired connection, and can display zones and mark events. Additionally, the Americaloc GPS be placed into a structure within the rocket within five minutes by anyone on the team due to its sturdy rectangular design. The SKY TEC GPS was given a score of five since it can be accessed using any tablet or phone without being wired to it. The SKY TEC can also be placed into the rocket quickly due to its small design. The BRB 9000 must have the ground station wired into a laptop to receive data in real time, and requires one team member to continuously monitor the ground station at all times. This GPS also does not have a sturdy exterior so it must be carefully designed into a safe location in the rocket and received a score of two as a result.

The Americaloc GPS has a volume of 4.3 x 2.6 x 2.6 inches and was given a score of one. The SKY TEC has a volume of 2 x 1 x .8 inches and so was given a score of five. The BRB 9000 has a volume of 2.6 x 1 x .5 inches and so was given a score of five for the size attribute.

For reliability, the Americaloc GPS was given a score of five since it has a two week battery life as well as a two year warranty. The SKY TEC GPS was given a score of four since it has a two week battery life, but its warranty needs to be purchased separately. The BRB 9000 has an estimated battery life of three days per charge and does not come with a warranty and was given a score of two as a result.

For the range attribute, both the Americaloc and the BRB 9000 are tracked by satellite and have unlimited range and received a score of five as a result. The SKY TEC requires a ground station to be within 15 miles of the large antenna that is attached and was given a score of three.

After summing up the weighted scores for each preliminary design option, the Americaloc GW300 and the SPY TEC STI tied. The team has decided to use the Americaloc GW300 as the 2018-2019 competition year GPS because the team has used this model before and members are already familiar it. This transmitter uses an AT&T brand cell phone SIM card to relay its position and it operates at 850 MHz. Since this GPS unit actively sends out its position, all the electronics in the rocket will have shielding to prevent interference.

### Recovery Harness

The recovery harness shock cords will be 27 feet for the main parachute and 24 feet for the drogue parachute. The shock cords will attach to a number five U-bolt shown in Figure 24. These recovery harnesses are these lengths to ensure that body tubes will not collide with each other after both drogue and main parachute deployment. The elasticity of the recovery harness also ensures that there is low inertial loading on the rocket frame during separation. The recovery harness had been selected to be a ½" width Kevlar cord chosen for its strength and durability. The cord is secured to the rocket by using ½" quick links that are connected to 3/8" steel U-bolts on the bulkheads. This design has been used for previous LTRL rockets, and has been comprehensively tested to be able to deal with all the forces acting on the rocket during the descent. Both main and drogue parachutes will be covered by protective Nomex blankets to ensure that the black powder charges do not burn or damage them during deployment. The Nomex blankets will be attached to the recovery harness along with the ½" quick links. A fireball will be connected to the recovery harness to prevent damage to the recovery harness and zippering of the body tubes. Figure 33 shows a diagram of the planned descent including the relative positioning of the sections during freefall and the location of the two events not to scale.

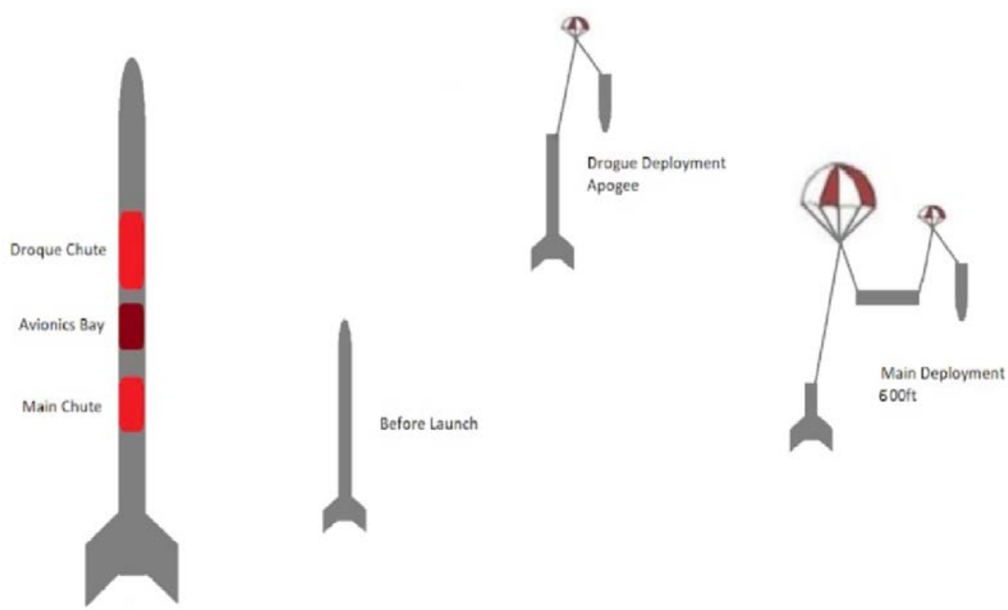


**Figure 34. Parachute Deployment Sequence**

# 4. Safety

LTRL understands that there are many inherent dangers when building, testing, and launching high powered model rockets. In the safety plan below, LTRL outlines the risks and hazards identified throughout the process of constructing, testing, and launching of the rocket, along with the preliminary steps to mitigate them.

## 4.1 Safety Officer Responsibilities

Ben Akhtar is the Safety Officer for LionTech Rocket Labs during the 2018-2019 season. As Safety Officer, he is responsible for the overall safety for the team, students, the public, and any other persons involved or at any LionTech Rocket Lab events. In the 2019 spring semester, Ben Akhtar is studying abroad and will not be able to oversee construction, testing, nor launch day assembly of the rocket and cannot enforce safety procedures as a result. Because of this, Matt Easler, the team's Flight Systems Lead, will act as the interim safety officer during construction, testing, and launch day procedures for duration of the 2019 spring semester.

### Statement of Work Requirements

The statement of work requirements for Safety provided by NASA are shown in the requirements verification in section 6.2 below.

### Safety Requirements Verification

LTRL has created a set of team derived responsibilities that will increase and ensure further safety throughout the 2018-2019 season. These responsibilities can be found in section 6.1.

## 4.2 Safety Statement

LTRL will comply with all National Association of Rocketry (NAR), Federal Aviation Authority (FAA) and National Fire Protection Association (NFPA) regulations pertaining to high powered model rocketry. For convenience, and to help ensure the safety of LTRL members and the general public, LTRL will only launch at NAR or Tripoli Rocket Association certified club launches. LTRL and its members will comply with all instructions and guidance issued by the Range Safety Officer (RSO) of these launches. LTRL and its members will also comply with all instructions and guidance issued by the RSOs at the USLI launch in Huntsville.

## 4.3 Launch Day Procedures

### Motor Preparation

Hardware List

Quantity is one of each item unless otherwise specified ([N] Item)

- 75mm Cesaroni 4-Grain Motor Case
- 75mm Aft Closure
- 75mm Forward Seal Disk (FSD)
- 75mm Smoke Charge Enclosure
- 75mm Cesaroni Spacer Ring
- 75mm Forward Closure
- Liner
- Nozzle
- Nozzle Cap
- [3] Propellant Grains
- Smoke Charge

- [2] Forward and Aft O-rings (1⁄8” thick x 2 3⁄4” O.D.)
- FSD O-ring (3/32” thick x 2 9/16” O.D.)
- [2] Grain Spacer O-rings (1/16” thick x 2 1⁄2” O.D.)
- Lubricating grease and popsicle stick
- Sharp blade (exacto knife or multitool blade)

### Pre-Assembly

1. **Required PPE: Latex gloves.** Apply a light coat of grease to all threads and O-rings (except the grain spacer O-rings). Caution: When working with the grease, the team member applying it needs to be wearing latex gloves. The grease can be an irritant if it comes into contact with skin. This caution applies to any and all later steps that involve working with grease.

Propulsion Lead Sign-off: ______________________________________________

### Case Assembly

1. Use a sharp blade to deburr the forward and aft inside edges of the liner tube to provide more friction for the fit of the nozzle and forward closure assembly. Warning! Using a sharp blade carelessly can result in serious injury. When using the blade, always concentrate completely on the task at hand.
2. Insert the larger diameter portion of the nozzle into the aft end of the liner and slide the nozzle all the way in to the point that the flange is in contact with the aft edge of the liner.
3. Ensure that all following procedures are carried out with the assembly in the horizontal position.
4. **Required PPE: Latex gloves.** Install the propellant grains into the liner, sliding them in from the forward end. Place a Grain Spacer O-ring between each propellant grain, and again ensure that they are not lubricated with grease. Warning! Before handling the propellant grains, the handler needs to put on well- fitting latex gloves. The propellant grains are classified as a dangerous explosive and can result in serious harm if not handled properly.
5. Once the propellant grains are installed in the liner, avoid letting any personnel stand directly in line with either end of the case assembly.
6. Place the lubricated FSD O-ring into the groove in the FSD.
7. Insert the end of the disk with a smaller cross-sectional area into the forward end of the liner so that the FSD O-ring is no longer visible and the flange on the FSD is in contact with the forward edge of the liner.
8. Apply a light coat of lubricating grease to the outside of the liner to facilitate liner assembly removal from the case after launch.
9. Insert the liner assembly into the aft end of the motor case until the nozzle protrudes from the aft end of the case by 1 3⁄4”.
10. Place the lubricated Forward O-ring into the groove in the Smoke Charge Enclosure.
11. Insert the Smoke Charge into the aft end of the Smoke Charge Enclosure.
12. Insert the fully assembled Smoke Charge Enclosure into the forward end of the motor case until it is firmly in contact with the forwardmost propellant grain.
13. Insert the 75mm Cesaroni Spacer Ring into the forward end of the motor casing until it touches the forward end of the Smoke Charge Enclosure.

14. Thread the Forward Closure into the forward end of the motor casing until it is firmly in contact with the forward end of the Spacer Ring, completing the Forward Closure Assembly.
15. Place the lubricated Aft O-ring into the groove on the aft end of the nozzle.
16. Thread the Aft Closure into the aft end of the motor case until the flange is firmly in contact with the aft face of nozzle flange.

Propulsion Lead Sign-off: ______________________________________________

Flight Systems Lead Sign-off: ____________________________________________

Safety Officer Sign-off: ________________________________________________

## Vehicle Assembly

Hardware List

Quantity is one of each item unless otherwise specified ([N] Item)

- 4:1 Ogive Fiberglass 6" Filament Wound Nose Cone with Metal Tip
- 24" Payload Carbon Fiber Body Tube
- 16" Drogue Carbon Fiber Body Tube
- 16" Main Carbon Fiber Body Tube
- 38" Booster Carbon Fiber Body Tube
- 12" Payload-Drogue Blue Tube Coupler
- 12" Avionics Bay Blue Tube Coupler
- 12" Main-Booster Blue Tube Coupler
- Avionics Bay Door
- Phillips Screwdriver
- [Sixteen (16)] 2-56 Shear Pins
- [Thirty-Four (34)] 1⁄2" #6 Screws
- GPS System
- Down Body Camera System

Warning! Safety glasses must be worn by every team member in the vicinity when a power drill is in operation.

## Nose cone

1. Slide the GPS Case down the all-thread rod on the nose cone shoulder bulkhead.
2. Fasten the case to the nose cone shoulder bulkhead with a washer and a nut.
3. Turn the GPS on, and verify the GPS is on by checking the activity lights.
4. Insert the GPS into the GPS case.
5. Close the GPS Case, and verify the case is closed with a manual tug test.
6. Insert the shoulder coupler into the open end of the nose cone.

7. Align the depth markings and the registration marks on the shoulder with the matching markings on the nose cone.
8. Screw in a half-inch #6 screw into each of the six (6) holes near the aft edge of the nose cone.

Structures Lead Sign-off: ______________________________________________

### Payload Section

1. Once the GPS is installed in the nose cone and the payload is installed in the payload body tube, insert the payload body tube over the aft end of the nose cone shoulder so that the eight (8) shear pin hole side of the payload body tube is over the nose cone shoulder.
2. Align the depth markings and the registration marks on the nose cone with the matching markings on the payload body tube.
3. Insert eight (8) 2-56 shear pins into the shear pin holes to connect the nose cone shoulder and payload separation point.
4. After the rover and nose cone deployment are ready for launch, insert the payload-drogue coupler into the payload section.
5. Align the depth markings and the registration marks on the payload body tube with the matching markings on the payload-drogue coupler.
6. Screw in six (6) half-inch #6 screws into the six (6) holes near the forward edge of the payload-drogue coupler to attach the payload body tube and the payload-drogue coupler.

Structures Lead Sign-off: ______________________________________________

### Drogue Section

This section has a 12" Fruity Chutes Classic Elliptical drogue parachute.

1. Connect one quicklink to each the end of the 24 ft shock cord labeled "drogue to av-bay."
2. Lay the folded parachute out next to the shock cord 2/3rd of the way up the shock cord from the AV Bay.
3. Run the parachute shroud lines under the shock cord and then loop them over the parachute.
4. Pull the shroud lines tight, this will tie the parachute to the shock cord.
5. Connect the third quicklink to the fire blanket and the other end to the knot where the parachute connects to the shock cord.
6. Cover the parachute and shroud lines with the fire blanket. Warning! The Nomex blanket must completely cover the side of the parachute facing the charges, or the parachute could be burned and damaged.
7. Making sure the shock cord runs through the drogue body tube, attach the quicklink on the end closest to the parachute the the U-bolt in the payload-drogue coupler.
8. Attach the quicklink on the end furthest from the parachute the the U-bolt in the AV Bay.
9. Insert the shock cord into the drogue body tube, followed by the drogue parachute. Note: If the parachute sticks, talcum powder will help it to slide in easily. Caution: A sticky parachute will not deploy easily and might cause a recovery failure.

10. Insert the aft end of the drogue body tube over the avionics bay coupler.
11. Align the depth markings and the registration marks on the forward end of the main body tube with the matching markings on the aft end of the drogue body tube.
12. Screw in six (6) half inch #6 screws into the six (6) screw holes to attach the avionics bay to the drogue body tube.
13. Insert the drogue-booster coupler into the forward end of the drogue body tube. Caution: Verify that the shock cord is entirely enclosed within the airframe, if the shock cord catched or snags on any hardware, it could result in a recovery failure.
14. Align the depth markings and the registration marks on the drogue body tube with the matching markings on the payload section.
15. Insert three (3) 2-56 shear pins into the shear pin holes to connect the payload-drogue coupler and the drogue body tube attachment point.

Structures Lead Sign-off: ______________________________________________

A&R Lead Sign-off: __________________________________________________

## Avionics Bay

1. Place one bulkhead against the avionics bay inner coupler so that the holes for the all-thread rods are on either side of where the avionics board resides.
2. Insert the insulated all-thread rods through the all-thread rods hole in the bulkhead.
3. Place the second bulkhead on the opposite side of the avionics bay such that the all-thread rod going through the orange hole in the first bulkhead, goes through the orange hole in the second bulkhead. Make sure the blue hole all-thread rod in the first bulkhead goes through the blue hole in the second bulkhead.
4. Screw in the all-threads and the nuts on either end and ensure that they are secure.
5. Insert the avionics board along the avionics board runners in the avionics bay and slide it back in until it contacts the back of the avionics board runners.

A&R Lead Sign-off: ______________________________________________

## Payload Assembly

Warning! Only leads should handle the black powder and the initiators.

1. Ensure that the correct code is loaded onto the communications system.
2. Mount communications system on removable shelf one.
3. Secure shelf one to the containment mechanism.
4. Secure counterweight to removable shelf two.
5. Secure shelf two to the containment mechanism.
6. Mount solenoid on the inside of the containment mechanism.
7. Secure solenoid wires to the containment mechanism with electrical tape.
8. Verify that the mechanical switch is in the off position.

9. **Required PPE: Latex gloves and safety glasses.** Have a lead put on gloves and safety goggles. Caution: Handle black powder with caution. Black powder is explosive and harmful if ingested.

10. The team member with the appropriate PPE will measure 2 grams of black powder into a plastic vial.

11. The same team member will pour the black powder into the blast cap located on the inside of the containment mechanism. Caution: Ensure that none of the electronics are turned on in the communications system and batteries are not plugged in.

12. **Required PPE: Latex gloves and safety glasses.** Another team member wearing gloves and safety goggles will place the initiator into the blast cap, followed by shredded packing material and electrical tape.

13. Plug batteries into the communications system.

14. Slide the containment mechanism into the inside of the rocket.

15. Grease the bolt that secures the containment mechanism.

16. Slide the bolt into the bulkhead on the opposite side of the containment mechanism.

17. Secure the bolt using a nut on the inside of the containment mechanism on the axis of rotation.

18. Slide the rover into the containment mechanism ensuring that the metal rod on the rover slides into the solenoid lock.

19. Use the ground station communications GUI to send a message to the rocket to secure the rover inside the containment mechanism.

20. Lightly pull on the rover to ensure the rover is secured and the solenoid is working properly.

Warning! Handle the body tube carefully so as to not displace any of the tape of black powder.

DANGER! THE BODY TUBE NOW CONTAINS BLACK POWDER CHARGES AND NO TEAM MEMBERS SHOULD STAND IN THE LINE OF FIRE OF EACH END OF THE COUPLER.

Payload Systems Lead Sign-off: ______________________________________________

Safety Officer Sign-off: ____________________________________________________

### Ejection Charges

Warning! Only leads should handle the black powder and the initiators.

1. Take orange plastic end protectors off four initiators. The avionics board may need to be all the way out of the avionics bay to access the altimeters.
2. Using wire cutters strip approximately 1/4th inch of the plastic from the ends of the initiator wire. Caution: Before continuing to the next step, make sure the toggle switches are in the off position!
3. Install the newly trimmed ends of the initiators into both the drogue and main ports on the primary and redundant altimeter. Label near the head with a piece of tape the primary

drogue and main initiator as well as the redundant drogue and main initiator. Caution: Ensure the mechanical switches are in the off position.

4. Feed the two drogue initiators through the initiator holes in the forward bulkhead.
5. Feed the two main initiators through the initiator holes in the booster side bulkhead.
6. Place the initiator heads into the blast caps and secure them with electrical tape. Caution: The initiators must be secure to ensure proper detonation.
7. **Required PPE: Latex gloves and safety glasses.** Locate the primary drogue and main black powder charge as well as the redundant drogue and main black powder charge. Caution: To avoid spilling black powder have a different team member hold the avionics coupler at approximately a 45 degree angle to the team member pouring the black powder.
8. Place the primary main black powder charge into the blast cap with the primary main initiator.
9. Pack the blast cap with shredded newspaper and cover it with electrical tape.
10. Repeat Step 7 for the primary drogue black powder charge as well as the redundant drogue and main black powder charge. Caution: The black powder must be tightly secured so that it does not leak or ignite incorrectly.

Warning! Handle the coupler carefully so as to not displace any of the tape of black powder.

DANGER! THE COUPLER NOW CONTAINS BLACK POWDER CHARGES AND NO TEAM MEMBERS SHOULD STAND IN THE LINE OF FIRE OF EACH END OF THE COUPLER.

A&R Lead Sign-off: ____________________________________________

Safety Officer Sign-off: __________________________________________

### Avionics Board Assembly

1. Attach the battery connectors to two 9V batteries. An avionics lead will confirm these batteries are new.
2. Place the batteries in the battery slots on the avionics board.
3. Locate the primary altimeter and redundant altimeter and make sure they are properly labeled.
4. Screw the four corners of the two Stratologger CF altimeters into the four altimeter port holes on the avionics board.
5. Install the battery connector wires into the altimeter power supply ports labeled "Battery." Note that the black wire is negative and should be screwed into the port with the black tab. Tug on each wire to ensure that the connection is secure. Caution: The altimeters will not turn on if the batteries are installed incorrectly.
6. Install the mechanical switches into the mechanical switch holes on the avionics board.
7. Connect the leads on the mechanical switches to the switch ports labeled "switch" on the altimeters. Place the switches if not already so in the off position.

8. Check that the avionics board has two altimeters, two switches and two batteries installed. Additionally, the altimeter should have the battery connector wires and switch wires installed.

A&R Lead Sign-off: ___________________________________________

## Main Section

This section has an 84” Fruity Chutes Iris Ultra as the main parachute.

1. Connect one quicklink to each the end of the 27 ft shock cord labeled “av-bay to main.”
2. Lay the folded parachute out next to the shock cord 2/3rd of the way up the shock cord from the booster section.
3. Run the parachute shroud lines under the shock cord and then loop them over the parachute.
4. Pull the shroud lines tight, this will tie the parachute to the shock cord.
5. Connect the third quicklink to the fire blanket and the other end to the knot where the parachute connects to the shock cord.
6. Cover the parachute and shroud lines with the fire blanket. Warning! The Nomex blanket must completely cover the side of the parachute facing the charges, or the parachute could be burned and damaged.
7. Making sure the shock cord runs through the main body tube, attach the quicklink on the end closest to the parachute the the U-bolt in the AV Bay.
8. Attach the quicklink on the end furthest from the parachute the the U-bolt in the main-booster coupler.
9. Insert the shock cord into the main body tube, followed by the main parachute. Note: If the parachute sticks, talcum powder will help it to slide in easily. Caution: A sticky parachute will not deploy easily and might cause a recovery failure.
10. Insert the forward end of the main body tube over the avionics bay coupler.
11. Align the depth markings and the registration marks on the forward end of the main body tube with the matching markings on the aft end of the drogue body tube.
12. Screw in six (6) half inch #6 screws into the six (6) screw holes to attach the avionics bay to the main body tube.
13. Insert the main-booster coupler into the aft end of the drogue body tube. Caution: Verify that the shock cord is entirely enclosed within the airframe, if the shock cord catched or snags on any hardware, it could result in a recovery failure.
14. Align the depth markings and the registration marks on the main body tube with the matching markings on the booster section.
15. Insert three (3) 2-56 shear pins into the shear pin holes to connect the main-booster coupler and the main body tube attachment point.

Structures Lead Sign-off: ___________________________________________

A&R Lead Sign-off: ______________________________________________________

### Booster Section

1. Attach the downbody camera system to the motor stop in the booster section.
2. Pull the camera through the dedicated slot in the booster body tube.
3. Fasten the camera to the camera cover outside the airframe.
4. Ensure that the camera cover is properly secured to the booster body tube by checking all screws between the booster body tube and the camera cover.
5. Insert the forward section of the booster body tube over the main-booster coupler.
6. Align the depth markings and the registration marks on the aft end of the drogue body tube with the matching markings on the forward end of the booster body tube.
7. Screw in six (6) half inch #6 screws into the six (6) screw holes to attach the booster body tube to the main-booster coupler.
8. Ensure that the fin brackets are properly secure by checking all screws between the body tube and fin bracket as well as the screws between the fins and the fin brackets.
9. Insert the completely assembled motor into the motor tube. Push the motor into the motor tube until the aft end of the motor casing is flush with the aft end of the motor retainer. Warning! The motor is categorized as a high explosive and should only be handled by subsystem leads.
10. Screw the motor retainer ring onto the motor retainer. Note: These threads are very well-fitting and should not require *any* force to fasten.
11. Verify that the motor is securely fastened to the motor tube with a brief shake test.

Structures Lead Sign-off: __________________________________________________

Safety Officer Sign-off: ___________________________________________________

### Transportation to Launcher

1. Assemble the launch team, which consists of the Flight Systems Lead, Payload Systems Lead, Propulsion Lead, and the Safety Officer to carry the rocket to the launcher and set it up. Warning! All team members must leave their cell phones in the launch preparation area after this step. Electromagnetic signals from the devices may cause the avionics to prematurely detonate the parachutes' black powder charges, causing serious harm to team members or even bystanders.
2. Make sure all members of the team have a firm grasp on the rocket, and lift the rocket to a comfortable carrying height. Make sure the rocket stays as close to horizontal as possible at all points during transportation.
3. Walk the rocket out to the launcher, ensuring that no people are too near or directly in line with either end of the rocket. Caution: Standing in-line with the either end of the rocket increases the likelihood a team member or bystander will sustain an injury in the event of an explosive failure.

Flight Systems Lead Sign-off: ______________________________________________

## Setup on the Pad

1. Have a member or two of the launch team bring the launch rail from vertical to horizontal and hold it in that position.
2. Align the rocket's rail buttons so that they are pointed directly down towards the ground.
3. Slide the aft rail button into the launch rail so that the weight of the rocket is resting on the rail buttons. Make sure the rocket is not "hanging" off the rail only attached at the rail buttons.
4. Slide the aft rail button towards the flame deflector at the base of the launch rail, minimizing twisting of the rocket relative to the launch rail and scraping of the rocket airframe against the leading edge of the launch rail.
5. Once the forward rail button is securely inserted into the launch rail, slide the rocket towards the flame deflector until it makes contact.
6. Several members of the team should then push the launch rail into a vertical position while the rest of the team stabilizes the rocket on the rail to prevent twisting relative to the rail.
7. Once the launch rail is in a vertical position, lock the rail into this position with a bolt or screw.
8. Verify that:
    a. The rocket is secured to the launch rail.
    b. The launch rail is secured in the upright position.
9. Flip the primary altimeter continuity switch to the "on" position.
10. Audibly verify that the sequence of beeps is first two for the setting. Then six, ten, and ten again for main deployment altitude. Then the previous apogee will beep out in four numbers and finally the voltage will be the last two sets of beeps, this should be at least 9.0. Note: If a different series of beeps or a wailing sound emits flip the switches off and then on again. If the problem persists consult the user manual for the Stratologger CF altimeters.
11. Audibly verify that the primary altimeter has continuity through the initiators in both the main and drogue charges by listening for three consecutive beeps.
12. Flip the secondary altimeter continuity switch to the "on" position.
13. Audibly verify that the sequence of beeps is first two for the setting. Then five, ten, and ten again for redundant main deployment altitude. Then the previous apogee will beep out in four numbers and finally the voltage will be the last two sets of beeps, this should be at least 9.0. Note: If a different series of beeps or a wailing sound emits flip the switches off and then on again. If the problem persists consult the user manual for the Stratologger CF altimeters.
14. Audibly verify that the secondary altimeter has continuity through the initiators in both the main and drogue charges by listening for three consecutive beeps.
15. Take the AV Bay Panel and have another team member hold it over the AV Bay access port.
16. Screw all four #6 screws into the four corners of the Panel, securing it in place for flight.
17. Flip the payload systems power switch to the "on" position.
18. Take the Payload Bay Panel and have another team member hold it over the Payload Bay access port.
19. Screw all four #6 screws into the four corners of the Panel, securing it in place for flight.
20. Flip the camera system power switch to the "on" position.

Flight Systems Lead Sign-off: ________________________________________

Payload Systems Lead Sign-off: ________________________________________

### Initiator Installation

Warning! The initiators are harmful explosives if not handled properly. After initially separating the initiator leads, do not allow them to come into contact with each other at any point.

1. Verify with the A&R lead that the altimeter is correctly and completely initialized.
2. If the rocket's nozzle is resting on the flame deflector, proceed to Step 3. Otherwise, proceed to Step 4.
3. Have several team members raise the rocket a few inches vertically so that it no longer rests on the flame deflector and ensure that the team members can hold the rocket in this position for as long as it takes to install the initiator.
4. Thread the initiator through the pre-cut hole in the wall of the nozzle cap. For now, ignore the nozzle cap but make sure it does not slide off the initiator wire.
5. Insert the end of initiator that contains the charge into the nozzle of the rocket and continue to slide the initiator upwards through the propellant grains.
6. When you feel the initiator contact the aft end of the smoke charge, stop feeding the initiator into the motor.
7. Secure the initiator wire to the nozzle with tape, making sure the initiator stays in contact with the aft end of the FSD.
8. Secure the nozzle cap over the end of the nozzle, again making sure not to pull the initiator wire any further out of the motor.
9. Separate the initiator wire leads as far apart as possible without damaging the wire.
10. Take one alligator clip from the power supply extension and connect it to one lead on the initiator wire.
11. Secure this connected wire to the launcher a safe distance from the second lead.
12. Take the second alligator clip from the power supply extension and connect it to the remaining lead on the initiator wire.
13. Secure this second wire to the launcher a safe distance from the first wire.

Propulsion Lead Sign-off: ________________________________________

Safety Officer Sign-off: ________________________________________

### Post-Flight Deployment Operation

Rover Deployment and Operation

Warning! Approach the rocket with caution because parts might be hot from the ejection charges, or ejection charges might still be live.

1. Open MATLAB and load the ground station controls system.
2. Send a signal to the rocket to deploy the black powder charge.
3. Once the rocket has settled from separation, send a signal to the rocket to unlock the rover from the containment mechanism.
4. Once the rover has been successfully been released, send a drive signal for the rover to begin its driving sequence.

Payload Systems Lead Sign-off: ______________________________________________

Rocket Retrieval and Recovery Harness Inspection

Warning! Approach the rocket with caution because parts might be hot from the ejection charges, or ejection charges might still be live.

1. Check to see that all charges have properly deployed. If not, notify the RSO, and maintain muzzle awareness on both ends of the rocket while an A&R lead disconnects the altimeters.
2. Disconnect any shock cords necessary in order to safely remove the rocket from the range or field to the launch preparation area.
3. Disassemble the recovery harness by detaching all of the quicklinks from the bulkhead eyebolts, parachutes and shock cords.
4. Wrap the shock cords to be stored.
5. Lay out parachutes and inspect them for any damage. Warning! Damaged parachutes must be replaced.
6. After inspection, fold and wrap the parachutes for storage, separating out and labeling any damaged parachutes.
7. Place all quicklinks, shock cords, fireballs and parachutes in their respective places to be transferred to the lab and stored.

A&R Lead Sign-off: ______________________________________________________

### Post Flight Avionics Inspection

1. Unscrew the avionics bay door.
2. Disconnect the secure wire connectors to turn the altimeters off.
3. Remove the avionics sled from the avionics coupler.
4. Unscrew all of the wire terminals of the two altimeters and remove the wires. Caution: Properly dispose of burnt initiators.
5. Unscrew the altimeters and place them into the A&R box.
6. Remove the batteries and place them into the A&R box.
7. Place the avionics sled back into the rocket for ease of transportation.

8. Screw the door back onto the rocket.
9. At a computer, plug the altimeters in and extract the data. Compare the actual flight data to the estimated data from computer simulations. IF there are any discrepancies, the flight model must be adjusted. The flight data should be stored on the computer for future reference.

A&R Lead Sign-off: ___________________________________________________________

## 4.4 NAR and TRA Regulations

### NAR Safety Code

Table 30 describes every component of the NAR High Power Rocket Safety Code and how LTRL plans on following with each and every rule or regulation.

**Table 30. NAR Safety Code**

| NAR High Power Rocket Safety Code | LTRL Policy to Follow the 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. | Only NAR motor certified team members or Justin, the team's NAR mentor will be allowed to purchase, handle, pack, or deal with the appropriate rocket motors. |
| 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. | Payload and the Structures subsystems will consider and select materials that follow this guideline while factoring in the weight, strength, durability, and other factors in their selection. |
| 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. | All motors will be purchased from professional, certified sellers such as AMW Pro-X. All motors and black powder are stored in the High Pressure Combustion Laboratory (HPCL), which is equipped with a type 4, indoor, portable BTFE explosives magazine. The lab that holds the motors is locked, and the area where the magazine is located in is only accessible to members with the proper NAR certification. Only appropriate motor certified NAR members shall be allowed to handle the rocket 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 | To ensure proper safety protocol, the Range Safety Officer will have final say over any possible issues with the ignition system on launch day. Additionally, to ensure that |

| | |
|---|---|
| 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. | charges do not go off prematurely, the altimeters will not be armed until on the launch pad. Finally, the onboard energetics will not be installed until on the launch site and given the go ahead that our rocket may fly. |
| 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. | Only the Range Safety Officer or Safety Officer of LTRL may disconnect the battery or remove the launcher's safety interlock. The Safety Officer will remind all members of LTRL of this on the launch site and ensure all members stand a safe distance away until the rocket has either fired or been completely disconnected for at least 2 minutes. |
| 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. | The Safety Officer will alert the team and the public before countdown begins to ensure proper awareness of the launch and safety risks. LTRL will make sure to follow the Minimum Distance Table at the very least and follow any other rules given by the Range Safety Officer on the day of the launch. Additionally, the team will be in compliance with all the other stated rules and ensure proper stability of the rocket for safety and proper flight. |
| 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 | LTRL and the Safety Officer will ensure to use the rails provided by the NAR at any launches and the competition. Furthermore, LTRL and the Safety Officer will ensure a proper launch angle and that there are no fire hazards below or near the exhaust of the rocket motor. |

| | |
|---|---|
| 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. | LTRL will not exceed the total impulse when using a rocket motor or motors in their rockets. |

| | |
|---|---|
| 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. | Weather conditions and wind conditions will be checked before each launch to ensure that LTRL follows these guidelines and if there is a possible safety risk, does not launch their rocket at that time. Additionally, the Safety Officer will ensure throughout the construction of the rover that no flammable objects could exist to create a flight hazard. The team will ensure that all launches have adequate FAA waivers in place for the rocket launch. |
| 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). | All launches will be at NAR/TRA events. All launches will be at either Maryland Delaware Rocketry Association (MDRA) or Pittsburgh Space Command (PSC). If any issues arise, the Range Safety Officer will have the final say over any decisions to launch at that site. |
| 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. | The team will ensure that the NAR sites they launch at comply with this rule and that if there is an issue that the Range Safety Officer alert the team immediately. The Range Safety Officer will have the final say over any decisions to launch at this 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. | The Avionics and Recovery subsystem will design, construct, and test to ensure that all avionics bays are safe for flight use. All rockets will use a dual deployment system with a drogue and main parachute. Additionally, only Kevlar recovery system wadding shall be added to the rocket. The Avionics and Recovery subsystem will also follow the launch day checklist to prevent any issues that may arise before launch. If any issues arise that cannot be fixed properly, the team shall not launch. |
| 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. | LTRL will make sure that if necessary, proper professionals are contacted to retrieve the rocket. |

## 4.5 Lab Safety

Design and construction of both the Subscale and fullscale requires the use of power tools, such as a dremel, a drill, and a finishing sander. Additionally, it requires the use of potentially harmful chemicals, typically epoxies. These create hazards, which can be mitigated by following proper protocols and rules and wearing proper personal protective equipment (PPE) and exercising extra caution when necessary to ensure the safety of all team members. To create a proper atmosphere, where safety is of the utmost importance, and to educate members about proper chemical safety and disposal, basic laboratory safety, and the proper use of PPE, all team members are required to take safety training that is offered through Penn State's Environmental Health and Safety (EHS). In addition, safety and emergency equipment is available to LTRL members in the lab and at launches.

### Safety Training

All LTRL team members are required to take a four-part Initial Lab Safety and Hazards Awareness training course offered online by Penn State's EHS. The course consists of four training videos: Introduction to Safety, Chemical Safety, Hazardous Waste Management and Disposal, and Emergency Preparedness. Each training video concludes with a quiz. Members must score at least an 80% to pass that portion of the training. LTRL Members who have already completed the initial course in a previous year can take a refresher course instead. The refresher course is also offered online, in a similar training video format. Members must score an 80% to pass the quiz at the end of the video. If they do not score 80% or higher, they must retake the quiz. If they do not pass after two times, they are required to set up an appointment with the Safety Officer and review all the topics covered in the videos and ask any questions they may have. In either case, participating in the four-part training course or the refresher, after passing the quiz, a certificate is generated, which is then submitted and verified by the Safety Officer, allowing that team member to work in the laboratory. The Safety Officer keeps both a physical and electronic database recording all members who have completed their safety training and are allowed to work in the laboratory. The physical storage of the safety certificates is in a binder, located within the laboratory. If a member has yet to complete their training once work beings in the laboratory, the appropriate subsystem lead is notified about which members are not compliant with the Safety Training requirement. Members who have not completed safety training are not allowed to work in the lab.

### Safety and Emergency Equipment

Safety glasses, dust masks, and gloves are available in the LTRL lab. They are also brought to launches and used as necessary. In case of an emergency, a first aid kit is available in the lab and brought to launches. Fire extinguishers, both dry chemical and $CO_2$ types, are available in the hallway directly outside of the lab. Additionally, there is a bathroom directly down the hallway from the lab in the case a team member needs to wash a chemical off.

## 4.6 Local/State/Federal Law Compliances

The team has closely examined, reviewed, and acknowledged all regulations regarding unmanned rocket launches and motor handling. The following regulations are included in the team's safety manual and available to all members: Federal Aviation Regulations 14 CFR, Subchapter F, Part 101, Subpart C, Code of Federal Regulation 27 Part 55: Commerce in Explosives; and fire prevention, and NFPA 1127 "Code for High Power Rocket Motors"

The team's preferred launch sites are listed below in Table 31.

**Table 31. Preferred launch sites for the 2018-2019 competition**

| Field Location (Group Name) | Status | Team Use |
|---|---|---|
| Grove City, Pittsburgh (Pittsburgh Space Command) | 1) Waiver up to 8,700 ft<br>2) Only two hours travel<br>3) Moderate size<br>4) Friendly and helpful<br>5) Available once a month | 1) Ideal site for test launches<br>2) Best location for travel<br>3) Ideal for low to moderate wind speeds |
| Higgs Farm and Central Sod Farm in Maryland (Maryland Delaware Rocketry Association) | 1) Waiver up to 16,900 ft<br>2) 4 ½ hours travel<br>3) Large size<br>4) Typically available more than once per month | 1) Ideal site for test launches<br>2) Inconvenient due to travel<br>3) Ideal for higher wind speeds |

All of these launch sites are in compliance with all federal, state, and local regulations as well as any rules and regulations put forth by the NRA. Additionally, both sites are have a high standard of safety. LTRL's main launch site for the 2018-2019 season will be in Grove City, Pennsylvania through Pittsburgh Space Command, which is an NRA affiliated launch site.

## 4.7 Motor Safety

LTRL plans to use an I-class motor for the subscale rocket. Last year a J-class motor was used. Additionally, LTRL used an L-class motor for the fullscale last year and LTRL tentatively plans that a similar class motor will be used for fullscale this year. The rocket motors are purchased, handled, and transported by Justin Hess. Justin Hess holds a NAR Level 2 certification. Any team member who has obtained at minimum a Level 2 certification will also be allowed to assist in this process. Additionally, Matt Easler, the team's Flight Systems lead and Gregory Schweiker, the team's President, currently hold NAR Level 1 certifications and are attempting their Level 2 certification launches during the season. An individual who has obtained at least a Level 2 certification has demonstrated that they understand the safety guidelines regarding motors and the proper procedures for purchasing, handling, and transporting them. Any certified team member that partakes in any of these activities is responsible for the appropriate safety measures. All motors are stored in the High Pressure Combustion Lab (HPCL) when not in use. The HPCL has storage magazines for H/D 1.1 and H/D 1.3 energetic materials and propellants. These magazines are sited, licensed, and operated in compliance with all local, state, and federal regulations. The motors for all launches will be transported by car to the launch site.

### Motor CATO Awareness and Prevention

In order to ensure the team's utmost safety, the team will monitor and reference the Manufacture Notifications and Modification Announcements at http://www.motorcato.org/ to ensure that scheduled motors for subscale and fullscale have no warnings issued or a higher risk for a hazard. Additionally, if a catastrophic event at take-off (CATO) occurs during any launch this season, the team will report through the malfunctioning engine statistical survey (MESS) to assist other teams and peoples in tracking the reliability of rocket motors.

## 4.8 Hazard Analysis

### Risk Assessment Matrix

By thoroughly examining every human interaction, environment, rocket system and components, and previous year's hazards, hazards for this season have been identified. These hazards are not the only hazards that may occur during the construction, testing, or launching of the rocket and as new hazards and risks are identified with new rocket components. These hazards will be added to the list of hazards and thoroughly analyzed to properly mitigate their risk. Hazard identification and risk assessment are vital to the safety and success of the team and the safety of the public.

Each currently identified hazard has been thoroughly evaluated through a risk assessment matrix that first identifies the hazard, then lays out the possible causes of the hazard, and the effects of the hazard occurring. Additionally, the risk assessment matrix identifies the likelihood and severity of the said hazard and mitigations of those hazards to demonstrate the pre-mitigation risk and the post-mitigation risk.

To determine the likelihood of every hazard, a score from one to five, with a score one being the highest, was given. To accurately give a likelihood score, the following conditions were considered:

- All team members have undergone proper lab safety training and understand how to properly use the equipment
- All team members understand when they are required to wear PPE and how to properly use the PPE to prevent harm
- All team members understand all rules set forth in the safety manual and any laws and regulations that may be in place relating to the project at hand
- All procedures were correctly followed during testing, launching, and construction of the rocket
- Any equipment was properly inspected before use and if determined inadequate, was properly disposed
- Any component used during testing, launching, or construction of the rocket was properly inspected before and if determined inadequate was either properly disposed of or replaced to ensure a safe build of the rocket for any tests or launches

The criteria for the selection of the likelihood value is outlined below in Table 32.

**Table 32. Likelihood Value Criteria**

| Likelihood | | |
|---|---|---|
| **Description** | **Corresponding Value** | **Criteria** |
| Almost Certain | 1 | Greater than a 90% chance the hazard will occur |
| Likely | 2 | Between a 90% and 50% chance the hazard will occur |
| Moderate | 3 | Between a 50% and 25% chance the hazard will occur |
| Unlikely | 4 | Between a 25% and 5% chance the hazard will occur |
| Improbable | 5 | Less than a 5% chance the hazard will occur |

A severity value has been assigned from 1 to 4 for all hazards, with a value of 1 being the most severe. To determine the severity value for each hazard, a set of criteria has been established based on injuries, damage to any equipment and/or the rocket, and any possible environmental damage, which will be compared to the possible outcome of the hazard or issue. This criteria can be found below in Table 33.

**Table 33. Severity Value Criteria**

| Severity | | |
|---|---|---|
| **Description** | **Corresponding Value** | **Criteria** |
| Catastrophic | 1 | Could result in any number of deaths, irreversible damage to the environment, mission failure, or monetary loss upwards of $5k. |
| Critical | 2 | Could result in severe injuries, many moderate environmental impacts or a severe but reversible environmental impact, partial mission failure, or monetary loss between $500 and $5k. |
| Marginal | 3 | Could result in minor injuries, a number of minor environmental effects or one moderate one, a complete failure of non-mission essential system, or a monetary loss between $100 and $500. |
| Negligible | 4 | Could result in insignificant injuries, a minor environmental impact, a partial failure of a non-mission essential system, or monetary loss of less than $100. |

By using the likelihood value and the severity value, an appropriate risk level has been determined and assigned using the risk assessment matrix found in Table 34. The matrix identifies all combinations of severity and likelihood as either, low, moderate, or high risk. An ideal outcome for the team is to have all hazards to be at a low risk by the time the competition launch occurs to ensure the safest environment. Hazards that are above a low risk level and are not an environmental risk that the team has no control over will be readdressed through a number of different options including redesign, additional safety regulations, analysis and tests, or other measures that may be required. Additionally, through verification systems, the risk may be further mitigated.

**Table 34. Risk Assessment Matrix**

| Risk Assessment Matrix | | | | |
|---|---|---|---|---|
| **Likelihood Value** | **Severity Value** | | | |
| | 1-Catastrophic | 2-Critical | 3-Marginal | 4-Negligible |
| 1-Almost Certain | 2-High | 3-High | 4-Moderate | 5-Moderate |
| 2-Likely | 3-High | 4-Moderate | 5-Moderate | 6-Low |
| 3-Moderate | 4-Moderate | 5-Moderate | 6-Low | 7-Low |
| 4-Unlikely | 5-Moderate | 6-L ow | 7-Low | 8-Low |
| 5-Improbable | 6-Low | 7-Low | 8-Low | 9-Low |

Preliminary risk assessments have been evaluated for possible hazards that have been identified so far in the design process for the 2018-2019 season. Identifying the hazards this early in the design process allows the team to pay special attention to possible failure mechanisms within at risk components. By redesigning, analyzing and testing, or creating safety procedures, the mechanisms can be reduced or further understood while creating a safer environment for the team at this design stage. The team will work through the design stage and throughout the year to mitigate current hazards and any other hazards that are identified throughout the year.

At this time, some identified risks are unacceptably high. This is because all risks have been identified and addressed through some early concept design work, recommended processes, and hand calculations as testing has not been able to occur yet for the specified risks. As these risks are analyzed and tested, designs will be mitigated and verified as safe or redesigned. Risk levels will only be lowered once physical testing or evidence has proven the safety of the mechanism and the design are verified.

### Overall Team Risk Assessment
During the project there are many possible hazards that could hinder the team as a whole, not just for specific subsystems. These all do not relate to the environment.

### Lab and Learning Factory Risk Assessment
During the construction and manufacturing of components for the rocket, there will be many risks associated. All of this construction and manufacturing will be conducted either at the Learning Factory or the LTRL Lab. The hazards assessed from working with machines, tools, or chemicals can be found in Table 35.

### Structures Risk Assessment
The hazards found in Table 39 are hazards that could be encountered during the launch of the vehicle or the assembly of the vehicle.

### Propulsion Risk Assessment
Because the team is buying commercially produced motors, this area is of lower risk than if team produced its own motors. There are still risks associated, however. The team plans on allowing only members who have proper motor level certifications to use, handle, purchase, and work with the rocket motors. The team plans on accurately producing a stable rocket that can handle the rocket motor the team chooses. All hazards associated with propulsion are found in Table 38.

### Avionics and Recovery Risk Assessment
Because LTRL is required by NASA to use dual deployment, many of the hazards stated would be possible for all of the systems. To be concise, all the stated hazards will only be stated once. The hazards that are associated with avionics and recovery can be found in Table 41.

### Payload Risk Assessment
Because the team is planning on building a rover this year, there are many associated hazards or possible outcomes that could cause a failure or pose a safety concern. The team plans to ensure that the payload is properly secured, which will require many different components to ensure safe deployment, testing, assembly, and other flight hazards. The hazards that are associated with the payload can be found in Table 40.

### Hazards to the Environment Risk Assessment
During construction, testing, or launching of the rocket there may be hazardous to the environment. The associated hazards can be found in Table 37.

### Environmental Hazards to Rocket Risk Assessment
The hazards found in Table 36 are risks that the environment could impact the rocket or a component of the rocket. Unfortunately, the team has no control over environmental hazards and cannot reduce the risk of the hazard. Because of this, these hazards can be considered outside of the team's ideal scenario of having all hazards be at a low risk level. To ensure proper safety, if the environment poses a moderate risk to the rocket or a component of the rocket, the launch will be delayed until the Safety Officer lowers the risk level to low and approves the team to consult the Range Safety Officer to see if it is safe to launch.

### Launch Procedures
Throughout the season, the Safety Officer is responsible for writing, maintaining, and ensuring that up to date and proper launch procedures are available at any time. These are critical to team members, the public, the range's personnel, the equipment, and the environment. Checklists will be required for all launches.

These checklists are divided into checklists for each subsystem for pre-launch preparations, necessary launch day equipment, and launch day. By creating these checklists, each subsystem remains more organized and can quickly and effectively prepare for launch day. For a checklist to be considered complete, the head of the appropriate subsystem must sign off on that checklist after verifying every single item on the checklist has been completed. The Safety Officer will collect and verify the completion of all subsystem checklists. Once all subsystems have completed their appropriate tasks, the final assembly of the launch vehicle may be occur. Once the final assembly is complete, all subsystem leads and executive members, including the Safety Officer, must approve the rocket for launch. Once the rocket is a go for launch, the launch pad checklist can be started. Subsystem leads or executive members will be assigned a specific component of the rocket to track during the flight and recovery of the rocket. If the Safety Officer or Range Safety Officer determine something may be unsafe at any time, then they may call off the launch at any time if they believe the risk level is too high.

### Safety Data Sheets (SDS)

All potentially hazardous materials that the team has stored in the lab or will be used throughout the competition have been identified and appropriate SDS have been found. These SDS can be found in Appendix A: MSDS Sheets. This appendix will include the name and the first page for each SDS along with the corresponding link to that SDS to view the full SDS.

## 4.9 Safety Risk Assessment

**Table 35. Lab and Learning Factory Risk Assessment**

| Lab and Learning Factory Risk Assessment | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **Hazard** | **Cause** | **Effect** | **Pre-Mitigation Likelihood** | **Pre-Mitigation Severity** | **Pre-Mitigation Risk** | **Mitigation** | **Post-Mitigation Likelihood** | **Post-Mitigation Severity** | **Post-Mitigation Risk** | **Verification** |
| The use of chemical components. | Chemical fumes being inhaled or splashed onto a person. | Possible mild to severe burns or asthma aggravation due to inhalation of fumes. | 2 | 2 | 4-Moderate | MSDS data sheets will be available to all members in the lab. Additionally, all team members must understand the risks that the chemical poses. All members will also wear nitrile gloves and have their body covered in clothing. | 4 | 2 | 6-Low | All members must agree to wear appropriate clothing in the lab and take proper training before working with any chemical to ensure they understand the risks. |
| A high voltage shock. | Improper use of welding leads to a team member being shocked. | A team member could suffer a severe injury or death. | 3 | 1 | 4-Moderate | All members must have certified training prior to welding. Two certified team members will be present when welding. One to watch for possible mistakes and one to weld. | 5 | 1 | 6-Low | All members with welding training shall present them to the Safety Officer before they are |

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| | | | | | | | | | | allowed to weld. If they do not, they shall not be permitted to use the welding equipment during the season. |
| The use of power tools such as saws, sanders, drills, or blades or other machines. | Improper use of the tool or lab equipment from poor training. | Possible burns or cuts to team members. The rocket or tool may also be damaged. | 3 | 2 | 5-Moderate | All members using the tool must have knowledge and training with using that tool. If they are using the tool for the first time, they shall be taught properly by a lead or executive member and then watched to make sure they properly follow procedure. Additionally, all members are required to wear safety glasses in the lab. Finally, if applicable, a vacuum will be placed near the point of cutting or drilling to ensure particulates or shards are properly disposed of. | 4 | 2 | 6-Low | All members with proper training for specific tools shall be kept in a log within the lab. When a member wishes to use a tool, a lead or executive member may check to see if they have the proper training. If they do not, the proper steps will be taken. |
| During sanding a team member may have particulates enter their throat. | The team member did not properly use their PPE. | This could cash a rash, a sore throat, nose, eyes, and possible asthma. | 2 | 3 | 5-Moderate | All individuals will be required and taught how to use proper PPE during sanding and using other tools. Additionally, team members will have to wear | 3 | 3 | 6-Low | All members will be made aware of the risks of sanding and all team members will |

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| | | | | | | long sleeves and long pants. | | | | have specific PPE just for them labeled in the lab. |
| Metal shards entering piercing the skin. | The use of a drill or other cutting equipment to machine metal parts. | Metal splinters lodged in the skin or in the eyes. | 2 | 2 | 4-Moderate | When entering the lab, all team members must have closed toe shoes, long pants, long sleeves, wear gloves when machining, and wear safety glasses. If applicable, a vacuum will be placed near the place of cutting or drilling | 2 | 5 | 7-Low | When metal is being cut, it will be required that at least two members are there to work together, one to use the vacuum and one to cut the metal. Additionally, the one cutting must have approval and proper training to use the tool to cut the metal. |
| The use of white lithium grease. | The grease contacts the skin while putting the motor inside the rocket. | The member may have skin irritation. | 2 | 3 | 5-Moderate | All members will be required to wear gloves and safety glasses when working with hazardous substances. | 4 | 3 | 7-Low | All team members will be made aware of the risks and have proper training to work with hazardous substances. |

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| A team member may get burns while soldering. | Improper use of the soldering iron. | The team member may suffer minor to severe burns. | 3 | 3 | 6-Low | All team members will be taught how to properly solder and their first few times will be supervised by an experienced member. | 4 | 3 | 7-Low | All members with proper training for specific tools shall be kept in a log within the lab. When a member wishes to use a tool, a lead or executive member may check to see if they have the proper training. If they do not, the proper steps will be taken. |

**Table 36. Environmental Hazards to the Rocket Risk Assessment**

| Environmental Hazards to the Rocket Risk Assessment | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **Hazard** | **Cause** | **Effect** | **Pre-Mitigation Likelihood** | **Pre-Mitigation Severity** | **Pre-Mitigation Risk** | **Mitigation** | **Post-Mitigation Likelihood** | **Post-Mitigation Severity** | **Post-Mitigation Risk** | **Verification** |
| The rover becomes stuck because of mud or dirt. | Tilling of the fields or recent rain causes the fields to be hard to traverse for the rover. | The wheels will be unable to gain proper traction resulting in the mission failure for the payload. | 2 | 2 | 4-Moderate | Ensure that the wheels will be able to handle difficult terrains and travel the necessary distance. | 4 | 2 | 6-Low | Test drive the rover many times throughout the design process to ensure the rover can adequately drive over the soil in any condition. |
| The recovery system or payload electronics are damaged by environmental conditions. | Extreme cold, extreme heat, or rain could damage the electronics. | The electronics fail to properly work, resulting in a total mission failure. | 3 | 1 | 4-Moderate | All electronics will be shielded properly from rain and light and verified to work under the anticipated operating temperature. If there are heavy rains, it will ensure the rocket and payload do not launch or operate. | 5 | 1 | 6-Low | All electronics will be encased in 3D printed parts that protect them from the anticipated light and precipitation. All flight conditions will be verified |

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| | | | | | | | | | | before launch to ensure the electronics can properly operate. |
| There is damage to the structure of the rocket or a launch pad fire occurs. | Hot temperatures combined with direct sunlight cause the inside of the rocket to get extremely hot. | High temperatures and extended exposure to sunlight causes overheating in the batteries, leading to a fire. | 3 | 1 | 4-Moderate | Ensure that batteries are stored in insulated bags until needed and the rocket is kept under a tent when possible. | 5 | 1 | 6-Low | The team shall try to bring a tent if at possible. All batteries will remain in their insulated bags until approval by the President or Safety Officer is given to remove them. |
| The Rover mission is halted because of large debris. | There is large debris in the rover's path. | The mission will be halted and payload would experience a mission failure | 3 | 2 | 5-Moderate | The rover will have the necessary sensors and wheels to either avoid or go over any debris. | 4 | 2 | 6-Low | Proper testing beforehand to ensure the rover can avoid debris during the mission. |
| The launch is pad is unlevel. | The launch pad sinks due to soft ground or is improperly leveled. | The launch vehicle is launched at an unanticipated launch trajectory. | 4 | 2 | 6-Low | The launch pad will be leveled prior to the launch vehicle being installed on it. | 5 | 2 | 7-Low | The President and Safety Officer will sign off on the leveling of the launch pad to ensure it is properly handled. |

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| The parachute or rocket body are damaged. | High winds or trees cause damage. | The recovery equipment being damaged causes the rocket to not properly land and the rover to not deploy. | 4 | 2 | 6-Low | To mitigate this issue the team will not launch when winds exceed 15 mph and ensure that he launch field adheres to the launching distances in the NAR handbook. | 5 | 2 | 7-Low | The weather will be checked throughout the day leading up to and including the day of the launch to check the windspeed. Before launching, a discussion with the Safety Officer may occur to ensure that it is safe to launch the rocket. |
| The vehicle assemble is difficult in the field. | Many or excessive changes in temperature or humidity cause swelling and/or shrinking of components. | New stresses are induced and increased separation between components may be introduced, causing the possibility of failed separations. | 2 | 4 | 6-Low | All fits will be verified before leaving to the launch site. Sand paper will be brought in case minute adjustments are required. | 4 | 4 | 8-Low | These steps will require the approval of both the President and Safety Officer during the launch procedures. |

**Table 37. Hazards to Environment Risk Assessment**

| Rocket Hazards to Environment Risk Assessment | | | | | | | | | | |
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| **Hazard** | **Cause** | **Effect** | **Pre-Mitigation Likelihood** | **Pre-Mitigation Severity** | **Pre-Mitigation Risk** | **Mitigation** | **Post-Mitigation Likelihood** | **Post-Mitigation Severity** | **Post-Mitigation Risk** | **Verification** |
| There is unsuccessful deployment of recovery systems. | The deployment charges fail to ignite, or insufficient deployment charges or improper pressure readings. | The launch vehicle plummets to Earth at a higher than expected speed resulting in a damaged launch vehicle and debris around the launch area. | 3 | 1 | 4-Moderate | Both separation charge calculations and separation tests will be done separately to ensure all sections separate properly. | 5 | 1 | 6-Low | Many ground tests will take place before the launch to ensure that the coupler can separate properly. Additionally, black power charges will be calculated by using precisely 4.5 grams of black powder into each canister. |
| There is a fire on the launch pad. = | After motor ignition, dry grass and brush may catch fire around the launch pad. | A wild fire occurs in the local area if not properly contained, destroying wildlife. | 3 | 2 | 5-Moderate | All launches shall be properly equipped with a fire extinguisher and the Safety Officer and others will ensure that there is no dry grass or brush under | 4 | 2 | 6-Low | In compliance with the NAR, we will not launch within 100ft of brush or dry grass according to |

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| | | | | | | the rocket or around the launch pad. | | | | launch procedures. And a fire extinguisher shall be present at each launch. |
| Rocket debris is scattered around the launch site. | Rocket parts are not properly secured or come apart during the flight. | The rocket could possibly start a fire if extremely hot or become a hazard to local wildlife. | 2 | 2 | 5-Moderate | All rocket parts must be checked before launch during launch procedures to ensure proper securement. Additionally, all parts will be tested to ensure they can withstand wind forces during flight. | 4 | 2 | 6-Low | The President and Safety Officer will inspect the rocket before it is launched and check off that all parts are securely fastened and ready for a launch. |
| The motor CATOs. | There is a motor defect. | The launch vehicle is destroyed and debris is launched everywhere. | 5 | 1 | 6-Low | The motor shall be purchased from a reputable, commercial source before the launch. | 5 | 1 | 6-Low | The team will ensure that before purchasing the motor, no reported defects have been reported for that motor and that it is safe to purchase. |
| There is chemical contamination to local water sources. | Batteries or other hazardous materials leaking out into water systems. | The leaking materials contaminate the local water | 4 | 2 | 6-Low | All batteries will be new and inspected prior to launch. | 5 | 2 | 7-Low | Launch procedures require visual inspection of all |

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| | | system, making it undrinkable to local wildlife. | | | | | | | | batteries and the Safety Officer will verify that the batteries are new and undamaged before allowing them into the rocket. |

## 4.10 Failure Modes and Analysis (FMEA)

**Table 38. Propulsion Risk Assessment**

| Propulsion Risk Assessment | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **Hazard** | **Cause** | **Effect** | **Pre-Mitigation Likelihood** | **Pre-Mitigation Severity** | **Pre-Mitigation Risk** | **Mitigation** | **Post-Mitigation Likelihood** | **Post-Mitigation Severity** | **Post-Mitigation Risk** | **Verification** |
| The Motor CATOs. | The Motor components fracture. | There is destructive damage to rocket that results in a critical failure. | 5 | 1 | 6-Low | 1. Inspect motor grains and components prior to installation.<br>2. Assemble the motor according to the assembly instructions with another observing. Develop an internal checklist.<br>3. Check for fracture on any motor components after the launch. | 5 | 1 | 6-Low | There are no motor CATOs records from the past launches. As a provisional measure, lead will inspect motor grains and check for fracture on all the motor components before and after the launch. |
| The motor does not stay retained. | The motor thrust pushes the motor through the motor block. | There is destructive damage to rocket. | 5 | 2 | 7-Low | 1. Verify that the motor retention system can handle the motor impulse by doing either static motor testing or load tests on the motor tube | 5 | 2 | 7-Low | Prior the launch, team will verify the motor retention system can withstand |

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| | | | | | | | | | | motor's thrust through motor testing. |
| The motor does not stay retained. | The ejection charges push motor out of the rocket. | The motor does not retain in rocket, causing a ballistic motor. | 5 | 2 | 7-Low | 1. Use of active motor retention. Use of lower impulse motor | 5 | 2 | 7-Low | Prior the launch, team will verify the motor retention system can withstand impulse from the ejection charges by doing ground ejection testing. |
| The motor does not ignite. | The initiators fail to properly ignite the motor. | The rocket remains static. | 3 | 4 | 7-Low | 1. Use recommended igniters. Properly store the motors to prevent oxidation.<br>2. Verify the initiator is inserted fully to the top of the motor grains on the launch pad. | 4 | 4 | 8-Low | Make sure a new recommended igniter is been used and has fully inserted at the top of the motor grains on the launch pad. |

**Table 39. Structures Risk Assessment**

| **Structures Risk Assessment** |
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| Hazard | Cause | Effect | Pre-Mitigation Likelihood | Pre-Mitigation Severity | Pre-Mitigation Risk | Mitigation | Post-Mitigation Likelihood | Post-Mitigation Severity | Post-Mitigation Risk | Verification |
|---|---|---|---|---|---|---|---|---|---|---|
| A premature ejection of the nosecone. | Early ejection of the nose cone deployment charge due to faulty wiring or shear pin failure. | The nose cone goes into free fall, possibly causing damage to anything in the surrounding area. | 2 | 2 | 4-Moderate | Test for continuity and wiring for charges before launch.<br>Optimize shear pin locations and use stress analysis to ensure the nose cone will eject only when needed. | 2 | 3 | 5-Moderate | Stress analysis has shown that the design currently ensures that the shear pins will keep the nose cone attached until the charge. The charge itself will be checked to make sure the charge will not be triggered early. |
| There is a failure in the Motor retention system. | If the motor force is stronger than expected, the motor could break free of the motor retention system. | The flight vehicle would become unstable and be hazardous to anything in the immediate area. | 4 | 1 | 5-Moderate | Use load testing on the motor block and centering rings to ensure that the forces from the motor do not exceed the failure limit of the motor retention system. | 5 | 1 | 6-Low | The max thrust from the motor (892 N) does not exceed the failure limits of the motor retention system. |
| The airframe or coupler experiences | Zippering occurs due to the force of | The airframe/coupler | 2 | 3 | 5-Moderate | Use shock-absorbers on the shock cord where it | 3 | 4 | 7-Low | Historical evidence from |

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| zippering. | the shock cord on parachute deployment. | becomes unusable for future launch, and may cause pieces to freefall. | | | | contacts the coupler. | | | | past launches shows using shock-absorbers significantly reduces the severity and possibility of zippering. |
| The airframe experiences buckling. | Intense G-forces cause the airframe to buckle. | This weakens the structural integrity of the airframe, and makes it unable to safely launch in the future. | 4 | 2 | 6-Low | Load test the materials used for the airframe and couplers to ensure the airframe is strong enough to resist buckling. | 5 | 2 | 7-Low | OpenRocket analysis shows no structural instability with current materials. Load tests also show that the airframe couplers and body tubes have failure limits much greater than any force expected throughout flight. |
| The airframe separates prematurely. | Airframe could separate prematurely due to stronger than expected Drag or internal pressure. | Premature separation would cause Parachutes deploy early and lead to a failure to reach altitude. | 2 | 4 | 6-Low | Use analysis models such as OpenRocket and formulaic analysis to ensure drag and internal pressure will not cause separation. | 3 | 4 | 7-Low | OpenRocket analysis shows no structural instability with the airframe when dealing with drag or internal |

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| | | | | | | | | | | pressure. |
| The shock cord attachment points fail. | Higher than expected forces on the shock cord during parachute deployment could cause the shock cord to rip or the bulkhead attachments to be ripped out of the body tube. | Attachment point failure would result in either a shock cord replacement or a bulkhead replacement. In either case, the launch vehicle would not be able to launch in the foreseeable future. Failure would also result in free falling debris. | 4 | 2 | 6-Low | Load test shock cords and the epoxy bulkhead connections to ensure that the failure limit of both are far greater than the forces expected during parachute deployment. | 5 | 2 | 7-Low | After load testing, the shock cords and bulkhead connections were found to have failure limits above the forces that are expected during parachute deployment. |
| The fin bracket fails on launch. | There is a possibility for the fin brackets to fracture on launch if the forces on it exceed the expected forces at takeoff and parachute deployment. | Fin bracket failure would possibly cause free-falling debris during flight and would make the fractured fin bracket unusable for future flights. | 4 | 2 | 6-Low | Use load testing on a fin bracket to ensure the failure limit is much greater than expected forces throughout the flight. | 5 | 2 | 7-Low | The forces on takeoff and parachute deployment are lower than the failure/fracture limit of the fin brackets. |
| The body tube fractures on launch. | There is a possibility for the body tube to fracture on launch if the forces on it exceed the expected forces at takeoff and | The fractured body tube would be unstable during flight and would be unable to be used for future flights. | 4 | 2 | 6-Low | Use load testing on a test piece of body tube to ensure that the failure limit of the body tube is much greater than any force expected throughout the launch. | 5 | 3 | 8-Low | The forces on the body tube during launch and parachute deployment did not exceed the failure limits of the body tube. |

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| | parachute deployment. | | | | | | | | | |
| The body tube fractures on landing. | If a body tube part lands too hard or lands awkwardly there is a possibility for the body tube to fracture. | The fractured body tube part would be unable to use for a future flight. | 4 | 3 | 7-Low | Use load testing on a test piece of body tube to ensure that the failure limit of the body tube is much greater than the force of landing. | 5 | 3 | 8-Low | The max force on landing does not exceed the fracture/failure limits of the body tubes. |
| The fin separates from the bracket. | The fins separate from the fin brackets during flight due to vibrations loosening of bolts due to vibrations throughout the flight. | Separation would cause potential free-falling debris during flight. | 4 | 3 | 7-Low | Use vibration simulations to ensure that bolts will not loosen enough to allow for separation. Also, inspect bolts before flight to ensure that they are tight. | 5 | 3 | 8-Low | Vibration simulations and historical data show that the vibrations are not enough to cause the bolts to loosen during flight. |
| The camera fails. | The camera on the flight vehicle fails to record the flight. | If the camera does not work correctly the flight recording will be lost. | 3 | 4 | 7-Low | Check the camera before flight. | 4 | 4 | 8-Low | As long as the camera is checked for power and recording space before flight, it should record without any problems. |
| The fins fail during flight. | Failure is caused by Fin flutter due to stronger than expected forces on the wings. | The fins may break off of the vehicle and go into freefall and would cause the flight to become | 4 | 4 | 8-Low | Use analysis models such as OpenRocket and formula analysis to ensure that fin flutter will not cause failure. | 5 | 4 | 9-Low | OpenRocket analysis shows no structural instability with the fins during |

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| | | unstable. | | | | | | | | flight. |
| Fin bracket fracture on landing | If the flight vehicle lands directly on a fin bracket or fin, there is a possibility for the fin bracket to fracture. | The fin bracket would be unable to be used for future flights. | 4 | 4 | 8-Low | Use load testing on a fin bracket to ensure that the fin bracket failure limit is much greater than the forces of impact on landing. Also, make fin brackets easily replaceable. | 5 | 4 | 9-Low | The fin brackets are strong enough to withstand regular landing forces, but may break under special conditions. However, they are easily replaceable so that if needed the launch vehicle can relaunch within 10 minutes. |
| The camera cover fails. | The camera cover has the possibility to detach from the flight vehicle if forces on it exceed what is expected, especially at launch and at parachute deployment. | If the camera cover detaches, the camera will not be protected and could result in a loss of footage. The cover would also be free-falling debris. | 4 | 4 | 8-Low | Use load testing on the camera cover to ensure its failure limit is much greater than any forces expected throughout the flight. | 5 | 4 | 9-Low | Load tests on the camera cover and screw attachments show that the failure limit is much greater than the forces expected on the cover during flight. |

**Table 40. Payload Risk Assessment**

| Payload Risk Assessment | | | | | | | | | | |
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| **Hazard** | **Cause** | **Effect** | **Pre-Mitigation Likelihood** | **Pre-Mitigation Severity** | **Pre-Mitigation Risk** | **Mitigation** | **Post-Mitigation Likelihood** | **Post-Mitigation Severity** | **Post-Mitigation Risk** | **Verification** |
| The rover containment fails during launch. | The retainment electronics fail and eject the nose cone prematurely. | This can cause large instability during launch, and free-falling body sections pose a serious danger to bystanders on the ground. | 3 | 1 | 4-Moderate | Operate the communications system on a 915 MHz frequency to ensure that the signal cannot activate due to interference. | 5 | 1 | 6-Low | Extensively test the communications system for nose cone separation on the ground before flight. |
| The retainment mechanism fails in flight. | The batteries in the solenoid die. | The rover would become unsecured during flight. | 2 | 2 | 4-Moderate | Perform calculations on the battery life. Implement an external switch that allows the containment to be turned on while the vehicle is on the launch pad. This reduces the amount of time it needs to remain operational. | 4 | 2 | 6-Low | Perform lab tests that verify the batteries can keep the solenoid operational for at least 2 hours. |
| There is a soil sample recovery failure. | There is damage to electronics during flight. | This would not allow the rover to complete its mission. | 3 | 3 | 6-Low | Verify strong soldering connections in the electronics. | 4 | 3 | 7-Low | Perform post separation ground testing of the soil recovery. This test will verify that everything |

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| | | | | | | | | | | post landing will work as expected. |
| There is physical damage to rover. | The black powder covering the electronics goes off. | The electronics become non-operational. | 4 | 3 | 7-Low | Align the black powder charge to be on top of the shelf so that debris does not go towards the rover. | 5 | 2 | 7-Low | Perform extensive ground tests with a cloth as an indicator to determine if black powder residue is landing on the rover. Also check to make sure the electronics are operational post separation. |
| The deployment mechanism fails to activate. | The communications system cannot communicate with the rocket because of the carbon fiber exterior acting as a Faraday cage. | The rover would not be able to exit the vehicle and recover the soil sample. | 2 | 3 | 5-Moderate | Allow the antenna inside of the rocket to stick outside through a tiny hole small enough to not effect pressurization. | 5 | 3 | 8-Low | Perform ground tests with the communications system at various distances. |
| The rover containment fails during launch. | The accelerations caused during launch and descent. | The rover becomes unsecured during flight. This can cause damage to the rover and instabilities during flight. | 3 | 3 | 6-Low | Perform lab tests that show that the solenoid can hold the rover in place during acceleration. | 5 | 3 | 8-Low | Perform testing during the full scale test launch that verifies all components can withstand launch |

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| | | | | | | | | | conditions. |
| The deployment mechanism fails to activate | There is a faulty initiator. | The rover would not be able to exit the vehicle and recover the soil sample. | 3 | 3 | 6-Low | Test the continuity of the initiator before launch. | 5 | 3 | 8-Low | Perform multiple lab tests beforehand to verify that the communications system can consistently deploy with continuity checked initiators. |
| There is physical damage to rover. | The accelerations caused during flight or during nose cone separation. | The rover could become non-operational. | 4 | 3 | 7-Low | Trim all soldered wire connections to ensure that nothing can short due to an acceleration. Verify all soldering connections are strong and will not short. | 5 | 3 | 8-Low | Perform extensive ground tests to verify that the electronics on the rover can operate after separation. |
| There is structural damage to payload bay. | The rocket hitting the ground at an unsafe speed. | The black powder would not be able to pressurize the payload bay to deploy the nose cone. | 4 | 3 | 7-Low | The payload bay will be made of carbon fiber which will be checked for voids. | 5 | 3 | 8-Low | Perform separation tests on the ground and verify structural integrity during full scale test launch. |

**Table 41. Avionics and Recovery Risk Assessment**

| **Avionics and Recovery Risk Assessment** |
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| Hazard | Cause | Effect | Pre-Mitigation Likelihood | Pre-Mitigation Severity | Pre-Mitigation Risk | Mitigation | Post-Mitigation Likelihood | Post-Mitigation Severity | Post-Mitigation Risk | Verification |
|---|---|---|---|---|---|---|---|---|---|---|
| The drogue section shear pins do not break during separation. | The separation charge was insufficient to break the shear pins. | The drogue parachute does not deploy and the rocket continues on ballistic a trajectory. This will result in structural failure in the launch vehicle upon main deployment and will be a critical safety concern. | 3 | 1 | 4-Moderate | The team will use a factor of safety to ensure that the charge required to break the shear pins is greater than calculated. The redundant system will have 50% more than the primary separation charge. | 5 | 1 | 6-Low | Many ground tests of the drogue separation event will be performed to ensure proper deployment. |
| The mechanical switch disconnects during flight. | The switch is mechanically agitated to the off position during flight. | The altimeter circuit is closed and turns the altimeter off. The altimeter is not able to record altitude or deploy the parachutes. | 4 | 1 | 5-Moderate | The team will use a sturdy switch and properly fasten it in place. | 5 | 2 | 7-Low | The switch will be tested by hitting it from different directions to ensure it does not move or switch to the off position. |
| An electromagnetic interference triggers an altimeter at an undesired time. | Altimeter is exposed to sufficient amounts of electromagnetic radiation to complete the altimeter's circuit. A potential failure | The altimeter prematurely activates an initiator. As a result, the rocket will separate and deploy one of its parachutes during | 3 | 2 | 5-Moderate | The avionics bay will be fully enclosed in a tin foil Faraday cage. | 5 | 2 | 7-Low | The Faraday cage will be tested in the lab to ensure complete signal blackout inside. |

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| | of the Faraday cage will increase the likelihood of this occurring. | ascent, or descent at incorrect altitudes. Premature deployment during ascent would cause instability and structural damage from shock cord zippering. Premature deployment during descent will result in drift distances over 2500 ft. and disqualification. | | | | | | | | |
| The altimeter is damaged during launch. | The flight forces cause the altimeter to become unsecured and damaged from ricochet. | If damage is critical, the altimeter will not be able to ignite its initiators at the correct altitudes. This will result in ejection charges not igniting and failure of separation and parachute deployment as a result. The rocket will fall ballistically as a result. This will result in structural failure in the launch vehicle upon impact and will be a critical | 4 | 2 | 6-Low | The altimeter will be screwed to the avionics board, which will be friction fit on rails to the avionics bay. The team will use a fully redundant system. | 5 | 2 | 7-Low | The altimeters have been successfully flown on subscale and thoroughly tested. |

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| | | safety concern. If damage is non-critical, the altimeter will not be able to retrieve mission critical flight data. | | | | | | | | |
| The drogue parachute remains inside the body tube during separation. | Screws connecting couplers to body tubes may catch the drogue parachute during deployment and prevent its ejection from the body tube. The drogue parachute may also become stuck due to the friction between the parachute and the inside of the body which would prevent full ejection. | The rocket will fall ballistically until main parachute deployment. If the rocket is falling at ballistic speeds at main deployment, then the main parachute may not fully deploy before landing and will cause significant airframe zippering. | 4 | 2 | 6-Low | Screws inside of the body tubes will be filed down. Baby powder will be spread lightly over the parachute fire blanket to decrease its coefficient of friction. | 5 | 2 | 7-Low | Many ground tests of the drogue separation event will be performed to ensure proper deployment. |
| The recovery harness breaks during separation or descent. | Flight forces exceed the maximum load that either the shock cord, quick link, or U-bolt can handle. | Individual sections of the rocket will impact the ground at terminal velocity | 4 | 2 | 6-Low | The recovery harnesses being used will be rated to withstand forces and order of magnitude greater than expected in flight forces. | 5 | 2 | 7-Low | Recovery harness components will be individually tested in simulation and physically with expected loads of in flight forces. |

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| The flight vehicle lands outside of maximum safe distance. | Simulations inaccurately predicted launch day conditions and the rocket drifts further than the allowable safe distance during descent. | The rocket could land outside of the property designated for launches and other rocket activity. This could lead to loss of the rocket, damage or destruction of property, or even injury to bystanders. | 5 | 2 | 7-Low | Simulations will be conducted to verify that the design meets the requirements. The simulations will be improved by comparing previous flight data to previous simulations. | 5 | 2 | 7-Low | Previous flight data will improve simulations making rocket drift safer and more predictable. |
| The altimeter loses connection with initiators. | The initiator's wire connection with altimeter is not adequately secured, and this connection becomes separated during flight due to forces experienced. | The initiators will not receive the required voltage from the altimeter and will not ignite at the correct altitudes. This will result in ejection charges not igniting and failure of separation and parachute deployment as a result. The rocket will fall ballistically as a result. This will result in structural failure in the launch vehicle upon impact and will be a critical safety concern. | 3 | 3 | 6-Low | All connections will be securely fastened with screws on both ends. The team will have a fully redundant deployment system. | 5 | 3 | 8-Low | All connections will be tug tested according to A&R Launch Procedures, Avionics Board Assembly Step 5 to ensure they are secured |

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| The altimeter does not properly register altitude. | The pressure port required for the altimeter to register altitude is not large enough for the altimeter to accurately read the atmospheric pressure. | An accurate altitude is not properly read, and the team is disqualified from the altitude competition. If the registered altitude is greatly inaccurate, then the drogue parachute may not occur at exact apogee and cause zippering of the airframe as a result. Additionally, the main parachute deployment will not occur at the designated altitude which may result in drift distances over 2500 ft., or incomplete full deployment of main parachute which would result in structural damage of the launch vehicle. | 3 | 3 | 6-Low | The team will ensure the port hole for pressure equalization is an adequate size to maintain atmospheric pressure inside the avionics chamber. The altimeters will be tested on multiple prior launches to confirm their reliability. There will be a fully redundant altimeter onboard the flight vehicle. | 5 | 3 | 8-Low | Altimeter readings will be compared to each other after test flights. Altimeter readings will be compared to other control altimeters during pressure testing. |
| The main section shear pins do not break during separation. | The separation charge was insufficient to break the shear pins. | Main parachute does not deploy and the rocket impact the ground with an unsafe | 3 | 3 | 6-Low | The team will use a factor of safety to ensure that the charge required to break the shear pins is greater than calculated. | 5 | 3 | 8-Low | Many ground tests of the main separation event will be performed to |

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| | | velocity. This will result in structural failure in the launch vehicle upon impact and will be a critical safety concern. | | | | The redundant system will have 50% more than the primary separation charge. | | | | ensure proper deployment. |
| The main parachute remains inside the body tube during separation. | Screws connecting couplers to body tubes may catch the main parachute during deployment and prevent its ejection from the body tube. The main parachute may also become stuck due to the friction between the parachute and the inside of the body which would prevent full ejection. | The rocket will fall at a high descent rate until impact. This would result in body tube sections not meeting the 75 ft-lbs. kinetic energy requirement and the team will be disqualified. Additionally, the rocket will experience non-nominal impact forces and will have structural damage. | 4 | 3 | 6-Low | Screws inside of the body tubes will be filled down. Baby powder will be spread lightly over the parachute fire blanket to decrease its coefficient of friction. | 5 | 3 | 8-Low | Many ground tests of the main parachute separation event will be performed to ensure proper deployment. |
| The drogue parachute is damaged during separation. | Screws connecting couplers to body tubes may catch the drogue parachute during deployment and cause partial tearing. Explosive forces and potential fire from ejection charges | The rocket will fall at a descent velocity faster than expected. If the rocket is falling too fast during main deployment, then the main parachute may not fully deploy before landing and will | 4 | 3 | 7-Low | Proper packing methods of the parachute will be followed. Protrusions inside the drogue parachute chamber and around the exit will be smoothed down. | 5 | 3 | 8-Low | Many ground tests of the drogue separation event will be performed to ensure proper deployment. |

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| | may also cause damage to the drogue parachute. | cause significant airframe zippering. | | | | | | | | |
| The main parachute is damaged during separation. | Screws connecting couplers to body tubes may catch the main parachute during deployment and cause partial tearing. Explosive forces and potential fire from ejection charges may also cause damage to the main parachute. | The rocket will fall at a higher descent rate until impact. This would result in body tube sections not meeting the 75 ft-lbs. kinetic energy requirement and the team will be disqualified. Additionally, the rocket will experience non-nominal impact forces and will have structural damage. | 4 | 3 | 7-Low | Proper packing methods of the parachute will be followed. Protrusions inside the main parachute chamber and around the exit will be smoothed down. | 5 | 3 | 8-Low | Many ground tests of the main parachute separation event will be performed to ensure proper deployment. |
| The main parachute does not unfold after exiting the body. | Tangling of the main parachute strings due to improper packing cause the parachute to not full deploy after ejection. | The rocket will fall at a higher descent rate until impact. This would result in body tube sections not meeting the 75 ft-lbs kinetic energy requirement and the team will be disqualified. Additionally, the rocket will experience non-nominal impact | 4 | 3 | 7-Low | Proper packing methods of the parachute will be followed. | 5 | 3 | 8-Low | Parachute packing methods detailed in A&R Launch Procedures, Parachute folding have been successful in subscale and full scale for the last two years. |

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| | | forces and will have structural damage. | | | | | | | | |
| The kinetic energy is over maximum landing threshold. | Simulations inaccurately predicted the descent rate of the rocket leading to a higher kinetic energy upon landing than the allowable limits. | If sections of the rocket land with kinetic energy greater than the maximum allowable, excessive harm could come to property and people within the designated landing areas. | 4 | 3 | 7-Low | Simulations will be conducted to verify that the design meets the requirements. The simulations will be improved by comparing previous flight data to previous simulations. | 5 | 3 | 8-Low | Previous flight data will improve simulations making rocket descent rate more predictable and reach a safer value. |
| The onboard 9V battery supplying voltage for the altimeter does not have the required voltage to fully power the altimeter. | This hazard would only potentially occur if the launch vehicle needs to be left on the launch pad while the team is waiting for their launch volley. | The altimeter is not powered and is not able to ignite its initiators at the correct altitudes. This will result in ejection charges not igniting and failure of separation and parachute deployment as a result. The rocket will fall ballistically as a result. This will result in structural failure in the launch vehicle upon impact and will be a critical safety concern. | 3 | 4 | 7-Low | The team will use only newly purchased standard commercially issued 9V batteries. The team will have a fully redundant deployment system. | 5 | 4 | 9-Low | Per A&R Launch Procedures, Avionics Board Assembly Step 1, the new batteries will be checked right before launch to ensure they are fully charged using a Voltmeter. |

| | | | | | | | | | | |
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| The 9V battery clip connecting the altimeter to the battery disconnects during the flight. | The flight forces cause the battery clip to disconnect from the battery. | The altimeter is no longer powered and is not able to ignite its initiators at the correct altitudes. This will result in ejection charges not igniting and failure of separation and parachute deployment as a result. The rocket will fall ballistically as a result. This will result in structural failure in the launch vehicle upon impact and will be a critical safety concern. | 3 | 4 | 7-Low | All connections will be securely fastened with screws on both ends. The team will have a fully redundant deployment system. | 5 | 4 | 9-Low | All connections will be tug tested according to A&R Launch Procedures, Avionics Board Assembly Step 5 to ensure they are secured. |
| The body sections collide during descent under parachute. | Body sections descend at a similar altitude to each other. | Collisions between sections damages them and internal components. | 3 | 4 | 7-Low | Shock cord lengths will be different between main and drogue. The parachutes will be attached at the 1/3rd point so that attached sections are different distances to prevent collisions. | 5 | 4 | 9-Low | Parachutes will be dropped with dummy weights attached in a manner similar to inflight configurations. Subscale descent will be observed to confirm recovery harness do not tangle. |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| The drogue parachute does not unfold after exiting the body. | Tangling of the drogue parachute strings due to improper packing cause the parachute to not full deploy after ejection. | The rocket will fall at a descent velocity faster than expected. If the rocket is falling too fast during main deployment, then the main parachute may not fully deploy before landing and will cause significant airframe zippering. | 4 | 4 | 8-Low | Proper packing methods of the parachute will be followed. | 5 | 4 | 9-Low | Parachute packing methods detailed in A&R Launch Procedures, Parachute folding have been successful in subscale and full scale for the last two years. |
| The main parachute deploys at apogee. | Incorrect packing of parachutes during launch preparation causes the main deployment to be packed where the drogue parachute is supposed to be packed. Another potential cause of this hazard is the incorrect wiring of the altimeter so that the main parachute initiators are wired into the drogue deployment port of the altimeter. | Main parachute deployment at apogee would result in extreme drift distances that would disqualify the team and increase the difficulty of the recovery of the launch vehicle. | 4 | 4 | 8-Low | Wires will be colored according to a schema and labeled. Connected wires will be double checked before launch. Parachutes will clearly be marked down on which section they are packed into. | 5 | 4 | 9-Low | A ground test will be performed prior to launch to ensure that main parachute deploys at its intended event. |
| The main parachute recovery harness becomes tangled in | The rocket is tumbling violently when main | One or both of the parachutes does not fully open resulting | 4 | 4 | 8-Low | The rocket will not be launched in high winds. The parachutes are | 5 | 4 | 9-Low | Parachutes will be dropped with dummy |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| drogue recovery harness. | deploys ejecting it into the drogue recovery harness, or in such a manner that the subsequent tumbles tangle them before main can unfold. | in a lower surface area and the rocket descending quickly. This can result in damage to the rocket or what it lands on. | | | | packed in opposite ends of the avionics bay so they deploy away from each other. | | | | weights attached in a manner similar to inflight configurations. Subscale descent will be observed to confirm recovery harness does not tangle. |

# 5. Payload Criteria

## 5.1 Design of Payload Equipment

The rover challenge was selected for this year's payload competition. To meet the requirements set by NASA, the rover will be retained through flight and descent using a solenoid locking mechanism. The nose cone will be separated from the rocket after a successful landing through a ground station communications system. The communications system will then release the rover from the solenoid locking mechanism and send a drive signal to the rover that will drive it at least ten feet from the landing site to recover a 10 milliliter soil sample.

Table 42 shows the masses for the components of the rover and the rotating containment mechanism. There is a possibility for slight fluctuations in 3D printed parts due to different infill densities and tolerance modifications. However, because the rover is well under the 50 oz maximum that is allowed by the team derived requirements, these fluctuations will not affect the performance of the payload.

**Table 42. Masses for Payload Components**

| Component | Mass (oz) |
|---|---|
| Arduino (2) | 0.40 |
| Radio Module (2) | 0.34 |
| Wires | 0.50 |
| 9V Batteries (3) | 4.80 |
| Perfboard (2) | 1.20 |
| Wheels (4) | 7.13 |
| Shelves (2) | 3.00 |
| Rover Body | 4.00 |
| Rotating Containment Mechanism | 15.81 |
| Epoxy and Miscellaneous | 5.00 |

Table 43 outlines the steps that will be executed to complete the payload mission. This is a summary of the launch and assembly procedures that are more explicitly outlined in the safety launch concerns and operation procedures section.

**Table 43. Mission Outline Descriptions**

| Mission Step | Description |
|---|---|
| 1 | The rover and communication system are placed into the payload section of the rocket according to launch and assembly procedures. |
| 2 | Launch vehicle ascends to apogee and descends under drogue and main parachute. |
| 3 | Once the launch vehicle has successfully landed and is sufficiently far from bystanders, the recovery team will approach the launch vehicle. |
| 4 | The ground station will be opened in MATLAB by a member of the recovery team and communication with the rocket will be established. |
| 5 | Once approved by the RSO, the signal will be sent to the launch vehicle to separate the nose cone via black powder pressurization. |
| 6 | After a successful separation of the nose cone, another signal will be sent from the ground station that will unlock the rover from the containment mechanism. |
| 7 | After the rover has been successfully released from the containment mechanism, another signal will be sent from the ground station to the rover to initiate the driving sequence. |
| 8 | The rover will drive for 60 seconds to ensure that it is at least ten feet from the launch vehicle. |
| 9 | The rover will begin to collect the soil sample using the servo powered collection device. |

## 5.2 Rotating Containment Mechanism

The purpose of the rotating containment mechanism is to allow the rover to have the correct orientation upon landing and hold the rover in place during flight. This system includes the attachment points to the bulkhead, the launch vehicle communication system with the ground station, and the solenoid that retains the rover during flight. Figure 35 below shows a three dimensional SolidWorks rendering of the rotating mechanism with the rover inside. The rotating mechanism is attached to the bulkhead seen at the top right of Figure 35 and is flush with the inside of the body tube.

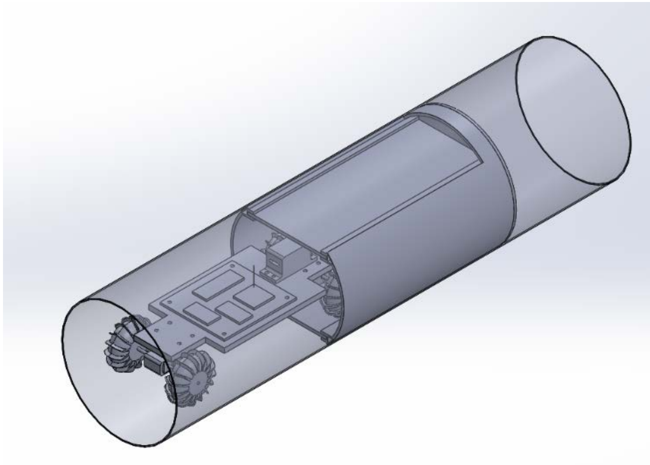

**Figure 35. Rotating Payload Bay Assembly with Rover**

The payload bay is able to rotate through a pin that is mounted on the bulkhead which the payload bay is able to freely rotate about. Figure 36 shows the pin connection point with the bulkhead. The pin will be a two and a half inch partially threaded hex bolt so that a nut can be used to keep the payload bay from sliding around in the body tube while still maintaining rotation.

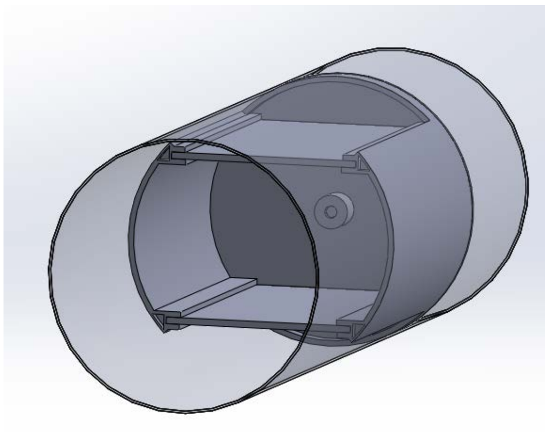

**Figure 36. Dimertriv View of the Pinning Mechanism**

The shelves shown in Figure 35 and Figure 36 will hold the communications system and the counterweight to balance the rover. The communications system will be used to control the solenoid containment and the initiator for separation after landing. The counterweight is additional weight that will be added to the shelves so that the rover balances out upon landing. Lab testing will be conducted in the future to determine the best amount of counterweight to use and the best distribution of weight based on the final assembly of the rover.

The solenoid is used to hold the rover in place during launch by acting as a lock. The 'key' is on the solenoid attached to the rotating mechanism and the locking mechanism is on the rover. The communications system will tell the solenoid to rotate the key into place before the launch and tell it to rotate the key out of place once the launch vehicle has safely landed and the nose cone has successfully separated. The locking mechanism will be discussed further in the Rover Hardware section.

One of the main design features of the rotating payload bay is the removable shelves and open top and bottom sections. The reason for these design decisions was so that the electronics could easily be integrated and worked on independently of the rotating mechanism. The communication system electronics are located on the removable shelves. This allows the electronics team to work at the same time as the hardware team. The open top and bottom as seen in Figure 35 and Figure 36 were included as part of the design to minimize the amount of material used and to allow the electronics to be integrated more easily. Additionally, the external switch which will be included for safety purposes can only be accessed when one of the open sides of the rotating payload bay is aligned with the external door on the outside of the of the rocket.

## 5.3 Rover Hardware

Figure 37 below shows the full assembly of the rover excluding the soil sample recovery system. The soil sample recovery is underneath the rover and will be discussed further in the Soil Sample Recovery System section. The design of the rover features angled tread wheels which are optimized for displacing soil and increasing traction, custom mounts for dual shaft DC motors, a 3D printed solenoid locking mechanism, and a communications system with a LoRa RFM95 radio, Arduino Nano, and 9V batteries. This section will discuss the design decisions made for various components of the rover.

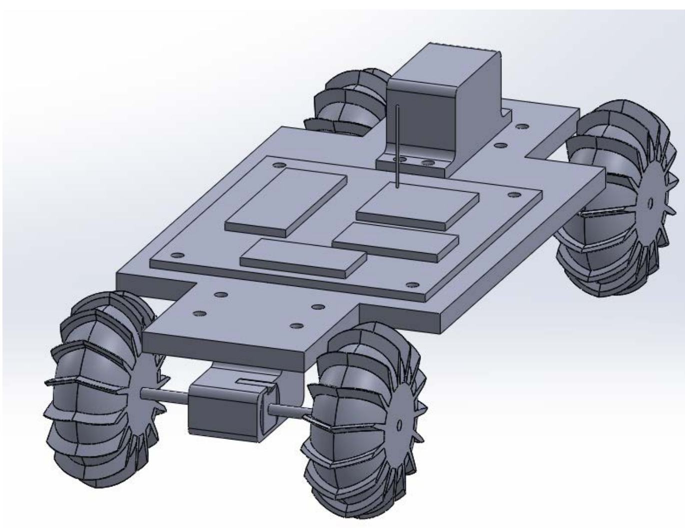

**Figure 37. Rover Full Assembly in SolidWorks**

## Wheel Design

In the 2018 competition, the rover experienced problems from a lack of traction. The team for the 2019 competition has decided to emphasize wheels with improved traction. The decision for which wheel was made using a design selection matrix shown in Table 44.

Three designs were considered for the current rover: a hollow wheel shown in Figure 38, an angled tread wheel shown in Figure 39, and a non-wheel, tank track design. The tank track was considered as an alternative to simple wheels.

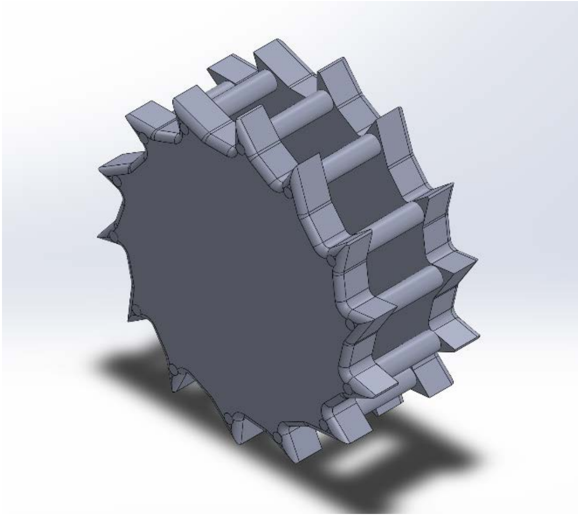

**Figure 38. Hollow Wheel Design**

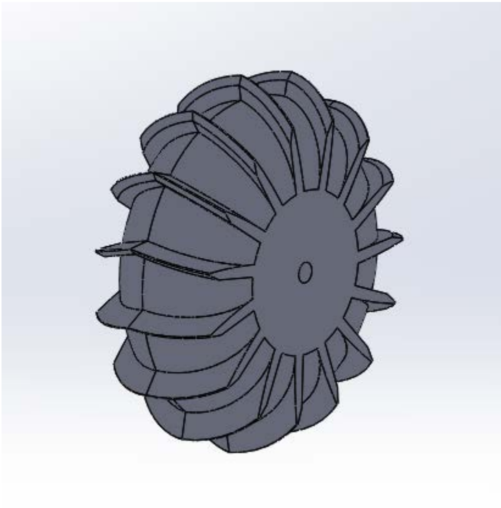

**Figure 39. Angled Tread Wheel Design**

The selection matrix is made up of five factors that were considered while determining the best design for the wheels. For each factor, a score of 1-5 was assigned based on each designs' performance. A score of one is considered the worst and a score of five is considered the best. The five factors that were taken into account were durability, ease of manufacturing, weight, traction, and simplicity. Durability is rated on the designs ability to withstand forces in flight and while driving. Ease of manufacturing is based on the time needed to design and 3D print the part. Designs with a lower weight will be given a better score. Traction is based on the effectiveness that the rover can move through loose dirt. Simplicity is based on how many parts make up each design. A design with more parts will have a lower score.

Each of the five factors was given a weight from 0-1. The factors with higher importance were given higher weights while the sum of all weights is equal to 1. Durability was given a weight of 0.10 to reflect the importance of surviving the flight and driving. It was not given a higher score because the expected stress on the wheels alone is not likely to cause failure. Ease of manufacturing was given a weight of 0.20 because of the impact on the team's available time. The weight of the design was given a weighting score of 0.15 to reflect the need to meet the team's goal of keeping the rover's total weight under 30 ounces. Traction was given a weight of 0.35 to reflect the importance of the wheels to allow for the rover to move through the soil at the launch site in Huntsville, Alabama. Simplicity was given a weight of 0.20 because fewer parts leads to a smaller chance of failure and easier 3D printing.

The weighted scores and corresponding rank for each design can be found in Table 44 below.

**Table 44. Wheel Design Selection Matrix**

| | | **Hollow Wheel (Figure 38)** | | **Angled Tread Wheel (Figure 39)** | | **Tank Tracks** | |
|---|---|---|---|---|---|---|---|
| **Attributes** | **Weight** | Score | Weighted Score | Score | Weighted Score | Score | Weighted Score |
| **Durability** | 0.10 | 4 | 0.40 | 5 | 0.50 | 3 | 0.30 |
| **Ease of Manufacturing** | 0.20 | 3 | 0.60 | 4 | 0.80 | 1 | 0.20 |
| **Weight** | 0.15 | 4 | 0.60 | 3 | 0.45 | 2 | 0.30 |
| **Traction** | 0.35 | 3 | 1.05 | 3 | 1.05 | 5 | 1.75 |
| **Simplicity** | 0.20 | 4 | 0.80 | 5 | 1.00 | 1 | 0.20 |
| **Total** | 1.00 | | **3.45** | | **3.80** | | **2.75** |
| **Rank** | | | **2** | | **1** | | **3** |

### Durability

The different wheel designs would each be made from the same type of 3D printing filament which has previously shown no problems from the stresses of the rocket's flight and landing. The hollow wheel design is made up of two sections connected with epoxy. The connection point has a potential for failure, specifically while driving on uneven soil. This failure is unlikely so the design was given a score of four. The ATV wheel design is made up of one piece with a solid exterior and a gridded interior for structural support. The wheel does not have any foreseeable points of failure (not including the connection to the motor which is common among any wheel design) and received the highest score. The tank tracks have the potential to either break or slip off of the wheels. The likelihood of both scenarios could be reduced through increased design so the design was given a score of three.

### Ease of Manufacturing

Time taken to design and draw the models of each wheel was the most important factor taken into consideration when scoring for ease of manufacturing. The hollow wheel and the ATV wheel took similar amounts of time to model, but the hollow wheel required revisions and received a score of three rather than four. The tank tracks would require a large time investment and because of this have not been modeled in SolidWorks. The tracks would take more than triple the time to model compared to either wheel and therefore was given the lowest score.

### Weight

When scoring the designs for weight, a lower weight corresponded with a higher score. The tank tracks would have the most weight because it requires the turning wheel along with the additional track. The hollow wheel had the least weight and the ATV wheel had a slightly higher weight based on expected values given by the 3D printing software. These values are subject to change based largely on the final infill density and wall thickness selected when printed. The two wheels could receive higher scores in the weight category if the team decides to reduce these 3D printing values. A small reduction in the infill density would not likely cause a significant reduction in the durability of the wheels. To determine the ideal infill density and wall thickness, more testing will be necessary.

### Traction

The traction of the wheel is determined by the ease at which it can move through loose soil. The tank tracks will have the most complete traction because of the larger surface area and additional grooves to help move the dirt. The tracks got the highest score based on research comparisons as the team does not have a 3D modeled version of the tracks. The traction for both wheels is similar but less than the expected traction of the tank tracts. The score given to the two wheels reflects this. These scores are subject to change upon further testing by the team.

### Simplicity

When scoring for the simplicity of the designs, the team decided that a simplistic design was one that required minimal time to 3D print, put together, and connect to the chassis of the rover. The ATV wheel would be the easiest to put together and attach to the rover. The time to print was also about as small as possible for a wheel of its size and could be changed based again on the infill density. The ATV wheel received the highest score to reflect the minimal time investment. The hollow wheel would have a similar print time to the ATV wheel but would require time to allow for the epoxy to set when connecting the parts. It was given a score of four because this additional time would not have much impact on the process. The tank tracks would take a significantly more amount of time to print, construct, and connect. Therefore, the design received the lowest score.

After the assigned scores were weighted and added, the ATV wheel design received the highest amount of points and was selected. As the team continues to test and change the designs, the scores could change slightly and will be taken into consideration when finalizing the rover.

### Retainment Mechanism

The retainment mechanism is used for keeping the rover inside the rocket through all stages of flight. The rover could be damaged if it is not secure inside the rocket and would be a safety hazard if it was ejected from the rocket mid-flight. The three retainment mechanism concepts that were considered are a door, a solenoid lock, and a series of tethers that would hold the rover in place.

Five weighted criteria were considered while determining the best concept for the retainment mechanism. Each of these factors was given a score of 1-5 where a score of one is considered the worst and a score of five is considered the best. The five criteria that were taken into account were durability, ease of manufacturing, weight, cost, and simplicity. Durability is rated on the concept's ability to withstand forces of the rocket's flight and landing. Ease of manufacturing is based on the time needed to design and 3D print or construct the parts. Concepts with lower weight and lower total cost will be given a better score for the respective criteria. Simplicity is based on the ease that each system can be connected on launch day. Concepts with more complexity and assembly time will have a lower score.

Each of the five criteria was given a weight from 0-1. The criteria with higher importance were given higher weights while the sum of all weights is equal to 1. Durability was given a weight of 0.35 to reflect the importance of surviving the flight. Any significant failure of the system could be hazardous to the rover and the people on the ground. Ease of manufacturing was given a weight of 0.20 because of the impact on the team's available time. The weight of the design was given a weighting score of 0.10 to reflect the need to meet the team's goal of keeping the total weight for the payload under 50 ounces. The cost was given a weight of 0.10 because the necessary parts for each concept should not exceed $50 which is small enough not to be of great concern. Simplicity was given a weight of 0.25 because a simpler design will make connecting the rover on launch day easier and less time-consuming allowing for more focus elsewhere.

The weighted scores and corresponding rank for each concept can be found in Table 45.

**Table 45. Retainment Mechanism Selection Matrix**

| | | **Door** | | **Solenoid Lock** | | **Tether** | |
|---|---|---|---|---|---|---|---|
| **Attributes** | **Weight** | Score | Weighted Score | Score | Weighted Score | Score | Weighted Score |
| **Durability** | 0.35 | 3 | 1.05 | 4 | 1.40 | 2 | 0.70 |
| **Ease of Manufacturing** | 0.20 | 3 | 0.60 | 5 | 1.00 | 3 | 0.60 |
| **Weight** | 0.10 | 3 | 0.30 | 5 | 0.50 | 5 | 0.50 |
| **Cost** | 0.10 | 4 | 0.40 | 2 | 0.20 | 5 | 0.50 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| **Simplicity** | 0.25 | 5 | 1.25 | 5 | 1.25 | 2 | 0.50 |
| **Total** | 1.00 | | **3.60** | | **4.35** | | **2.80** |
| **Rank** | | | **2** | | **1** | | **3** |

### Durability

The durability of a concept was rated when taking into consideration the likelihood of failure and the ability to withstand multiple launches and landings. The door could have a risk of opening prematurely after repeated launches. This risk is not high due to the strength of 3D printed parts and an isolated circuit. The team gave the door a score of three to reflect the potential for failure. The solenoid lock is expected to have a low risk of failure in flight based on manufacturer specifications and the secure attachment to the payload bay. The solenoid lock was therefore given a score of four. The tether could allow for the rover to either slip out of the payload bay from loosening wires or could break entirely. Secondary tethers could be installed to lower the chance of failure. The team gave the tether concept a score of two to reflect that multiple launches and landings could weaken the tethers holding the rover inside the payload bay. Because of the importance of safety, further testing will be conducted to ensure the risk of failure is mitigated. As a result, the scores of each concept could be subject to change to reflect the future tests.

### Ease of Manufacturing

The door would take a moderate amount of time to design and model in SolidWorks. The software required to close and open the door upon receiving a signal would also take a moderate time commitment and as a result, this concept received a score of three. The solenoid lock can be purchased online and would only require a small addition to the rover to hold it in place during the flight. The solenoid lock can also be easily installed inside the payload bay with simple software to turn on and off. The tether would take a similar amount of time to write software to lock and unlock the wires. The wires would also take time to cut to size and install in the payload bay. It received a three because of the similar time investment to the door concept.

### Weight

The door concept would require the door to be 3D printed. This would add weight to the payload bay, however, the printed plastic is still light when infill density is minimized. The door was given a score of three due to the lightweight plastic. Both the solenoid lock and the tether concepts received a score of five. The solenoid lock would only the weight of the lock itself and the small additional piece on the rover. The tether would similarly be light because only the weight of the tethers and a small locking mechanism would be added.

### Cost

The tether concept could be created using materials from previous years and therefore would cost the team nothing unless additional parts are needed. The tether concept received a score of five because of the minimal cost. The door would also be constructed using parts from previous years and from 3D printing filament. The small amount of filament would not cost a large amount so the team gave the concept a score of four. The solenoid comparatively would more than the other two concepts and was given a score of two. Estimated costs for each concept are given in Table 46 below.

**Table 46. Retainment Mechanism Cost Comparison**

| Concept: | Cost (in $): |
|---|---|
| Door | 5.00 |
| Solenoid Lock | 40.00 |
| Tether | 0 |

### Simplicity

The door and solenoid lock concepts received a score of five to reflect the ease of which the rover can be inserted and secured inside the payload bay on launch day. The solenoid lock would only require turning on after placing the rover in the payload bay. The door only needs to be shut and locked to secure the rover. The tether concept would take a considerably larger amount of time to tie down the rover and ensure each connection point would withstand the launch. For this reason, the tether concept received a score of two in this criteria.

After the scores were weighted and tallied, the solenoid lock received the highest total score and was chosen for the rover's retainment mechanism inside the payload bay. The solenoid lock will be attached to end of the payload bay opposite of the separation opening.

### Rover Body

The body of the rover will be made from a single primary piece of material to which the electronic components will be attached. The decision to make the rover from a single sheet of material was made to decrease excess body material which would both improve clearance and decrease the weight of the rover. To decide the type of material to use for the rover, the team used a weighted selection matrix to compare wood, acrylic, and 3D printed polylactic acid (PLA) filament.

The factors impacting the selection of the material were as follows: cost, strength, production time, workability, and weight. Each category is given a score from one-to-five where five is the best and one is the worst. Materials with lower costs were given a higher score. Strength was dependent on the material's ability to withstand stresses during flight and landing as well as that of driving on uneven soil. Production time was based on the amount of time it would take one to cut and prepare the material for use on the rover. For the 3D printed body, the team did not include the time taken to print the body piece because this can be completed autonomously. Workability was based on the ease of which the body can be changed. Materials with a lower weight were given a higher score.

Each factor was given a weight between zero and one. The sum of the weights is equal to one. Cost was given a weight of 0.15 based on the need to stay within the team's budget. The strength of the material was given a weight of 0.30 to reflect the importance of withstanding multiple launches. Production time was given a weight of 0.20 to account for the importance of time management as a team. Workability was also given a weight of 0.20 based on the need to quickly and easily make changes to the body of the rover while designing and testing. Weight was given a score of 0.15 to reflect the goal of keeping the rover under 30 ounces.

Table 47 shows the selection matrix for the rover body material.

**Table 47. Rover Body Material Selection Matrix**

| | | Wood | | Acrylic | | 3D Printed | |
|---|---|---|---|---|---|---|---|
| **Attributes** | **Weight** | Score | Weighted Score | Score | Weighted Score | Score | Weighted Score |
| **Cost** | 0.15 | 5 | 0.75 | 2 | 0.30 | 4 | 0.60 |
| **Strength** | 0.30 | 2 | 0.60 | 4 | 1.20 | 4 | 1.20 |
| **Production Time** | 0.20 | 3 | 0.60 | 1 | 0.20 | 5 | 1.00 |
| **Workability** | 0.20 | 3 | 0.60 | 4 | 0.80 | 2 | 0.40 |
| **Weight** | 0.15 | 5 | 0.75 | 2 | 0.30 | 4 | 0.60 |
| **Total** | 1.00 | | 3.30 | | 2.80 | | 3.80 |
| **Rank** | | | **2** | | **3** | | **1** |

## Cost

The cost of each material can be found in Table 48. The team compared estimates for materials in sheets that are 0.25 inch thick by 12 inches square. The team used pine wood for the estimate. The 3D printed sheet estimate was given an estimate based on the cost of printing the same sized sheet with PLA filament.

**Table 48. Material Cost for Rover Body**

| Material: | Cost (in $): |
|---|---|
| Wood | 1.75 |
| Acrylic | 8.50 |
| 3D Printed (PLA) | 3.00 |

The scores given to each material were based on the range shown in Table 49.

**Table 49. Scoring Table by Cost for Rover Body**

| Score | Cost (in $): |
|---|---|
| 5 | 0.00 - 2.49 |
| 4 | 2.50 - 4.99 |
| 3 | 5.00 - 7.49 |
| 2 | 7.50 - 9.99 |
| 1 | 10.00+ |

**Strength**

The strength of each material was compared using the tensile strength and the flexural modulus given in Table 50.

**Table 50. Material Tensile and Flexural Modulus Comparison**

| Material: | Tensile Strength (ksi) | Flexural Modulus (ksi): |
|---|---|---|
| Wood | 0.26 | 1070 |
| Acrylic | 8.37 | 370 |
| 3D Printed PLA | 6.79 | 561 |

The acrylic and 3D printed PLA were both given scores of four. The tensile strength for Acrylic was slightly higher than the PLA, however, the flexural modulus was lower. For this reason, both materials received the same score. The wood has a significantly lower tensile strength than both acrylic and 3D printed PLA, but had a higher flexural modulus. The team decided to give the wood a score of two to reflect the lower strength while retaining a high flexural modulus.

### Production Time

The wood would be easy to work with in the lab and could be cut for prototyping without a large time investment. Cutting the wood to the high precision which will be necessary for the final iterations of the rover will take more time so the wood was given a score of three. The acrylic will take more time to achieve the same precision and will also require two team members to safely cut. A score of one was given to acrylic to reflect the additional time and second team member needed to cut and prepare the material. 3D printing the body of the rover would only require the team to make a simple model in SolidWorks before printing it out. While the body is printing, the team can work on other tasks because it would not require any monitoring. Additionally, it would be easy to print multiple iterations at once and make minor adjustments without sacrificing large amounts of material. The time needed to model the body would be brief while still very precise so a score of five was given to the 3D printed body.

### Workability

Wood was given a score of three because it can be changed a number of times before a new body must be cut. The wood has a limited number of modifications that can be made before the strength is reduced. Acrylic can similarly be modified multiple times before a new body is needed. The limit to the number of modifications is expected to be higher than wood and therefore was given a score of four. 3D printing the body limits the number of changes that can be made to a print, but the model can be easily and quickly changed in SolidWorks before printing a new body. 3D printing received a score of two because the model can be changed quickly but the new print will take a longer time than the changes that could be made to the other materials. This would slow down the prototyping process.

### Weight

The average weights for each material are given in Table 51 below. The weight of each material was estimated using the same size sheet as the cost comparison (0.25 x 12 x 12 inches).

**Table 51. Mass estimates for Rover Body Materials**

| Material | Weight (in ounces) |
|---|---|
| Wood | 7.0 |
| Acrylic | 19.2 |
| 3D Printed (PLA) | 10.4 |

The wood received a score of five because it is the lightest of the three materials and would likely be lightest of most materials suitable for the body of the rover. The 3D printed PLA would be slightly heavier for the body of the rover, but the weight is subject to change based on the infill density for the body. It received a score of four because it is similar to the weight of the wood. The acrylic weighted significantly more than either of the other materials and was given a score of two as a result. An acrylic body would increase the weight of the rover by a few ounces (the rover will not be using the whole sheet from the estimations so the weight increase would not be as significant as shown in the table).

After scoring each of the five criteria, the values were weighted and added together to find the highest total. The 3D printed rover body using PLA filament received the highest score total and will be used. During the prototyping and testing process, changes may be made to the rover body material if the 3D printed body is determined to be underperforming. The other two materials could be tested or the 3D printed filament could be changed.

## 5.4 Rover Software

Figure 40 below shows the software logic for the payload subsystem. The rover and rocket communication systems are constantly listening for unique signals from the ground station that allow them to execute their respective tasks. All of the software is written in Arduino and all of the logic is executed by Arduino Nano micro-controllers.

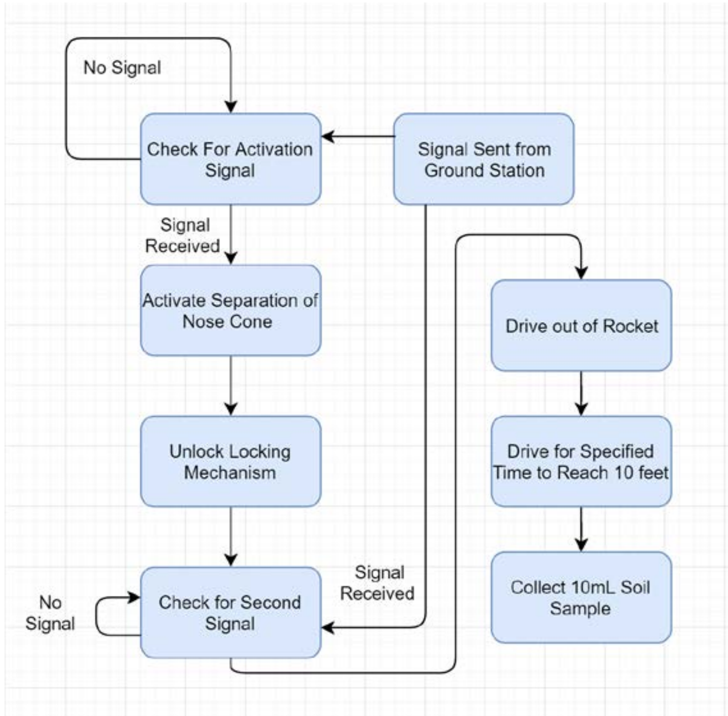


**Figure 40. Software Control Logic for the Payload Subsystem**

The ground station software is written in a combination of Arduino and MATLAB. The ground station control GUI was written in MATLAB to send commands through the serial port to the Arduino, which then sends signals to the rocket and rover communication systems. The details of the communications software will be further outlined in the communications section.

Once the rover receives the signal to initiate the driving sequence, it will power its 2 dual shaft DC motors for 60 seconds. This allows the rover enough time to get at least ten feet from the launch vehicle. After the 60 second driving sequence, the rover will then deploy its soil sample recovery mechanism by rotating a servo arm by 180 degrees to scoop up soil. The details of this will be further discussed in the Soil Sample Recovery System section.

Figure 41 shows the circuit diagram for the external switch on the launch vehicle communication system. This allows the RSO to disable the black powder separation mechanism on the launch pad if it is necessary. The external switch connects and disconnects the 9V battery from the Arduino.

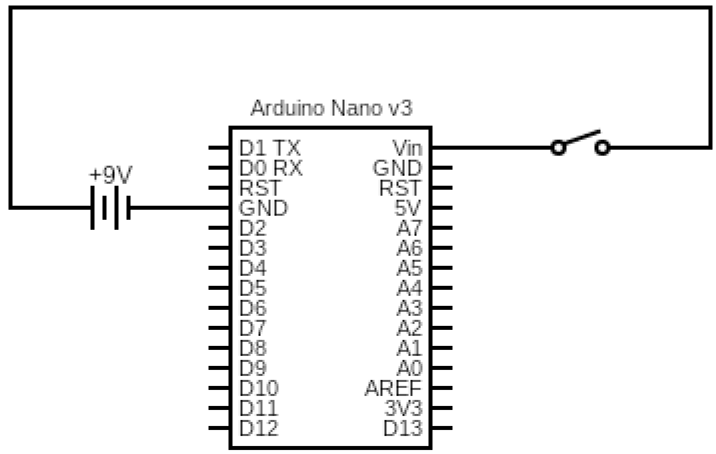


**Figure 41. Circuit Diagram for External Switch**

Figure 42 shows the electrical wiring for the launch vehicle communication system with the initiator. The two transistors shown act as a switch to connect the 9 volt battery to the initiator when the Arduino is given a signal from the ground station. The initiator detonates the black powder charge to pressurize the payload section and separate the nose cone from the body tube.

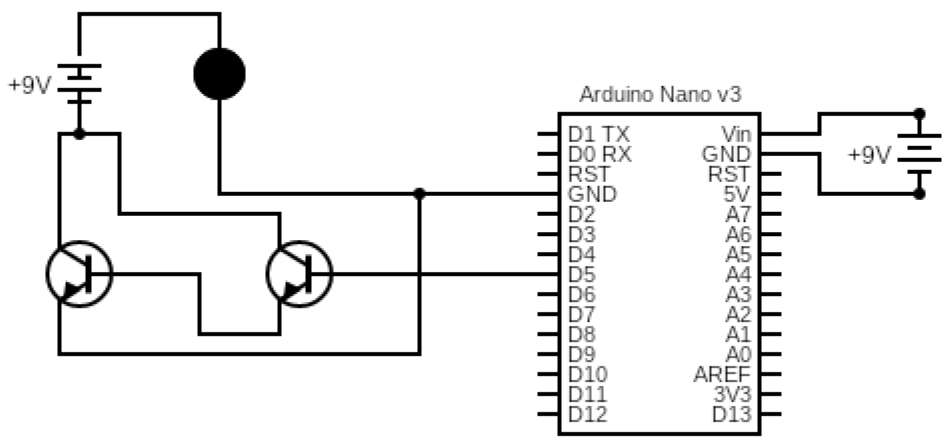


**Figure 42. Initiator Electrical Diagram**

Figure 43 shows the electrical wiring for the solenoid mechanism on the launch vehicle communication system. Similar to the initiator circuit, the transistors act as switches to allow 27 volts to go to the solenoid. This allows the solenoid to rotate to the unlocked position. The rover can then exit the launch vehicle. This is a fail-safe system because if the power source for the solenoid somehow fails, the rover will not be unlocked from the launch vehicle and will not be able to exit.

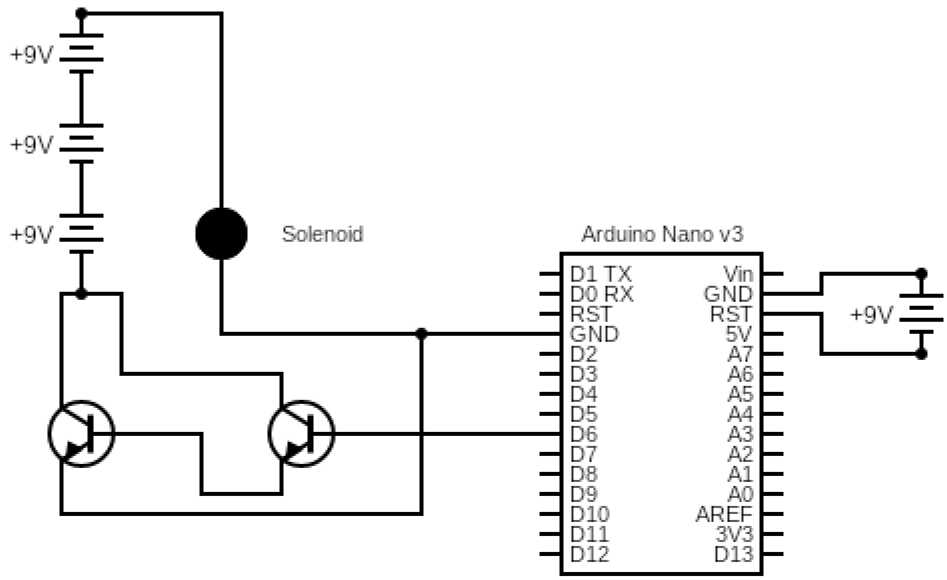


**Figure 43. Solenoid Electrical Diagram**

## 5.5 Communication System

The purpose of this communication system is to send unique signals to the rover and the on board communication systems from a ground station control. Both the rover and on board communications systems are listening for unique strings to execute specific tasks. The reason for designing the communications system this way is so that there is no way for interference signals from other teams to accidentally detonate the black powder charge or solenoid lock prematurely. All three parts of the communication system use an Arduino Nano, LoRa RFM radio module and operate at 915 MHz. Figure 44 shows a visual for the communication system components and signals.

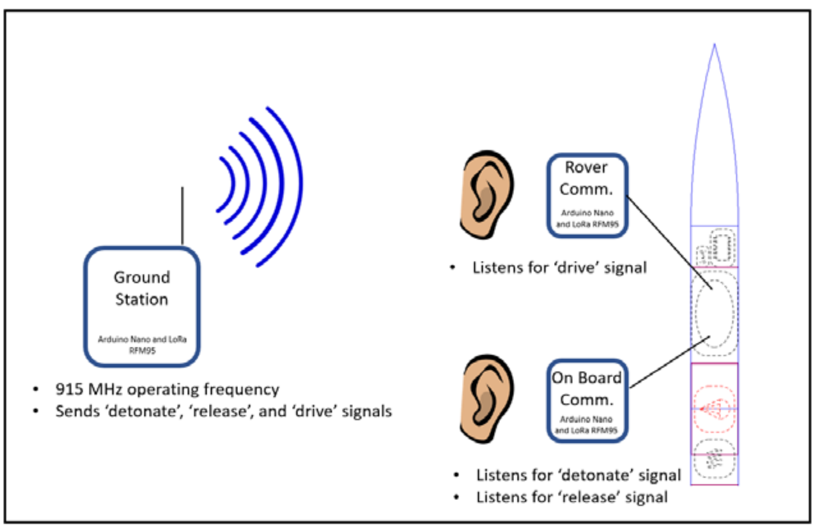


**Figure 44. Visual for Communication System Setup**

Figure 45 shows the ground station controls which were written in MATLAB using the GUI development tool, guide. The 'Separate Nose Cone' button sends a 'detonate' signal to the on board communication system which tells the Arduino Nano to detonate the black powder charge with an initiator. This black powder charge was chosen to be two grams based on volume calculations performed by the avionics and recovery team. The 'Release Rover' button sends a 'release' signal to the on board communication system which tells the Arduino Nano to rotate the solenoid to the open position. This will allow the rover to drive out of the launch vehicle. The 'Initiate Driving Sequence' button sends a signal to the rover to begin the driving sequence. The driving sequence begins by powering the motors for 60 seconds to make sure the rover is at least ten feet from the launch vehicle and then starting the soil sample recovery system. The control GUI also includes two check boxes which were added as safety features. The 'Enable Communication' checkbox must be checked for the ground station to be able to send any signals. This is to prevent any buttons from accidentally being pressed prematurely. Another checkbox, 'Enable Detonation', must be checked to be able to send the 'Separate Nose Cone' signal. Additionally, there have also been conditions written into the code that ensures the buttons can only be pressed from left to right and one cannot accidentally be pushed before another.

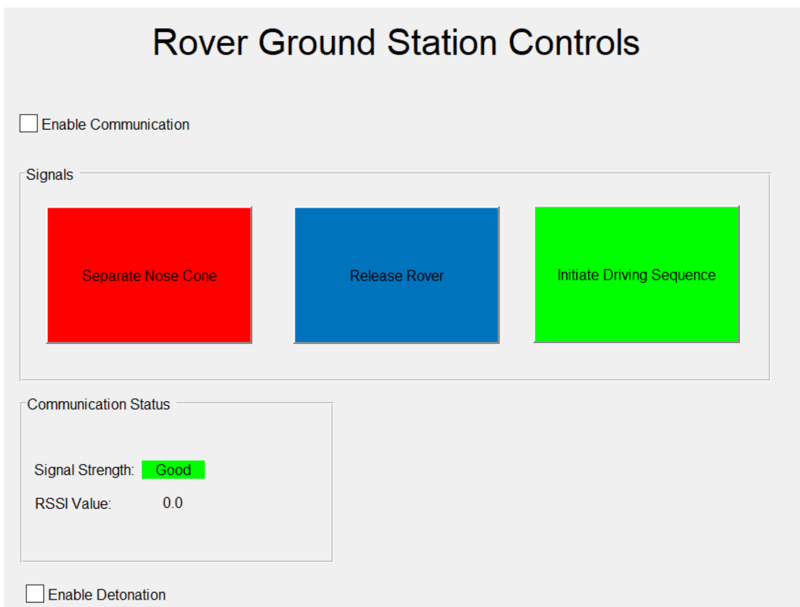


**Figure 45. MATLAB GUI for Ground Station Controls**

The ground station control GUI also includes a 'Communication Status' panel as shown in Figure 45, which displays the strength of the signal as a raw RSSI number and a relative signal strength. This panel was added so that the recovery team would have an idea of whether or not they were within range of the rover and on board communication systems.

The separation of the nose cone is executed through a black powder pressurization of the payload section after successful launch and landing. Since the payload needs to be able to open the nose cone after the rocket has landed so the rover may exit, the nose cone is attached to the body of the rocket by shear pins, able to support up to 25 lbf each, that can be broken with the black powder pressurization. However, during flight, the rocket will experience a large drag force when the main parachute deploys so it must be ensured that the force of the parachute does not break the shear pins; by calculating this force the number of shear pins required for safety can be determined. The purpose of the measurements is to calculate an approximate maximum force exerted on the shear pins connecting the nose cone to the rest of the body. To calculate the maximum force applied to the nose cone of the rocket is to calculate the force of drag the main parachute will create when it opens. The equation below shows the equation used to calculate the drag force on the rocket.

$$F_{Drag} = \frac{1}{2} * p * C_d * A * v_{max}^2$$

$p$ is the density of air (1.225 kg/m3), $A$ is the cross-sectional area of the main parachute in $m2$, while $Cd$ is the coefficient of drag of the parachute. The velocity, $vmax$, is the maximum velocity of the rocket after drogue deployment, experimentally measured to be 120 ft/s. When calculating this, the maximum drag force would be a 600 N force, which is 134 lbf.
That means it would require at least 6 shear pins to prevent the nose cone from breaking off during the deployment of the main parachute. Since the black powder charge applies a much greater force once the rocket has landed, 8 shear pins are being used to ensure that the nose cone will not separate before the rocket is on the ground. The separation will be executed with 2 grams of black powder. 2 grams was determined by volume calculations conducted by the avionics and recovery team.

## 5.6 Soil Sample Recovery System

The ultimate goal of the rover is to collect a ten-milliliter soil sample. To do this the team plans to create a mechanical bucket shown in Figure 46 that will be connected to the underside of the rover. While driving, the bucket arm will be oriented horizontally to maximize clearance. Upon reaching ten feet away from the rocket, the bucket will be rotated down using a servo to collect a soil sample from beneath the rover. After the soil is within the bucket, the servo will continue to turn until the bucket arm has turned 180 degrees and is again attached to the rover. The rover will have a designated space on the bottom where the bucket can be retained while also safely and securely storing the soil sample.

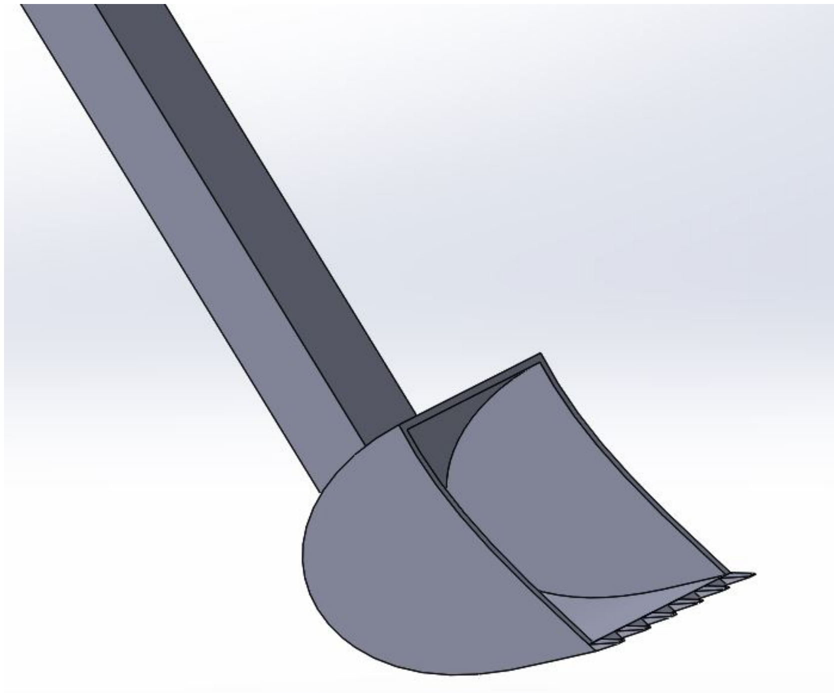

**Figure 46. Soil Sample Collection Bucket**

The bucket shown in Figure 46 will be made by 3D printing the SolidWorks model. The use of 3D printing will allow for increased prototyping and testing because of the speed at which the model can be changed and re-printed. Additionally, 3D printing can be adjusted to fit the tolerances of the rover to make the bucket fit flush within the designated space. With the bucket flush inside the cut-out space, the soil sample will be secure.

# 6. Project Plan

## 6.1 Testing

### Structures

One test will be to determine the amount of layers of carbon fiber needed for the launch vehicle. To determine this, the team considered the max q condition. The max q condition is the point when an aerospace vehicle reaches its maximum dynamic pressure during its flight. This is a significant factor as it is proportional to the structural load the launch vehicle can handle. The team considered using the Cesaroni L851 motor when calculating the dynamic pressure of the launch vehicle. The dynamic pressure equation is represented by:

$$q = \frac{1}{2}\rho v^2 \tag{21}$$

Where q is the dynamic pressure, ρ is the local air density, and v is the velocity of the launch vehicle.

The team considered two different points when calculating the dynamic pressure. The first was at ground level in Alabama. The height of Alabama above sea-level is 636 feet. This height was denoted as ground-level. The team also used the velocity of the launch vehicle as it leaves the rail, which is 58.7 feet/s. To determine the pressure at ground-level, the following equation was used:

$$P_h = P_0 e^{\frac{-Mgh}{RT}} \tag{22}$$

Phis the pressure at ground-level, P0 is the average pressure at sea-level, M is the molar mass of Earth's air, g is Earth's gravitational acceleration, h is the height above sea-level, R is the universal gas constant, and T is the temperature. To determine the temperature the launch vehicle will most likely encounter on launch day, the team looked at past average temperatures in Alabama during the month of April. After looking at the different averages over the years, the team decided to use 72 degrees Fahrenheit.

After determining the pressure at ground-level, the team calculated the density of air utilizing:

$$\rho = \frac{P_h}{rT} \tag{23}$$

Where ρ is the local air density and r is the specific gas constant.

Plugging in the calculated local air density and the velocity of the launch vehicle, the dynamic pressure yielded was 125.683 lbft2.

This value seemed fairly small, so the team decided to determine the dynamic pressure at the point of the launch vehicle's maximum velocity. The team chose this position since the launch vehicle will not be reaching a height further than a mile above ground-level, so velocity will have the largest impact.

This point was found to be when the launch vehicle was 2146 feet above sea-level, which is 1510 feet above ground-level. The velocity of the launch vehicle at this point is 674 feet/s. Using Equations 1, 2 and 3, the dynamic pressure exerted on the launch vehicle was found to be 15859.2 lbft2. This value seemed to be fairly high, but the team decided to use it and move forward with calculating the amount of layers of carbon fiber needed.

Since the dynamic pressure is proportional to the maximum stress the launch vehicle will encounter, the following equation can be used:

$$\sigma = \frac{F}{A} \tag{24}$$

Where σ is the maximum stress or dynamic pressure, F is the force exerted on the launch vehicle, and A is the area the force is exerted on. Because the dynamic pressure is exerted on the whole launch vehicle, the total area was utilized. To determine the amount of layers needed, the area of a cylinder with an outer radius denoted as X and an area of a cone were used. These can be found in Equation 5 and Equation 6 respectively:

$$A_h = 2\pi(X + r)(h + X - r) \tag{25}$$

Equation 5 denotes the area of a hollow cylinder, where X is the outer diameter, r is the inner diameter, and h is height of the cylinder. Equation 6 (below) denotes the area of a cone:

$$A_c = \pi r(r + \sqrt{h^2 + r^2}\,) \tag{26}$$

Where r is the radius on the base of the cone and h is the height of the cone.

The areas calculated in Equations 5 and 6 were then added together and plugged into A found in Equation 4.

The force was determined through using Newton's Second Law:

$$F = ma \tag{27}$$

Where m is the mass of the launch vehicle at the point where the dynamic pressure was calculated, and a is the acceleration of the launch vehicle at the same point.

Using 3K Carbon Fiber Plain Weave thickness of 0.012 inches and solving for X, it was determined that the amount of layers needed was 6.4. The team will test the structural integrity of the launch vehicle using six and seven layers to determine how each act provided the forces the team believes the launch vehicle will encounter during flight.

One of these forces the airframe will have to resist is zippering during deployment of the main parachute. The zippering force of the shock cord will be due to the force of drag caused by main parachute:

$$F_D = \frac{1}{2}\rho v^2 S C_d \tag{28}$$

Where FD is the force of drag, ρ is the air density, v is the velocity, S is the surface area, and Cd is the coefficient of drag. A successful test is defined by obtaining a tensile strength value that is higher than the force that the shock cord will exhibit on the airframe during main parachute deployment. The exact procedure for tensile testing of the airframe can be found in Appendix D: Tensile Test Procedure.

Another test the structures team will take part in is to determine if PLA will be a good substitute for bulkheads instead of plywood. PLA and plywood have relatively the same tensile strength, but PLA has a higher flexural modulus. The weight of PLA can be similar, heavier, or lighter than plywood depending on the infill percentage used during the print. The cost of PLA and plywood are also very similar. Because of the similarities that team found between the two materials, it was determined that a tensile test was needed to conclude whether or not PLA would be a sufficient alternative to plywood.

The bulkheads are an important component of the launch vehicle because they hold the avionics bay in place, so they cannot fail during flight under any circumstance. The bulkheads support forces from the parachute and body tube of the launch vehicle. To determine if PLA will be a sufficient alternative, the team will run a SolidWorks FEA simulation. The team will compare these results to simulations run using plywood and previous knowledge of how plywood bulkheads held up during the duration of the flight.

The structures team will also manufacture a test piece and place a bulkhead made out of PLA into the body tube using epoxy. The team will then provide relatively the same amount of force the bulkheads will encounter during the duration of the flight to determine if the PLA bulkhead will fail or not under these loads.

### Payload

Table 52 describes the testing that will be conducted to verify the design elements of the rover and payload bay. The table includes the design being tested, the objective of the test, the criteria for a successful test, and the justification for conducting the test.

**Table 52. Planned Payload Testing**

| Test | Objective | Success Criteria | Justification |
|---|---|---|---|
| Communication System | Show that the rover and containment mechanism can | The rover receives the signal from the | It is necessary for the rover to receive the signal from |

| | | | |
|---|---|---|---|
| | receive signals from the ground station | ground and drives from the payload bay | the ground station to begin its objective |
| Ejection Mechanism | Show that the ejection charge can separate the payload bay and the containment mechanism releases | The nose cone is separated from the payload bay and the containment mechanism releases | It is necessary for the payload bay to be separated and the containment mechanism to be released before the rover can exit |
| Wheel Traction | Show that the wheels can drive effectively through loose soil | The rover is able to drive through loose soil without the wheels slipping or spinning | The rover must be able to drive effectively in the soil of Huntsville, Alabama to both reach ten feet away and obtain a soil sample |
| Containment Mechanism | Show the rover can stay attached to the rocket throughout the whole flight | The rover does not detach or exit from the rocket prematurely | It is necessary to ensure the rover does not exit the rocket until after the landing for safety |
| Rotating Payload Bay Mechanism | Show that the rover can always exit the rocket with the correct orientation | The rotating payload bay returns to the upright position from any starting orientation | It is necessary to ensure the rover can exit the rocket with correct orientation to begin its objective |

The data obtained from testing will be used to verify design elements if the success criteria is met or determine changes that need to be made to the payload before retesting. For the communication system, if the rover or containment mechanism fails to receive signals from the ground station a change must be made to method of transmission or the equipment. If the ejection mechanism fails to separate the payload bay then a change to the amount of shear pins or black powder charges used must be made. If the rover is unable to drive on loose soil then changes need to be made to the wheel design to increase traction. If the containment mechanism does not hold the rover within the payload bay, a redesign of the mechanism will be necessary. If the rotating payload bay does not correctly orient itself from any starting position, a change to the design, balancing weights, or additional lubrication will be needed.

### Test Plan and Procedures

To test the communication system, signals tests can be conducted in the lab between the ground station and the rover’s Arduino. To verify the signal that is being received, the Arduino can be connected to a computer to see the message being sent by the ground station. The same test can then be conducted outdoors to test the distance at which the signal can be received from while still retaining all of the necessary information.

To test the ejection mechanism, a full-scale model of the payload bay will be constructed. The focus of this test is to determine the correct amount of black powder charges and shear pins needed to separate the rocket. The tests will be performed on the ground, first without any payload inside the bay. When the results from the separation are consistent, the payload and containment mechanism will be added. The ground tests with the payload inside will be used to determine if the electronic and mechanical components of both parts remain undamaged and functional.

To test the traction of the wheel designs, each model will be 3D printed and attached to a test rover body. The test rover will have added weight to simulate the additional weight of the electronics and the payload challenge. The rover will then run through a sample of loose soil to simulate conditions in Huntsville, Alabama. After confirming the rover can successfully drive though the soil, progressively larger drag weights will be added on to systematically find the design with the most traction.

To test the containment mechanism, a full-scale model of the payload bay will be constructed. Using this model, the containment mechanism will be attached and the rover will be connected to it within the bay. The full-scale model will then undergo tests to simulate vibrations from launch as well as the shock from parachute deployment and landing. As mentioned previously, the containment mechanism will also be included in the ejection mechanism testing to ensure there will be no damage to the electronics or the mechanical parts of the system prior to landing or after rocket separation on the ground.

To test the rotating payload bay mechanism, the team will use a section of carbon fiber body to simulate the payload section of the rocket. A bulkhead and faceplate can then be epoxied inside and connected to the rotating bay. To accurately test the rotation in similar conditions to launch day, a simulation rover and electronics will be connected to the shelves to reproduce the actual weight that will be in the bay. The rotating bay will then be oriented in all possible directions to test all outcomes of the rocket’s landing. While testing, small balancing weights can be added to the bottom shelf to bring the system back to the upright position.

## 6.2 Requirements Verification

### General Requirements

| Requirement | Method of Verification | Verification |
|---|---|---|
| **1.1** | Demonstration | The team will design, build, test the entirety of the rocket and its payload as well as write all milestone reports. Additionally, the team's mentor, Justin Hess who is accredited with a NAR HPR Level 2 certification, will handle motor assembly, ejection charges, and electric matches. |
| **1.2** | Demonstration | The team will follow a strict project plan based on each subsystem's Gantt charts and well as the team's overall Gantt chart. Additionally, the team will outreach to local schools, and create all risk mitigation tables, checklists, budget tables. |
| **1.3** | Demonstration | The team only has one foreign national member, Wilson Chiang, who's contact information has been submitted prior to PDR. |
| **1.4.1-.3** | Demonstration | The rocket will decide all team members that are going to Alabama for the competition by the CDR milestone. Additionally, the team mentor and adult educator have already been identified by the team. |
| **1.5** | Demonstration | The team has a dedicated Outreach Chair who will be responsible for the team's contribution to educating 200 participants in STEM related material. |
| **1.6** | Demonstration | The team has identified its only social media account (Instagram) to NASA student launch representative. |
| **1.7** | Demonstration | The team will email milestone deliverables by the specified deadlines. |

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| **1.8** | Demonstration | All milestone deliverables will be in PDF format. |
| **1.9** | Demonstration | The team will include an appropriate table of contents in each milestone report. |
| **1.10** | Demonstration | The team will include correct page numbers at the bottom of every page for milestone reports. |
| **1.11** | Demonstration | The team will be given access to conference rooms will teleconference abilities through Pennsylvania State's SEDTAPP department. |
| **1.12** | Demonstration | The launch vehicle will use 15-15 rail buttons so it can be successfully launched from the provided launch rails. |
| **1.13** | Demonstration | The team has already identified its team mentor, Justin Hess, who fulfills are mentor requirements stated. |

## Vehicle Requirements

| **Requirement** | **Method of Verification** | **Verification** |
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| **2.1** | Analysis | Data from the altimeters used during flight will verify that the rocket reaches an apogee of 5,280 ft. altitude with the payload in it. |
| **2.2** | N/A | The declared target altitude goal is 5,280 ft. and will not be changed after this report is published. |
| **2.3** | Inspection | The AV bay will contain an altimeter that is built by a certified company that will record the official apogee of the launch vehicle. |

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| **2.4** | Inspection | Each altimeter will be armed by connecting two connection points through mechanical means on the exterior of the flight vehicle prior to launch. |
| **2.5** | Inspection | Each altimeter will be wired to a commercially available 9 volt battery that is secured to the avionics bay. |
| **2.6** | Testing | The avionics switch will be secured via a robust mechanical linkage so that it will remain in the ON position during flight without possibility of the switch disarming. |
| **2.7** | Demonstration / Inspection | The rocket will be launched on launch day and inspected afterwards to confirm that no damage was done and the vehicle is able to launch again. |
| **2.8** | Demonstration | The rocket is designed with only four independent sections. The four sections are the payload body tube, main body tube, drogue body tube, and the booster body tube. |
| **2.8.1** | Demonstration | The rocket is designed with airframe couplers and shoulders that are no shorter than 10 in. in length which is 1.67 times larger than the 6” diameter of the airframe. |
| **2.8.2** | Demonstration | The nose cone shoulder is 5.5” in length which is ½ the diameter of the rocket. Additionally, the nose cone will be separated during flight. |
| **2.9** | Demonstration | The rocket’s propulsion system contains one solid rocket motor and no additional stages. |
| **2.10** | Demonstration / Testing | The team will keep a timer during all fullscale test launches to ensure that the build time does not take longer than 2 hours. The rocket will be designed with assembly timing in mind, extensive launch day procedures will be written and followed to ensure timeliness on launch day. |

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| **2.11** | Demonstration / Testing | The launch vehicle is designed so that all components such as avionics can remain functional for an extended period of time after the vehicle is in launch-ready configuration. Testing can be done on test launch days to assure the functionality of the components after a certain amount of time. |
| **2.12** | Testing | Tests will be performed on a fullscale primary motor prior to the fullscale test launch to demonstrate that the motor can be ignited with a 12-volt direct current firing system. These tests will be part of the larger test goal to gather operational and performance characteristics of the primary fullscale motor before the fullscale test launch. |
| **2.13** | Demonstration | All electronics will be contained within the launch vehicle with the exception of the initiator required to light the motor upon launch. |
| **2.14** | Demonstration | The motor used for competition launch will be from a trusted manufacturer (Cesaroni or Aerotech), using NAR approved APCP propellant. |
| **2.14.1** | Analysis | In-depth mass analysis of the rocket using OpenRocket and SolidWorks will be performed to ensure mass estimates are accurate by CDR. After this analysis, a proper motor will be selected. |
| **2.14.2** | N/A | The final flight vehicle motor will not be changed after CDR. |
| **2.15.1 - 3** | N/A | The final flight vehicle will not contain any custom pressure devices. |
| **2.16** | Analysis | Analysis will be conducted via OpenRocket and MATLAB models to simulate the flight profile of the vehicle, and the associated motor selection process will be limited to motors approved by the aforementioned bodies. |

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| **2.17** | Analysis | Stability will be calculated with various programs to ensure that the vehicle's stability is over 2.0 calibers off the rail. |
| **2.18** | Analysis | Launch velocity will be calculated with various programs to ensure that the vehicle's velocity off the rail is at least 52 fps. |
| **2.19** | Demonstration | A launch vehicle exactly 50% the size of the fullscale rocket will be designed and launched to accurately imitate the fullscale rocket's main design features and aerodynamics. |
| **2.19.1** | Demonstration | All major design features such as airframe material, avionics bay design, fin brackets, and camera cover will be included in the subscale launch vehicle. |
| **2.19.2** | Demonstration | The avionics bay will be designed to include an altimeter that will record the altitude the launch rocket reaches. |
| **2.19.3** | N/A | The subscale rocket will be a newly constructed rocket, designed and built specifically for this year's project. |
| **2.19.4** | Demonstration / Analysis | The subscale rocket will be successfully launched and recovered before CDR, altimeter data from the flight will be provided to prove a successful flight. |
| **2.20** | Demonstration | The team will launch the rocket as soon as the design is finalized to make sure each system is working properly and can be fixed if failure occurs. |
| **2.20.1** | Inspection / Analysis | After the rocket is launched, the team will inspect each system to confirm that it functioned properly. The structural integrity of the vehicle will be inspected to ensure that no part of the rocket suffered severe damages during flight, and flight data will be analyzed to ensure that recovery systems were deployed at their correct altitudes, and to determine if drift calculations were correct. |

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| **2.20.1.1** | Analysis | After the rocket is recovered the team will analyze the altimeter data and compare it to the mission performance predictions calculated before the launch. Flight characteristics that will be analyzed include deployment altitudes, drift distance, and landing velocity. |
| **2.20.1.2** | N/A | The fullscale rocket will be a newly constructed rocket, designed and built specifically for this year's project. |
| **2.20.1.3** | Demonstration | Appropriate ballast will be added to each section to simulate missing payload mass. |
| **2.20.1.3.1** | Demonstration | If the payload is not ready for a fullscale test launch, it will not be flown, but it should be thoroughly tested regardless. |
| **2.20.1.3.2** | Demonstration | The simulated payload mass will be placed in a calculated area to best simulate the missing payload mass. |
| **2.20.1.4** | Demonstration | The vehicle will account for the payload's potential changes to the rocket's external surface or energy during full scale test launches to ensure accurate flight data. The camera system that will be used for footage during launch day will be active during fullscale test launches. |
| **2.20.1.5** | Analysis | If the fullscale motor is not flown during the fullscale test flight, analysis will be performed via OpenRocket and MATLAB with the motor used during the flight to verify that major flight characteristics such as maximum velocity, maximum acceleration, and maximum altitude are as close to originally predicted as possible. |
| **2.20.1.6** | Demonstration | All ballast that will be used in the rocket for full scale launch will also be used during full scale test launches. The ballast needed for launch day will be confirmed by the time fullscale test launches to ensure that the ballast is an accurate representation for launch day's rocket. |

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| **2.20.1.7** | Inspection | Between the full scale test flight and Student Launch competition, the final flight vehicle will not be modified in any way. |
| **2.20.1.8** | Demonstration / Analysis | The fullscale rocket will be successfully launched and recovered before FRR, altimeter data from the flight will be provided to prove a successful flight. |
| **2.20.1.9** | Demonstration | LTRL will strictly follow its Gantt charts and own deadlines to ensure that the fullscale rocket can be launched prior to March 6th. |
| **2.20.2** | Inspection / Analysis | After the rocket is launched, the team will inspect each payload system to confirm that it functioned properly. The structural integrity of the payload will be inspected to ensure that no part of the system suffered severe damages during flight and that the retention system functioned as intended. |
| **2.20.2.1** | Demonstration / Analysis | The retention system will be flown in its final configuration during the payload demonstration flight and the results of the flight will be analyzed after recovery to ensure that the system functioned properly. |
| **2.20.2.2** | N/A | The payload flown will be the final, active version. |
| **2.20.2.3** | Demonstration | The team is planning on flying the final, active version of the payload on the fullscale vehicle demonstration flight. If the team cannot carry out that plan, the team is prepared to fly the separate fullscale Payload Demonstration Flight. |
| **2.20.2.4** | Demonstration | The team has allowed for the inclusion of a fullscale payload demonstration flight in the project plan if the original plan of flying the payload on the vehicle demonstration flight cannot be met. |
| **2.21** | N/A | An FRR-Addendum will be completed by the team if either of the original fullscale demonstration flights fails. |

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| **2.21.1** | Demonstration | The team has planned for a possible fullscale demonstration re-flight and allowed time in the schedule for an FRR-Addendum to be competed. |
| **2.21.2** | Demonstration | The team will complete the competition launch with an accurate payload mass simulation if the Payload Demonstration Flight cannot be successfully completed by FRR. |
| **2.21.3** | Demonstration | The team will be prepared to present a petition to the NASA RSO and Review Panel to prove the safety of the payload design if a Payload Demonstration Flight cannot be successfully completed by FRR. |
| **2.22** | Demonstration | The rocket will be designed so that all possible protuberances such as the camera cover will be located aft of the burnout center of gravity. |
| **2.23** | Demonstration | Each section of the rocket will have the appropriate contact information located in an easy-to-access location. |
| **2.24.1** | Demonstration | The rocket will be designed so that no forward canards are necessary to the vehicle's flight or payload. |
| **2.24.2** | Demonstration | It will be demonstrated through launch vehicle design specifications and test launches that the launch vehicle does not include or utilize forward firing motors. |
| **2.24.3** | Analysis | Analysis will be conducted via OpenRocket and MATLAB models to simulate the flight profile of the vehicle, and the associated motor selection process will be limited to motors that do not expel titanium sponges. |
| **2.24.4** | Analysis | Analysis will be conducted via OpenRocket and MATLAB models to simulate the flight profile of the vehicle, and the associated motor selection process will be limited to APCP solid-fuel motors that are not of the hybrid design. |

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| **2.24.5** | Analysis | Analysis will be conducted via OpenRocket and MATLAB models to simulate the flight profile of the vehicle, and the associated motor selection process will be limited to a single motor that is not clustered. |
| **2.24.6** | Demonstration | The motor tube and motor will be attached to the airframe of the launch vehicle with plywood centering rings that will be epoxied between the airframe and the motor tube. |
| **2.24.7** | Analysis | Analysis will be conducted via OpenRocket and MATLAB models to simulate the flight profile of the vehicle, and the associated motor selection process will be limited to motors that do not accelerate the vehicle past Mach 1 at any point during the flight. This will primarily be achieved by ensuring that motors with higher average thrust values are not included in the selection process. |
| **2.24.8** | Demonstration | The rocket's weight and potential ballast will be calculated carefully so that a ballast no more than 10% of the rocket's weight is needed. The mass of the rocket will be thoroughly fleshed out by CDR so that there will be no mass issues after design changes cannot be made. |
| **2.24.9** | N/A | The team will limit design choices of transmitters to those that do not exceed 250 mW of power. |
| **2.24.10** | Demonstration | The team will design the vehicle with this requirement in mind, use of metal in the construction of the rocket will be limited to the motor casing and various parts of the recovery system. |

### Recovery System Requirements

| **Requirement** | **Method of Verification** | **Verification** |
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| **3.1** | Demonstration | Drogue parachute will deploy at apogee and main will deploy at 600 ft. This will be demonstrated through subscale and fullscale launch. |
| **3.1.1** | Demonstration | Main parachute will deploy at 600 ft. This will be demonstrated through subscale and fullscale launch. |
| **3.1.2** | Demonstration | Drogue parachute will deploy at apogee, and the redundant altimeter will be set to a two second delay to ensure drogue deployment. |
| **3.2** | Testing | LTRL will ground test ejection charges prior to the first subscale and fullscale launch. Ground tests will be performed before each initial launch to demonstrate successful ground ejection test. |
| **3.3** | Analysis | Both parachutes will be correctly sized, based on MATLAB and OpenRocket modeling, in order for each component of the rocket to land within the kinetic energy constraint of 75 ft-lbs. |
| **3.4** | Inspection | The recovery system, including all wiring, will be completely independent of any payload retention, deployment or vehicle wiring. |
| **3.5** | Inspection | All avionics systems will be powered by new, commercially available 9V batteries. |
| **3.6** | Inspection | The recovery system will contain two redundant altimeters with corresponding independent charges, power supplies, and switches to ensure a fully redundant recovery system. The selected StratologgerCF altimeters are commercially available. |
| **3.7** | Inspection | The StratologgerCF altimeter will control all the recovery system's ejection charges. |
| **3.8** | Demonstration | Removable shear pins will be installed for both the main body tube and the drogue body tube to be broken by ejection charges during parachute deployment. |

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| **3.9** | Analysis | Using a MATLAB and OpenRocket simulation the drift distance will be confirmed to be less than 2500 ft in up to 20 mph winds. |
| **3.10** | Analysis | Using a MATLAB and OpenRocket simulation the descent time will be confirmed to be less than 90 seconds after apogee. |
| **3.11** | Inspection | There will be a working and tested GPS unit installed in the nose cone of the rocket which will constantly send the position of the rocket to the team. |
| **3.11.1** | Demonstration | All sections of the rocket will be tethered to each other through a recovery harness at all times. |
| **3.11.2** | Testing | The GPS unit will be functional and tested prior to launch on launch day. There will be a spare GPS unit in case of any electronic failures before the launch. |
| **3.12** | Inspection | The avionics bay containing all avionics electronics will be contained in a faraday cage so that it is electronically shielded from any electromagnetic interference. |
| **3.12.1** | Demonstration | The recovery system will be in its own coupler, and will be isolated from all other electronic components. |
| **3.12.2** | Testing | The faraday cage will protect the recovery system from any internal or external interference. Testing before launch will confirm this requirement. |
| **3.12.3** | Testing | The faraday cage will protect the recovery system from any internal or external interference. Testing before launch will confirm this requirement. |

## Payload

| Requirement | Identification | Associated Plan |
|---|---|---|
| **4.3.1** | Demonstration | A custom rover was constructed from PLA and is powered by an Arduino Nano and 2 dual shaft DC motors. |
| **4.3.2** | Testing, Demonstration | A locking mechanism was developed using a rotating solenoid that can only rotate when a signal is sent to the communication system to do so. The system is fail safe because if there is any communication or electronics failure on board, the rover will remain in the locked position and will not be able to exit the launch vehicle. |
| **4.3.3** | Demonstration | A ground station control system and communication system was developed that can remotely ignite a black powder charge using a unique radio signal. |
| **4.3.4** | Inspection, Testing, Demonstration | A rover was developed that can drive using two dual shaft DC motors and is programmed to recover a soil sample after traveling for 60 seconds. Testing has determined that waiting 60 seconds is the best way to ensure that the rover is at least 10 feet away from the launch vehicle. |
| **4.3.5** | Inspection, Testing, Demonstration | A scooping mechanism was developed that will be rotated using a servo. The bucket will be made sufficiently large to hold more than the minimum of 10 milliliters. Testing will be done to determine how much soil is retained after it is enclosed. |

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| **4.3.6** | Demonstration, Testing | The scooping mechanism will be 3D printed to fit the tolerances of the designated space for the soil sample. Testing will ensure that the soil sample is closed and secured within the given space. |
| **4.3.7** | Demonstration, Testing, Analysis | The batteries have been securely attached to the rover and the shelves of the rotating payload bay. A custom mount was developed in SolidWorks, FEA tested, and printed using a Lulzbot Taz 6 3D printer. |
| **4.3.8** | Demonstration | Bright pink tape will be used to identify the batteries easily. |

## Safety

| Requirement Number | Requirement | Verification |
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| **5.1** | Each team will use a launch and safety checklist. The final checklists will be included in the FRR report and used during the Launch Readiness Review (LRR) and any launch day operations. | **Demonstration:** Comprehensive checklists will be created prior to all launches and will require a lead or executive member relevant to that task to sign off after the completion of that task. The checklists will be updated after each launch and will be finalized and printed in the report prior to FRR. |
| **5.2** | Each team must identify a student safety officer who will be responsible for all items in section 5.3. | **Demonstration:** Ben Akhtar is the Safety Officer for the 2018-2019 season. |
| **5.3** | The role and responsibilities of each safety officer will include, but not limited to: Safety 5.3.1.- Safety 5.3.4. | **Demonstration:** Ben Akhtar will make sure all of these responsibilities are upheld and all rules are followed throughout the year through procedures, documents, and verification. |

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| **5.3.1** | Monitor team activities with an emphasis on Safety during: design, construction, assembly, and ground testing of vehicle and payload, subscale and fullscale launch tests, launch day, recovery activities, and educational engagement activities. | **Demonstration:** Leads will hold meetings every two weeks to review the design and construction progress. Additionally, all constructing, testing, launching, and educational activities that may have any hazards involved will have a review of all safety requirements and necessary steps to mitigate the risk as much as possible. |

## 6.3 Team Derived Requirements

### Vehicle

| Requirement | Justification | Verification |
|---|---|---|
| Launch vehicle fins will be removable. | The fins are often the first point of impact on the rocket during landing and often break as a result. Having removable fins means that if they break, the team can replace them on launch day to aid in satisfying Requirement 2.10. Additionally, the team will not have to create a whole new booster tube every time the fins break as would be the case if the fins were epoxied to the motor tube and booster body tube. | The fin brackets for the launch vehicle are designed as a separate component than the booster body tube and are fastened to the body tube in a modular fashion with bolts. |
| Launch fin brackets will be removable. | Since the fins are often the first point of impact on the rocket during landing, the associated hardware often breaks. Having removable fin brackets means that if they break, the team can replace them on launch day to aid in satisfying Requirement 2.10. Additionally, the team will not have to create a whole new booster tube every time the fins brackets break. | The fin brackets for the launch vehicle are designed as a separate component than the booster body tube and are fastened to the body tube in a modular fashion with bolts. |
| Camera will be housed in the launch vehicle with aerodynamics in mind. | Getting down-body footage of the rocket in flight is a crucial aspect of the post-flight analysis process. | The team will design an aerodynamic cover to minimize the effect of the external camera. A 3D-printed camera cover will be screwed into the rocket so that the camera can film without disturbing aerodynamics. |

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| Maintain a circular profile after laying up the carbon fiber body tubes | During the wrapping process, the carbon fiber layup curing and the vacuum pulled on the tubes will lead to stress on the mandrel. With standard aluminum mandrels this is not an issue, but our hollow phenolic mandrels may deform and cause the carbon fiber layups to be deformed as well. | The team will test different methods of wrapping the mandrel with carbon fiber to ensure that the mandrel will not warp after wrapping and compressing. Bulkheads will be epoxied into the hollow mandrel at certain spots to help reduce stress experienced by the body tube. |
| Flush cuts between separation points to ensure structural integrity | Non-flat cuts at the ends of body tubes can lead to “wobble” in the rocket under axial loads. This causes an unsafe and inefficient flight path. | The team will test different methods of cutting the body tube to ensure straight cuts and a flush body tube sections. |
| Cut screws so that they will not interfere with parachute deployment | Screws fastening airframe sections together will be cut to length so they do not protrude into the body tube sections holding parachutes and shock cord. Screws that protrude into these sections can lacerate parachutes and tangle shock cords. This could potentially prevent a safe recovery of the vehicle. | Screws will be measured and cut to a length that remains long enough to maintain structural integrity but short enough so that they do not interfere with parachute deployment. |
| Coupler length is 1.5 times the diameter of the rocket to ensure structural integrity | Coupler length can have a significant impact on the dynamic stability of the vehicle. The team believes that exceeding Requirement 2.8.1 by 50% will help improve the dynamic stability of the rocket. The team has struggled with dynamic stability in the past. | The team will purchase couplers that are 1.5 times the length of the diameter and measure couplers to verify length. |

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| Rocket is designed to optimize assembly efficiency on launch day | While adherence to requirement 2.10 ensures the rocket will be assembled in under two hours on launch day, the team believes even more efficient procedures can be developed for use on launch day. | When finalizing the design of the rocket, separation points will be picked so that each respective subsystem can work on their section of the rocket without having to wait for other subsystems. Additionally, launch day procedures will be created and strictly followed on launch day to ensure quick assembly of the rocket. |
| Camera can start recording after it is fastened into the rocket. | Since down body footage of the rocket in flight is such a crucial aspect of post-flight analysis, it is essential that the memory card in the camera system does not run out of space while sitting on the pad so that the fight can be successfully recorded. | The 3D-printed camera housing system will be modified so that an external recording button can be threaded through the rocket and accessed from the outside of the rocket after full assembly. |
| Reduce motor assembly time on launch day to 15 minutes. | While the team takes every precaution to ensure the safe handling of hazardous material, the longer the material is being worked with, the greater the chance of an accident occurring. | Create and follow a very detailed checklist for motor assembly on launch day. |

### Recovery

| **Requirement** | **Justification** | **Verification** |
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| Altimeters and their wiring will be accessible without having to unpack the parachutes. | To decrease the assembly time on launch day. | The avionics board will be removable while the parachutes are in the rocket. |
| Altimeters and their wiring will be accessible without having to disconnect sections of the rocket. | To allow for the arming of the altimeters to be the last action before the launch of the rocket the team must be able to have the entire rocket assembled. | The avionics board containing the altimeters and their wiring will be a separate removable component from and body section of the rocket. |

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| Altimeter circuit will be able to be armed while altimeters are inside of the rocket. | To prevent any damage to the avionics circuit prior to launch the switches will be accessible without having to move or adjust any flight hardware. | The switches will be located on the outward facing side of the avionics board so that the altimeters will remain on the internal side of the avionics board while manipulating the switches. |
| Altimeter circuit will be able to be disconnected while on the pad without removing the altimeters from the rocket. | If the rocket undergoes a malfunction on the pad the first switches need to be able to be flipped off without having to touch any of the avionics circuitry. | The switches will be located on the outward facing side of the avionics board so that the altimeters will remain on the internal side of the avionics board while manipulating the switches. |
| Altimeters and batteries will be allowed no relative degrees of motion. | To prevent the connecting wires from tangling or disconnecting the altimeters and batteries need to be motionless on the ground and during flight. | The altimeters and batteries will be attached to the same avionics board to restrict any motion both on the ground and in flight. |
| Altimeters and switches will be allowed no relative degrees of motion. | To prevent the connecting wires from tangling or disconnecting the altimeters and switches need to be motionless on the ground and during flight. | The altimeters and switches will be attached to the same avionics board to restrict any motion both on the ground and in flight. |
| Altimeters and their wiring will be accessible without interacting with the avionics bay faraday cage. | To prevent any damage to the faraday cage or breaking the circuit the faraday cage will be isolated from the avionics system during instalment. | The faraday cage will be inserted into a slotted channel in the avionics bay to prevent it being touched when accessing the avionics circuitry. |
| All load-bearing hardware in the recovery system shall be independent of the components attached to the altimeters and their wiring. | The team does not want stresses from in-flight forces transmitted through the sensitive electronics. They are not built to handle high loads and could be disrupted or damaged. | The team will use two all-threads that will run through the avionics bay and connect to the bulkheads on either end. SolidWorks simulations will be run to ensure the design has the loads transmitted through them. The electronics will also be placed on the avionics board which will rest within the avionics bay and only friction fit to it. |

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| The detonation of primary and redundant ejection charges will not occur at the same time. | To prevent overpressurization of the parachute chambers which could cause structural damage the redundant altimeter will trigger separation events after the primary altimeter. | The redundant altimeter will be set to deploy drogue 2 seconds after apogee and main 100ft lower. There will be a ground test before launch to confirm that the redundant altimeter is not firing at the same time as the primary altimeter. |
| The detonation of drogue ejection charge will not produce enough force to break the shear pins in the main section. | Main parachute must deploy after drogue is deployed so the main section shear pins cannot break during drogue separation event. | Several black powder calculations measurements were made and a factor of safety was taken into consideration. There will be a ground test prior to launch to confirm that drogue does not break main shear pins. |
| No avionics components will be in the same section the ejection charges fire into. | The avionics electronics are sensitive and may not handle the pressures required to deploy the parachutes. | The parachute chambers will be separated from the avionics bay chamber by a bulkhead that only has holes drilled in it large enough for the initiators to fit through. |
| Parachutes will be made of fire resistant material. | Burned parachutes to not provide the same drag as a fully functioning parachute. This will cause the rocket to descend and drift in unpredictable and likely unsafe ways. | Both parachutes and their shroud lines are made of nylon and will be wrapped in a Nomex blanket when packed inside the parachute chambers. These will be examined after a ground test prior to launch. |
| Shock cords will be made of fire resistant material. | Burned shock cords may break causing the rocket to split into multiple sections, some of which may fall in a ballistic descent hitting the ground at unsafe speeds. | Shock cords will be half inch thick Kevlar. These will be examined after a ground test prior to launch. |
| The inside of the section of body tube where a parachute resides will have no protrusions. | Protrusions may prevent the parachutes from exiting the rocket body or damaging the parachute upon exit. This will cause the rocket to descend and drift in unpredictable and likely unsafe ways. | Protrusions inside the parachute chambers will be filed or sanded down. After a ground test the parachutes will be examined for damage. |

## Payload

| Requirement | Justification | Verification |
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| Rover mass will be kept under 30 oz. | The rover must be kept to a low mass because the motors are only powerful enough to move a rover under 30 oz. Additionally, this will help the launch vehicle meet the expected altitude requirement. | Use lightweight materials such as PLA plastic with low infill density. Only use necessary amounts of wire. Only use sensors and electronics that are absolutely necessary for the mission. Keep the containment electronics external to the rover itself. |
| Total payload mass will be kept under 50 oz. | This value was the agreed upon maximum value for the payload section from the structures subsystem. Meeting this mass requirement will allow the rocket to reach its target altitude. | Using lightweight materials such as PLA will minimize the amount of wasted mass in the payload section. Additionally, infill densities will be optimized to avoid unnecessary mass. |
| Have the rover keep the correct orientation upon landing. | The rover must exit the vehicle upright so that clearances can be maximized. Previous design tried to make the rover able to drive regardless of orientation but this restricted the amount of clearance the rover could have in loose soil. | Create a rotating containment mechanism that will use gravity to move to the correct orientation. Communications electronics will be used as a counterweight to pull the shelves to the correct orientation. |
| Keep rover and rocket communications electronics independent. | This will minimize the chance of failure due to a short circuit and keep the electronics relatively simple to solder and integrate. | Make a separate communications system for the rover and containment mechanism. The rocket will have a communications system on the shelf that will control the initiator and the solenoid. The rover will have a communications system that is listening for the drive signal and only controls driving and soil sample recovery. |

## Safety

| Requirement Number | Requirement | Verification | Justification |
| --- | --- | --- | --- |
| Safety 1.1 | Provide the team with PPE requirements, SDS, machine instructions, FAA laws, and NAR and TRA regulations. | **<u>Demonstration</u>**<br>The Safety Officer must keep all documents available to all team members in the lab to be accessed at any time. | To ensure the team is able to protect themselves from harmful particles and can easily access important rules and regulation if they have any questions. |
| Safety 1.2 | Require and confirm that all team members have completed the Lab Safety and Hazards Awareness training course provided by Penn State. | **<u>Demonstration</u>**<br>The Safety Officer will collect physical copies of the completed quizzes in the lab, displaying the member has completed and passed in the course. Additionally, the Safety Officer will keep a electronic database of every person who has and has not completed their safety training. | To ensure that all team members have completed necessary safety training and are ready to participate in a potentially hazardous environment. Also, to ensure the Safety Officer knows who is not allowed in the lab if they have not completed the proper safety training. |
| Safety 1.3 | Identify safety violations and take appropriate action to correct them. | **<u>Demonstration</u>**<br>Team members that violate the safety requirements set forth by NASA, the University, the NRA, the Safety Officer, or any other relevant governing body shall not be allowed to work in the lab or attend launches until they meet with the Safety | To ensure proper safety techniques are followed and that all rules are rigidly followed. This creates a safe environment for the team to work in. |

| | | | |
|---|---|---|---|
| | | Officer and agree to comply with all rules and regulations. | |
| Safety 1.4 | Participate in preparations of testing and the testing to ensure that risks are mitigated. | **<u>Demonstration</u>**<br>The Safety Officer must approve and sign off on each testing procedure before it occurs. | The Safety Officer must understand the risks of the testing so as to adequately assess whether or not it is safe to conduct. This ensures safety for all team members and creates a safety-first attitude. |
| Safety 1.5 | Enforce proper use of PPE during manufacturing, construction, testing, and launch of the rocket. | **<u>Inspection</u>**<br>The Safety Officer will oversee these processes. If the Safety Officer cannot attend and supervise, a lead or executive member that is qualified will supervise in the Safety Officer's absence. | To ensure all team members remain safe during all phases of the competition and reduce the severity or likelihood of being harmed. |
| Safety 1.6 | Create a Safety manual throughout the season that will be completed by the end of this season and be implemented next year. The Safety manual will include NAR and TRA rules and regulations along with FAA, federal, state, and local regulations relevant to LTRL. Additionally, it will include any PPE requirements and other requirements | **<u>Demonstration</u>**<br>The Safety Officer will work with other members of the team to effectively create a safety manual throughout the year and will give updates at each leads meeting. | To proper store and file all necessary rules and regulations regarding the USLI competition and have easy access to the documents. Additionally, to ensure members have access to any policies at all times and the team can verify if they are in compliance with all rules at any time. |

| | | | |
|---|---|---|---|
| | to work in the lab as determined by the Safety Officer and the team. Finally, it will include all SDS for materials stored in the lab or used by the team. | | |

## 6.4 Gantt Charts

LionTech Rocket Labs Gantt Chart

**Student Launch Gantt Chart**

| | |
|---|---|
| **CLUB NAME** | Liontech Rocket Labs |
| **DATE** | 1/11/19 |

**LionTech Rocket Labs**

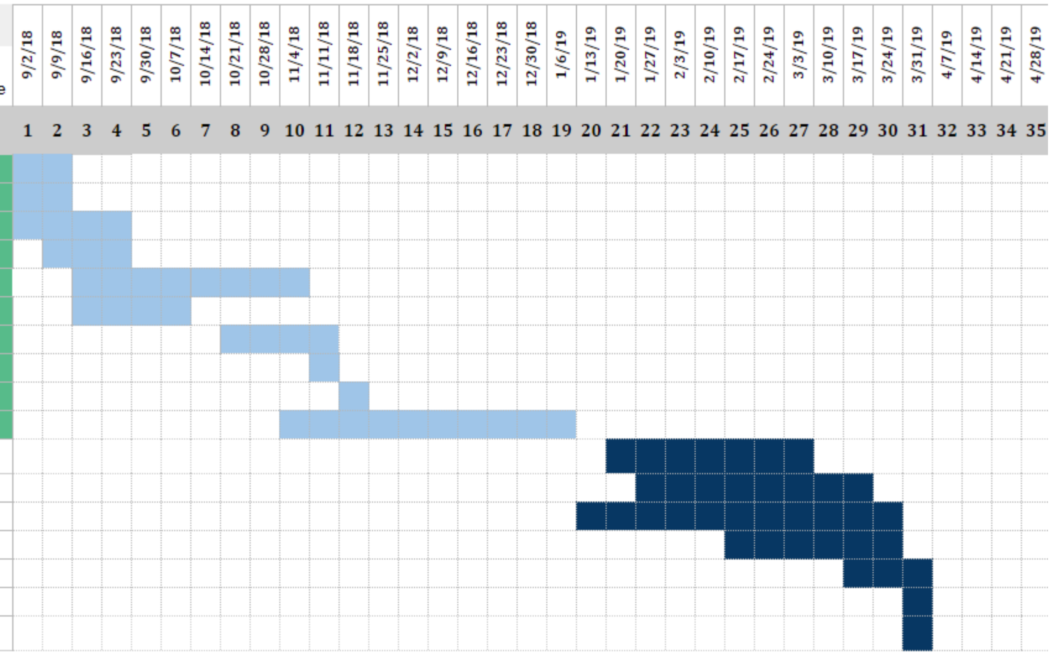
**2018-2019 Student Launch Gantt Chart**

**Legend**

Actual Date

Planned Date

| Project Milestones | Plan Start | Plan Duration | Actual Start | Actual Duration | Progress |
|---|---|---|---|---|---|
| Fullscale Initial Design | 9/2/18 | 2 weeks | 9/2/18 | 2 weeks | 100% |
| Payload Initial Design | 9/2/18 | 2 weeks | 9/2/18 | 2 weeks | 100% |
| Proposal | 9/2/18 | 3 weeks | 9/9/18 | 4 weeks | 100% |
| Subscale Design | 9/9/18 | 2 weeks | 9/9/18 | 3 weeks | 100% |
| Payload Design | 9/16/18 | 8 weeks | 9/16/18 | 8 weeks | 100% |
| Subscale Construction | 9/23/18 | 3 weeks | 9/16/18 | 4 weeks | 100% |
| PDR | 9/23/18 | 4 weeks | 10/21/18 | 4 weeks | 100% |
| Subscale Flight | 11/4/18 | 1 week | 11/4/18 | 1 week | 100% |
| Redesign | 11/5/18 | 1 week | 11/5/18 | 1 week | 100% |
| CDR | 11/4/18 | 8 weeks | 11/4/18 | 8 weeks | 100% |
| Fullscale Testing | 1/20/19 | 7 weeks | N/A | N/A | 0% |
| Payload Constuction | 1/27/19 | 8 weeks | N/A | N/A | 0% |
| FRR | 1/13/19 | 11 weeks | N/A | N/A | 0% |
| Payload Integration | 2/17/19 | 6 weeks | NA | NA | 0% |
| Competition Preparation | 3/17/19 | 3 weeks | NA | NA | 0% |
| LRR | 3/31/19 | 1 week | NA | NA | 0% |
| Competition Launch | 3/31/19 | 1 week | N/A | N/A | 0% |



# Structures and Propulsion Gantt Chart

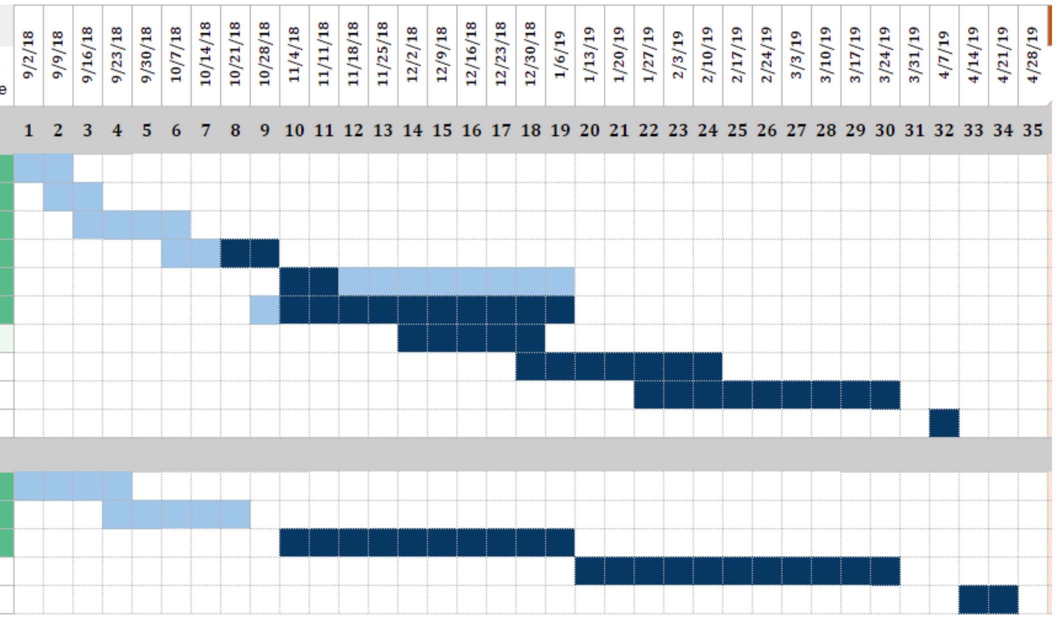
| | | | |
|---|---|---|---|
| Structures 2018-2019 | | CLUB NAME | Liontech Rocket Labs |
| Student Launch Gantt Chart | | DATE | 1/11/19 |

**Structures / Propulsion**

**2018-2019 Student Launch Gantt Chart**

**Legend**: Actual Date (light blue); Planned Date (dark blue)

| Technical Builds | Plan Start | Plan Duration | Actual Start | Actual Duration | Progress |
|---|---|---|---|---|---|
| Preliminary Vehicle Design | 9/2/18 | 2 weeks | 9/2/18 | 2 weeks | 100% |
| Subscale Design | 9/9/18 | 2 weeks | 9/9/18 | 3 weeks | 100% |
| Subscale Construction | 9/23/18 | 3 weeks | 9/16/18 | 4 weeks | 100% |
| Subscale Testing | 9/30/18 | 5 weeks | 10/7/18 | 4 weeks | 100% |
| Subscale Flight Analysis | 11/4/18 | 2 weeks | 11/4/18 | 4 weeks | 100% |
| Fullscale Desgin | 11/4/18 | 9 weeks | | N/A | 100% |
| Fullscale Construction | 12/2/18 | 5 weeks | N/A | N/A | 10% |
| Fullscale Testing | 1/20/19 | 7 weeks | N/A | N/A | 0% |
| Fullscale Flight Analysis | 1/27/19 | 9 weeks | N/A | N/A | 0% |
| Competition Launch | 4/7/19 | 1 week | N/A | N/A | 0% |
| **Reports** | | | | | |
| Proposal | 9/2/18 | 3 weeks | 9/2/18 | 4 weeks | 100% |
| PDR | 9/23/18 | 4 weeks | 10/21/18 | 4 weeks | 100% |
| CDR | 11/4/18 | 8 weeks | NA | NA | 100% |
| FRR | 1/13/19 | 11 weeks | NA | NA | 0% |
| PLAR | 4/14/19 | 2 weeks | NA | NA | 0% |



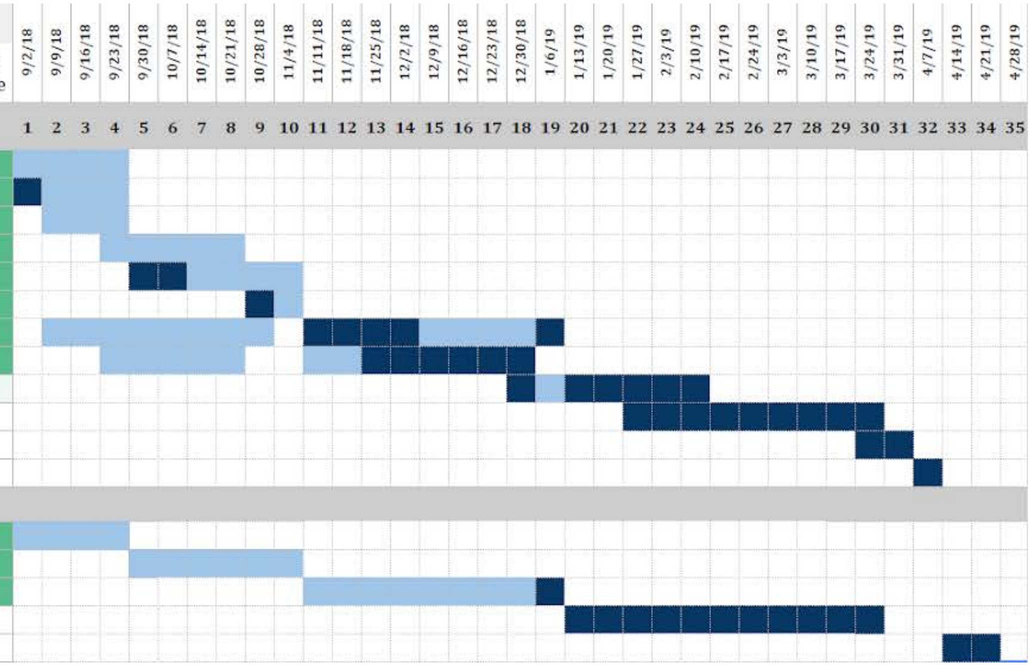
## Avionics and Recovery Gantt Chart

**Avionics and Recovery**

**2018-2019 SLI Gantt Chart**

**Legend**: Actual Date (light blue), Planned Date (dark blue)

| Technical Builds | Plan Start | Plan Duration | Actual Start | Actual Duration | Progress |
|---|---|---|---|---|---|
| Preliminary Recovery System Concept | 9/2/18 | 4 weeks | 9/2/18 | 4 weeks | 100% |
| Subscale AV Bay Design | 9/2/18 | 4 weeks | 9/9/18 | 3 weeks | 100% |
| Subscale Parachute Selection | 9/9/18 | 3 weeks | 9/9/18 | 3 weeks | 100% |
| Subscale AV Bay Construction | 9/23/18 | 5 weeks | 9/23/18 | 5 weeks | 100% |
| Subscale Recovery System Testing | 9/30/18 | 6 weeks | 10/14/18 | 4 weeks | 100% |
| Final Subscale Recovery System Verification | 10/28/18 | 2 weeks | 11/4/18 | 1 week | 100% |
| Fullscale AV Bay Desgin | 11/11/18 | 9 weeks | 9/2/18 | 12 weeks | 100% |
| Fullscale Parachute Selection | 12/2/18 | 5 weeks | 9/23/18 | 7 weeks | 100% |
| Fullscale AV Bay Construction | 12/30/18 | 7 weeks | 1/6/19 | NA | 10% |
| Fullscale Recovery System Testing | 1/27/19 | 9 weeks | NA | NA | 0% |
| Final Fullscale Recovery System Verification | 3/24/19 | 2 weeks | NA | NA | 0% |
| USLI Launch | 4/7/19 | 1 week | NA | NA | 0% |
| **Reports** | | | | | |
| Proposal | 9/2/18 | 4 weeks | 9/2/18 | 4 weeks | 100% |
| PDR | 9/30/18 | 7 weeks | 9/30/18 | 7 weeks | 100% |
| CDR | 11/18/18 | 8 weeks | 11/18/18 | 8 weeks | 99% |
| FRR | 1/13/19 | 11 weeks | NA | NA | 0% |
| PLAR | 4/14/19 | 2 weeks | NA | NA | 0% |



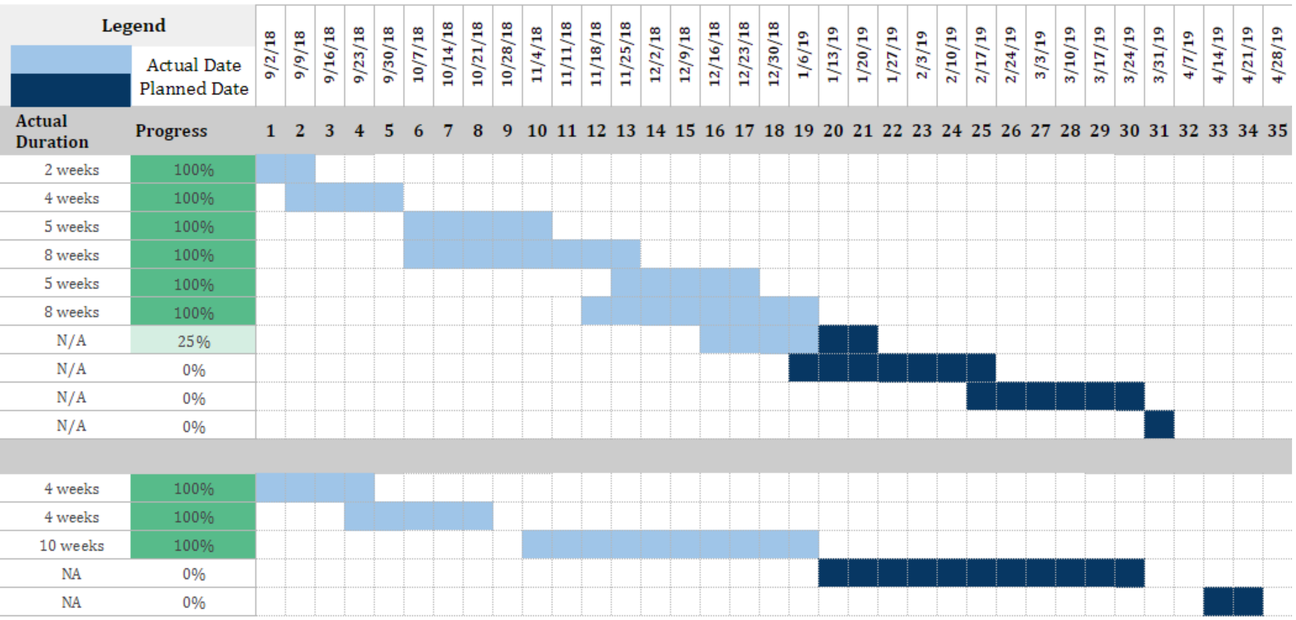
## Payload Gantt Chart

| | |
|---|---|
| Payload 2018-2019 | |
| Student Launch Gantt Chart | |
| CLUB NAME | Liontech Rocket Labs |
| DATE | 1/11/19 |

**Payload**

**2018-2019 Student Launch Gantt Chart**

| Technical Builds | Plan Start | Plan Duration | Actual Start | Actual Duration | Progress |
|---|---|---|---|---|---|
| Preliminary Vehicle Design | 9/2/18 | 2 weeks | 9/2/18 | 2 weeks | 100% |
| Equipment Selection | 9/9/18 | 2 weeks | 9/9/18 | 4 weeks | 100% |
| Motor Selection/Tread Design | 10/7/18 | 3 weeks | 10/7/18 | 5 weeks | 100% |
| Drive Train Design | 10/7/18 | 5 weeks | 10/7/18 | 8 weeks | 100% |
| Assembly of Rover | 11/18/18 | 4 weeks | 11/25/18 | 5 weeks | 100% |
| Complete Software | 11/18/18 | 9 weeks | 11/18/18 | 8 weeks | 100% |
| Consolodate Modules | 12/9/18 | 6 weeks | 12/16/18 | N/A | 25% |
| Test Subsystems of Rover | 1/6/19 | 7 weeks | N/A | N/A | 0% |
| Test Ful Assembly of Rover | 2/17/19 | 6 weeks | N/A | N/A | 0% |
| Pre Launch Modifications | 3/31/19 | 1 week | N/A | N/A | 0% |
| **Reports** | | | | | |
| Proposal | 9/2/18 | 3 weeks | 9/2/18 | 4 weeks | 100% |
| PDR | 9/23/18 | 4 weeks | 10/21/18 | 4 weeks | 100% |
| CDR | 11/4/18 | 8 weeks | 11/11/18 | 10 weeks | 100% |
| FRR | 1/13/19 | 11 weeks | NA | NA | 0% |
| PLAR | 4/14/19 | 2 weeks | NA | NA | 0% |



## 6.5 Budget

Table 52 displays the expected costs of the 2018-2019 with the updated design. This table includes every individual item that has been purchased so far and all of the projected costs.

**Table 53. Expected Outflow for 2018-2019**

| **Fullscale** | | | |
|---|---|---|---|
| Payload | Qt | Per item | Total |
| Radio | 1 | $58.22 | $58.22 |
| Soldering Iron and Soldering wire | 1 | | |
| Stainless Steel Tubing | 1 | | |
| Dual Shaft Motor | 1 | $7.62 | $7.62 |
| Miscellaneous | 1 | $100.00 | $100.00 |
| Structures | | | |
| 6.0” Fiberglass 4:1 Ogive Nosecone | 1 | $149.95 | $149.95 |
| 6.0” Fiberglass Coupler | 1 | $69.13 | $69.13 |
| 6.0” Blue Tube Couplers | 2 | $19.95 | $39.90 |
| 3K Plain Weave Carbon Fiber Wrapping | 2 | $249.95 | $499.90 |
| Low Temperature Release Film | 2 | $14.95 | $29.90 |
| Vacuum tubing | 1 | $1.55 | $1.55 |
| Vacuum Connectors | 1 | $5.25 | $5.25 |
| 2 Quart Resin Trap | 1 | $129.95 | $129.95 |
| 1.5” Rail Buttons | 1 | $4.65 | $4.65 |
| Center Rings 75mm to 6.00” | 3 | $13.55 | $40.65 |
| 3.0” Fiberglass Motor Tube | 1 | $50.00 | $50.00 |
| Plywood Bulkheads | 11 | $8.93 | $98.23 |
| 3.0” G12 Coupler | 1 | $15.00 | $15.00 |
| 6.0” Body Tube Full Length Coupler | 1 | $66.95 | $66.95 |

| | | | |
|---|---|---|---|
| Avionics and Recovery | | | |
| GPS Subscription | 1 | $65.00 | $65.00 |
| Propulsion | | | |
| L-Class Motor | 2 | $300.00 | $600.00 |
| | | **Fullscale Total** | **$2031.85** |
| **Subscale** | | | |
| Structures | | | |
| 75mm Blue Tube Full Length Coupler | 1 | $31.95 | $31.95 |
| Coupler Bulkhead Disk 75mm | 5 | $3.83 | $19.15 |
| PVA Release Form | 1 | $10.75 | $10.75 |
| 60 Minute Pot Life Hardener | 1 | $44.95 | $44.95 |
| Receipt Paper | 1 | $19.99 | $19.99 |
| Plastic Scrapers | 1 | $2.99 | $2.99 |
| Vacuum Connector | 1 | $4.95 | $4.95 |
| Vacuum Tubing | 3 | $1.45 | $4.35 |
| Plumber's Tape | 1 | $3.95 | $3.95 |
| Nylon Bagging Film | 1 | $24.95 | $24.95 |
| Low Temperature Release Film | 1 | $29.95 | $29.95 |
| Breather and Bleeder Cloth | 1 | $24.95 | $24.95 |
| Nylon Release Peel Ply | 1 | $39.95 | $39.95 |
| Sealant Tape (581-A) | 1 | $10.95 | $10.95 |
| 75mm Blue Tube Coupler | 1 | $9.95 | $9.95 |
| Carbon Fiber Fabric (530-C) | 1 | $249.95 | $249.95 |
| Centering Rings 54mm to 75mm | 3 | $7.30 | $21.90 |
| Tube Bulkhead Disk 75mm | 6 | $3.83 | $22.98 |

| | | | |
|---|---|---|---|
| Coupler Bulkhead Disk 75mm | 5 | $3.83 | $19.15 |
| Aeropak 54mm Retainer - L | 1 | $31.03 | $31.03 |
| Coupler Bulkhead Disk 6.0 | 5 | $8.93 | $44.65 |
| 75mm Blue Tube Coupler | 2 | $10.65 | $21.30 |
| Shipping Expenses | 1 | $100 | $100 |
| Propulsion | | | |
| Cesaroni J293BS | 1 | $73.00 | $73.00 |
| | | **Subscale Total** | **$867.69** |
| **Travel** | | | |
| Expected Hotel Costs - 2 Queen Bed Suites | 6 | $500.00 | $3,000.00 |
| Hotel Tax | 1 | $550 | $550 |
| Minivan Car Rentals | 5 | $400.00 | $2,000.00 |
| Fuel Costs - Alabama Trip | 5 | $140.00 | $700.00 |
| Fuel Costs - Fullscale | 1 | $400.00 | $400.00 |
| Fuel Costs - Subscale Launch | 1 | $100.00 | $100.00 |
| | | **Travel Total** | **$6,750.00** |
| **Outreach** | | | |
| Miscellaneous Supplies | 1 | $300.00 | $300.00 |
| | | **Outreach Total** | **$300.00** |
| | | **Final Total** | **10,949.54** |

In Table 52, the expected costs are broken up by fullscale, subscale, travel, outreach, and miscellaneous supplies and equipment. Fullscale and subscale are both broken up by subsystems. Subscale only lists purchased items from structures and propulsion because they are the only subsystems that bought new materials, as payload and avionics and recovery used equipment from the lab. Fullscale is a combination between purchased items and expected costs of items. Since the fullscale rocket is still being worked on, the subtotal for fullscale is not yet finalized. Travel continues to be the most expensive subsection. The estimates are becoming more accurate since the Alabama trip is approaching and this gives the club the opportunity to find specific estimates for the actual dates of the trip. Outreach costs contribute to the club's budget as miscellaneous supplies is necessary to host certain outreach events. Miscellaneous supplies and equipment are expenditures that are common use items in the lab. Most of these items are shared amongst subsystems, so these costs are noted under this header. Table 53 gives an overall outlook on where the club's funds are going for the 2018-2019 school year.

**Table 54. Overall Outflow**

| Budget | Total Cost |
|---|---|
| Fullscale | $2,031.85 |
| Subscale | $867.69 |
| Travel | $6,750.00 |
| Outreach | $300.00 |
| Miscellaneous | $500.00 |
| **Total** | **$10,449.54** |

Table 53 shows the total cost of each subsection from Table 52. This gives a better viewpoint of where the club's funds are going. The outflow shown in Table 53 can also be seen in chart form in Figure 47. Travel and fullscale continue to be the most expensive. Since the club tries to take as many students to Alabama as possible, a large amount of transportation and housing is necessary. Fullscale is also costly due to the large sized rocket and having proper equipment and materials to ensure the success of the rocket.

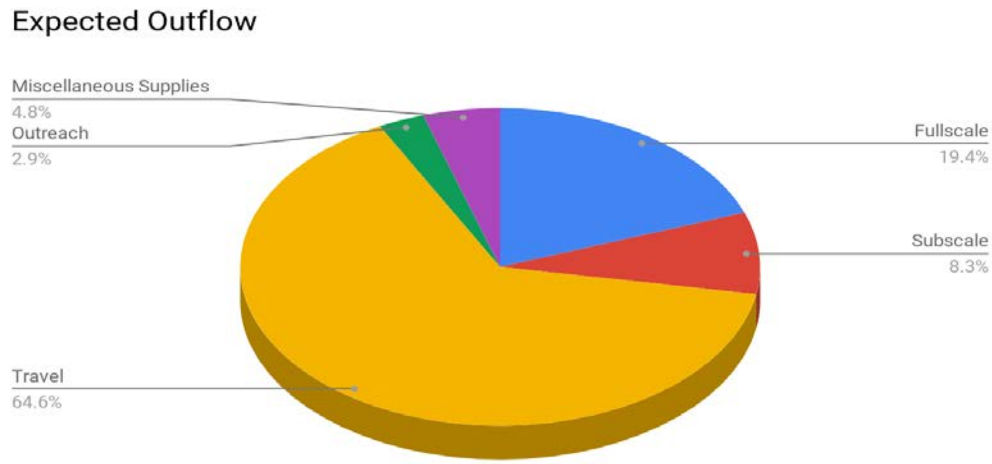



**Figure 47. Expected Outflow**

## 6.6 Funding

**Table 55. Expected Inflow for 2018-2019**

| Source of Funds | Received Funds |
|---|---|
| **Penn State College of Engineering** | $1,000.00 |
| **Penn State Aerospace Engineering Department** | $2,000.00 |
| **Penn State Mechanical Engineering Department** | $1,500.00 |
| **University Park Allocations Committee (UPAC)** | $10,000.00 |
| **Club Fundraising** | $1,250.00 |
| **Pennsylvania Space Grant** | $2,000.00 |
| **The Boeing Company** | $500.00 |
| **Total** | $18,250.00 |

Table 54 shows the club's current funding plan. The club believes to have ample funding needed in order to complete our mission. The College of Engineering has showed generous support last year and continues to. Penn State's Aerospace Engineering Department has not provided any funds this year so far but we expect to receive funding similar to last year. The PSU Mechanical and Nuclear Engineering Department has donated $1,500.00 to LTRL. The club expects to get $10,000.00 in funding from University Park Allocations Committee (UPAC) for both equipment and travel expenses. UPAC is a university sponsored club that helps other organizations financially. Their help will cover the majority of the travel expenses. Club fundraising accounts for the money the club itself brought about. This is mainly through dues as well as any other fundraising opportunities that may come about. The club has raised $1,250.00 so far by collecting dues. In order to better visualize the club's funding, the chart shown in Figure 48 displays the expected inflow.

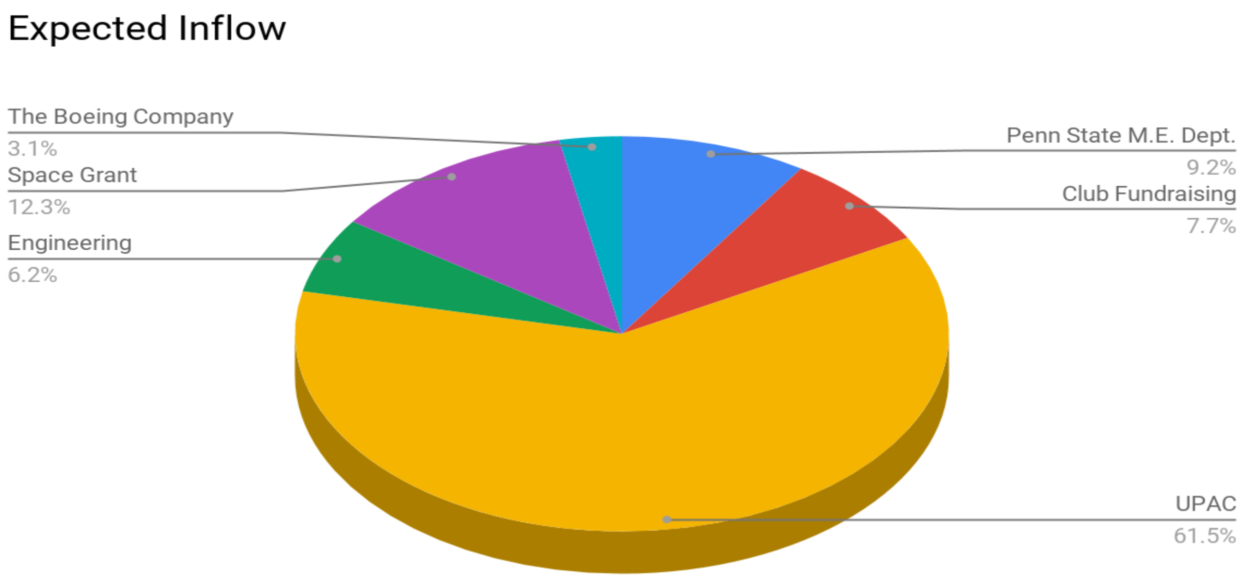



**Figure 48. Expected Inflow**

# 7. Appendix A: MSDS Sheets

Fibre Glast
Developments Corporation

**GHS SAFETY DATA SHEET (SDS)**

**SECTION 1 - PRODUCT AND COMPANY IDENTIFICATION**

**PRODUCT:** Part #2000 System 2000 Epoxy Resin

FIBRE GLAST DEVELOPMENTS CORP.
385 CARR DRIVE
BROOKVILLE, OH 45309

TELEPHONE: (937) 833-5200
FAX: (937) 833-6555
**FOR CHEMICAL EMERGENCY**
**CALL (801) 629-0667 24 HRS.**

**RECOMMENDED USE:** Industrial Epoxy Resin supplied exclusively for workplace use.

**SECTION 2 – HAZARDS IDENTIFICATION**

**GHS CLASSIFICATION**

| | |
|---|---|
| Eye Irritation | : Category 2B |
| Acute Toxicity (Oral) | : Category 5 |
| Skin Irritation | : Category 2 |
| Skin Sensitizer | : Category 1 |
| Respiratory Irritation | : STOT SE3 |

**GHS Label Element**
Hazard pictogram :

| | |
|---|---|
| Signal Word | : Warning |
| Hazard statements | : H320 Causes eye irritation.<br>H303 May be harmful if swallowed.<br>H315 Causes skin irritation.<br>H317 May cause an allergic skin reaction. |

PDCT-SDS-00130 [Version 1.01]
Page 1 of 6

Full SDS: https://s3.amazonaws.com/cdn.fibreglast.com/downloads/PDCT-SDS-00130.pdf

## Epoxy Hardener SDS

Fibre Glast Developments Corporation

### GHS SAFETY DATA SHEET (SDS)

**SECTION 1 - PRODUCT AND COMPANY IDENTIFICATION**

**PRODUCT:** Part #2060 Epoxy Hardener

FIBRE GLAST DEVELOPMENTS CORP.
385 CARR DRIVE
BROOKVILLE, OH 45309

TELEPHONE: (937) 833-5200
FAX: (937) 833-6555
**FOR CHEMICAL EMERGENCY**
**CALL (801) 629-0667 24 HRS.**

**RECOMMENDED USE:** Industrial Curing Agent supplied exclusively for workplace use.

**SECTION 2 – HAZARDS IDENTIFICATION**

**GHS CLASSIFICATION**

| | |
|---|---|
| Eye Damage | : Category 1 |
| Acute Toxicity (Oral and Inhalation) | : Category 4 |
| Skin Sensitizer | : Category 1 |

**GHS Label Element**
Hazard pictograms :

| | |
|---|---|
| Signal Word | : Danger |
| Hazard statements | : H318 Causes serious eye damage.<br>H302+332 Harmful if swallowed, or if inhaled.<br>H317 May cause an allergic skin reaction. |
| Precautionary statements | : P202 Do not handle until all safety precautions have been read/understood.<br>P261 Avoid breathing dust/fume/gas/mist/vapours/spray.<br>P270 Do not eat, drink or smoke when using this product.<br>P281 Use personal protective equipment as required.<br>P285 In case of inadequate ventilation wear respiratory protection.<br>P273 Avoid release to the environment. |

PDCT-SDS-00132 [Version 1.02]
Page 1 of 6

Full SDS: https://s3.amazonaws.com/cdn.fibreglast.com/downloads/PDCT-SDS-00132.pdf

## Black Powder SDS

1

**SAFETY DATA SHEET-BLACK POWDER**

**Section 1: Identification**

**Product Identifier**: Black Powder (includes all grades)

**Manufacturer's Name**: GOEX Powder, Inc. **Informational Telephone Number**:1-(318) 382-9300

**Address**: P.O. Box 659 **Emerg. Phone Number**: 1-(800) 255-3924 (Chem Tel)
Doyline, LA 71023-0659

**Recommended Use**: for use in competitive and recreational shooting, muzzleloading hunting and the U.S. Military .

**Section 2: Hazard(s) Identification**

| Hazard category: | Signal Word | Hazard statement | Pictogram |
|---|---|---|---|
| Division 1.1 | Danger | Explosive; mass explosion hazard |  |

**Target Organ Warning**: Above OSHA levels, chronic exposure may cause skin irritation and damage to the respiratory system, and acute exposure can cause skin, eye, and respiratory irritation.

**Section 3: Composition/information on ingredients**

| Component | CAS-Number | Weight % |
|---|---|---|
| Charcoal | 16291-96-6 | 8-18% |
| Sulfur | 7704-34-9 | 9-20% |
| Potassium Nitrate | 7757-79-1 | 70-76% |
| Graphite (note: not contained in all grades of black powder) | 7782-42-5 | <1% |

**Section 4: First-aid measures**

**Ingestion**: * Not a likely route of exposure. If ingested, dilute by giving two glasses of water and induce vomiting. Avoid, when possible and contact a Poison control center for advice on treatment, if unsure.

**Eye Contact**: * Not a likely route of exposure. Flush eyes with water.

**Inhalation**: * Remove patient from area to fresh air. If not breathing, give artificial respiration, preferably by mouth to mouth. If breathing is difficult, give oxygen. Seek prompt medical attention. Avoid when possible.

**Skin Contact**: * wash the affected area with copious amounts of water. Some persons may be sensitive to product.

**Injury from detonation**: * Seek prompt medical attention immediately.

**Note to Physician**: * Treat symptomatically.

**Section 5: Fire-fighting measures**

**Extinguishing media**: * Water may be used as the extinguishing method. DO NOT FIGHT EXPLOSIVES FIRES. Evacuate the area according to Emergency Response Guide 112 guidelines. Isolate the area and guard against any intruders.

**Special Procedures**: * Black Powder is extremely flammable and may deflagrate. Get away and evacuate the area.

**Unusual Hazards**: * As with any pyrotechnic, if under confinement or piled in slight confinement, Black Powder can explode. No known toxic fumes are emitted, but good ventilation should still be present.

**Flash Point**: not applicable.

**Auto ignition Temp**: Approximate range: 392° -867°F /(200°-464°C)

**NFPA Ratings**: **Health=1** **Flammability=3** **Reactivity=1**

**Advice and PPE for Firefighters**: * Fires involving Black Powder should not be fought unless extinguishing media can be applied from a well protected and distant location from the point of fire. Self-contained breathing apparatus (SCBA) and protective clothing must be worn. Follow Emergency Response Guide 112. Wash all clothes prior to reuse.

Full SDS: https://goexpowder.com/wp-content/uploads/2018/05/sds-sheets-goex-black-powder.pdf

# Carbon Fiber SDS

Fibre Glast Developments Corporation

**GHS SAFETY DATA SHEET (SDS)**

## SECTION 1 - PRODUCT AND COMPANY IDENTIFICATION

**PRODUCT:** Part #530 – 3K Plain Weave Carbon Fiber Fabric

FIBRE GLAST DEVELOPMENTS CORP.
385 Carr Drive
BROOKVILLE, OH 45309

TELEPHONE: (937) 833-5200
FAX: (937) 833-6555
**FOR CHEMICAL EMERGENCY**
**CALL (801) 629-0667 24 HRS.**

**RECOMMENDED USE:** Standard Composite Manufacturing

## SECTION 2 – HAZARDS IDENTIFICATION

**Classification of the substance or mixture**

| | |
|---|---|
| **OSHA Regulatory Status** | : This Product is Not Hazardous under the OSHA Hazard Communication Standard. |
| **Physical Hazards** | : Combustible Dust – USH01 |
| **Health Hazards** | : Not Classified |
| **Environmental Hazards** | : Not Classified |
| **Physicochemical** | : Physical: Carbon fiber contained in some products is electrically conductive. |

**Label elements**

| | |
|---|---|
| **Signal Word** | : Warning |
| **Hazard Statements** | : USH01 May form combustible dust concentrations in air |

**Other hazards**
Warning! This may cause mild, temporary mechanical eye and skin irritation. Vapor or fumes evolved during use and/or heating or curing the product may cause respiratory tract and eye irritation. Dust or particulates from machining, grinding or sawing the cured product may cause skin, eye and upper respiratory tract irritation, allergic skin reaction and possible sensitization.

PDCT-SDS-00074 [Version 1.01]
Page 1 of 7

Full SDS: https://s3.amazonaws.com/cdn.fibreglast.com/downloads/PDCT-SDS-00074.pdf

## Fiberglass SDS



# Fiberglass Safety Data Sheet

## SECTION 1: Identification of the substance/mixture and of the company/undertaking

**1.1 Product identifier**

- Fiberglass

**1.2 Relevant identified uses of the substance or mixture and uses advised against**

- Structural reinforcement for thermoset resin products.

**1.3 Details of the supplier of the safety data sheet**

- NOV Fiber Glass Systems
  17115 San Pedro Avenue, Suite 200
  San Antonio, Texas 78232 USA
  Tel: 1-210-477-7500
  Fax: 1-210-231-5915
  E-mail: Mike.Thayer@nov.com

**1.4 Emergency telephone number(s)**

- 3E Company, 24-Hour Support (Access Code/Contract Number: 333386)
  - USA, Canada .................................... 1-888-298-2344
  - Asia, Pacific ...................................... 1-760-476-3960
  - Europe, Middle East, Africa ............. 1-760-476-3961
  - Americas ........................................... 1-760-476-3962

## SECTION 2: Hazards identification

**2.1 Classification of the substance or mixture**

Physical

- Not classified

Health

- Skin irritation, Category 2
- Eye irritation – Category 2
- Specific target organ systemic toxicity – single exposure, Category 3 (respiratory tract irritation)

Environmental

- Not classified





Full SDS: http://www.nov.com/docHandler.aspx?puid=UvdNvuUs3oL35C

## Isopropyl Alcohol SDS

TSI MSDS 1080546 Rev H

Version: 1.2
Revision date: 03-06-2015

# SAFETY DATA SHEET

## 1. Identification

**Product identifier:** Isopropyl Alcohol

**Other means of identification**
**Product No.:** 9088, 5892, 9095, 9084, 9083, 9082, 9079, 9078, 9059, 9055, 9045, 5986, 5978, 5977, 5967, 5873, 5863, 9827, 5373, 9334

**Recommended use and restriction on use**
**Recommended use:** For use in the PortaCount® Respirator Fit Tester
**Restrictions on use:** Not known.

**Manufacturer/Importer/Supplier/Distributor information**
**Manufacturer**

| | |
|---|---|
| Company Name: | TSI Incorporated |
| Address: | 500 Cardigan Road<br>Shoreview, MN 55126 |
| Telephone: | Customer Service: 800-874-2811 |
| Fax: | |
| Contact Person: | |
| e-mail: | answers@tsi.com |

**Emergency telephone number:**
24 Hour Emergency: 908-859-2151

Chemtrec: 800-424-9300

## 2. Hazard(s) identification

**Hazard classification**

**Physical hazards**

| | |
|---|---|
| Flammable liquids | Category 2 |

**Health hazards**

| | |
|---|---|
| Serious eye damage/eye irritation | Category 2A |
| Specific target organ toxicity - single exposure | Category 3 |

**Label elements**
**Hazard symbol:**

**Signal word:** Danger

**Hazard statement:** Highly flammable liquid and vapor. Causes serious eye irritation. May cause respiratory irritation. May cause drowsiness or dizziness.

SDS_US - SDS000000696 Page 1 of 10

Full SDS: http://www.tsi.com/uploadedFiles/_Site_Root/Products/Literature/MSDS/1080546-MSDS-Isopropyl-Alcohol-TSI.pdf

## J-B Kwik SDS

# MATERIAL SAFETY DATA SHEET

## 1. Product and Company Identification

| | |
|---|---|
| **Product Name** | **J-B Kwik** |
| **Synonym(s)** | Resin and Hardener |
| **CAS #** | Mixture |
| **Product use** | Bonds and repairs |
| **Manufacturer** | J-B Weld Company<br>P.O. Box 483<br>Sulphur Springs, TX 75482 US<br>Phone: 903-885-7696 |

## 2. Hazards Identification

**Emergency overview**
CAUTION
MAY CAUSE EYE IRRITATION. MAY CAUSE SKIN IRRITATION.
MAY CAUSE ALLERGIC SKIN REACTION.

**Potential short term health effects**

- **Routes of exposure**: Eye, Skin contact, Ingestion.
- **Eyes**: May cause irritation.
- **Skin**: Contact with skin can cause irritation and allergic reaction (sensitization) in some individuals.
- **Inhalation**: Not a normal route of exposure.
- **Ingestion**: May cause stomach distress, nausea or vomiting.

**Target organs**: Eyes. Skin.

**Chronic effects**: Prolonged or repeated exposure can cause drying, defatting and dermatitis.

**Signs and symptoms**: Symptoms may include redness, edema, drying, defatting and cracking of the skin. Symptoms of overexposure may be headache, dizziness, tiredness, nausea and vomiting.

**OSHA Regulatory Status**: This product is a "Hazardous Chemical" as defined by the OSHA Hazard Communication Standard, 29 CFR 1910.1200.

**Potential environmental effects**: See section 12.

## 3. Composition / Information on Ingredients

| Ingredient(s) | CAS # | Percent |
|---|---|---|
| Iron | 7439-89-6 | 5 - 10 |
| Limestone | 1317-65-3 | 10 - 30 |
| Oxirane, 2,2-[(1-methylethylidene)bis(4,1-phenyleneoxymethylene)]bis, homopolymer | 25085-99-8 | 10 - 30 |
| Phenol, 2,4,6-tris[(dimethylamino)methyl]- | 90-72-2 | 1 - 5 |
| Phenol, polymer with formaldehyde, glycidyl ether | 28064-14-4 | 1 - 5 |
| Carbon black | 1333-86-4 | 0.1 - 1 |
| Titanium oxide | 13463-67-7 | 0.1 - 1 |

## 4. First Aid Measures

**First aid procedures**

- **Eye contact**: Flush with cool water. Remove contact lenses, if applicable, and continue flushing. Obtain medical attention if irritation persists.
- **Skin contact**: Flush with cool water. Wash with soap and water. Obtain medical attention if irritation persists.
- **Inhalation**: Not a normal route of exposure.
- **Ingestion**: Do not induce vomiting. Never give anything by mouth if victim is unconscious, or is convulsing. Obtain medical attention.

#19863 Page 1 of 8 Issue date 10-May-2012

Full SDS: https://cdn.shopify.com/s/files/1/0411/5921/files/J-B-Weld-MSDS-KwikWeld.pdf?1921

## J-B Steel Reinforced Epoxy Resin SDS

# SAFETY DATA SHEET

**Issuing Date** 11-Nov- 2014 **Revision Date** 11-Nov-2014 **Revision Number** 1

### 1. IDENTIFICATION OF THE SUBSTANCE/PREPARATION AND OF THE COMPANY/UNDERTAKING

**Product identifier**

**Product SDS Name** **Steel Reinforced Epoxy Resin – Twin Tubes - Part A**

**J-B Weld FG SKU Part Numbers Covered**

**8265, 8265F, 8276, 8276F, 8265S, 8265A, 8265H, 8272, 8272F, 8280, 8280F, 8281, 80165, 7265S, 7280, 8276A, 8273H, 8270, 8270F, 8271, 80176, 7276, 7270**

**J-B Weld Product Names Covered**

**J-B Weld™ (all Twin Tubes), KwikWeld™ (all Twin Tubes), MarineWeld™ (Twin Tubes Only)**

**J-B Weld Product Type**

**Steel Reinforced Epoxy**

**Recommended use of the chemical and restrictions on use**

| | |
|---|---|
| **Recommended Use** | General Purpose Adhesive |
| **Uses advised against** | No information available |

**Details of the supplier of the safety data sheet**

| | |
|---|---|
| **Supplier Name** | J-B WELD COMPANY,LLC |
| **Supplier Address** | 1130 COMO ST<br>SULPHUR SPRINGS, TX 75482<br>USA |
| **Emergency Telephone Numbers** | Transportation Emergencies: Chemtrec (24 hour transportation emergency response info): 800-424-9300 or 703-527-3887<br>Poison/Medical Emergencies: Poison Control Centers (24 hour emergency poison / medical response info): 800-222-1222 |
| **Supplier Email** | info@jbweld.com |
| **Supplier Phone Number** | 903-885-7696 |

### 2. HAZARDS IDENTIFICATION

| | |
|---|---|
| **OSHA/HCS status** | This material is considered hazardous by the OSHA Hazard Communication Standard (29 CFR 1910.1200). |
| **Classification of the substance or mixture** | SKIN CORROSION/IRRITATION - Category 2<br>SERIOUS EYE DAMAGE/ EYE IRRITATION - Category 2B |
| **GHS label elements** | SKIN SENSITIZATION - Category 1 |

| | |
|---|---|
| **Hazard pictograms** | |
| **Signal word** | Warning! |
| **Hazard statements** | Causes skin and eye irritation.<br>May cause an allergic skin reaction. |

Full SDS:
https://cdn.shopify.com/s/files/1/0411/5921/files/Steel_Reinforced_Epoxy_Twin_Tubes.pdf?785811878289892783

Synthetic Hi-Temp Grease, No.2 SDS

# SAFETY DATA SHEET

Mystik® JT-6® Synthetic Hi-Temp Grease, No. 2, ISO 220

Mystik LUBRICANTS

## Section 1. Identification

| | | |
|---|---|---|
| **GHS product identifier** | : | Mystik® JT-6® Synthetic Hi-Temp Grease, No. 2, ISO 220 |
| **Synonyms** | : | Lubricating grease;<br>CITGO® Material Code: 665077002 |
| **Code** | : | 665077002 |
| **MSDS #** | : | 665077002 |
| **Supplier's details** | : | CITGO Petroleum Corporation<br>P.O. Box 4689<br>Houston, TX 77210<br>sdsvend@citgo.com |
| **Emergency telephone number** | : | Technical Contact: (800) 248-4684<br>Medical Emergency: (832) 486-4700<br>CHEMTREC Emergency: (800) 424-9300<br>(United States Only) |

## Section 2. Hazards identification

| | | |
|---|---|---|
| **OSHA/HCS status** | : | While this material is not considered hazardous by the OSHA Hazard Communication Standard (29 CFR 1910.1200), this SDS contains valuable information critical to the safe handling and proper use of the product. This SDS should be retained and available for employees and other users of this product. |
| **Classification of the substance or mixture** | : | Not classified. |
| **GHS label elements** | | |
| **Signal word** | : | Warning |
| **Hazard statements** | : | Injection under the skin can cause severe injury.<br>Most damage occurs in the first few hours.<br>Initial symptoms may be minimal. |
| **Precautionary statements** | | |
| **General** | : | Avoid contact with eyes, skin and clothing.. IF IN EYES: Rinse cautiously with water for several minutes. IF SWALLOWED: Do NOT induce vomiting. After handling, always wash hands thoroughly with soap and water. If you feel unwell, seek medical attention and show the label when possible. Keep out of reach of children. |
| **Prevention** | : | Not applicable. |
| **Response** | : | Not applicable. |
| **Storage** | : | Store in a dry place and/or in closed container. Store in accordance with all local, regional, national and international regulations. |
| **Disposal** | : | Dispose of contents and container in accordance with all local, regional, national and international regulations. |
| **Hazards not otherwise classified** | : | Injection of petroleum hydrocarbons requires immediate medical attention |

## Section 3. Composition/information on ingredients

| | | |
|---|---|---|
| **Substance/mixture** | : | Mixture |
| **Other means of identification** | : | Lubricating grease;<br>CITGO® Material Code: 665077002 |
| **CAS number/other identifiers** | | |
| **CAS number** | : | Not applicable. |

*Date of issue/Date of revision* : 1/21/2016 1/9

Full SDS: http://docs.mystiklubes.com/msds_pi/665077002.pdf

## Spray Paint SDS

# SAFETY DATA SHEET

51601

## Section 1. Identification

| | |
|---|---|
| **Product name** | : KRYLON® ColorMaster™ with Covermax™ Technology Paint + Primer Gloss Black |
| **Product code** | : 51601 |
| **Other means of identification** | : Not available. |
| **Product type** | : Aerosol. |

**Relevant identified uses of the substance or mixture and uses advised against**

Paint or paint related material.

| | |
|---|---|
| **Manufacturer** | : Krylon Products Group<br>101 W. Prospect Avenue<br>Cleveland, OH 44115 |
| **Emergency telephone number of the company** | : US / Canada: (216) 566-2917<br>Mexico: SETIQ 01-800-00-214-00 / (52) 55-5559-1588 24 hours / 365 days a year |
| **Product Information Telephone Number** | : US / Canada: (800) 457-9566<br>Mexico: Not Available |
| **Regulatory Information Telephone Number** | : US / Canada: (216) 566-2902<br>Mexico: Not Available |
| **Transportation Emergency Telephone Number** | : US / Canada: (216) 566-2917<br>Mexico: SETIQ 01-800-00-214-00 / (52) 55-5559-1588 24 hours / 365 days a year |

## Section 2. Hazards identification

| | |
|---|---|
| **OSHA/HCS status** | : This material is considered hazardous by the OSHA Hazard Communication Standard (29 CFR 1910.1200). |
| **Classification of the substance or mixture** | : FLAMMABLE AEROSOLS - Category 1<br>GASES UNDER PRESSURE - Compressed gas<br>SKIN CORROSION/IRRITATION - Category 2<br>SERIOUS EYE DAMAGE/ EYE IRRITATION - Category 2A<br>CARCINOGENICITY - Category 2<br>SPECIFIC TARGET ORGAN TOXICITY (SINGLE EXPOSURE) (Respiratory tract irritation) - Category 3<br>SPECIFIC TARGET ORGAN TOXICITY (SINGLE EXPOSURE) (Narcotic effects) - Category 3<br>SPECIFIC TARGET ORGAN TOXICITY (REPEATED EXPOSURE) - Category 2<br>ASPIRATION HAZARD - Category 1<br>Percentage of the mixture consisting of ingredient(s) of unknown oral toxicity: 39.3%<br>Percentage of the mixture consisting of ingredient(s) of unknown dermal toxicity: 70.8%<br>Percentage of the mixture consisting of ingredient(s) of unknown inhalation toxicity: 72.2% |

**GHS label elements**

**Hazard pictograms** :

**Signal word** : Danger

| | | | | | |
|---|---|---|---|---|---|
| *Date of issue/Date of revision* | *: 10/26/2018* | *Date of previous issue* | *: 10/12/2018* | *Version : 11* | *1/17* |
| 51601 | KRYLON® ColorMaster™ with Covermax™ Technology Paint + Primer Gloss Black | | | **SHW-85-NA-GHS-US** | |

Full SDS: https://www.krylon.com/document/SDS/en/US/724504016014

## Talcum Powder Resin SDS

# TALC

Safety Data Sheet

according to Federal Register / Vol. 77, No. 58 / Monday, March 26, 2012 / Rules and Regulations

Date of issue: 09/11/2012 Revision date: 05/09/2016 Supersedes: 02/06/2015 Version: 2.1

## SECTION 1: Identification

### 1.1. Identification

| | |
|---|---|
| Product form | : Mixture |
| Product name | : TALC |
| Product code | : C-MS-AT-2042STDTALC |
| Other means of identification | : A-0005 FILLER, ABT® 1000, ABT® 2500, ABT® 2501, CERCRON® MB 2900, CERCRON® MB 3900, CERCRON® MB 50-60, CERCRON® MB 93-37, CERCRON® MB 96-67, CERCRON® MB 96-68, CERCRON® MB 99-01, CERCRON® MP 97-30, CERCRON® MP 98-25, CERCRON® MP 99-48, MICROTALC® BP-210, MICROTALC® DM 12-50, MICROTALC® MP 10-52, MICROTALC® MP 11-51, MICROTALC ®MP 12-50, 399 TALC, MICROTALC® MPD 12-50, MICROTALC® MP 12-52, MICROTALC® MP 15-38, MICROTALC® MP 20-40, MICROTALC® MP 25-38, MICROTALC® MP 30-36, MICROTALC® MP 50-26, MICROTALC® MP 70-22, MICROTALC® MP 98-28BC, MICROTALC® MP 45-26 BC, MICROTALC® MPD 2500, MICROTALC® MPD 2501, MICROTALC MPD1250UC, MICROTALC MP210, MICROTUFF® 111, MICROTUFF® 191, PC 2000, TALCRON® MP 10-52, TALCRON® MP 12-50, TALCRON® MP 15-38, TALCRON® MP 25-38, TALCRON® MP 30-36, TALCRON® MP 40-27, TALCRON® MP 44-26, TALCRON® 45-26, ULTRATALC® 609, ULTRATALC® 609D, 9910 Talc, TALCRON 25 LOA, TALCRON 35 LOA, TALCRON 40 LOA, TALCRON 45 LOA, TALCRON 30 LOA, FLEXTALC 405D, FORTI-TALC™ 609LC TALC, FORTI-TALC™ 609HC TALC, FORTI-TALC™ MP1250LC TALC, FORTI-TALC™ MP1250HC TALC, FORTI-TALC™ MP1250UC TALC, FORTI-TALC™ MP1538LC TALC, FORTI-TALC™ MP1538HC TALC, TALCRON MP2040, PC 2000, ICMP 4426, FORTI-TALC™ AG111 LC TALC, FORTI-TALC™ AG111 HC TALC |

### 1.2. Relevant identified uses of the substance or mixture and uses advised against

Use of the substance/mixture : Mineral Additive

### 1.3. Details of the supplier of the safety data sheet

Barretts Minerals Inc.
8625 Highway 91 South
Dillon,. MT 59725
USA

Tel. 406-683-3323

### 1.4. Emergency telephone number

Emergency number : +1 760 476 3962
3E Global Emergency Response Services. Access code: 333336 (if you mention SDS name and company name-you don't need the access code)

## SECTION 2: Hazard(s) identification

### 2.1. Classification of the substance or mixture

**GHS-US classification**

Carcinogenicity Category 1A H350

Full text of H statements : see section 16

### 2.2. Label elements

**GHS-US labeling**

Hazard pictograms (GHS-US) :

GHS08

| | |
|---|---|
| Signal word (GHS-US) | : Danger |
| Hazard statements (GHS-US) | : H350 - May cause cancer (Inhalation) |
| Precautionary statements (GHS-US) | : P201 - Obtain special instructions before use<br>P202 - Do not handle until all safety precautions have been read and understood<br>P260 - Do not breathe dust<br>P280 - Wear protective gloves, protective clothing, eye protection, face protection |

05/09/2016 EN (English US) Page 1

Full SDS:
https://www.mineralstech.com/docs/defaultsource/company/talc.pdf?sfvrsn=47ea573b_2

## Acetone SDS

**SAFETY DATA SHEET**

**Klean-Strip Acetone**

Page: 1

Revision: 05/24/2017
Supersedes Revision: 04/15/2015

### 1. PRODUCT AND COMPANY IDENTIFICATION

| | | |
|---|---|---|
| **Product Name:** | Klean-Strip Acetone | |
| **Company Name:** | W. M. Barr<br>2105 Channel Avenue<br>Memphis, TN 38113 | **Phone Number:**<br>(901)775-0100 |
| **Web site address:** | www.wmbarr.com | |
| **Emergency Contact: Information:** | 3E 24 Hour Emergency Contact<br>W.M. Barr Customer Service | (800)451-8346<br>(800)398-3892 |
| **Intended Use:** | Paint, stain, and varnish thinning. | |
| **Product Code:** | CAC18, DAC18, GAC18, GAC182, QAC18, QAC184, PA12270, GAC18HDQP, GAC18HDWS, GAC18P, PAC181 | |

### 2. HAZARDS IDENTIFICATION

**Flammable Liquids, Category 2**
**Serious Eye Damage/Eye Irritation, Category 2**
**Specific Target Organ Toxicity (single exposure), Category 3**

| | |
|---|---|
| **GHS Signal Word:** | **Danger** |
| **GHS Hazard Phrases:** | H225: Highly flammable liquid and vapor.<br>H319: Causes serious eye irritation.<br>H335: May cause respiratory irritation.<br>H336: May cause drowsiness or dizziness. |
| **GHS Precaution Phrases:** | P233: Keep container tightly closed.<br>P210: Keep away from heat/sparks/open flames/hot surfaces. - No smoking.<br>P280: Wear protective gloves/protective clothing/eye protection/face protection.<br>P240: Ground/bond container and receiving equipment.<br>P241: Use explosion-proof electrical/ventilating/lighting equipment.<br>P243: Take precautionary measures against static discharge.<br>P242: Use only non-sparking tools.<br>P264: Wash hands thoroughly after handling.<br>P261: Avoid breathing gas/mist/vapours/spray.<br>P271: Use only outdoors or in a well-ventilated area. |
| **GHS Response Phrases:** | P370+378: In case of fire, use dry chemical to extinguish.<br>P303+361+353: IF ON SKIN (or hair): Remove/take off immediately all contaminated clothing. Rinse skin with water/shower.<br>P305+351+338: IF IN EYES: Rinse cautiously with water for several minutes. Remove contact lenses, if present and easy to do. Continue rinsing.<br>P337+313: If eye irritation persists, get medical advice/attention.<br>P304+340: IF INHALED: Remove victim to fresh air and keep at rest in a position comfortable for breathing.<br>P312: Call a POISON CENTER/doctor if you feel unwell. |
| **GHS Storage and Disposal Phrases:** | P403+235: Store in cool/well-ventilated place.<br>P501: Dispose of contents/container according to local, state and federal regulations.<br>P403+233: Store container tightly closed in well-ventilated place - if product is as volatile as to generate hazardous atmosphere.<br>P405: Store locked up. |



**GHS format**

Full SDS: http://www.kleanstrip.com/uploads/documents/GAC18_SDS-LL34.pdf

Water Seal SDS

# SAFETY DATA SHEET

2411-

## Section 1. Identification

**Product name** : THOMPSON'S WATER SEAL® Clear Multi-Surface Waterproofer

**Product code** : 2411-

**Other means of identification** : Not available.

**Product type** : Liquid.

**Relevant identified uses of the substance or mixture and uses advised against**

Not applicable.

**Manufacturer** : THE THOMPSON'S COMPANY
101 Prospect Ave. N.W.
Cleveland, OH 44115

**Emergency telephone number of the company** : (216) 566-2917

**Product Information Telephone Number** : (800) 367-6297

**Regulatory Information Telephone Number** : (216) 566-2902

**Transportation Emergency Telephone Number** : (800) 424-9300

## Section 2. Hazards identification

**OSHA/HCS status** : This material is considered hazardous by the OSHA Hazard Communication Standard (29 CFR 1910.1200).

**Classification of the substance or mixture** : CARCINOGENICITY - Category 2
SPECIFIC TARGET ORGAN TOXICITY (REPEATED EXPOSURE) - Category 2

Percentage of the mixture consisting of ingredient(s) of unknown toxicity: 15.4%

**GHS label elements**

**Hazard pictograms** :

**Signal word** : Warning

**Hazard statements** : Suspected of causing cancer.
May cause damage to organs through prolonged or repeated exposure.

**Precautionary statements**

**General** : Read label before use. Keep out of reach of children. If medical advice is needed, have product container or label at hand.

**Prevention** : Obtain special instructions before use. Do not handle until all safety precautions have been read and understood. Use personal protective equipment as required. Do not breathe vapor.

**Response** : Get medical attention if you feel unwell. IF exposed or concerned: Get medical attention.

**Storage** : Store locked up.

**Disposal** Dispose of contents and container in accordance with all local, regional, national and international regulations.

| Date of issue/Date of revision | : 4/7/2015. | Date of previous issue | : No previous validation. | Version : 1 | 1/10 |
|---|---|---|---|---|---|

Full SDS: http://archpdfs.lps.org/Chemicals/Thompsons-Water-Seal.pdf

## Paint Thinner SDS

**SAFETY DATA SHEET**
**Klean Strip Paint Thinner**

Page: 1

Revision: 05/24/2017
Supersedes Revision: 11/16/2015

### 1. PRODUCT AND COMPANY IDENTIFICATION

| | | |
|---|---|---|
| **Product Name:** | Klean Strip Paint Thinner | |
| **Company Name:** | W. M. Barr<br>2105 Channel Avenue<br>Memphis, TN 38113 | **Phone Number:**<br>(901)775-0100 |
| **Web site address:** | www.wmbarr.com | |
| **Emergency Contact: Information:** | 3E 24 Hour Emergency Contact<br>W.M. Barr Customer Service | (800)451-8346<br>(800)398-3892 |
| **Intended Use:** | Paint, stain, and varnish thinning. | |
| **Product Code:** | CKPT94402, GKPT94002B, DKPT94403CA, EKPT94401, GKPT94002, GKPT94002P, GKPT94002T, GKPT94400, PA12779, QKPT94003, QKPT94203, GKPT94002HDWS, GKPT94002PT, PKPT94004 | |

### 2. HAZARDS IDENTIFICATION

**Flammable Liquids, Category 3**
**Acute Toxicity: Inhalation, Category 4**
**Skin Corrosion/Irritation, Category 2**
**Serious Eye Damage/Eye Irritation, Category 2B**
**Germ Cell Mutagenicity, Category 1B**
**Toxic To Reproduction, Category 2**
**Specific Target Organ Toxicity (single exposure), Category 3**
**Specific Target Organ Toxicity (repeated exposure), Category 2**
**Aspiration Toxicity, Category 1**

**GHS Signal Word:** **Danger**

**GHS Hazard Phrases:**
H226: Flammable liquid and vapor.
H304: May be fatal if swallowed and enters airways.
H315: Causes skin irritation.
H320: Causes eye irritation.
H332: Harmful if inhaled.
H336: May cause drowsiness or dizziness.
H340: May cause genetic defects.
H361: Suspected of damaging fertility or the unborn child.
H373: May cause damage to Central Nervous System (CNS) through prolonged or repeated exposure.

**GHS Precaution Phrases:**
P201: Obtain special instructions before use.
P202: Do not handle until all safety precautions have been read and understood.
P210: Keep away from heat/sparks/open flames/hot surfaces. - No smoking.
P233: Keep container tightly closed.
P240: Ground/bond container and receiving equipment.
P241: Use explosion-proof electrical/ventilating/lighting equipment.
P242: Use only non-sparking tools.
P243: Take precautionary measures against static discharge.
P260: Do not breathe gas/mist/vapors/spray.
P264: Wash hands thoroughly after handling.
P271: Use only outdoors or in a well-ventilated area.
P280: Wear protective gloves/protective clothing/eye protection/face protection.
P281: Use personal protective equipment as required.

Licensed to W.M. Barr and Company — **GHS format**

Full SDS: http://www.kleanstrip.com/uploads/documents/GKPT94002_SDS-GL42E.pdf

## Fiberglass Resin SDS

Bondo® Fiberglass Resin Kit, P.N. 401, 401C, 402, 402M, 402C, 402ES, 402T, 402Z, 404, 404C, 404Z 01/12/18

# Safety Data Sheet



| | | | |
|---|---|---|---|
| **Document Group:** | 24-2437-2 | **Version Number:** | 7.01 |
| **Issue Date:** | 01/12/18 | **Supercedes Date:** | 09/04/15 |

**Product identifier**
Bondo® Fiberglass Resin Kit, P.N. 401, 401C, 402, 402M, 402C, 402ES, 402T, 402Z, 404, 404C, 404Z

**ID Number(s):**

60-4550-4826-8, 60-4550-5662-6, 60-4550-5663-4, 60-4550-5664-2, 60-4550-5665-9, 60-4550-5666-7, 60-4550-5667-5, 60-4550-6602-1, 60-4550-6603-9, 60-4550-6605-4, 60-4550-6742-5, 60-4550-7373-8, 60-4550-7374-6, 60-4550-7375-3, 60-4550-7376-1, 60-4550-7377-9, 60-4550-8100-4, 60-4550-8101-2, 60-4550-8102-0, 60-4550-8287-9, 60-4550-8288-7, 60-4550-8297-8, 60-4550-8298-6, 60-4550-8299-4, 60-4550-8325-7, 60-4550-8326-5, 60-4550-8327-3, 70-0080-0014-6, 70-0080-0015-3, 70-0080-0016-1, 70-0080-0148-2, 70-0080-0149-0, 70-0080-0150-8, 70-0080-0151-6, 70-0080-0152-4, 70-0080-0153-2

**Recommended use**
Automotive, Repairing Auto Body

**Supplier's details**

| | |
|---|---|
| **MANUFACTURER:** | 3M |
| **DIVISION:** | Automotive Aftermarket |
| **ADDRESS:** | 3M Center, St. Paul, MN 55144-1000, USA |
| **Telephone:** | 1-888-3M HELPS (1-888-364-3577) |

**Emergency telephone number**
1-800-364-3577 or (651) 737-6501 (24 hours)

**This product is a kit or a multipart product which consists of multiple, independently packaged components. A Safety Data Sheet (SDS), Article Information Sheet (AIS), or Article Information Letter (AIL) for each of these components is included. Please do not separate the component documents from this cover page. The document numbers for components of this product are:**

24-2429-9, 24-2440-6

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Page 1 of 2

Full SDS:
https://multimedia.3m.com/mws/mediawebserver?mwsId=SSSSSuUn_zu8l00xM8tvNxm1Mv70k17zHvu9lxtD7SSSSSS--

## Pyro-Paint SDS

# SAFETY DATA SHEET

**Product:** **634-ZO**
Revision Date: 6/01/2015

## 1. MATERIAL IDENTIFICATION

**Product Name:** **Pyro-Paint 634-ZO**

**Product Description:** Off-White, Odorless Liquid
**Product Use:** High Temperature Coating

**Manufacturer:** Aremco Products, Inc.
707-B Executive Blvd.
Valley Cottage, NY 10989

**Telephone:** 845-268-0039
**Emergency Phone:** 845-268-0039 or Infotrac (24/7) 800-535-5053

## 2. HAZARDS IDENTIFICATION

***GHS Classification:***
Eye Irritation Category 2A
Skin Irritation Category 2

***GHS Symbol:***

***GHS Signal Word:***
Warning

***GHS Hazard Determining Components:***
Silicate Solution
Zirconium Oxide
Alumino-Silicate

***GHS Hazard Statements for Health Hazards:***

| | |
|---|---|
| H303 | Harmful if swallowed. |
| H315 | Causes skin irritation. |
| H319 | Causes serious eye irritation. |

***GHS Precautionary Statements - Prevention:***

| | |
|---|---|
| P264 | Wash hands thoroughly after handling. |
| P280 | Wear protective gloves. Wear eye protection. |

***GHS Precautionary Statements – Response:***

| | |
|---|---|
| P302 + P352 | IF ON SKIN: Wash with plenty of soap and water. |
| P332 + P313 | If skin irritation occurs: Get medical advice/attention. |
| P305 + P351 + P338 | IF IN EYES: Remove contact lenses, if present and easy to do. Rinse cautiously with water for several minutes. |
| P312 | IF SWALLOWED: Call a poison center or doctor if you feel unwell |
| P362 | Take off contaminated clothing and wash before reuse. |

***GHS Storage/Disposal:***

| | |
|---|---|
| P501 | Dispose in accordance with local, regional, national or international regulations |

1

Full SDS: https://www.audec.co.jp/products/pdf/msds_bond107.pdf

## WD-40 SDS


# Safety Data Sheet

**1 - Identification**

| | |
|---|---|
| **Product Name: WD-40 Multi-Use Product Aerosol** ***NOT FOR SALE IN CALIFORNIA*** <br><br> **Product Use: Lubricant, Penetrant, Drives Out Moisture, Removes and Protects Surfaces From Corrosion** <br><br> **Restrictions on Use: None identified** <br><br> **SDS Date Of Preparation: 07/20/2014** | **Manufacturer: WD-40 Company** <br> **Address: 1061 Cudahy Place (92110)** <br> **P.O. Box 80607** <br> **San Diego, California, USA** <br> **92138 –0607** <br> **Telephone:** <br> **Emergency only: 1-888-324-7596 (PROSAR)** <br> **Information: 1-888-324-7596** <br> **Chemical Spills: 1-800-424-9300 (Chemtrec)** <br> **1-703-527-3887 (International Calls)** |

**2 – Hazards Identification**

**Hazcom 2012/GHS Classification:**
Flammable Aerosol Category 1
Gas Under Pressure: Compressed Gas
Aspiration Toxicity Category 1

Note: This product is a consumer product and is labeled in accordance with the US Consumer Product Safety Commission regulations which take precedence over OSHA Hazard Communication labeling. The actual container label will not include the label elements below. The labeling below applies to industrial/professional products.

**Label Elements:**

**DANGER!**
Extremely Flammable Aerosol.
Contains gas under pressure; may explode if heated.
May be fatal if swallowed and enters airways.
**Prevention**
Keep away from heat, sparks, open flames, hot surfaces – No smoking.
Do not spray on an open flame or other ignition source.
Pressurized container: Do not pierce or burn, even after use.
**Response**
IF SWALLOWED: Immediately call a POISON CENTER or physician. Do NOT induce vomiting.
**Storage**
Store locked up.
Protect from sunlight. Do not expose to temperatures exceeding 50°C/122°F. Store in a well-ventilated place.
**Disposal**
Dispose of contents and container in accordance with local and national regulations.

**3 - Composition/Information on Ingredients**

| Ingredient | CAS # | Weight Percent | US Hazcom 2012/ GHS Classification |
|---|---|---|---|
| Aliphatic Hydrocarbon | 64742-47-8 | 45-50 | Flammable Liquid Category 3 |

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Full SDS: https://www.wd40company.com/files/pdf/sds/mup/wd-40-multi-use-product-aerosol-sds-us-ghs-7-20-14.pdf

## Great Stuff Gaps and Cracks SDS

GREAT STUFF* Gaps and Cracks
GMID 277059

# MATERIAL SAFETY DATA SHEET

## 1) PRODUCT AND COMPANY IDENTIFICATION

THE DOW CHEMICAL COMPANY
Midland Michigan 48674
USA

24-Hour Emergency Phone Number: 989-636-4400
Customer Service: 800-366-4740

PRODUCT NAME : GREAT STUFF* Gaps and Cracks
MATERIAL TYPE : One component system
ISSUE DATE : 04/26/2007
REVISION DATE : 01/25/2007

## 2) COMPOSITION/INFORMATION ON INGREDIENTS

| Ingredient | CAS Number | % |
|---|---|---|
| Prepolymer of MDI and Polyether polyol | mixture | 40-70, 60-100 % |
| Polymethylene polyphenyl Isocyanate containing approx. 40-50 % MDI (4,4methylene bisphenyl isocyanate) CAS# 101-68-8 | 9016-87-9 | 5-10, 10-30 % |
| Liquified Petroleum Mixture containing Isobutane (CAS#75-28-5), propane (CAS# 74-98-6) and dimethyl ether (CAS# 115-10-6) | mixture | 10-30% |

## 3) HAZARDS IDENTIFICATION

EMERGENCY OVERVIEW
Sprayed or heated material harmful if inhaled. May cause allergic skin reaction. May cause allergic respiratory reaction and lung injury. Avoid temperatures above 105F (41C). Toxic flammable gases and heat are released under decomposition conditions. Toxic fumes may be released in fire situations. Reacts slowly with water, releasing carbon dioxide, which can cause pressure buildup and rupture of closed containers. Elevated temperatures accelerate this process.

EYE
May cause moderate eye irritation. May cause very slight transient (temporary) corneal injury.

SKIN
Prolonged or repeated exposure may cause slight skin irritation. May cause allergic skin reaction in susceptible individuals. Animal studies have shown that skin contact with isocyanates may play a role in respiratory sensitization. May stain skin. A single prolonged exposure is not likely to result in the material being absorbed in harmful amounts.

INGESTION
Single dose oral toxicity is considered to be low. No hazards anticipated from swallowing small amounts incidental to normal handling operations.

INHALATION
At room temperature, vapors are minimal due to low vapor pressure. However, certain operations may generate vapor or aerosol concentrations sufficient to cause irritation or other adverse effects. Such operations include those in which the material is heated, sprayed or otherwise mechanically dispersed such as drumming, venting or

"*" or (R) Indicates a Trademark of The Dow Chemical Company

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Full SDS:
https://www.vercounty.org/MSDS/EMA/34Dow%20Great%20Stuff%20Spray%20Foam.pdf

## Gloss Protective Enamel SDS



# Safety Data Sheet

RUST-OLEUM CORPORATION
• Trusted Quality Since 1921 •
www.rustoleum.com

## 1. Identification

| | | | |
|---|---|---|---|
| **Product Name:** | STRUST +SSPR 6PK GLOSS NAVY BLUE | **Revision Date:** | 5/9/2017 |
| **Product Identifier:** | 7723830 | **Supercedes Date:** | 3/8/2017 |
| **Product Use/Class:** | Topcoat/Aerosols | | |
| **Supplier:** | Rust-Oleum Corporation<br>11 Hawthorn Parkway<br>Vernon Hills, IL 60061<br>USA | **Manufacturer:** | Rust-Oleum Corporation<br>11 Hawthorn Parkway<br>Vernon Hills, IL 60061<br>USA |
| **Preparer:** | Regulatory Department | | |
| **Emergency Telephone:** | 24 Hour Hotline: 847-367-7700 | | |

## 2. Hazard Identification

**Classification**

**Symbol(s) of Product**

**Signal Word**
Danger

**Possible Hazards**
32% of the mixture consists of ingredient(s) of unknown acute toxicity.

**GHS HAZARD STATEMENTS**

| | | |
|---|---|---|
| Carcinogenicity, category 2 | H351 | Suspected of causing cancer. |
| Compressed Gas | H280 | Contains gas under pressure; may explode if heated. |
| Eye Irritation, category 2 | H319 | Causes serious eye irritation. |
| Flammable Aerosol, category 1 | H222 | Extremely flammable aerosol. |
| STOT, repeated exposure, category 2 | H373 | May cause damage to organs through prolonged or repeated exposure. |
| STOT, single exposure, category 3, NE | H336 | May cause drowsiness or dizziness. |

**GHS LABEL PRECAUTIONARY STATEMENTS**

| | |
|---|---|
| P201 | Obtain special instructions before use. |
| P210 | Keep away from heat, hot surfaces, sparks, open flames and other ignition sources. No smoking. |
| P211 | Do not spray on an open flame or other ignition source. |
| P251 | Do not pierce or burn, even after use. |
| P260 | Do not breathe dust/fume/gas/mist/vapors/spray. |
| P264 | Wash hands thoroughly after handling. |
| P271 | Use only outdoors or in a well-ventilated area. |
| P280 | Wear protective gloves/protective clothing/eye protection/face protection. |
| P304+P340 | IF INHALED: Remove person to fresh air and keep comfortable for breathing. |
| P305+P351+P338 | IF IN EYES: Rinse cautiously with water for several minutes. Remove contact lenses, if present and easy to do. Continue rinsing. |

Full SDS: https://www.rustoleum.com/MSDS/ENGLISH/7723830.pdf

## Cleaner Degreaser Disinfectant SDS

THE CLOROX COMPANY

# SAFETY DATA SHEET

**Issuing Date** January 5, 2015 **Revision Date** New **Revision Number** 0

## 1. IDENTIFICATION OF THE SUBSTANCE/PREPARATION AND OF THE COMPANY/UNDERTAKING

**Product identifier**

**Product Name** **Clorox Commercial Solutions® Formula 409® Cleaner Degreaser Disinfectant**

**Other means of identification**

**EPA Registration Number** 67619-10

**Recommended use of the chemical and restrictions on use**

**Recommended Use** General purpose cleaner, degreaser, and disinfectant

**Uses advised against** No information available

**Details of the supplier of the safety data sheet**

**Supplier Address**
Clorox Professional Products Company
1221 Broadway
Oakland, CA 94612

Phone: 1-510-271-7000

**Emergency telephone number**

**Emergency Phone Numbers** For Medical Emergencies call: 1-800-446-1014
For Transportation Emergencies, call Chemtrec: 1-800-424-9300

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Full SDS: https://www.parish-supply.com/documents/CLO35296-01.pdf

## Adhesive Spray SDS



# MATERIAL SAFETY DATA SHEET

**Finished Product**

TECHSPRAY

**Date Issued:** 01/18/2003
**MSDS No:** 3500-A
**Date Revised:** 02/01/2012
**Revision No:** 7

## Heavy Duty Adhesive Spray

### 1. PRODUCT AND COMPANY IDENTIFICATION

**PRODUCT NAME:** Heavy Duty Adhesive Spray
**PRODUCT DESCRIPTION:** Contact Adhesive
**PRODUCT CODE:** 3500-11S

**MANUFACTURER**
Techspray, L.P.
1001 N.W. 1st Street
P.O. Box 949
Amarillo, TX 79107
**Emergency Contact:** Chemtrec
**Emergency Phone:** 1-800-858-4043
**Service Number:** 1-800-858-4043

**24 HR. EMERGENCY TELEPHONE NUMBERS**
**CHEMTREC CCN#21858 (US Transportation) :**(800) 424 - 9300
**CANUTEC (Canadian Transportation) :**(613) 996 - 6666
**Emergency Phone :**(800) 858 - 4043

### 2. HAZARDS IDENTIFICATION

**EMERGENCY OVERVIEW**

**PHYSICAL APPEARANCE:** Clear to amber, sticky resin.

**POTENTIAL HEALTH EFFECTS**

**EYES:** Liquid contact can cause irritation, which may be severe.
**SKIN:** Prolonged or repeated contact may cause skin irritation.
**INGESTION:** Harmful if swallowed.
**INHALATION:** Prolonged or excessive inhalation may cause respiratory tract irritation.

**SIGNS AND SYMPTOMS OF OVEREXPOSURE**

**EYES:** Symptoms of overexposure include: stinging, tearing, redness and pain.
**SKIN:** May cause slight irritation.
**INGESTION:** Not a likely route of exposure.

### 3. COMPOSITION / INFORMATION ON INGREDIENTS

| Chemical Name | Wt.% | CAS | EINECS |
|---|---|---|---|
| Hexane | 10 - 50 | 110-54-3 | 203-777-6 |
| L.P.G. | 10 - 25 | 68476-85-7 | |
| Acetone | 10 - 30 | 67-64-1 | 200-662-2 |
| Petroleum Distillates | 0 | 64742-89-8 | |
| N-Butane | < 5 | 106-97-8 | |

### 4. FIRST AID MEASURES

**EYES:** Immediately flush eyes with plenty of water for at least 15 minutes. Get immediate medical attention.
**SKIN:** Wash with soap and water. Get medical attention if irritation develops or persists.

Full SDS: https://www.techspray.com/content/msds/3500_US_ENG_SDS.pdf

## All Purpose Putty SDS

**Bondo® All-Purpose Putty, 20052, 20054, 30054, 31252, 31254 03/19/15**

# Safety Data Sheet



| | | | |
|---|---|---|---|
| **Document Group:** | 30-8055-3 | **Version Number:** | 2.00 |
| **Issue Date:** | 03/19/15 | **Supercedes Date:** | 06/22/12 |

**Product identifier**
Bondo® All-Purpose Putty, 20052, 20054, 30054, 31252, 31254

**ID Number(s):**

41-0003-7991-1, 41-0003-7992-9, 60-4550-6801-9, 60-4550-6802-7, 60-4550-6829-0, 60-4550-8112-9, 60-4550-8113-7

**Recommended use**
Putty/Filler used for home repairs.

**Supplier's details**

| | |
|---|---|
| **MANUFACTURER:** | 3M |
| **DIVISION:** | Automotive Aftermarket |
| **ADDRESS:** | 3M Center, St. Paul, MN 55144-1000, USA |
| **Telephone:** | 1-888-3M HELPS (1-888-364-3577) |

**Emergency telephone number**
1-800-364-3577 or (651) 737-6501 (24 hours)

**This product is a kit or a multipart product which consists of multiple, independently packaged components. A Safety Data Sheet (SDS), Article Information Sheet (AIS), or Article Information Letter (AIL) for each of these components is included. Please do not separate the component documents from this cover page. The document numbers for components of this product are:**

30-8057-9, 29-5993-0

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Full SDS:
https://multimedia.3m.com/mws/mediawebserver?mwsId=SSSSSuUn_zu8l00xmxtel8_9mv70k17zHvu9lxtD7SSSSSS--

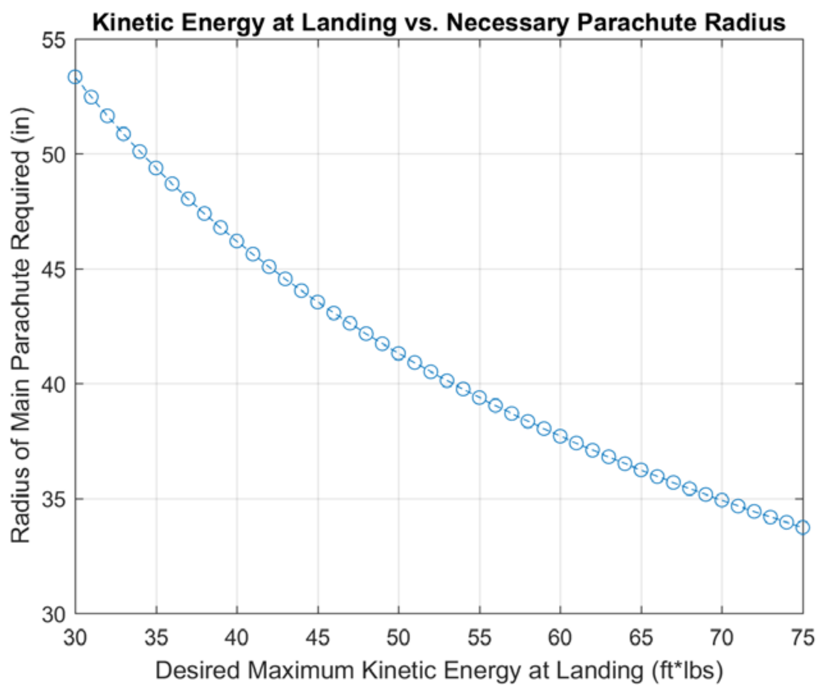
# 8. Appendix B: Recovery Decent Profile Calculator

```
% RECOVERY DESCENT PROFILE CALCULATOR (RDPC)
% WRITTEN BY EVAN KERR
% PENN STATE LION TECH ROCKET LABS
% AVIONICS AND RECOVERY LEAD
% LATEST UPDATE: 4/20/2017
```

## Calculate necessary area of Parachute to meet certain KE on landing

```
clc, clear, close all
%Gravitational acceleration, units: m/s^2
g = 9.81;
%Density in kg/m^3
rho = 1.225;
%Kinetic Energy Limit in ft-lbs
keMax = 75;

%%%%%%%%%%%%%%%%%%%%%%%%%% Input Begin %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%Coefficient of drag of drogue, main, and tumbling rocket respectively
Cdd = 1.5;
Cdm = 2.2;
Cdr = 1.0;

%These should be in kg
mass(1) = 4.030; %For the fore
mass(2) = 3.478; %For the avionics bay (model minus chord, chutes, and copter)
mass(3) = 4.660; %For the booster
mass(4) = 0.953; %Main parachute
mass(5) = 0.502; %Drogue parachute
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%% Input End %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

maxMass = max(mass);
totMass = sum(mass);

radiusMainM = ones(1,10);
keMatFtLbs = (30:1:75);
keMatJoule = keMatFtLbs*1.3358;

for i = 1:length(keMatJoule)
    radiusMainM(i) = sqrt((maxMass*totMass*g)/(Cdm*keMatJoule(i)*rho*pi));
end

radiusMainFt = 3.281*radiusMainM;
radiusMainIn = radiusMainFt * 12;
```

```
figure(1);
plot(keMatFtLbs,radiusMainIn,'--o')
title('Kinetic Energy at Landing vs. Necessary Parachute Radius');
xlabel('Desired Maximum Kinetic Energy at Landing (ft*lbs)');
ylabel('Radius of Main Parachute Required (in)');
grid on;
```



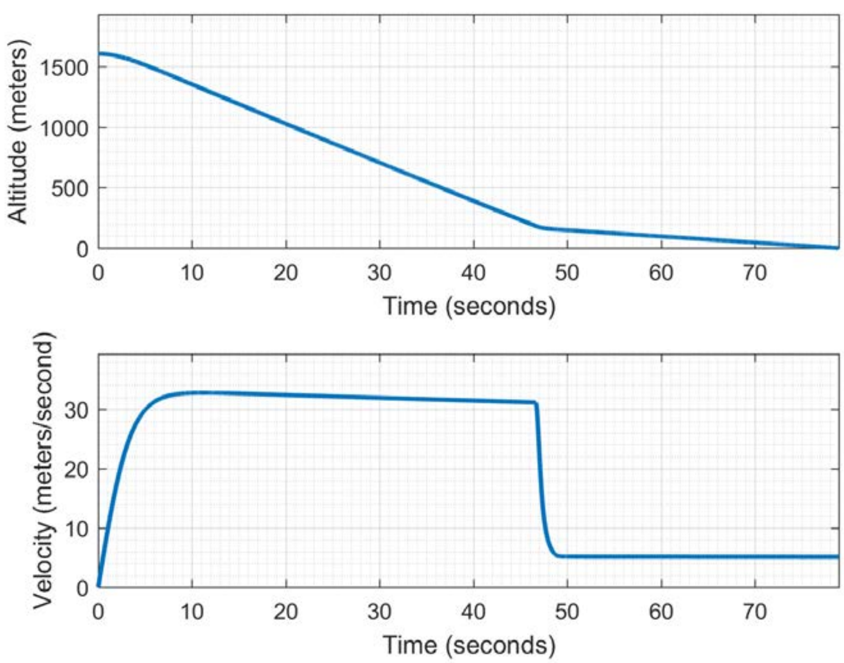

## Calculating Force based results

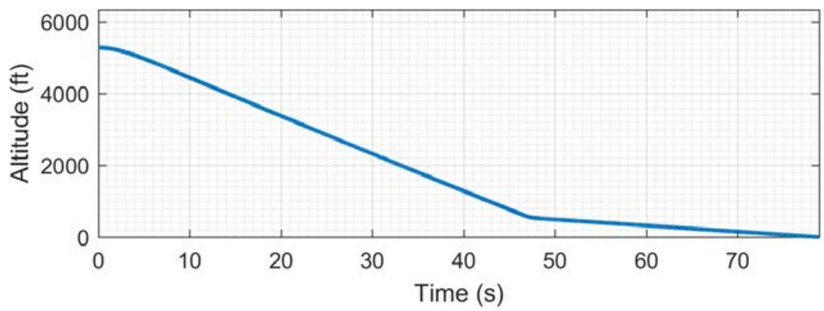
```
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%% Input Begin %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
Rd_in = 6; %radius of drogue[in]
Rm_in = 42; %radius of main[in]
Rr_in = 7.5; %simulated radius of "tumbling" rocket parachute[in]

apogeeft = 5280; %apogee altitude above ground level [ft]
altDrogueft = apogeeft-1; %altitude above ground level of drogue deployment[ft]
altMainft = 600; %altitude above ground level of main parachute deployment[ft]

altLaunchSite = 183; % Altitiude above sea level of the launch site in meters
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%% Input End %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

Rd = 0.0254*Rd_in; %radius of drogue[m]
Rm = 0.0254*Rm_in; %radius of main[m]
Rr = 0.0254*Rr_in; %simulated radius of "tumbling" rocket parachute[m]

apogee = 0.3048*apogeeft;
```

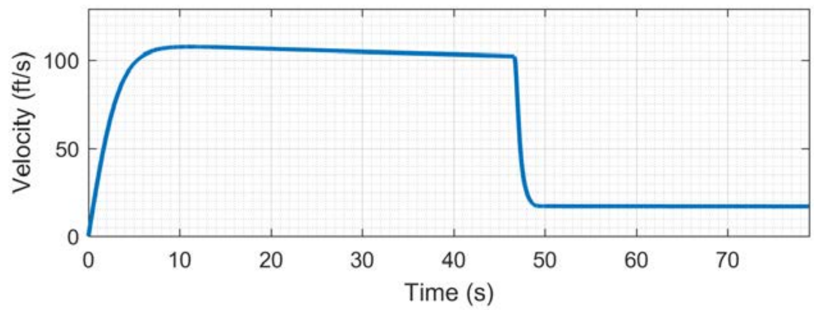
```
altDrogue = 0.3048*altDrogueft;
altMain = 0.3048*altMainft;

% Declare Constants
h = apogee+altLaunchSite; % Initial altitude of the rocket above sea level
h_matrix(1) = h;
time(1) = 0;
dt = 0.01;
v(1) = 0;
a(1) = g;
i = 1; % Counter variable
Temp = 2; % Temperature in Celcius at ground level.
Weight = totMass*g;

% Deployment time and counter initialization for the main and drogue
% parachutes
Kd_dep = 0; % Drogue deployment factor, or how many iterations have run since the drogue was deployed.
Td_dep = 0.25; % Drogue deployment time (how long it takes) in seconds
Td_dep_elapsed = 0;  % Time elapsed since drogue deployment
Km_dep = 0; % Main deployment factor, or how many iterations have run since the main was deployed
Tm_dep = 2;
Tm_dep_elapsed = 0;

%Drag Calculation
while(h >= altLaunchSite) % Although we are integrating over time, the check is whether the height is still above ground level.
   rho_new = rhocalcestSI(h,Temp); % Calculate the density at the given altitude and temperature
   Dragr(i) = .5*Cdr*rho_new*v(i)^2*pi*Rr^2; % Drag of the rocket body
   Dragd(i) = .5*Cdd*rho_new*v(i)^2*pi*Rd^2; % Drag of the drogue parachute
   Dragm(i) = .5*Cdm*rho_new*v(i)^2*pi*Rm^2; % Drag of the main parachute

      if h > (altDrogue + altLaunchSite)% Determines which state of descent the rocket is in and adjusts accordingly by adding the drags
         Drag = Dragr(i); % If the drogue has yet to deploy, the drag of the rocket is the only factor
      elseif h > (altMain + altLaunchSite)
         Kd_dep = Kd_dep + 1; % Increment drogue deployment factor
         Td_dep_elapsed = Kd_dep*dt; % Use the drogue deployment factor to calculate time since drogue deployed
         Drag = Dragr(i) + Dragd(i); % Calculate drage when drogue fully deployed

         % This loop only runs right after chute deployment and models
         % the chute as opening in a linear matter
         if Td_dep_elapsed < Td_dep
            Drag = Dragr(i) + (Td_dep_elapsed/Td_dep)*Dragd(i);
         end
      else
         Km_dep = Km_dep + 1;
         Tm_dep_elapsed = Km_dep*dt;
         Drag = Dragr(i) + Dragd(i) + Dragm(i);
```

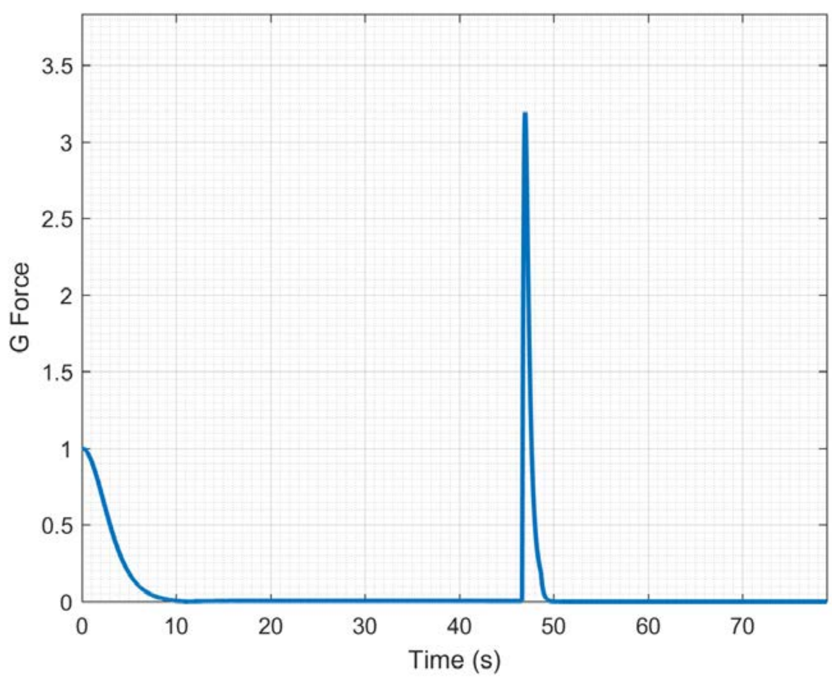
```
            if Tm_dep_elapsed < Tm_dep
                Drag = Dragr(i) + Dragd(i) + (Tm_dep_elapsed/Tm_dep)*Dragm(i);
            end
        end
    i = i + 1; % Increment i, the current index value
    a(i) = (-Drag+Weight)/totMass;
    v(i) = v(i-1)+a(i)*dt;
    delh(i) = v(i)*dt;
    h = h-delh(i);
    h_matrix(i) = h;

    time(i) = time(i-1) + dt;
end

figure(2);
ax11 = subplot(2,1,1);
title('Descent Profile In SI Units');

plot(time,h_matrix-altLaunchSite,'LineWidth',2)
ylabel('Altitude (meters)');
xlabel('Time (seconds)');
grid on;
grid minor;
axis([0 max(time) 0 max(h_matrix-altLaunchSite)*1.2]);

ax21 = subplot(2,1,2);
plot(time,v,'LineWidth',2);
ylabel('Velocity (meters/second)');
xlabel('Time (seconds)');
grid on;
grid minor;
axis([0 max(time) 0 max(v)*1.2]);
linkaxes([ax11 ax21],'x');

figure(3)
ax12 = subplot(2,1,1);
title('Descent Profile in English Units');

plot(time,(h_matrix-altLaunchSite)*3.281,'LineWidth',2);
ylabel('Altitude (ft)');
xlabel('Time (s)');
grid on;
grid minor;
axis([0 max(time) 0 max(h_matrix-altLaunchSite)*3.281*1.2]);
```

```
ax22 = subplot(2,1,2);
plot(time,v*3.281,'LineWidth',2);
ylabel('Velocity (ft/s)');
xlabel('Time (s)');
grid on;
grid minor;
axis([0 max(time) 0 max(v)*3.281*1.2]);
linkaxes([ax12 ax22],'x');

figure(4)
title('G Forces vs Time');
plot(time,abs(a/g),'LineWidth',2);
ylabel('G Force');
xlabel('Time (s)');
grid on;
grid minor;
axis([0 max(time) 0 max(abs(a/g))*1.2]);
```





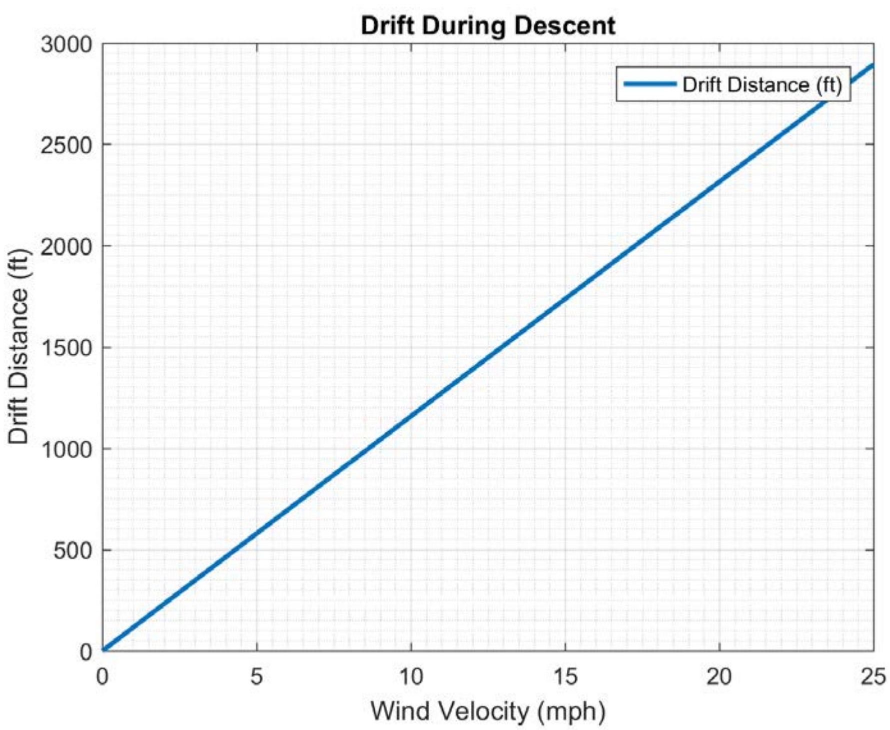




## Calculate Drift Distance

```
Windmph = 0:1:25; % Velocity of wind[mph]
Windfps = 1.467*Windmph;
Windmps = Windfps*0.3048;

% Calculate drift distance in metric and standard
descentTime = max(time);
```

```
driftDistM = Windmps*descentTime;
driftDistFt = Windfps*descentTime;

% Plot drift distance
figure(5)
plot(Windmph,driftDistFt,'LineWidth', 2);
ylabel('Drift Distance (ft)');
xlabel('Wind Velocity (mph)');
grid on;
grid minor;
title('Drift During Descent');
legend('Drift Distance (ft)');

% Output max drift distance
fprintf('The drift distance at a wind velocity of 25 mph is %6.1f ft\n\n', max(driftDistFt));
```

The drift distance at a wind velocity of 25 mph is 2894.0 ft



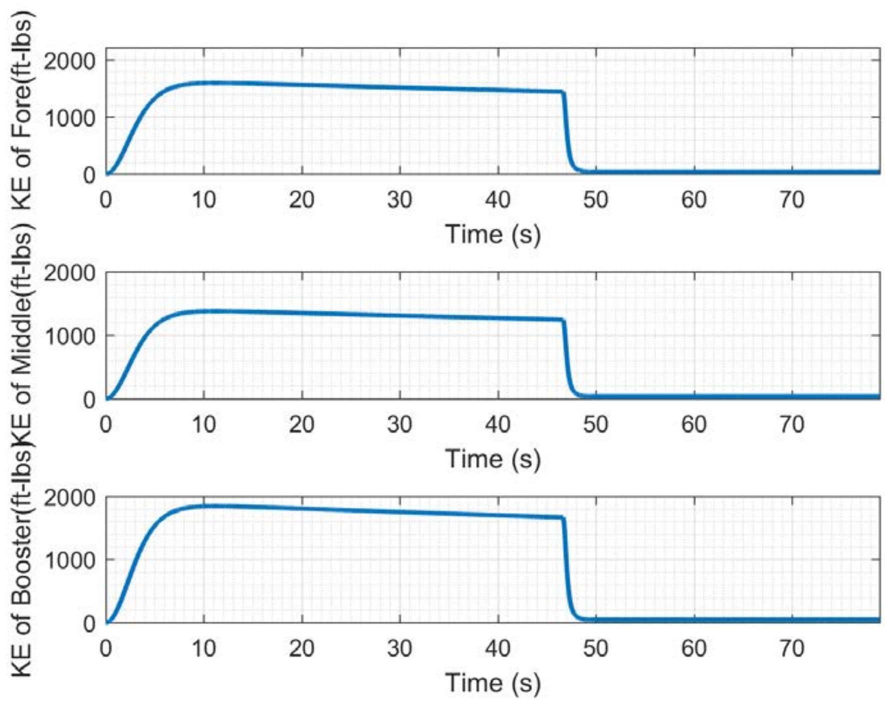

## Calculate KE History of each component

```
KEforeSI_mat = (1/2)*v.^2*mass(1);
KEavSI_mat = (1/2)*v.^2*mass(2);
KEboostSI_mat = (1/2)*v.^2*mass(3);

maxKE_SI = max([max(KEforeSI_mat),max(KEavSI_mat),max(KEboostSI_mat)]);
```

```
KEforeST_mat = KEforeSI_mat*0.7376;
KEavST_mat = KEavSI_mat*0.7376;
KEboostST_mat = KEboostSI_mat*0.7376;

maxKE_ST = max([max(KEforeST_mat),max(KEavST_mat),max(KEboostST_mat)]);

% Calculate the KE of each component in Joules at landing
KEforeSI = KEforeSI_mat(end);
KEavSI = KEavSI_mat(end);
KEboostSI = KEboostSI_mat(end);

maxLandingKE_SI = max([KEforeSI,KEavSI,KEboostSI]);

% Calculate the KE of each component in Ft-lbs at landing
KEforeST = KEforeST_mat(end);
KEavST = KEavST_mat(end);
KEboostST = KEboostST_mat(end);

maxLandingKE_ST = max([KEforeST,KEavST,KEboostST]);

figure(6)
ax13 = subplot(3,1,1);
title('Kinetic Energy of Each Component vs. Altitude');

plot(time,KEforeST_mat,'LineWidth',2);
ylabel('KE of Fore(ft-lbs)');
xlabel('Time (s)');
grid on;
grid minor;
axis([0 max(time) 0 maxKE_ST*1.2]);

ax23 = subplot(3,1,2);
plot(time,KEavST_mat,'LineWidth',2);
ylabel('KE of Middle(ft-lbs)');
xlabel('Time (s)');
grid on;
grid minor;
linkaxes([ax13 ax23],'x');

ax33 = subplot(3,1,3);
plot(time,KEboostST_mat,'LineWidth',2);
ylabel('KE of Booster(ft-lbs)');
xlabel('Time (s)');
grid on;
grid minor;
linkaxes([ax23 ax33],'x');
```

```
vf = v(end); %Find final landing velocity

% Print Results
fprintf('The kinetic energy of the nosecone section is %4.2f ft*lbs\n', KEforeST);
fprintf('The kinetic energy of the avionics bay section is %4.2f ft*lbs\n', KEavST);
fprintf('The kinetic energy of the booster section is %4.2f ft*lbs\n\n', KEboostST);

fprintf('The velocity at landing is %4.2f m/s or %4.2f ft/s \n', v(end),v(end) * 3.281);
```

```
The kinetic energy of the nosecone section is 38.96 ft*lbs
The kinetic energy of the avionics bay section is 33.63 ft*lbs
The kinetic energy of the booster section is 45.05 ft*lbs

The velocity at landing is 5.12 m/s or 16.80 ft/s
```

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# 9. Appendix C: Verification of OpenRocket Flight Calculations

```
clc
clear

%CONSTANTS --------------------------------

%Center of Pressure
Ln  = 0.5499;      %length of nosecone [m]
Cnn = 2;           %coeficient of drag for nosecone
Xb  = 2.616;       %length from tip to fin root chord [m]
Xr  = 0.127;       %length from fin root leading edge to fin tip leading edge [m]
Cr  = 0.2032;      %fin root chord length [m]
Ct  = 0.102;       %fin tip chord length [m]
S   = 0.1778;      %fin semispan [m]
N   = 3;           %number of fins
Lf  = 0.19356;     %length of the fin mid-chord line [m]

%Center of Gravity
dn  = 0.4258;      %distance of the nose CG to nose tip [m]
mn  = 1.607;       %mass of the nose [kg]
dp  = 0.8766;      %distance of the payload CG to nose tip [m]
mpayload  = 2.379; %mass of payload [kg]
dm  = 1.5316;      %distance of the main CG to nose tip [m]
mm  = 4.848;       %mass of main [kg]
dd  = 1.9379;      %distance of the drogue CG to the nose top [m]
md  = 0.907;       %mass of drogue [kg]
db  = 2.563;       %distance of the booster CG to nose tip [m]
mb  = 6.065;       %mass of the booster (with motor) [kg]
M   = mn + mpayload + mm + md + mb;   %mass of the rocket (with motor) [kg]

%Apogee
mr  = 11.964;      %mass of rocket (no motor) [kg]
me  = 3.5635;      %mass of motor [kg]
mprop  = 1.582;    %mass of propellant [kg]
rho = 1.225;       %density of air [kg/m^3]
Cd  = 0.55;        %drag coefficient
D   = 0.1397;      %diameter of body tube [m]
R   = D/2;         %radius of body tube [m]
g   = 9.81;        %gravity constant [m/s^2]
T   = 1405;        %average thrust of motor [N]
t   = 3.63;        %motor burnout time [s]

%CALCULATIONS -------------------------------------
```

```
%Center of Pressure
Xn  = 0.466 * Ln;   %CP location for fins, from tip [m]
Xf  = Xb + ((Xr*(Cr + 2*Ct))/(3*(Cr + Ct))) + (1/6)*((Cr + Ct) - ((Cr*Ct)/(Cr+Ct)));    %CP location of fins, from tip [m]
Cnf = (1+R/(S+R))*(4*N*(S/D)^2/(1+sqrt(1+(2*Lf/(Cr+Ct))^2)));   %CP of fins, from tip [m]
X   = ((Cnn*Xn + Cnf*Xf)/(Cnn+Cnf));    %CP location of rocket from tip [m]

%Center of Gravity
cg = (dn*mn + dp*mpayload + dm*mm + dd*md + db*mb)/M; %CG location of rocket from tip [m]

%Static Stability Calculation
stab = (X - cg) / D;    %static stability margin [calibers]

%Apogee

%Burn Calculations
ma  = mr + me - (mprop/2); %(average) burn mass [kg]
A   = pi*(R^2);         %cross-sectional area of rocket [m^2]
k   = (1/2)*rho*Cd*A;   %aerodynamic drag coefficient [kg/m]
q1  = sqrt((T - (ma*g))/k); %burnout velocity coefficient [m/s]
x1  = (2*k*q1)/ma;      %burnout velocity decay coefficient [1/s]
v1  = q1*((1-exp(-x1*t))/(1+exp(-x1*t)));   %burnout velocity [m/s]
y1  = (-ma/(2*k))*log((T - (ma*g) - (k*v1*v1))/(T-ma*g));   %burnout altitude [m]

%Coast Calculation
mc  = mr + me - mprop;     %coast mass [kg]
qc  = sqrt((T-mc*g)/k); %coast velocity coefficient [m/s]
xc  = ((2*k*qc)/mc);    %coast velocity decay coefficient [1/s]
vc  = qc*((1-exp(-xc*t))/(1+exp(-xc*t)));   %coast velocity [m/s]
yc  = (mc/(2*k))*log((mc*g + k*(vc^2))/(T-mc*g));  %coast distance [m]

%Total Calculation
PA  = y1 + abs(yc);     %apogee [m]

%PRINT VALUES


fprintf('Center of Pressure: %2.4f inches \n', X*39.37);    %print CP [in]
fprintf('Center of Gravity: %2.4f inches \n', cg*39.37);    %print CG [in]
fprintf('Static Stability Margin: %2.4f calibers \n', stab);   %print static stability margin [calibers]
fprintf('Apogee: %2.4f feet \n', PA*3.281);                %print aprogee [ft]
```

```
Attempt to execute SCRIPT fullscale_simulations as a function:
C:\Users\Evan\Downloads\fullscale_simulations.m
```

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# 10. Appendix D: Tensile Test Procedure

## Carbon Fiber Airframe Testing Procedure

**Objective:**

Determine the tensile load that can be applied to the tube made from 6 layers and 7 layers of carbon fiber. Using these results and predicted loads experience during flight, a safety factor can be obtained to validate the design choice.

**Necessary Equipment:**

- Sample of 2, 6-inch diameter tubes made from 6 layers and 7 layers of carbon fiber
- 2 Aluminum blocks machined to fit the interior of each body tube and contains 4 threaded holes for machined screws
- 2 Aluminum rods machined to fit through the blocks. These rods are used as attachment points for the tensile equipment
- Minimum of 8 machine screws
- Tensile loading equipment (to be determined by equipment faculty/provider)
- Carbon Fiber Airframe Testing Procedure Document

## Assembly

For reliable results, proper assembly of testing equipment is imperative. The assembly procedure shall go as follows:

1. Prepare each tube section for testing; this includes cutting the tube to necessary length (as required by testing equipment or faculty), drilling 4 holes on each end of the tube and ensure alignment of those holes with the aluminum block
2. Align one end of the tube with an aluminum block and secure it using 4 machined screws.
3. **(Important)** Check that the aluminum is aligned perpendicularly to the tube. *Misalignment will disturb testing results as the load will no longer be purely tensile.
4. Feed aluminum rod through the aluminum block with the stop on the interior of the tube; clamp the block once fed through so it cannot fall into the tube.
5. Feed second aluminum rod into second aluminum rod, again with the stop on the side of the block to the interior of the tube. Again clamp the rod so it won't slide out of the block.
6. Align the other end of the tube with the second block-and-rod assembly.
7. **(Important)** Check that the aluminum is aligned perpendicularly to the tube. *Misalignment will disturb testing results as the load will no longer be purely tensile.
8. If alignment is true, this assembly is ready to load into the testing equipment. Load the assembly into the testing equipment by attaching each end of the rod to the testing grips (or similar mechanism depending on tensile equipment).
9. Run the experiment
10. Record the load at failure in the table below.
11. Repeat steps 1-10 for the remaining configurations

**Results:**

| Configuration | Load at failure |
|---|---|
| 6 layers of carbon fiber | |
| 7 layers of carbon fiber | |

**Success of results:**

The test can be deemed successful if all of the following are true:

a. Results are realistic
b. A trend can be examined (i.e. load at failure for 7 layers is higher than 6 layers)
c. Failure is at the screw holes as expected

**Validation of design**

Determine the safety factor of fullscale design using the failure strength and expected maximum load experienced during flight.