NC STATE UNIVERSITY

Tacho Lycos
2017 NASA Student Launch
PDR

High-Powered Rocketry Team

911 Oval Drive

Raleigh NC, 27695

November 4, 2016

1. Table of Contents

Table of Tables:

Table of Figures:

Table of Appendices:

1. Summary of PDR

1.1. Team Summary

1.1.1. Name and Mailing Address

North Carolina State University

Tacho Lycos High-Powered Rocketry Club
Engineering Building III
911 Oval Drive
Raleigh, NC 27606

1.1.2. Mentors

Alan Whitmore	James Livingston	Dr. Charles Hall
TRA Certification: 05945	TRA Certification: 02204	TRA Certification: 14134
Certification Level: 3	Certification Level: 3	Certification Level: 3

1.2. Launch Vehicle Summary

1.2.1. Size and Mass

Table 1: Size and Mass Properties

PDR	
Length	113 in
Diameter	6.2in
Loaded Weight	46.2 lbs
Center of Pressure	84.8 in
Center of Gravity	71.7 in
Stability	2.1 Caliber
Apogee	5455 ft
Max Velocity	604 ft/s
Max Acceleration	217 ft/s^2
Recovery System	1 Drogue/1 Main Parachute
Motor	L1120W

1.2.2. Motor Choice

The team has selected the Aerotech L1120W motor for the full-scale rocket. It is a 76-100% L-Class motor, has a total impulse of 4922 N-s and a burn time of 5.01 seconds. It is 26.18 inches long and has a diameter of 2.95 inches. This motor provides the best stability and performance characteristics for carrying the launch vehicle to the target altitude.

1.2.3. Recovery System

The vehicle will descend in three sections attached by shock cord and supported by one 2 ft diameter drogue parachute and one 15 ft diameter main parachute. At apogee, the launch vehicle will separate between the fin can and payload bay thus ejecting the payload and deploying the drogue chute. At 700 ft AGL the launch vehicle will separate between the nosecone and upper airframe and the main parachute will deploy. The launch vehicle will touchdown with a kinetic energy of approximately 55 ft-lb and velocity of 8.5 ft/s discussed in S3.3.3.

1.3. Payload Summary

Piston Battering Ram (PBR)

After payload deployment, the ULS will automatically deploy from its stowed position. Two completely redundant Target Differentiation Systems (TDS) on the payload, one run with a Raspberry Pi and the other with a BeagleBone Black, will control all autonomous tasking for the (collective) on-board Target Differentiation System.

Each computer will control a camera used to take images of the targets and will process the images to identify and differentiate between the targets. The two systems managed by the microcontrollers are completely redundant and as such will perform all tasks simultaneously. The payload recovery system will manage the descent velocity of the payload and the Upright Landing System (ULS) will absorb the shock from ground contact and ensure a stable and upright landing of the payload.

2. Changes Made Since Proposal

2.1. Vehicle Criteria

The overall configuration of the launch vehicle does not significantly differ from the initially proposed design. The launch vehicle is still broken into three sections with the payload being deployed from the interface between the payload bay and fin can and utilizes four fins. However, some of the dimensions and weights have been altered to more accurately represent the final full-scale design. The length of the vehicle has increased by two inches to 113 total inches and the total weight has increased by four pounds to 46.2 lbs. An extra body tube piece has been added to allow for easier access into the avionics and payload bays in order to activate altimeters and other electronics necessary for launch.

The most significant contributor to the increased weight gain was an increase to the size of the main recovery device. Initial estimates had the main parachute at an 8 ft diameter; however, it was found that this figure should be on the order of 15 ft. This increased weight led to a motor change in order to maintain a target apogee of 5280 ft. The initial motor choice was an AeroTech L1420R with 4616 N·s of total impulse and has been updated to an AeroTech L1120W with 4916 N·s of total impulse.

2.2. Payload Criteria

In the Proposal, the payload was defined as a cylindrical aluminum body with a parachute recovery system in the forward part of the payload, torsional spring ULS mounted between the retainer/viewing surface and payload body, and a completely redundant camera system with electronics mounted on both faces of a 3D printed ABS plastic plate.

The payload defined in the PDR is a cylindrical aluminum body with a parachute recovery system in the forward part of the payload, strut-truss ULS mounted externally on the payload body wall, and a completely redundant camera system with electronics mounted on 3D printed ABS plastic sleds in a tiered configuration.

In the Proposal, the only ULS design was the torsional spring system. Now the current leading alternative design for the ULS is the strut-truss system, which will be mounted externally on the payload body wall. The strut-truss ULS will be discussed in §5.2.4.5. The changes made to the ULS were driven by increased stability offered by a system which include a damping system, components to handle side-loading, and increased surface area contact with the ground via the foot pads.

The orientation of the electrical hardware in the proposal was on both faces of a 3D printed ABS plastic sled. Tier systems are currently being researched and investigated. The purpose of the tier system is to better utilize the volume inside the payload in hopes of reducing the payload's total height. The electrical systems and integration will be explained in §5.2.1. and § 5.2.3.

Many more design options have been vetted between the submission of the Proposal and the submission of the PDR. Most of the current leading alternative designs remain the same; however, the current design choices are less fixed due to the development of new alternative designs which may be tested after further research has been done.

2.3. Project Plan

As the team has moved forward with the design, a more robust schedule has been developed. Dates have been added for subscale build, full-scale build, parts ordering, construction milestone dates, and experimentation. More specific items have been added to the budget and the funding plan has been edited to reflect funding awards received from the Engineering Council and projected funding rewards from other sources. The updated budget can be found in §6.1, the updated funding plan can be found in §6.2, and the updated schedule can be found in §6.3.

3. Vehicle Criteria

3.1. Selection, Design, and Rationale of Launch Vehicle

3.1.1. Mission Statement

The Tacho Lycos team will design a launch vehicle capable of maintaining stable flight and delivering a payload to an apogee altitude of 5,280 feet AGL. The payload will be capable of autonomous target detection and identification and will land in an upright orientation upon completion of its mission.

3.1.2. Mission Success Criteria

NASA has provided competing teams with a comprehensive and complete description of requirements in the NASA SL 2017 Handbook which is available at:

http://www.nasa.gov/audience/forstudents/studentlaunch/home/index.html

The compliance matrix can be found in Appendix D of this document; the matrix identifies each requirement and how the team plans to comply with the requirements.

3.1.3. Subsystem Descriptions

3.1.3.1. Nosecone

Model rocketry nosecones can be chosen for a wide variety of flight conditions depending on speed and purpose. From OpenRocket simulations and per NASA SL Competition requirements, it was determined that the rocket would operate well below supersonic speeds. For rockets traveling at subsonic speeds it is more important to focus on weight and ballast when choosing a nosecone. When traveling subsonic, common nosecone shapes such as conical, Ogive, elliptical, and Von Karman are not affected by drag in a significantly different way. Based on these factors, a 5:1 Ogive nosecone geometry was selected due to its availability and previous success on other rockets launched by the club. An example of this nosecone can be seen in Figure 1. An Ogive nosecone has slightly higher drag compared to an elliptical or Von Karman nosecone bringing the apogee closer to target altitude of 5280 ft when paired with the L1120W motor.

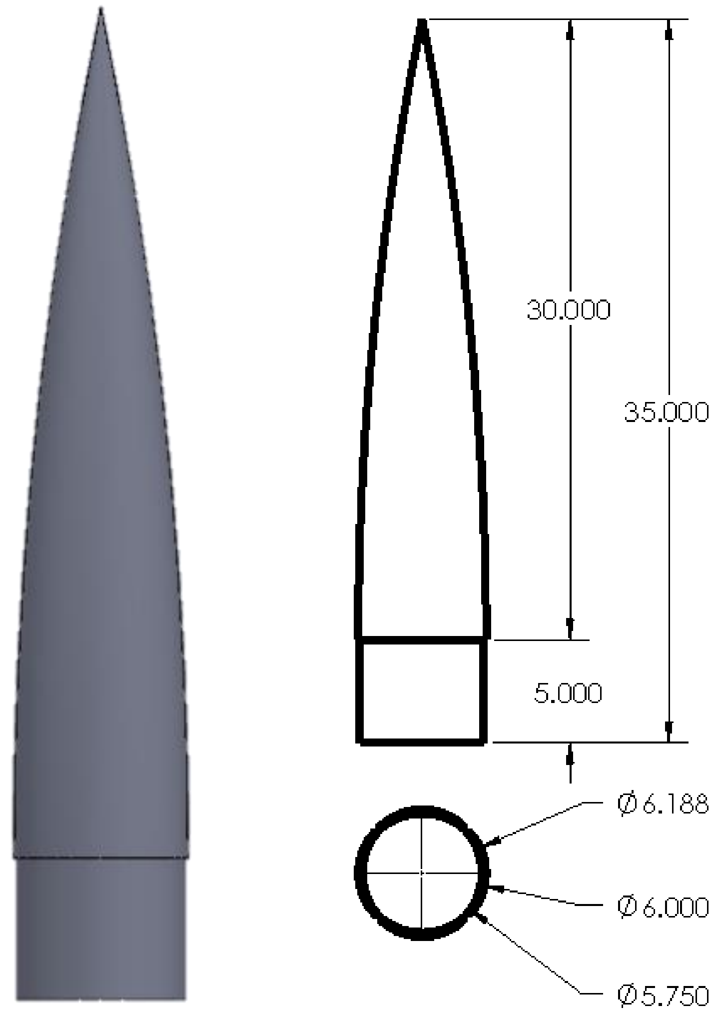

Figure 1: 5:1 Ogive Nosecone

The nosecone will be constructed of wound fiberglass for durability and will implement a metal tip to prevent crumpling when landing. The nosecone has a base diameter of 6 inches with a 5-inch shoulder and a 30-inch exposed length. There will be a 0.5-inch-thick aircraft grade birch plywood bulkhead in the nosecone with an appropriately sized U-bolt to attach the main parachute to the forward airframe.

3.1.3.2. Airframe

The basic purpose of the airframe is to house various components such as parachutes, avionics, motors, and any scientific payloads. Additionally, it is designed to provide structural support during all phases of the flight. Strength, weight, and durability were the main factors when choosing material for the body tube of each section of the launch vehicle. Typical materials used in high powered rocket construction include thick wall Kraft paper, blue tube, and fiberglass. Due to the high strength to weight ratio and increased durability, filament-wound fiberglass was chosen for all segments of the airframe. Fiberglass also adds increased waterproofing compared to Kraft paper or blue tube.

The airframe has a body diameter of 6 inches and is broken into four internal compartments. From forward to aft these include the main parachute, avionics bay, payload bay, and fin can. The launch vehicle will separate at two break points, one between the payload bay and fin can and the other between the nose cone and forward airframe.

3.1.3.3. Forward Airframe

The forward airframe houses the main chute and the avionics bay and can be seen in Figure 2. This section will be constructed from two separate fiberglass body tubes that will be fixed by a fiberglass coupler for the duration of the flight. The coupler will be epoxied to the upper tube and bolted into the aft tube. Two birch plywood bulkheads of 0.5-inch thickness will shield the avionics bay from ejection charges and provide structural support along the airframe. One bulkhead will be mounted on the forward side of the avionics bay and will attach the main chute to the nose cone when deployed. The other bulkhead will be mounted on the aft side of the avionics bay and will attach the drogue chute to the fin can upon deployment.

However, containing the avionics between two structural bulkheads presents the issue of accessibility. Two solutions were presented in order to accommodate this problem. The first involved cutting a section of the body tube out and creating a hatch to allow direct access. This method was unfavorable as the structural properties of the body tube are compromised by cutting into it. The second method involved having the aft bulkhead mounted on two internal threaded rods allowing this bulkhead to be removed from the launch vehicle. The second method was chosen in order to maintain the external rigidity of the launch vehicle. This method also allows for the avionics to be mounted on a removable sled that can slide along the threaded rods for ease of access. For detailed discussion on avionics, see §3.1.3.6.

The forward airframe will attach at the aft end to the payload bay by way of bolting into a fiberglass coupler that is epoxied to the body tube of the payload bay. At the forward end, it will be shear pinned to the nosecone. At the appropriate time (discussed §3.2) the ejection charges for the main parachute will fire and separate the nose cone and the forward airframe and deploy the main parachute.

The U-bolts and connecting rods shown in Figure 2 represent approximate size and will be verified as the design matures. Verification will take place through physical testing as well as preliminary simulations.

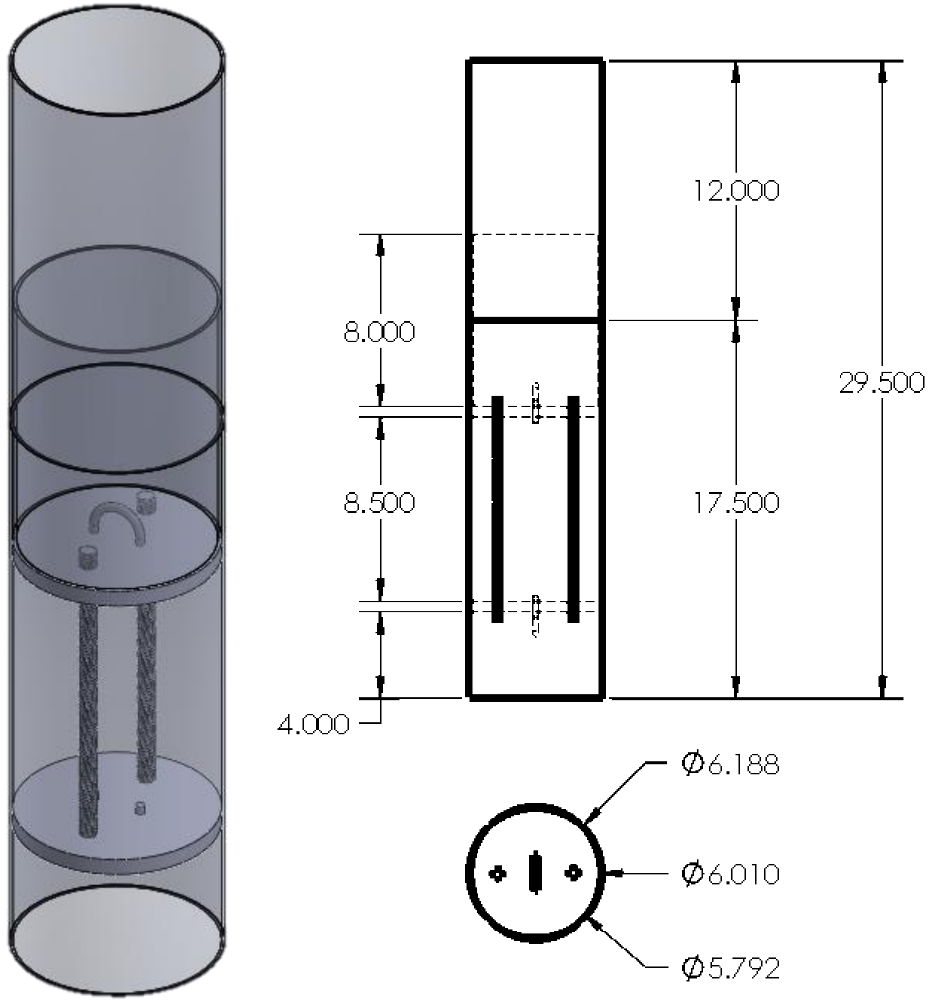

Figure 2: Forward Airframe

3.1.3.4. Payload Bay

The payload bay is located aft of the forward airframe and forward of the fin can. The payload bay can be seen in Figure 3, which shows the payload bay fully assembled with the payload loaded inside the section. This section of the launch vehicle houses the payload during ascent and assists in payload deployment at apogee. The drogue parachute is also contained within this section and sits forward of the payload, thus following it out upon deployment at apogee. Along with these items an internal rail system will allow the payload to exit the launch vehicle smoothly and along a specified path until it is clear of the forward section of the rocket.

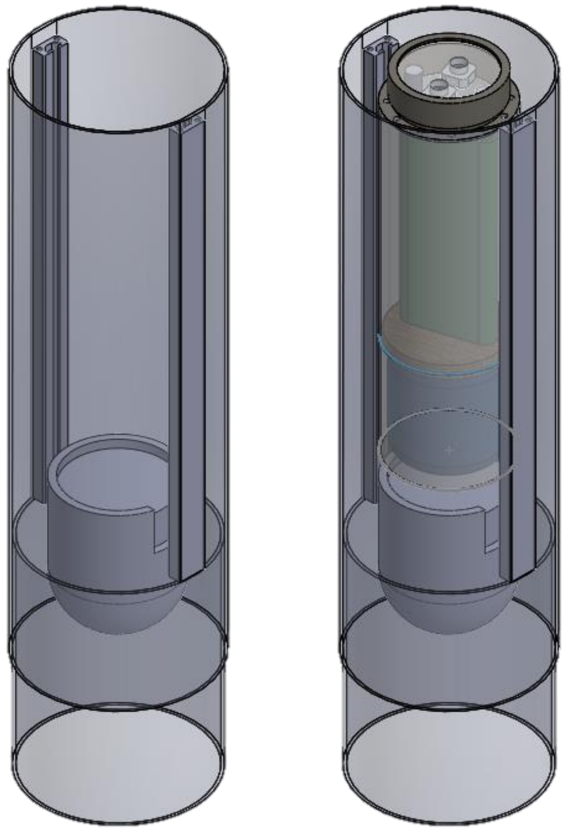

Figure 3: Payload Bay

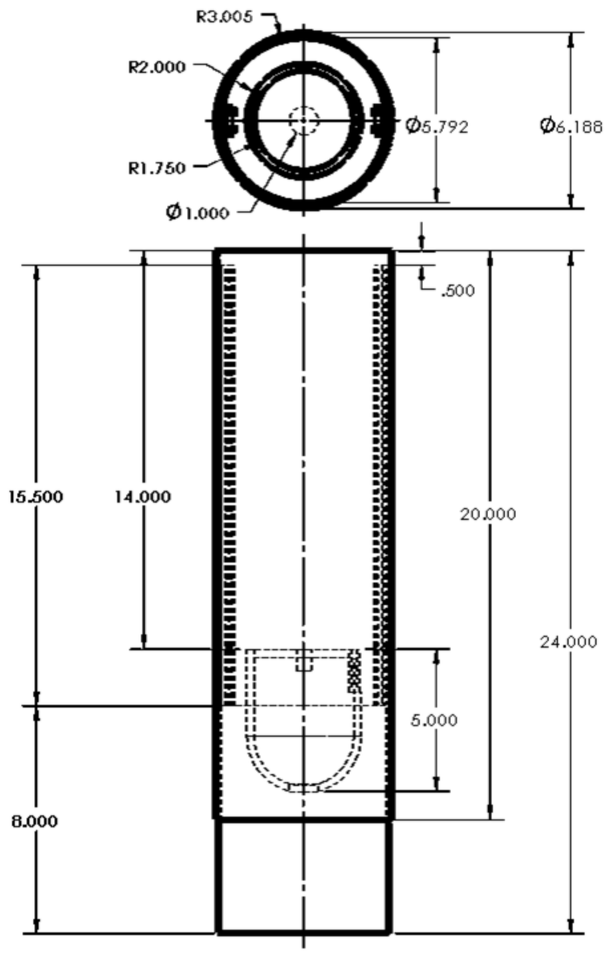

Figure 4: Payload Bay Dimensional Drawing (Payload not shown)

There will be two aluminum T-slot rails running the length of the payload bay which will be epoxied to the inner walls. An example of the rails can be seen in Figure 5. Alternative designs included no rail system and had the legs of the payload contacting the inner wall of the launch vehicle. The rails were included to reduce stress on the legs and provide a more consistent path for the payload to follow as it exited the vehicle.

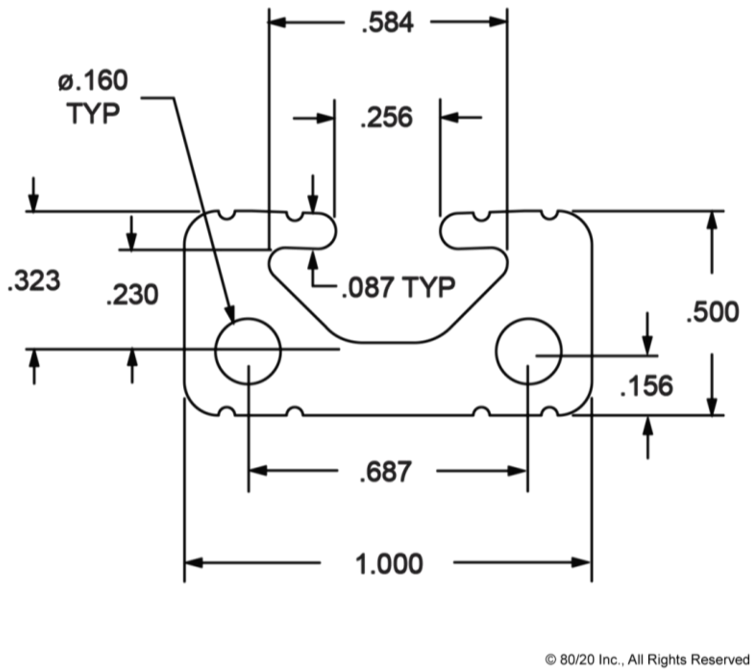

Figure 5: Payload Bay Rail Cross-Section

The current design involves the payload to be forced out of the payload bay by the ejection charges that deploy the drogue chute and separate the rocket. A plastic, bowl shaped canister will house the drogue chute and assist with transferring the load through the payload to the fin can to separate the launch vehicle. This canister will be fixed to the shock cord of the drogue chute and will only be able to extend to the edge of the opening of the payload bay; that is, the canister will never leave the launch vehicle.

Kevlar shock cord will be used to attach the drogue chute to the fin can and payload bay through each section's respective bulkhead. All of the shock cord will be stored forward of the payload except for the length needed to connect it to the fin can while housed in the launch vehicle. This length of shock cord will run parallel to the payload and should prevent tangling as the payload is deployed. No excess cord will enter this area as the payload slides out of the launch vehicle.

3.1.3.5. Fin Section

The fin can or aft-most section of the launch vehicle will house the motor and be the first section of the rocket that decouples allowing jettison of the payload. It will house the L1120W motor and be tethered to the payload bay via a U-bolt firmly secured within a bulk head. The fin can will connect to the payload bay via an 8-inch coupler. Figure 6 and Figure 7 show the dimensions of the fin can itself and the inner components.

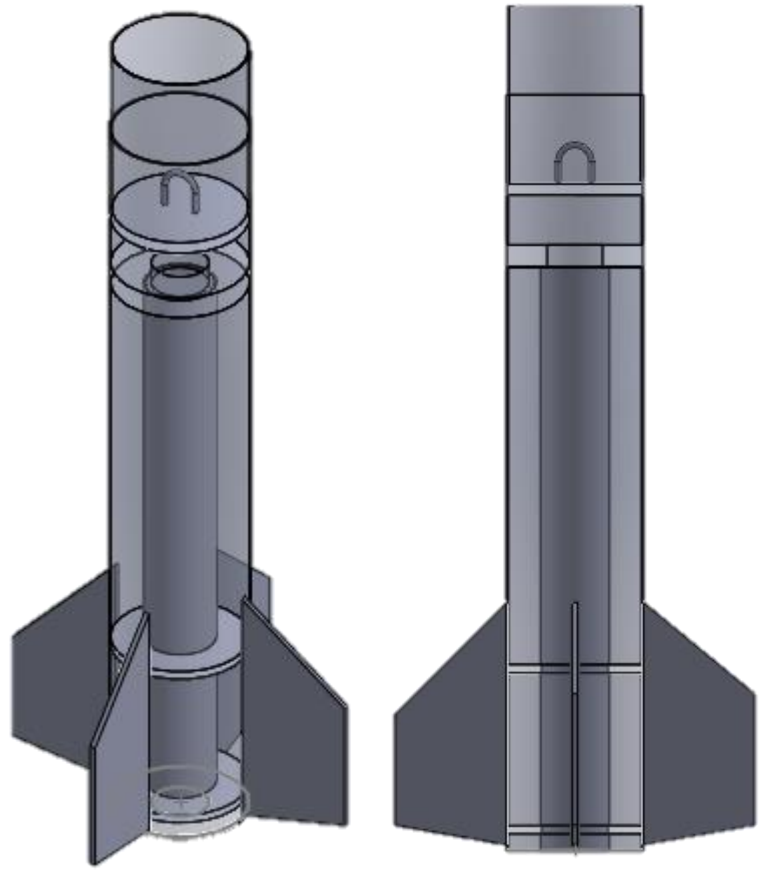

Figure 6: SolidWorks Fin Section Models

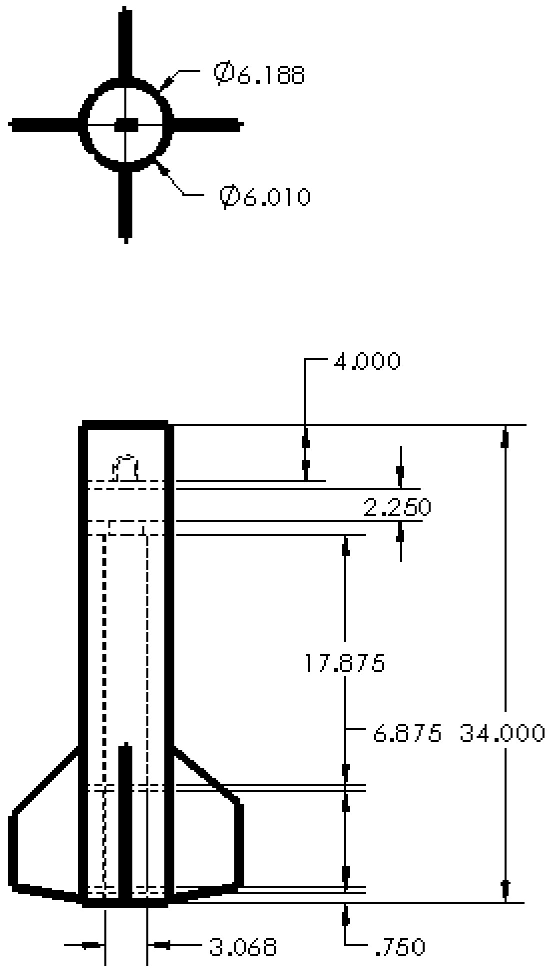

Figure 7: SolidWorks Fin Can Drawing

The inner components of the fin can include the L1120W motor and its retainer. Two 0.375-inch thick centering rings will secure the motor within the launch vehicle and will be fabricated from aircraft grade birch plywood, the same as the bulkheads. The motor will rest flush against a 1-inch engine block for further security of the motor. Lastly, the bulkhead that the payload section will connect to is 0.5-inch thick and has a U-bolt that the shock chord will connect to. Figure 7 shows that each of the fins are separated by 90^{o} creating a symmetrical fin alignment.

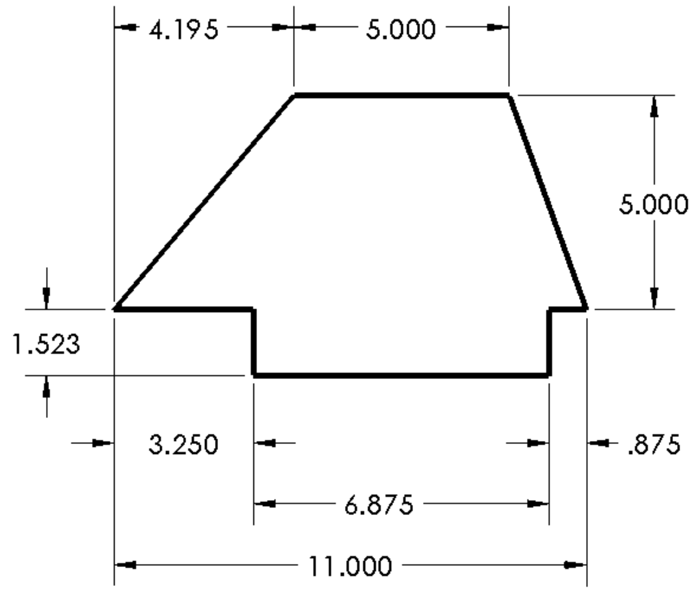

Figure 8: Fin Dimensions

Figure 8 shows the fin and fin tab that will insert into the fin can. The fins will be attached via tabs that extend through the bottom of the individual trapezoids. The fin can will utilize trapezoidal fins that will be positioned 22.75 inches aft of the top of the fin can. Each fin will have a root chord of 11 inches and a tip chord of 5 inches. The fins will have a height of 5 inches and a front sweep angle of 40^{o}, thickness of 0.25 inches, and be constructed out of aircraft grade plywood.

The fin tabs have tab lengths of 6.875 inches and have a height of 1.523 inches that will fit in slots in the aft section of the fin can. The fin tabs will be positioned 3.25 inches from the root chord leading edge of the fin.

3.1.3.6. Avionics

The launch vehicle contains a single avionics bay as discussed in §3.1.3.3. The payload will have a self-contained avionics attachment to deploy its own parachute. The launch vehicle avionics bay will contain two altimeters for redundancy within the ejection sequence. One Stratologger SL100 and one Entacore AIM 3.0 will be used to fire the black powder charges that decouple the rocket sections to release the payload and parachutes. The Stratologger will be programmed to fire ejection charges that decouple the fin can and payload section of the rocket at apogee, releasing the payload and the drogue. A redundant charge will then be fired 1 second after apogee. At 700 ft AGL another designated altimeter will initiate the main chute deployment from the upper airframe. Another redundant charge will be programmed to fire after an additional second. Each altimeter will be independently powered by a 9-volt battery and wired to its own switch. The switches will not be armed until the launch vehicle is erected on the launch rail to avoid battery drain. Each altimeter shall be armed by a dedicated arming switch that is accessible from the exterior of the rocket airframe when the rocket is in the launch configuration on the launch pad. Each arming switch shall be capable of being locked in the ON position for launch. Recovery system electronics shall be housed separately in the vehicle in order to shield them from other onboard devices which may adversely affect their proper operation. To ensure all altimeters and batteries are secure, prefabricated mounts or custom fitted 3D printed avionics sleds will be produced. Figures 9 and 10 show a rendering of what would be used for the mounting and a drawing highlighting the dimensions, respectively.

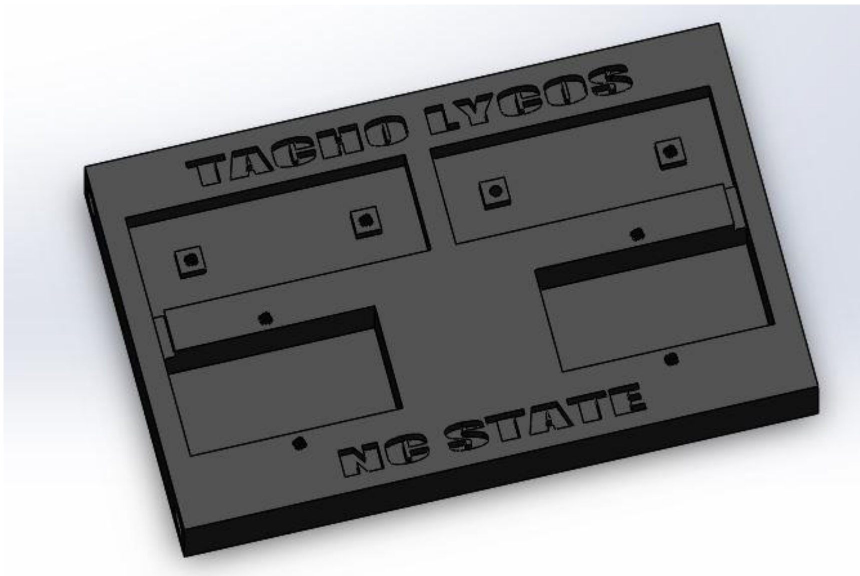

Figure 9: Avionics Sled Bay

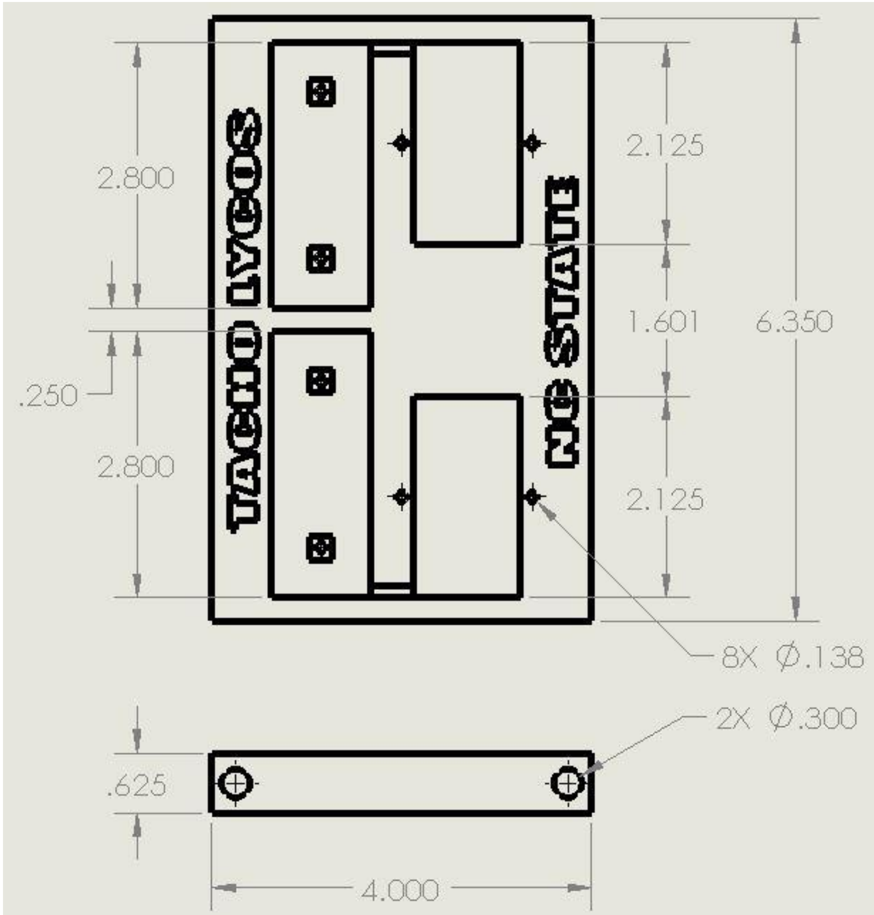

Figure 10: Avionics Sled Bay Dimensions

3.1.3.7. Motor

Given the projected weight of the rocket, 46.2 lbs, the team is currently considering three different Aerotech motors, the L1420R-P, the L2200G-18, and the L1120W-P. The L1420R-P flight simulation shows a projected altitude of 5,107 ft. This is shy of the competition altitude and would require that the launch vehicle shed weight throughout the design and build process. The L2200G-flight simulation shows a projected altitude of 5,838 ft. This is far beyond the competition altitude and would require us to create a lot of weight as the design process moves forward. Finally, the L1120W-P flight simulation shows a projected altitude of 5,455 ft. While still beyond the target altitude by nearly 200 ft this is more reasonable when it comes to accounting for extra weight due to paint, variations in manufacturing; and in the event it is needed, ballast can be added.

3.1.4. Verification Plan

A series of experiments will be conducted to ensure the viability of the launch vehicle subsystems and verify that they are ready for flight.

3.1.4.1. Altimeter Pressure Test

To ensure that the altimeters used for ejection charges onboard the rocket execute correctly; altimeters will be placed in a vacuum chamber and will be hooked up to an LED. If the LED illuminates at the correct pressure, then it will be deemed worthy for flight. The same test will be run on the altimeters that will be used for the air brake system.

3.1.4.2. GPS Transmitter Experiment

To ensure that all transmitting devices function properly, the team will perform a test using 2 BigRedBee GPS units. All the units transmit at the same frequency so it will be necessary to set the devices to different channels. A range test will also be conducted to make sure that signals from over a mile (line of sight) away are received.

3.1.4.3. Stage Separation

Black powder ejection charge testing will take place to confirm calculations performed in §3.2. These calculations rely on a constant to find the ideal pressure for a certain separation force. Testing will start with the calculated amount of black powder loaded into a mock-up of each section that is weighted and connected appropriately. Further tests will be performed until the sections separate by the appropriate amount.

3.1.4.4. Payload Deployment System

When testing stage separation extra considerations will be taken to ensure the payload properly deploys from the launch vehicle. The most important considerations in payload deployment are rapid clearance from payload bay and fin can, structural integrity of payload and fin can, absence of shock cord/payload entanglement, and drogue chute deployment. Some of these tests will be completed on the ground and some will need to take part on a subscale launch.

Ground tests include initial clearance testing, structural integrity of the payload and fin can, and preventing shock chord and payload entanglement. Similar to stage separation testing, the amount of black powder will be varied until an appropriate clearance is attained. Following this test the payload body and fin can mating surface will be examined for buckling and bending. If there is structural damage to either the payload or fin can, compromises will be made to reduce the ejection force and thus distance of separation. Along with this inspection, the shock cord will be examined for signs of excess wear. If the payload is entangled in the shock cord it may not deploy properly and mission success will be compromised. If the payload does not properly deploy the drogue chute may not fully deploy and extra stress will be placed on the main chute when it is released.

Subscale launch testing will be needed to further verify complete payload deployment and increase confidence in the design.

3.1.5. Understanding of Project Components

All risks defined in Appendix B (the FMECA diagrams) must be considered when designing the vehicle and payload. Accounting for these risks will ensure the safety of the team. Any of the safety risks coming to fruition would severely impact progress on the design, or halt the work completely. As with any project, there is also the risk of going over budget. This risk should be avoided, and can be if proper care is taken to keep up with team's capital. If the team goes over budget, at the very least points will be lost or the team may be disqualified overall. Lastly, ample time must be allotted to each section of the design, documentation included. Any delays would quickly compound and push back progress on other aspects of the design, potentially preventing the project to be finished. Therefore, it is imperative that the team remain on schedule.

3.1.6. Assembly Drawing

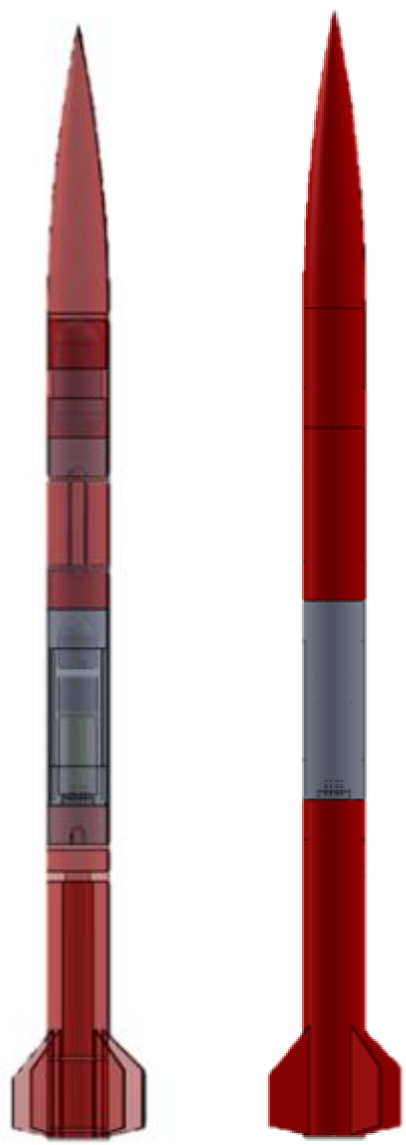

Figure 11: Full Scale Rocket Assemblies

3.1.7. Mass Statement

The rocket is currently estimated to weigh 46.2 lbs. This weight comes from OpenRocket and SolidWorks models, and thus is an accurate preliminary approximation. A large portion of the launch vehicle weight comes from the motor and casing along with a significant portion coming from the payload. Currently the empty rocket weight (weight to be supported by launch vehicle recovery systems) is 33.1 lbs. This weight approximation does not include the epoxy or paint needed to build the rocket, so the team is expecting an 8% increase in the total weight. The extra weight should not interfere with the launch vehicle performance because calculations were made to accommodate greater mass assumptions. Table 2 shows the weight of each section of the launch vehicle, including all internal components of that section.

Table 2: Mass Statement

Component	Weight (lbs)
Nosecone	3.56
Forward Airframe	11.0
Payload Bay (Not counting Payload)	4.98
Payload (Maximum weight estimate)	7.00
Fin Section	9.39
Motor and Casing	10.3
Total	**46.2**

3.2. Recovery Subsystem

The recovery system for the launch vehicle will consist of two parachutes, two altimeters, electronic matches, and black powder charges. At apogee, the 2 ft drogue parachute will deploy between the middle and aft rocket sections. The avionics bay housed forward of the payload bay will control the ejection charges for the drogue, with the Stratologger SL100 programmed to fire the primary charge at apogee and the Entacore programmed to fire the redundant charge 1 second later.

At apogee, the fin can will separate from the middle airframe, with the drogue attached to the aft airframe. At 700 ft, the 15 ft main parachute will deploy between the nosecone and upper airframe. Both events will be controlled by the forward avionics bay with the primary charges controlled by the Stratologger and the secondary charges controlled by the Entacore. Secondary charges are to be detonated 1 second after primary charges

Black powder charge sizes were calculated with the following formula:

$$m = L * D^2 * 0.006 \quad \text{Eq. 1}$$

Where L is the length of the section in inches, D is the diameter in inches, and 0.006 is a constant used to convert cubic inches to grams of black powder. From the preliminary design, the forward main parachute cavity requires 2.3 grams of black powder and will therefore have a 2.5-gram redundant charge. The drogue parachute cavity will require 1.8 grams of black powder and will have a 2.0-gram redundant charge. These charge sizes may be subject to change if the volumes of the parachute cavities change or the ground ejection testing proves a more energetic ejection is necessary to fully deploy the parachutes. There will be four 4-40 nylon shear pins at each separation point to hold the rocket together until decoupling

3.2.1. Electrical Schematic for Recovery System

Below is Figure 12, a block diagram of the recovery system that will be responsible for the deployment of the drogue and main parachutes.

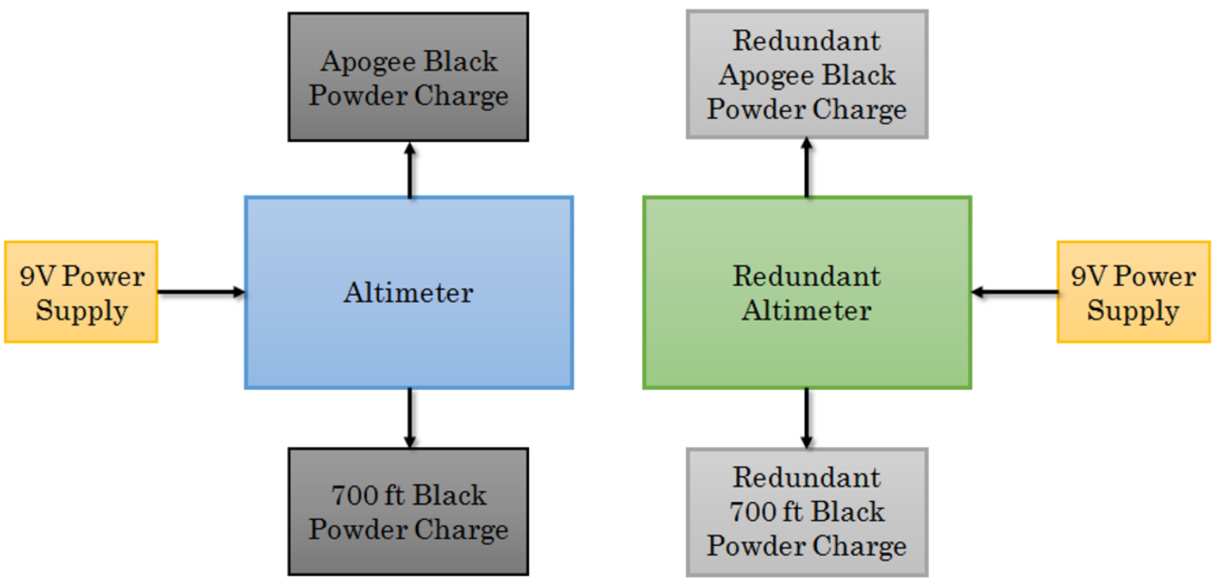

Figure 12: Rocket Parachute Deployments

3.3. Mission Performance Predictions

3.3.1. Flight Profile Simulations

Figure 13, below, shows a flight profile simulation from OpenRocket using the AeroTech L1120W motor. The drogue parachute is deployed on a one second delay after apogee and the main parachute deploys at 700 feet AGL. This simulation does not account for the fact that the payload mass is ejected at apogee. Therefore, the descent rates are an over estimate as the reduced mass will decrease the descent velocity of the launch vehicle. These simulations could be considered a worst-case scenario if the payload does not detach from the launch vehicle at apogee. The simulation shown in Figure 13 was performed using a launch altitude of 600 feet above sea level (approximate altitude in Huntsville, AL), 10 mph wind, 5° from vertical launch angle, and standard atmosphere conditions.

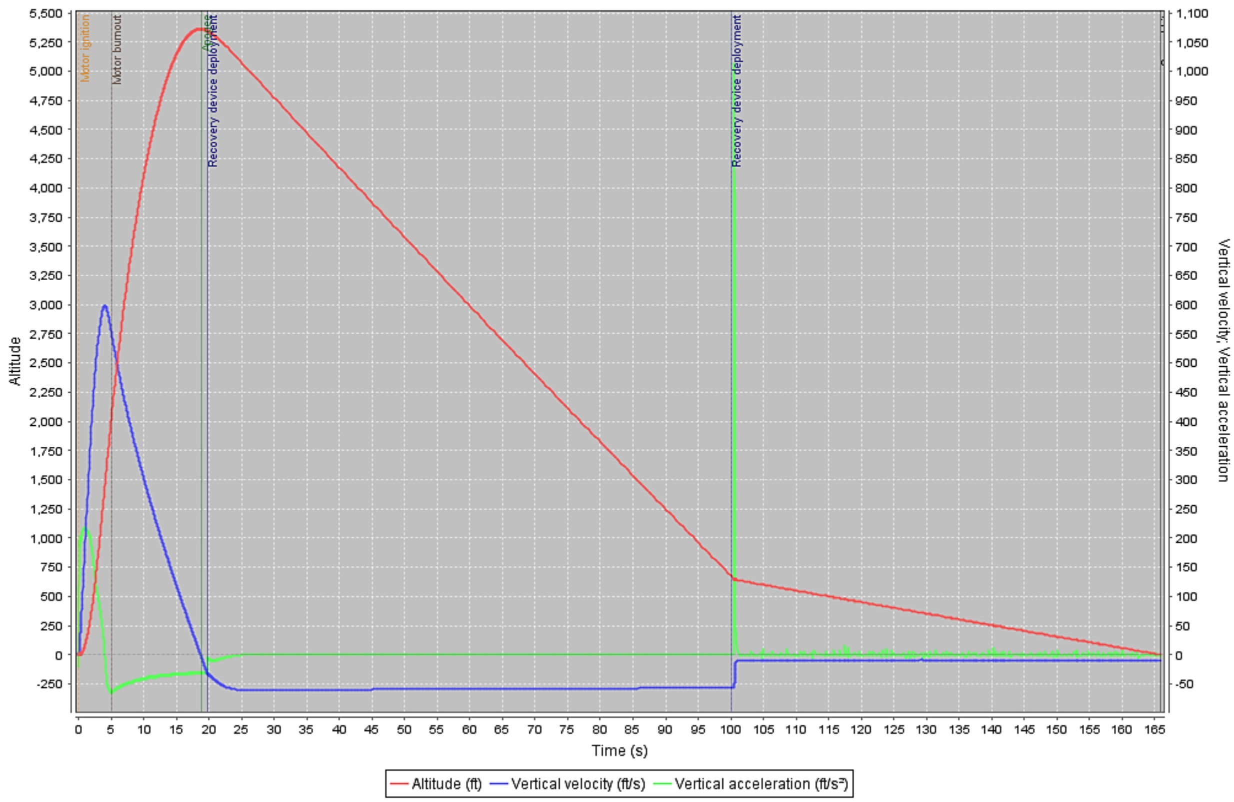

Figure 13: OpenRocket Flight Simulation

Altitude predictions were also taken from the OpenRocket flight simulation, with the current design and no wind the apogee can be expected to be 5438 ft. This estimate overshoots the target apogee of 5280 ft but a zero-wind prediction is not realistic. The altitude predictions for 5, 10, 15, and 20 mile per hour winds are shown in Table 3 and come from OpenRocket simulations of the same parameters as listed above.

Table 3: Altitude Predictions at Various Constant Wind Speeds

Wind Speed (mph)	Predicted Altitude (feet)
0	5438
5	5385
10	5315
15	5250
20	5180

From the altitude simulations, it is seen that at wind velocities around 10 mph the apogee of the rocket is within 1% of the target altitude. This is ideal because average wind speeds in the area can be estimated to be in this range. Even if wind speeds increase to near unsafe levels (20 mph), the performance of the launch vehicle will not be severely compromised.

3.3.2. Motor Thrust Curve

Figure 14 shows the simulated thrust curve as reported by the manufacture and reproduced in OpenRocket's library of motors.

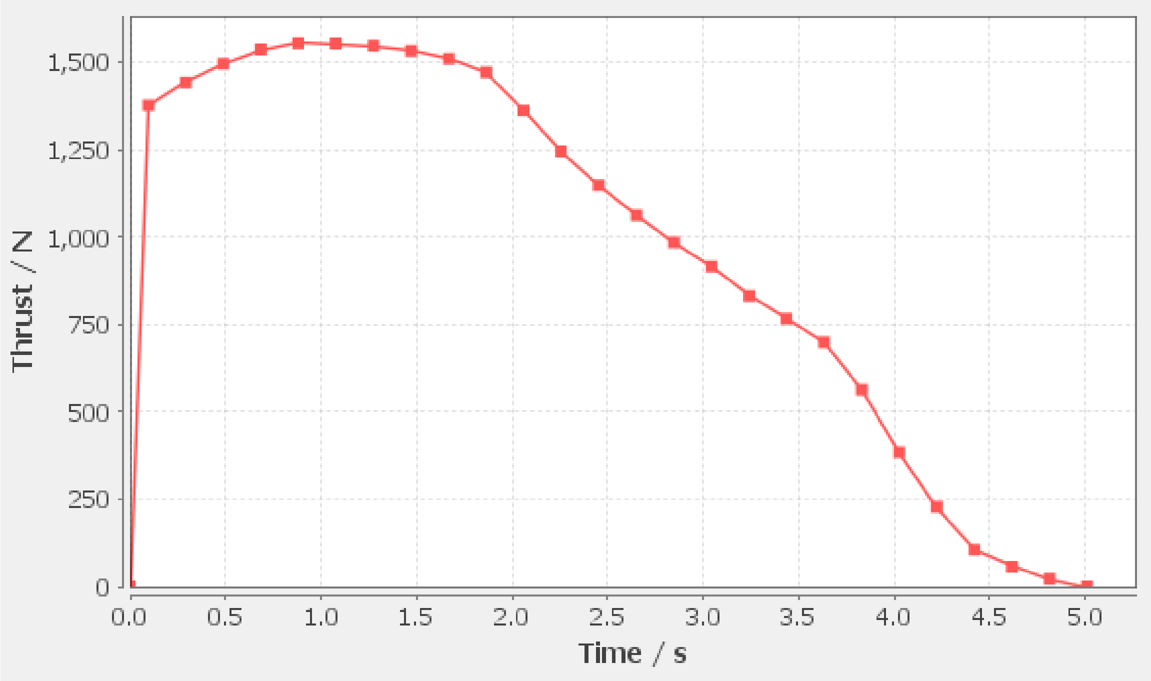

Figure 14:L1120W Simulated Thrust Curve

3.3.3. Stability Margin, Center of Pressure, Center of Gravity

OpenRocket and Barrowman's equations were both used to find the stability margin, center of gravity, and center of pressure of the vehicle. OpenRocket gives a static margin of 2.12 cal. with the CG located 71.7 inches aft of the datum and the CP located 84.8 inches aft of datum. In comparison, Barrowman's equations gave a stability margin of 2.10 cal. with the CG at 71.7 inches aft of datum and CP at 84.7 inches aft of datum. The center of pressure for an ogive nosecone is 46.6 percent of the length, measured from the tip of the nose. Center of gravity will be physically determined by weight and balance and from SolidWorks models once all components are brought together.

Due to the well accepted use of Barrowman's equations in rocket stability calculations and the correlation to OpenRocket values, it is safe to use OpenRocket calculations for preliminary stability analysis. Figure 15 shows the location of CG (blue and white cross) and CP (red circle with red dot).

Figure 15: Center of Gravity and Center of Pressure Locations Along Launch Vehicle

Launch rail exit velocity is crucial to the vehicle's stability. Per Vehicle Requirements Section 1.15 of NASA SLI Student Handbook "The launch vehicle shall accelerate to a minimum velocity of 52 fps at rail exit." Assuming that the top rail button is 26.3 inches from the bottom of the rocket, the rail button will travel 69.7 inches for an 8-foot rail or 118 inches for a 12-foot rail before leaving the rail. For the L1120W motor and a 96-inch launch rail, it was found that the vehicle's top rail button would leave the rail at only 45.5 feet per second. However, using a 144-inch launch rail with the same motor, the vehicle's top rail button would leave the rail at 59.2 feet per second. Therefore, a 12-foot rail will be required to safely launch the vehicle from the pad.

Equation 2 shown below was used to calculate this velocity. This equation is derived using the assumption that the forces acting on the vehicle as well as its mass are constant over the short time on the rail. In addition, rail friction was neglected as well as drag due to the low velocities being considered.

$$V_{exit} = \sqrt{\frac{2L(T - W\sin\theta)}{m}} \qquad \text{Eq.2}$$

L is the distance the top rail button travels before it leaves the rail. This distance is equal to the rail length minus the distance from the top rail button to the aft most point on the rocket. Thrust was assumed to be 300lb and is the L1120W motor's average thrust over the first instant of flight, W and m are the vehicle's weight and mass respectively, and θ is the launch rail's angle from the horizontal (specified from the launch requirements to be 85 degrees).

While this rail exit velocity is above the minimum value, drag, rail friction, non-constant thrust, and the propellant burn-off were not taken into account. Also, the vehicle's weight is likely to increase between the preliminary design and the final construction. This rail exit velocity will be verified using drag estimates from ANSYS's Fluent CFD program, propellant burn-off estimates, a final vehicle weight, and varying thrust values. The launch rail length will be adjusted if this more accurate method of estimating launch velocity does not meet the minimum value.

3.3.4. Kinetic Energy at Landing

The requirement for the impact force was stated at no more than 75 ft-lb. Using MATLAB, a program was compiled to determine approximate parachute sizes required to keep the velocity and kinetic energy within acceptable levels. Using Equation 3 below, the velocity can be calculated to determine the speed at which the payload and rocket body can fall.

$$KE = \frac{1}{2} m V^2 \qquad \text{Eq. 3}$$

Knowing the mass of the body, m, and the maximum kinetic energy, KE, the maximum descent velocity, V, can be determined. The current weight estimation of the rocket after burn and payload are 39.86 lbs and 7 lbs respectively. Solving this equation yields a maximum impact velocity of 10.637 ft/s for the rocket and 26.27 ft/s for the payload. The impact velocity for each parachute area A can be determined using another formula found below in Equation 4.

$$V = \sqrt{\frac{2D}{C_D \rho A}} \qquad \text{Eq. 4}$$

D in this equation is drag force but is equated to the weight of the body falling straight down. C_D is the drag coefficient, ρ is the air density, and Area is A. The constants used for C_D and ρ were 2.2 and 0.002377slugs/ft^3 respectively. The results are plotted below using variable diameter parachutes.

Figure 16 below shows the speed in which the rocket body will fall under different sized drogue parachutes.

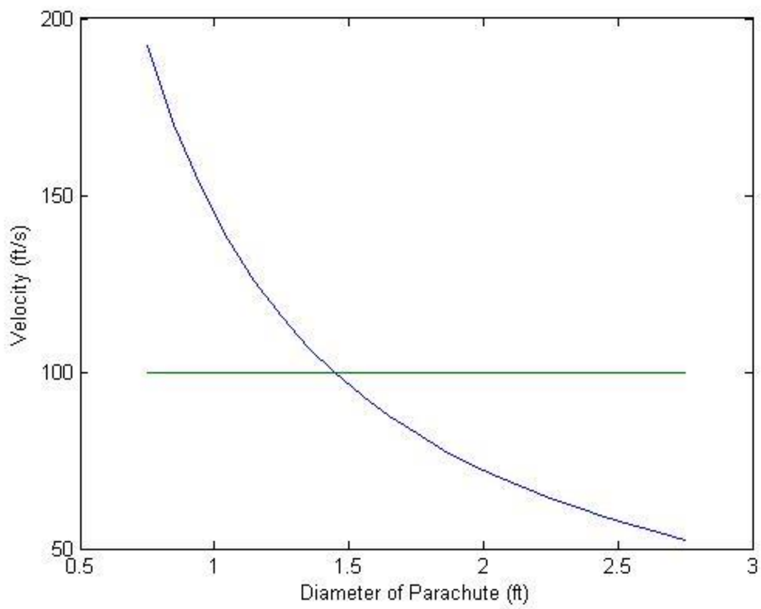

Figure 16: Vehicle under Drogue Velocity

For the drogue sizing, 100 ft/s was chosen as the maximum velocity at which the vehicle will fall. Based on figure 16, a 2 ft drogue parachute was chosen to deploy at apogee slowing the rocket body to 90 ft/s.

At 700 ft, the main parachute will deploy between the nose cone and body tube connection. The entire main rocket will be tethered together with shock chords meaning the entire weight of the rocket will rely upon the main parachute slowing the velocity of the rocket enough to get the kinetic energy under the 75 ft-lb threshold. As calculated above the rocket needs to be slowed to a velocity of less than 10.64 ft/s. Figure 17 below shows the impact speed compared to different diameter parachutes.

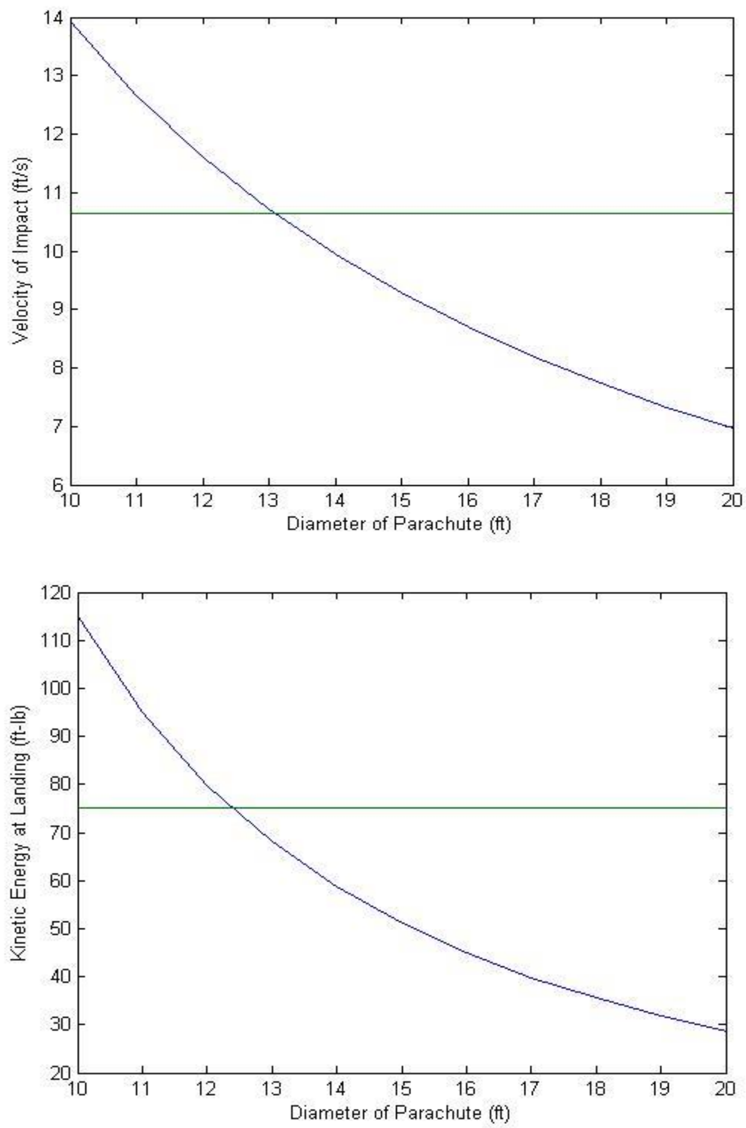

Figure 17: Main Parachute Calculations

From Figure 17, it was determined that a parachute of greater than 13 ft is necessary to bring the impact force under the allowable threshold. To account for projected weight gains involved with fabrication of the rocket a 15 ft parachute will be used as the main parachute for the rocket so that fabrication will have some factor of safety with regard to the recovery system. The 15 ft parachute will slow that rocket body down to an impact velocity of 8.5 ft/s.

The payload will have a streamer that instant deploys upon ejection from the main rocket body for proper vertical orientation. It will also require a parachute deployment to complete the data collection and still fall under the impact force limits. Figure 18 shows the maximum velocity at which the payload can fall. It was also determined that a speed of 15 ft/s descent would allow for proper target location and differentiation.

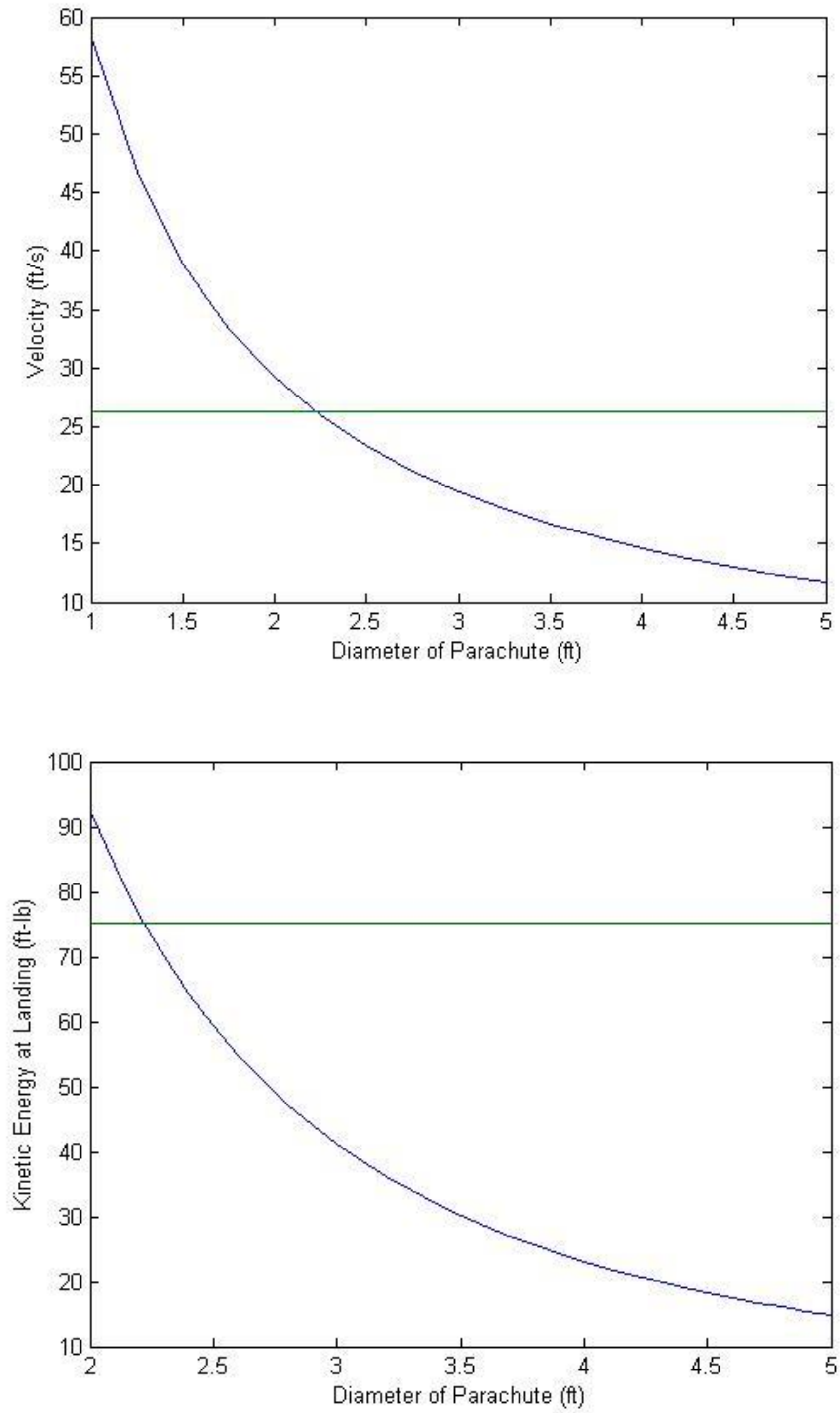

Figure 18: Payload Parachute Controlled Descent Calculations

From Figure 18, it was determined that a parachute with a 4 ft diameter would provide enough drag to complete the mission and fall well under the maximum velocity from the requirements. The calculated impact velocity will be 14.9 ft/s. Since the payload is much lighter than the rocket body it is allowed a much higher impact velocity and can remain under the impact force allowable.

3.3.5. Wind Drift

Drift is an important consideration because the rocket and payload must be retrieved walking on foot. Calculations were made to determine the maximum drift distances at different wind speeds. The distances were calculated for the rocket airframe that will fall in three separate pieces yet still be tethered together on impact and the payload section with its own separate avionics controlled recovery system. For the calculations, the rocket was assumed to have shot straight up at a 90^{o} angle with the ground. Assuming perpendicular launch is a safe assumption and simplifies the calculations involved with wind drift. Table 4 below shows the predicted wind drift for five different wind cases. Figure 19 shows a top view visual for the potential drift distances.

Table 4: Wind Drift Predictions

Wind (mph)	Rocket Airframe (ft)	Payload (ft)
0 (blue)	0	0
5 (green)	603.9	344.5
10 (brown)	1207.8	689
15 (yellow)	1811.8	1033.6
20 (red)	2415.7	1378.1

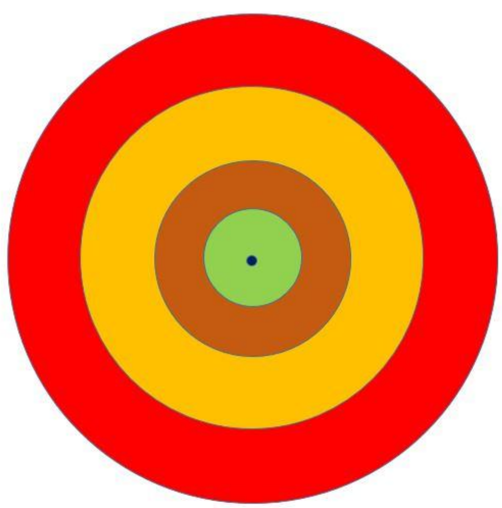

Figure 19: Wind Drift Diagram

These values were calculated from determining how quickly the payload and launch vehicle will be descending when the parachutes deploy and finding how long they will be in the air from the altitude at which the parachutes open. The launch vehicle has a greater surface area than the payload meaning that the launch vehicle will experience perpendicular wind forces for a longer time thus increasing the total potential drift distance.

3.4. Interfaces and Integration

3.4.1. Payload

The independent payload will be seated inside the rocket, toward the aft section of the avionics bay during flight. It rests atop the fin can and, at apogee, will be jettisoned using the payload deployment rail system described in §3.1.3.4. The payload will carry a fully redundant target detection system, each with a microprocessor, camera, GPS unit, altimeter, orientation sensor, LED functionality indicator and battery. After the payload is jettisoned and falling independently, the ULS will deploy automatically by the absence of the foot pad housing allowing for upright landing upon contact with the ground.

3.4.2. Launch Vehicle and Ground Station

The launch vehicle will contain GPS units for each of the sections that will decouple per regulation. There are four total sections so four BigRedBee (BRB) 900 MHz GPS transmitters. The GPS units have provided the team with reliable location information in the past and has allowed for recovery of the launch vehicle. These GPS units will be responsible for relaying telemetry data to the ground station which will consist of a handheld GPS receiver that will allow the team to locate and find the payload and rocket body. The team will conduct experiments to ensure that the system reliably transmits and receives data. The transmitters are on the same frequency; the team will make sure that all transmitting devices are on separate channels.

4. Safety

4.1.1. Launch Operation Procedures

To ensure all hazards and accidents are avoided; the NC State HPRC will follow the published Tripoli Pre-Flight Review Checklist:

a. General
    i. Is this member known to the TAP reviewer?
    ii. Does this member have the appropriate Certification Level or will this be a Certification Flight?
    iii. Does the proposed launch site and date have the appropriate recovery area and launch set-up for this flight?
    iv. Does the Prefect require TAP Review?
b. Rocket Review
    i. General
        1. Are there attachments to the Pre-Flight Data Capture?
        2. Drawings: airframe; structures; payloads, etc.

3. Schematics: avionics, ignition systems, payloads, etc.
4. Performance calculations: Center of Pressure; Center of Gravity, motor type, altitude, velocity, etc.

ii. Airframe
1. Is the design generally suitable for the application?
2. Is the airframe material suitable for this rocket?
3. Is the fin material/attachment sound?
4. Is the motor mount sound?
5. Is the nosecone suitable?
6. What are the most probable airframe faults and corrective actions?
7. What are the safety implications of an airframe failure?
8. Are there any design change recommendations?

iii. Recovery System
1. Is the recovery system attachment secure/suitable?
2. Does the recovery system have sufficient capacity for a safe descent?
3. What is the deployment system?
4. What are the most probable deployment system faults and corrective actions?
5. What are the safety implications of a recovery system failure?
6. Are there any design change recommendations?

iv. Avionics Description
1. Commercial or unique design?
2. What are the functions of the avionics components?
3. Are the avionics appropriate to the application?
4. Do the avionics have flight safety implications?
5. Can the avionics and inhibits be accessible from outside the vehicle?
6. Are there safeing/arming indicators?
7. Are any of the systems redundant?
8. What are the most probable avionics system faults and corrective actions?
9. What are the safety implications of an avionics system failure?
10. Are there any design change recommendations?

v. Motor
1. Is the motor suitable for the rocket?
2. Is the motor Tripoli Certified?
3. Is the motor ignition suitable?
4. What are the most probable motor faults and corrective actions?
5. What are the safety implications of a motor failure?
6. Are there any design change recommendations?

vi. Launcher
1. Is the launcher suitable for the rocket?
2. Is the launch lug, or rail guide suitable for the rocket?
3. What will the launch angle be?
4. Are there any special launch control requirements?
5. What are the most probable faults with the launcher?

6. What are the safety implications of a launcher failure?
7. Are there any design change recommendations?

vii. Performance

1. How were the performance calculations done?
2. Were the calculations done manually?
3. Are the algorithms used correct?
4. Were the calculations accomplished correctly?
5. Was a computer used?
6. What is the source of the software?
7. Is the software suitable for this rocket?
8. Are there printouts?
9. Should the calculations be independently run?
10. What are the safety implications of poor performance data?
11. Are there any changes or recommendations?

viii. Operations

4.1.2. Personnel Hazards

While competing in the NASA Student Launch project, there are many hazards that team members must consider in order to keep safety at the forefront. From the laboratory to the launch pad, there are possibly harmful tools, materials, and chemicals. Before using any of the power tools in the laboratory, the safety officer gives a demonstration on the correct procedure for use of each tool. The team members are then supervised until they are proficient on the lab tools. The correct personnel protective equipment (PPE) must also be worn by team members depending on the tools, materials, or chemicals they are working on. Team members must also follow the Material Safety and Data Sheets (MSDS, Appendix C) when handling any hazardous materials and chemicals. Tables 5 and 6 contain a personnel safety matrix for construction and launch pad. Table 7 contains a safety matrix for environmental safety concerns.

Table 5: Construction Personnel Hazards

Safety Concern	Risks	Likelihood / Severity 1-not likely/severe 5-very likely/severe	Mitigation	Confidence
Drill Press	Physical harm to extremities. Damage to lungs, eyes, and ears of the user and of others. Electric shock hazard.	2 / 4 2/ 3 1 / 3	All personnel in the lab space are notified before powering on the drill press. Safety glasses and earplugs are to be worn by persons operating the press. Precise set up of the drill press and retention of the material being drilled will ensure the press is operated safely, smoothly, and within operating limits.	The drill press is a safe piece of machinery. Team members are trained on how to use the press safety and are supervised until proficient. Proper PPE will be worn at all times during operation.
Band Saw	Cutting of extremities. Damage to lungs, eyes, and ears of the user and of others. Damage from ejected debris. Electric shock hazard	2 / 4 2/ 3 1/ 3 1 / 3	All personnel in the lab space are notified before powering on the band saw. Safety glasses and earplugs are to be worn by persons operating the band saw. Saw calibration and setup are checked prior to use. Only select materials and thickness will be used on the band saw.	Proper setup (tightness and alignment of band) is the most important part of safe operation of the band saw. Team members are trained on the band saw and supervised until proficient. Proper PPE will be worn at all times during operation.

Belt Sander	Abrasion of extremities Damage to lungs, eyes, and ears of the user and of others. Damage from ejected debris. Electric shock hazard.	2 / 1 3/ 3 2/ 3 1 / 3	All personnel in the lab space are notified shortly before powering on the belt sander. Safety glasses and earplugs are to be worn by persons operating the belt sander.	The belt sander will be checked for proper tightness before use. Proper PPE will be worn at all times during operation. Only individuals who are trained in the proper use of the belt sander will be permitted to use it.
Manual Mill	N/A	N/A	For any items that need the manual mill, the team goes to the director of the Mechanical Engineering Shop. The director of the shop is a professional machinist hired by NC State.	The shop director ensures the safety of his lab and helps teach those concerns to team members. All shop procedures are followed when the manual mill is used.
Chop Saw	N/A	N/A	For any items that need the chop saw, the team goes to the director of the Mechanical Engineering Shop. The director of the shop is a professional machinist hired by NC State.	The shop director ensures the safety of his lab and helps teach those concerns to team members. All shop procedures are followed when the chop saw is used.

Black Powder	Burns from accidental ignition. Inhalation. Eye irritation.	1 / 4 1 / 2 1 / 1	Black powder is handled in an isolated location, premeasured, and placed into vials before taking it out to the launch site. The black powder is stored separately in a safe environment away from potential ignition sources.	Black powder is one of the more dangerous substances handled by the club, so extreme caution is taken when handling. There is minimal chance for problems with black powder.
Epoxy	Adhesion between body parts/between body parts and objects. Inhalation of fumes.	2 / 1 3 / 2	Epoxy is applied in ventilated areas. Persons using epoxy wear gloves and eye protection.	Safety procedures and observers ensure epoxy is a minimal safety concern in the lab.
Power Supply	Electric shock hazard.	2 / 4	Power supplies are left unplugged when not in use. They are not used near water and cords are inspected for bare wires before use. Circuitry is checked prior to use to ensure they can handle the applied loads.	Relatively low power uses with stringent safety requirements ensure proper use and safety when using electrical equipment.
Soldering Iron	Burns. Electric shock hazard.	3 / 3 1 / 3	Soldering irons are left unplugged when not in use. They are not used near water and cords are inspected for bare wires before use. User ensures proper spacing during operation.	Primary concerns with soldering irons focus around electrical safety and minimizes the misplacement of the heat source. Keeping these two

				risks in check ensures the safety of the equipment operation.
3D Printer	Burns. Electric shock hazard.	3 / 2 1 / 3	3D printer is turned off when not in use. The area near the printer is clear of foreign debris and bare wires.	Individuals will take an instructional training course with the safety officer to ensure safe and proper use of the 3D printer to avoid the possibility of burns and damage to the equipment.

Table 6: Launch Personnel Hazards

Safety Concern	Mitigation	Confidence
Assembly of Rocket Motor	The rocket motor is carefully carried from the car to the rocket assembly point. During assembly, all points specified by the manufacturer's instructions are followed step by step while the team's mentor, Alan, supervises.	Assembling the rocket motor is a critical procedure to ensure the safety and success of the launch. Special attention to manufacturer as well as advisor's instructions ensures the motor ignites and burns properly.
Handling of Vehicle	Two hands are used to transport each component when taking the rocket from the car to the assembling area. Electronics and blast caps are armed and filled shortly before launch.	Cautious handling protects the rocket from falls that could damage components and harm the launch.
Launch Vicinity	Monitoring the location of everyone that is in attendance on the launch site and preventing them from getting too close will be a simple task by giving warnings prior to launch.	Having set distances specified by launch officials mitigates this concern.
Location	Launches are only done at locations specified by the North Carolina Rocketry Association or NASA Student Launch.	The team is confident in these organizations to choose proper locations for launches.

Table 7: Launch Environmental Hazards

Safety Concern	Hazard	Mitigation
Cloud Cover	NAR Safety Codes prevent launch into cloudy conditions.	Make sure to check the weather forecast before launching and have a backup launch day in case of inclement weather
Rain, Snow or Hail	NAR Safety Codes prevent launch into cloudy conditions. Wet conditions can damage electrical components on the rocket.	Make sure to check the weather forecast before launching and have a backup launch day in case of inclement weather. In case of precipitation bring a tarp to put over the rocket. In case of hail stow the rocket under a protective shelter like a picnic shelter or inside the trunk of a car.
High Winds	NAR Safety Codes prevent launch into winds greater than 20 miles per hour. For winds less than 20 miles per hour the rocket may drift into an inaccessible area	Make sure to check the weather forecast before launching and have a backup launch day in case of inclement weather. If possible launch at a time during the day where there is the least amount of wind
Bodies of Water	The rocket can fall into the water and the electronics could be damaged. The rocket may fall into a deep body of water and cannot be recovered.	Make sure to launch in an area free from rivers, ponds, large puddles and the ocean. If the rocket falls into a body of water remove it as quickly as possible and disconnect the batteries from the electronics. Make sure to test electronic components before using them again
Cold Temperatures	Cold temperatures cause the batteries to discharge more quickly and cause the fiberglass body tube and fiberglass nose cone to shrink	Check to make sure the flight batteries and AGSE batteries are functional before launch. Check that the fiberglass body tube can still be separated by the black powder charge

High Humidity	Black powder charges become moist and don't ignite. Altimeters become uncalibrated in a high temperature high humidity atmosphere.	Store black powder in a cool, dry environment, check the calibration of the altimeters before launch
UV Exposure	Adhesives on the rocket can weaken. The body tube may warp or electrical components may become damaged	Limit the exposure of the rocket to direct sunlight. Visually inspect the rocket before launch
Road, Concrete of Hard Surfaces	Rocket is damaged because of an impact with a hard surface	Make sure to launch in an area that has soft surfaces for the rocket to land on
Trees or other Vegetation	The parachute may become tangled in a tree or can be ripped while being retrieved from a tree. The rocket can get stuck in a tree or other piece of vegetation, or may become damaged from an impact with a tree.	Make sure to launch in an area that is clear of trees or other objects that the rocket or parachute could impact
Ground Support Crew	Members of the ground crew may become injured by falling rocket parts or by being too close to the rocket at takeoff.	Make sure that all crew members remain alert and vigilant during the duration of the rocket launch and recovery. All crew should maintain a safe distance from the rocket at launch.

4.1.3. Failure Mode Effects and Criticality Analysis

The FMECA Diagram Spreadsheet is located in Appendix A and B.

NAR Environmental Regulations

The NAR High Power Rocket Safety Code document addresses the following environmental regulations:

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.

The team will fulfill this regulation by only launching at approved launch sites and with approved payloads. The team will comply with all FAA regulations and will not launch into winds greater than 20 miles per hour.

Launch Site. I will launch my rocket outdoors, in an open area where trees, power lines, 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.

The team will fulfill this regulation by only launching at approved launch sites.

Launcher Location. My launcher will be 1500 feet from any inhabited 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 fulfill this regulation by only launching at approved launch sites and by placing the accompanying table at least the Minimum Personnel Distance from the boundary of the launch site.

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 team will fulfill this regulation by including two commercial parachutes in the rocket and by testing the rocket airframe to the expected impact loads. Only flame resistant wadding will be used in the rocket.

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.

The team will fulfill this regulation by only flying at approved launch sites where there are no power lines, tall trees or dangerous places to have to retrieve the rocket from. No one will attempt to catch the rocket as it approaches the ground.

Table 8: Project Risk Analysis

Risk	Likelihood	Impact	Mitigation	Mitigation Cost
Overspending	Low	Medium	Proper budgeting	May have to find other income
Delays	Medium	High	Proper planning and diligence	May lose time delegated to other areas
Lack of Resources	Low	High	Thorough bill of materials	Sacrifice items from other areas
Improper Design	Medium	High	Proper analysis of each subsystem	May attempt to spend too much time on a single system
Rocket Motor Failure	Low	High	Use well-established motors	May need to purchase a more expensive rocket
Payload Deployment Failure	Low	High	Proper testing of payload ejection	May need to spend more on different design components
Target Identification Failure	Low	High	Ensure electronics and code are compatible	May have to purchase different camera system
Insufficient Power Supply	Medium	High	Use larger power supply	Increase in weight of payload

5. Payload Criteria

5.1. Selection, Design, and Rationale of Payload

5.1.1. System Level Requirements

The following was taken from the NASA SL 2016 Handbook for its comprehensive and complete descriptions:

1. Target Detection and Upright Landing
    1. Teams shall design an onboard camera system capable of identifying and differentiating between 3 randomly placed targets.
        a. Each target shall be represented by a different colored ground tarp located on the field.

b. Target samples shall be provided to teams upon acceptance and prior to PDR.
c. All targets shall be approximately 40'X40' in size.
d. The three targets will be adjacent to each other, and that group shall be within 300 ft of the launch pads.

2. After identifying and differentiating between the three targets, the launch vehicle section housing the cameras shall land upright, and provide proof of a successful controlled landing.
3. Data from the camera system shall be analyzed in real time by a custom designed on-board software package that shall identify and differentiate between the three targets.

5.1.2. Subsystem Requirements and Performance Characteristics

5.1.2.1. Payload Deployment

The payload will be separated from the launch vehicle upon the initiation of the payload deployment sequence at apogee. During a successful payload deployment sequence, no payload components will separate from the. Upon jettison from the launch vehicle the streamer will provide drag and orient the payload; at which time the TDS will have the ability to begin recording and processing images of the ground for target identification and differentiation. Furthermore, the ULS will successfully deploy from its stowed position during the payload deployment sequence.

5.1.2.2. Target Differentiation System (TDS)

The TDS will begin collecting data at a specified time or altitude. During the time the system is recording and processing data it will capture images of the ground which will include the three targets. Upon capture of the image, the system will attempt to identify that there are three targets and differentiate between them. A successful TDS will identify the three targets and differentiate between the targets at some point during the time it collects data.

5.1.2.3. Upright Landing System (ULS)

The payload will descend from its deployment at apogee and land on the ground in the same orientation as it was on the launch pad. A successful ULS will deploy from its stowed position after being deployed from the launch vehicle and absorb the impact from ground contact while keeping the payload oriented upright (as defined by the orientation of the payload on the launch pad). Telemetry data from the payload will provide proof of a successful landing.

5.2. Payload Concept Features and Design

5.2.1. Integration Plan

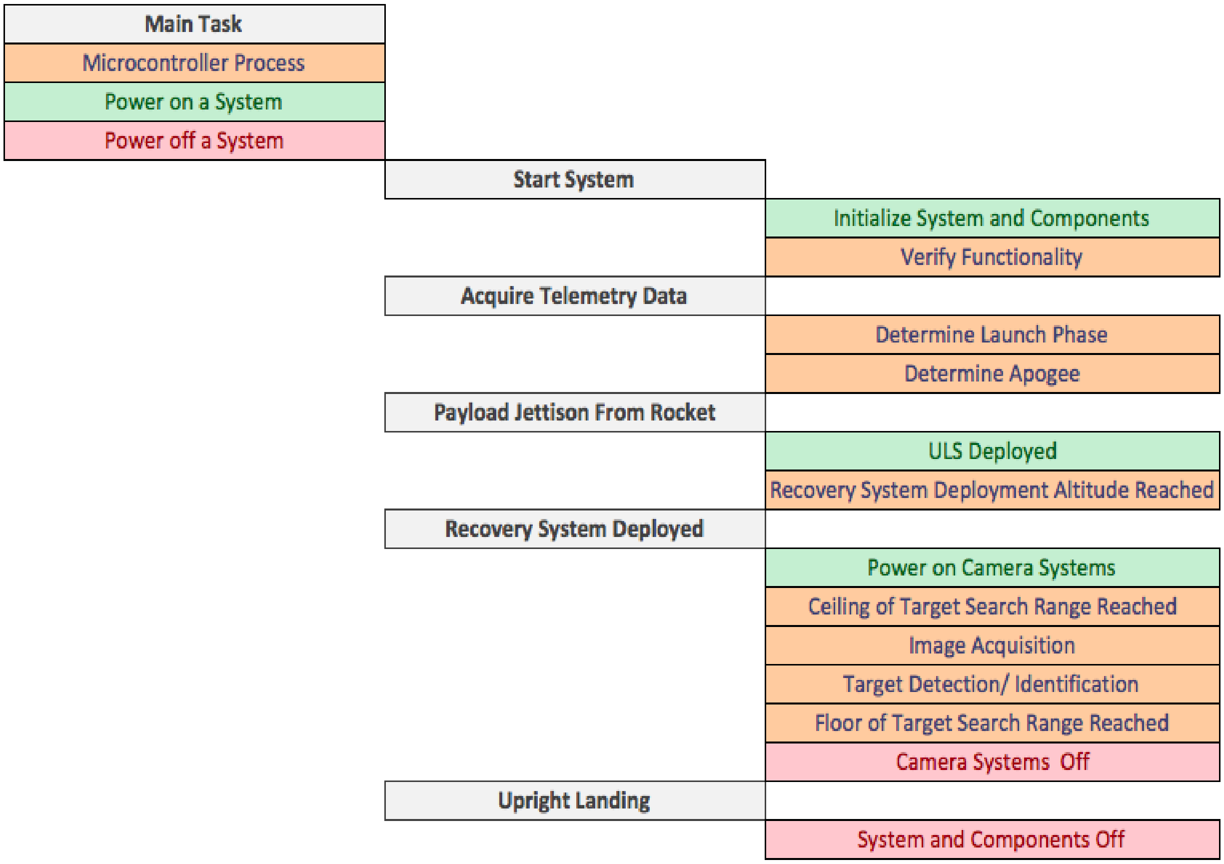

Figure 20: System Hierarchy

5.2.2. Assembly Drawing

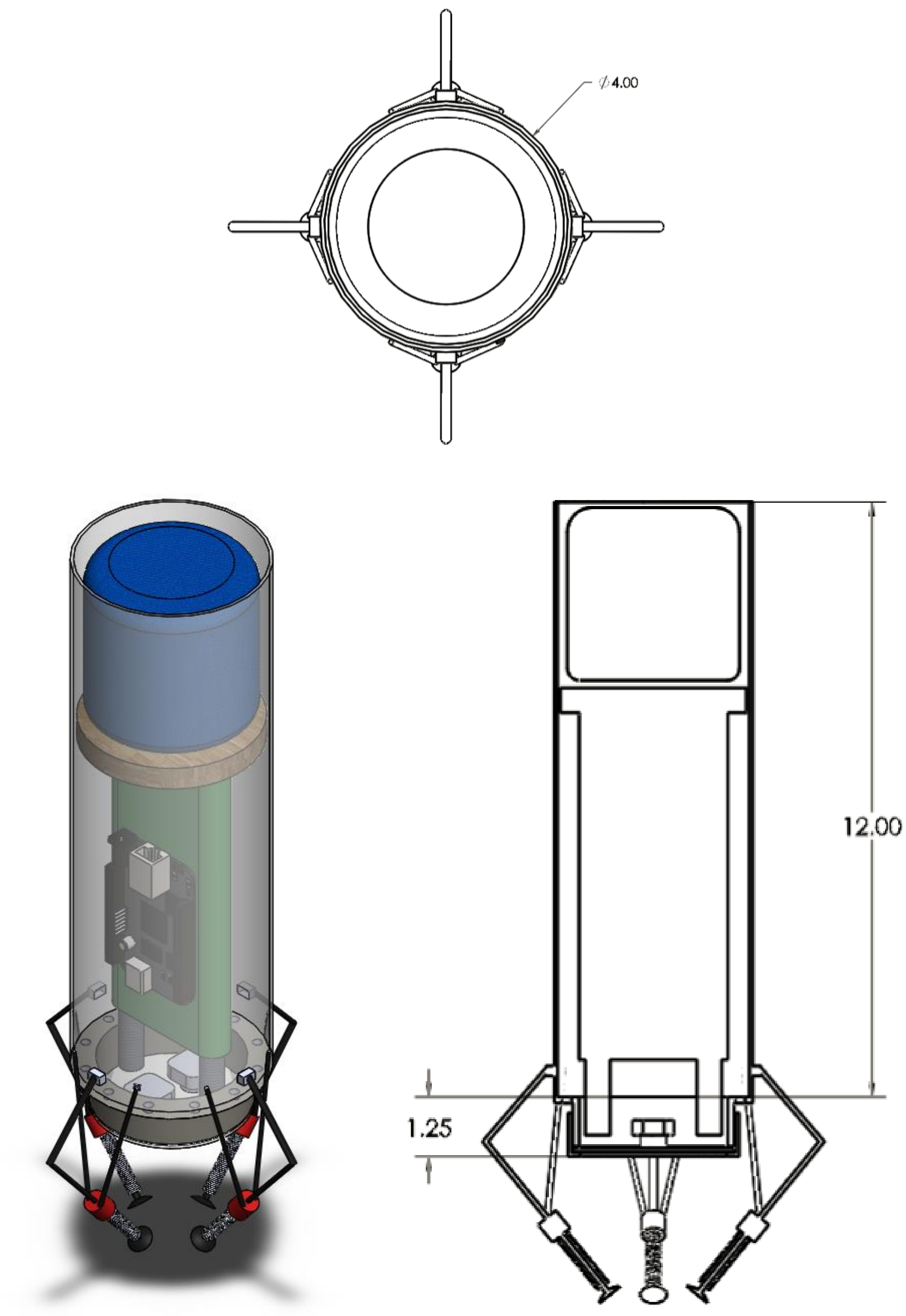

Figure 21: PBR SolidWorks Model

5.2.3. Electrical Schematic

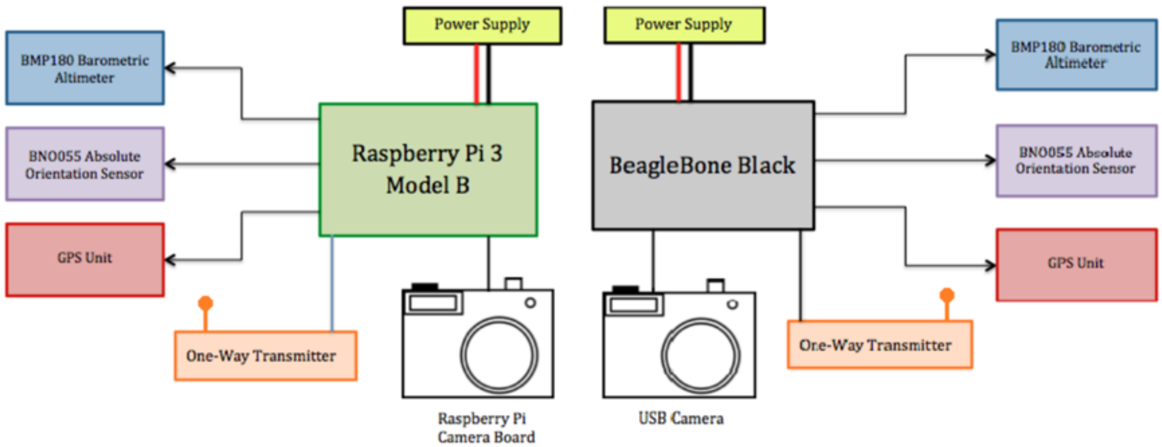

Figure 22: Payload Electronics Schematic

5.2.4. Alternative Designs

Several payload deployment systems have been discussed during the planning and proposal stages of this project: the payload being a section of the launch vehicle, varying the position of the payload within the launch vehicle, perpendicular jettison of the payload, forward jettison after nose cone separation, and aft deployment via rail system. The following section deals with the other potential designs and explains each in further detail.

5.2.4.1. Payload Deployment System

The payload was initially designed as a section of the launch vehicle airframe. One of the issues that presented itself early on when working with the torsional spring ULS design was the possibility of unintended ULS deployment during launch vehicle flight. This event would have potential to separate the rocket, resulting in a catastrophic failure mode. Another downside is there is no way to attach the sections forward of the payload to those aft of it after payload deployment; therefore, three to four independent objects would be descending after reaching apogee. One revision of this design includes the payload being a transition in the rocket (this would only be the case if a varying cross-section payload body was chosen). In addition to overcoming the challenges of including a transition, the ULS would have to have a stowed deign that is flush with the payload body. A transition would produce more drag than a constant cross-section rocket and any objects not flush with the transition would increase the drag. Furthermore, a perturbation of the rocket's flight path would be amplified by the applied aerodynamic moment caused by the drag of a protruding component.

The intent of the design for perpendicular deployment of the payload was to have a crescent-shaped section of the rocket that "holds onto" the payload, in a similar fashion to that of a claw. The deployment mechanism would be either an applied impulse to separate the payload or a release of the claw. This design would require a lot of development and testing in order to prove safety and repeatability. The claw-release mechanism is the more feasible of the two deployment ideas presented within this design.

Payload deployment and different positions of the payload within the launch vehicle were the next alternative designs to be introduced. The position of the payload within the launch vehicle included forward jettison from the midsection after nosecone separation and aft deployment from the midsection after fin can separation.

The aft jettison design was a passive deployment system—the launch vehicle would separate in such a way that the payload would be able to slide out of the midsection without any applied loads aiding its ejection. However, it is hard to prove that such a scenario exists without extensive testing and analysis. With the time constraints and facilities/funding available, it was decided that the system would need to be active to ensure successful jettison if aft deployment was desired.

The forward jettison design was an active deployment system in which the nose cone and midsection or midsection and fin can would be forced to separate by the ejection of the payload. This system is very similar to active aft jettison design. The main issue with this design is the launch vehicle body would need to have independent recovery systems and avionics, which greatly degraded feasibility.

(It is interesting to note the transition of the payload's placement radially between the first three major ideas. The designs developed from a payload on the exterior of the rocket, to fully enclose.)

Active aft deployment of the payload using a rail system is the most recent alternative design to be investigated. In this system, the payload will be housed in the same bay as the drogue parachute, which will be attached to the avionics bay bulkhead and the fin can bulkhead by a shock cord. The drogue will be packed forward of the payload with the payload resting on a shelf attached to the fin can bulkhead and will be contained in a bowl-shaped PVC canister which is attached to the shock cord. This canister will transfer the force from the ejection charge through the payload and into the fin can to break the shear pins attached to the coupler.

Two equally spaced rails will be attached to the walls of the rocket body for the payload to slide along as it exits the rocket. The rails will be 1" x 0.5" T-slotted aluminum or plastic and fit on rods that are attached to the avionics bulkhead. A centering ring will attach to the aft end of both rails to increase rigidity in separation. Rail buttons will be mounted on the payload to guide the payload along the rails.

The shock cord will be routed from the avionics bay bulkhead through the chute canister, around the payload, through the shelf, and connected to the fin can bulkhead. The chute canister will only have enough shock cord to reach the exit of the bay. To avoid the payload traveling with the fin can until the entire shock cord is taught, a shear pin will attach the chute canister and the payload. This shear pin will break at payload clearance of the bay and will decelerate and impart a moment to turn the payload away from the fin case.

The major pro of this design is the rocket will descend as a single unit tethered together by Kevlar shock cords capable of withstanding the decoupling forces. This means that there will only be two independent objects descending, rather than three or four. Additionally, it is the most developed and repeatable system to have been designed thus far. The repeatability payload deployment from the rail system design far exceeds that of any other payload deployment system design. The added difficulty in implementing the rail system design is offset by its repeatability and is the current leading alternative payload deployment system design.

5.2.4.2. Target Differentiation System (TDS)

Three designs for the TDS system have been explored: a single camera system, one on the forward face and one on the aft, and system with two completely redundant camera systems.

The single camera system was the first target acquisition system designed. The on-board electrical load for a single camera system is low, keeping the overall size of the payload small. Thus, the recovery system and ULS would also be able to be smaller. However, if the single camera system loses power or stops functioning mid-flight, no data would be taken and the mission would fail.

The system utilizing one forward facing camera and one aft facing camera addressed two needs in the early stages of the project: the need for a redundant system; and, with the correct payload body geometry, one camera would be recording useful data regardless of whether the forward or aft face of the payload was facing the ground during descent. However, this idea is very inefficient because it will either result in one or both camera systems taking data with no value to the experiment. Furthermore, after the NASA SL team stated that the payload must land in the same orientation it would be on the launch pad; this design had to be dismissed altogether.

The completely redundant TDS is the most recent alternative design for the experiment. With a recovery system that orients the payload after deployment from the launch vehicle there is no need to place cameras on more than one surface. Completely redundant systems eliminate the issue of one camera failing and the mission failing as a result. Each camera system will run on its own independently wired power supply and computer so any electrical failure in the system will only affect one camera system. The downside to this system is that much more space in the payload will need to be delegated to the camera system electronics, and two independent power supplies will necessitate a larger payload body than either of the two previous systems.

The current leading TDS is the completely redundant camera systems. The system being still functional after a camera-out event easily compensates for the increased payload size and need for completely independent electrical systems.

5.2.4.3. Recovery System

Two alternative designs currently exist for the payload recovery system: an autorotating velocity management recovery system (AVMARS) which mimics objects found in nature and a parachute recovery system with Jolly Logic release.

The design intent of the AVMARS is to mimic a naturally autorotating object. The model object currently being researched is a samara or rotary seed. A composite, multiflash image of a maple seed in descent is shown in Figure 23.

Figure 23: Rotary Maple Seed [5]

A large percentage of rotary seeds' mass is contained within the fruit, which is located along the axis of rotation in Figure 23. The wing of the rotary seed forms the helical profile of the flight path. This design is of interest because the natural system is passive; the wing inherently creates a decrease in descent rate.

The rotor is a single-degree-of-freedom (SDOF) system which can only rotate about the its line of action. The up-lock mechanism would restrict the upward rotation of the wing to orient parallel to the payload body, which would be controlled by a SDOF rotating component.

An electric motor to counteract the natural spinning of the wings due to descent would be incorporated, thus decreasing the rate of descent. The current preliminary design uses four wings and an electric motor to reduce and manage the descent velocity. Research on rotary seeds and other auto rotating objects is being conducted to accelerate the team's understanding of alternative recovery systems and the design maturity of the AVMARS system.

A downside to the AVMARS is the surface area needed to control the landing of the payload to a kinetic energy both under 75 ft-lb and manageable by the ULS would have to be thoroughly tested. A stowed position would also have to be vetted more to assess if volume exists within the launch vehicle for the AVMARS to be stowed. Another downside to the AVMARS is the transfer of angular momentum to the payload body, which would require a "tail rotor" of sorts to limit payload rotation. A pro to the AVMARS is the potential for wind drag is decreased due to the nature of the system and its potential to incorporate a resting position similar to the stowed position.

The second alternative design for the payload recovery system is a parachute with a release mechanism. An image of the chute release mechanism, the Jolly Logic Chute Release, can be seen below in Figure 24.

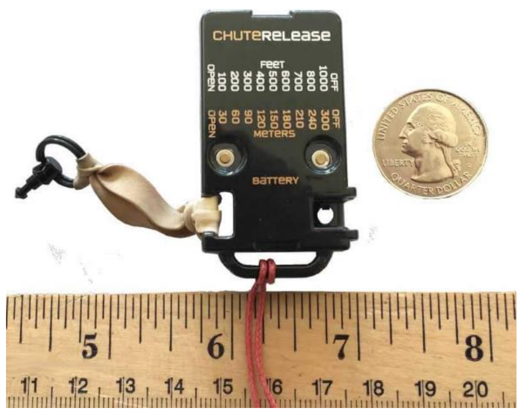

Figure 24: Jolly Logic Chute Release [6]

The Jolly Logic Chute Release allows for the deployment of the parachute at a desired altitude. The current parachute to be tested is the Fruity Chutes Iris Ultra Standard Parachute, which has a 4ft diameter rated for 12.5 lbs at 20 fps [7]. These ratings are well within the scope of both the NASA SL Handbook requirements and the payload system's weight while not being unnecessarily large.

The main upside to the parachute recovery system is the research for the system has already been done—an itemized list to buy and test from exists and testing will begin in mid-to-late November. Additionally, subscale testing of the parachute system will give the team a very good idea of how the full-scale system will behave prior to the full-scale test launch. The NCSU High-Powered Rocketry Team has a vast amount of experience with Fruity Chutes parachutes and the Jolly Logic Chute Release mechanism.

The current leading alternative design is the parachute system with release mechanism due to it being the more commonly used recovery system. The AVMARS is still in an early design stage and needs further research before its applicability in this system can be assessed. However, testing needs to be done to confirm at what wind conditions, if any, the payload has potential to be dragged or tipped by the parachute due to wind drag after the payload has landed.

To combat this issue, a detachable parachute alternative was considered. The NASA SL team was contacted regarding the use of detachable parachutes and responded that detachable parachutes are not allowed. The viability of the parachute recovery system is currently being further explored concurrently with the brainstorming of additional alternative payload recovery systems and further vetting of the AVMARS.

5.2.4.4. Structure

Two material options exist for the payload body: aluminum 6061-T6 tube or Quantum Composites QC-2150LD NT 25% Fiberglass Reinforced Phenolic SMC.

Buying a cylinder made of ductile metal, such as aluminum 6061-T6 would allow the potential to weld components to the payload body. This is of particular interest because a flange to connect the viewing surface retainer system to the payload body could be easily welded to the payload body. It is not foreseen that aluminum 6061-T6 would have any material integrity issues with drilling or multiple insertions/removals of hardware.

Drilling into brittle composite materials introduces stress concentrations which can lead to cracks in the payload. Attaching the rail buttons and potentially securing the bulkhead using metal tabs will require holes in the payload body to be drilled relatively close to one another—this may lead to brittle material failure if exposed to an applied load. Figure 25, below, shows an image of a fiberglass body tube after screws have been inserted and removed.

Figure 25: Quantum Composites Fiberglass with Screw Holes

As shown in Figure 25, imperfections in the fiberglass tube can be easily seen. If hardware needs to be inserted and removed several times during the construction of the payload, it may be the case that the integrity of the fiberglass is compromised and the diameter of the holes increases. This scenario would prove detrimental to the payload body as an item that would have previously fit tightly into the hole would then have room to move. For instance, if the rail buttons were insecure, the payload deployment system may fail because of an asymmetric jettison from the launch vehicle. Another possibility is the creation of layer imperfections which, depending on how close the holes are to another, could propagate and result in parts of a composite layer being stripped from the payload. Thus, the material properties at this location would change which may influence the system at a higher level.

The thinnest fiberglass tube wall thickness found online was 0.125 inches, which is almost double the thickness of the aluminum body tube. A wall thickness of 0.125 inches would solicit a redesign of the payload system because the screws that fasten the retainer body to the payload body would be bored into the payload wall through the flange; of which would need to be fiberglass if a fiberglass body was used. This would greatly increase the stress concentrations around a critical section of the payload body and is not desirable. If the outer diameter of the payload was increased, a larger retainer system would be needed. A fiberglass flange with twelve holes going through it susceptible to applied loads would still not be desirable—any impact to the retainer system would translate directly to the fiberglass flange and the corner connecting it to the fiberglass body.

Quantum Composites QC-2150LD NT 25% Fiberglass Reinforced Phenolic SMC has a tensile strength of 10,900 psi [1] compared to 6061-T6 aluminum's ultimate tensile strength of 45,000 psi [2]. The difference in weight between the 6061-T6 aluminum payload body and QC-2150LD payload body is on the order of 0.2 lbs when comparing identically sized tubes on vendor websites [3, 4].

The current leading payload body material is aluminum 6061-T6, due to its ability to retain material integrity after multiple insertions and removals of hardware attaching to the payload body, thinner wall thickness, ability to be purchased online in a variety of dimensions, and material properties. The increased weight of aluminum 6061-T6 when compared to Quantum Composites QC-2150LD NT 25% Fiberglass Reinforced Phenolic SMC has been considered worth the aforementioned benefits of selecting aluminum 6061-T6.

Two structural design options exist for the payload: a rounded conical module similar to the Apollo Command Module and a constant cross-section cylinder.

The Apollo Command Module design would allow for the ULS to be stored against the payload body walls. Since the cross-section area of a rounded cone decreases as height increases, the ULS could rotate about the larger circular face (bottom edge) of the payload which would minimize any increase to the effective diameter of the payload system. The only increase to the effective diameter would be the component(s) managing the stowage and deployment of the ULS.

The decreasing cross-section area at increasing height would also limit the amount of usable space inside the payload.

The payload deployment system would have to be revised if the Apollo Command Module design was chosen because the rail buttons would be much more difficult to install on a conical body. Creating stress concentrations on the bottom edge of the module would introduce material failure concerns.

Furthermore, the manufacturing of a rounded cone would be very time consuming, limit the potential manufacturing materials, and decrease accessibility to the payload interior. If the rounded cone payload body is to be chosen, the manufacturing would have to be completely custom. A mold would have to be created for the system. Then a composite layup would have to be constructed to create the payload body. The layup would need to be correctly cured and removed from the mold without damaging the payload body. Any imperfections in the structure would mean the build would be scrapped and the team would have to start the process over. A hatch system would need to be designed to allow access to the payload interior. Any holes drilled into the composite would introduce stress concentrations close to the edge of the structure, which would be prone to failure after repeated closing and opening. A threaded system would not be possible and connecting an aftermarket threaded system would mean introducing holes into the composite. The latching system which keeping the hatch closed would induce an applied stress, and potentially a strain, into the system. Cycling the latch may cause material failure after repeated use. Because the cross-section area of the top of the rounded cone is so much smaller than that of the bottom, access to the payload interior would be limited to one side unless a hatch on the payload body wall was to be implemented. A side hatch is not desirable for the same reasons as the lower hatch system is not. Single-side access to the payload interior would make working on, getting light into, and seeing into the payload very difficult.

The cylindrical design would eliminate the option for the ULS to be stored without significantly impacting the effective diameter of the payload system. However, it would be easier to install the ULS and the payload deployment rail buttons on the payload walls of a cylindrical body.

The total volume inside the payload body would increase with a constant cross-section cylinder when compared to that of a rounded cone. This is advantageous because more target differentiation and recovery system components can be housed inside the payload. This greatly increases the potential for redundant TDSs to exist within the payload.

A variety of constant cross-section cylinder tube materials, lengths, and thicknesses can be purchased online. Indeed, a composite system could be constructed as well. However, purchasing a tube online would greatly decrease the amount of time spent on procuring a payload body.

A constant cross-section cylinder would allow easy entry to the payload interior from both the top and bottom of the body. Double-side access would greatly improve the accessibility of the payload interior when compared to the rounded cone.

The current leading payload body design is the constant cross-section cylinder design because of its improved accessibility, ease of procurement, material variety, and greater volume compared to the rounded cone design. The assumed larger effective diameter because of this choice has been considered worth the benefits of the advantages.

5.2.4.5. Upright Landing System (ULS)

Two ULS designs have been identified: a torsional spring system and an "Apollo Lunar Module" strut-truss system. Both systems have been thoroughly vetted and will be discussed now.

The torsional spring system is the original ULS design created during the proposal stage of the project lifecycle.

The torsional spring ULS would deploy from the lower edge of the payload body; it would be connected between the retainer body and the payload body flange. With this design, the leg is only connected in one place instead of two, and there is no need to drill into the payload body to place connecting hardware. The legs would be stowed with the feet parallel and pointing upright while inside the launch vehicle. Due to the load being applied to the torsional springs in the stowed position, the system would automatically deploy when enough space for the legs to rotate is available. This quality creates a safety concern: if the system is being stowed by a team member and the team member's hand slips, releasing the spring load, the deploying leg could damage a person or equipment. For this reason, the torsional spring is not ideal.

A servo-released deployment system for the torsional spring ULS was introduced to combat the aforementioned safety concerns. The legs would be held in place by a centering ring with one tooth for each leg and the servo would rotate the centering ring to release the ULS in the same manner described above. It was decided that too many different systems on the outside of the payload body would become overly complicated, and a more robust design for the ULS could be designed after the proposal was completed.

The strut-truss system functions in a similar way to that of the Apollo Lunar Module (LM) in that it employs a locking mechanism, struts, and truss system. Figure 26 shows a rendering of the strut-truss ULS on the payload and Figure 27 includes a labeled diagram of the system.

Figure 26: Front and Side Views of Strut-Truss ULS Rendering

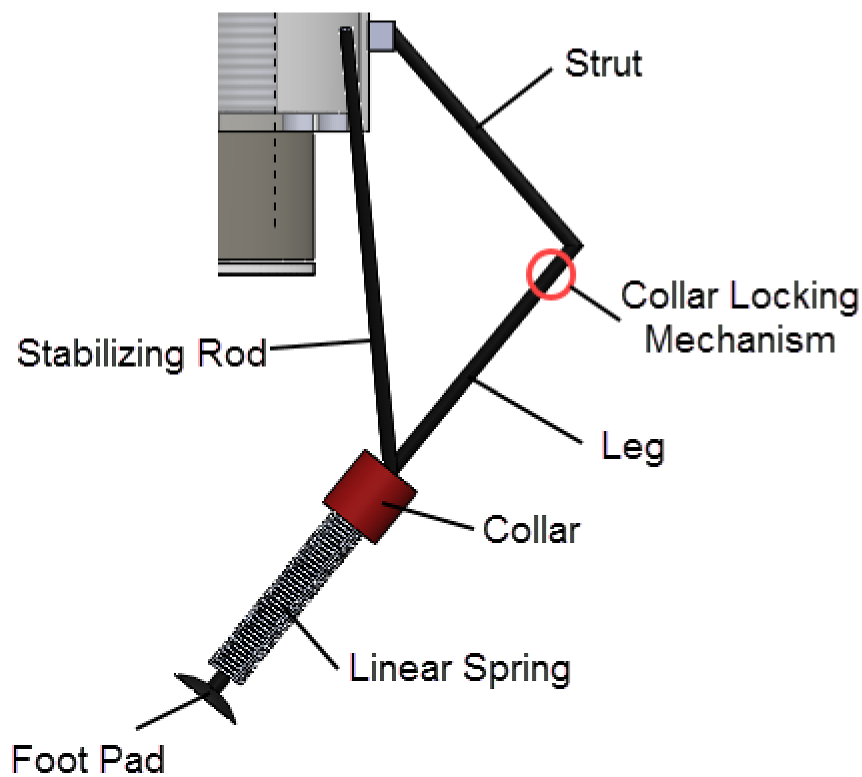

Figure 27: Strut-Truss ULS Diagram, Stowed Configuration

The strut-truss ULS utilizes a collar locking mechanism which is driven by a linear spring. It differs from the LM in that the locking mechanism is not a down lock mechanism, but a fully locking one. Furthermore, the point at which the system locks is entirely different than the LM. The spring will be positively displaced in the ULS's stowed position such that it will slide the collar up to its locked position. At that point the spring will not have any impact on the system thereafter and any shock absorption will be transferred from the leg to the strut. During the deployment of the strut-truss ULS, the stabilizing rods (two per leg) will rotate about their point of connection to the payload body as the collar slides up the leg. The stabilizing rods will mitigate any buckling or side-loading that may result from an angled landing with respect to the horizontal plane made by the ground. Radially offsetting the stabilizing rods with respect to the strut will decrease the payload diameter when loaded into the launch vehicle with the ULS stowed. If there were only one stabilizing rod located directly below the strut, it would have to compete with the stabilizing rod for stowage space.

The design intent of the probe foot is to increase the surface area of the ground contacted by the ULS, thus increasing landing stability. The probe foot will be connected to the leg via a ball and socket joint to allow for three degree-of-freedom (TDOF) movement. The TDOF probe foot will provide additional landing stability on uneven surfaces or upon an angled landing.

The strut-truss ULS provides improved stability when compared to a conventional leg. The deployment operation is more complicated and the assembly of the system will be more time intensive than a single-point-of-rotation leg. However, the enhanced capabilities of the strut-truss system greatly make up for the shortcomings.

The simplicity of the torsional spring ULS is enticing; however, testing torsional springs may prove to be a very exhaustive process. The current leading alternative design for the ULS is the strut-truss system. The strut-truss system's ability to stabilize itself in suboptimal landing conditions is much more favorable than the simplicity of the torsional spring system. In particular, the strut-truss system's ability to handle side-loading makes it a much more robust design than the torsional spring system. Drilling into the aluminum 6061-T6 body to connect the strut-truss ULS should not cause any material failures or concerning stress concentrations due to the characteristics of the alloy.

5.2.5. Uniqueness

This payload design differs from others the team has seen in several aspects. This payload is the only design yet to be seen which exhibits a completely redundant TDS. The active deployment method of this design differs as well—all other known designs jettison the payload from the launch vehicle passively. Some then perform an active deployment operation. Lastly, this is the only known design to include a ULS having legs that utilize dampers to absorb shock and truss-like mechanical stabilizers for controlling any side-loading the payload may experience during ground contact.

5.2.6. Level of Challenge

The Target Detection and Upright Landing Challenge was determined to be the most challenging and potentially the most rewarding for the team. The team is tasked with fitting an independent electromechanical system into the rocket body under restrictions such as weight, height, and a maximum number of rocket sections allowed. The ULS will present its own set of unique challenges. The active deployment of the payload and successful upright landing further increase the level of difficulty.

The team is attempting to increase the utilization of space inside the payload in hopes of lessening the amount of unused internal payload volume. An opportunity to decrease the size of the payload body exists if this is done effectively; which may, in turn, change the design of the launch vehicle. Increasing the overall efficiency of the system is a challenge that will exist throughout the entire lifecycle of this project.

5.3. Verification Plan

The team will complete several experiments to confirm that the payload system and subsystems can complete all the tasks required for mission success.

5.3.1. Field of View (FOV)

The purpose of this test is to determine the camera's actual FOV (as opposed to theoretical) in order to increase the efficiency of the TDS. The altitudes at which the TDS will become effective in capturing and processing images within a ~600 ft radius on the ground can be determined from this testing. The radius was chosen as such because the targets will be placed within 300 ft of the launch pad, so if the payload begins its descent opposite of the targets, the furthest away it can be is 600 ft. It is assumed, however, that the TDS system will be able to complete its mission at a high enough altitude that the aforementioned scenario will not come in to play. For example, at 2640 ft altitude, the FOV needed to span a 600 ft radius is ~26°.

The FOV test will be performed on a smaller scale using similar triangles and scaled-down targets prior to the subscale launch. The subscale launch will provide more rigorous data because the payload will be exposed to environmental phenomena which will not be present in a laboratory test, such as uncontrolled motion due to drag and wind. It should be noted; however, that this does not mean the TDS must process images during the subscale launch—it is possible images may only be captured and saved on the on-board computer. Analysis may be done at a later time to determine if the FOV is acceptable.

5.3.2. Battery Life

The battery life constraints, which will be adhered to, taken from the NASA Student Launch Handbook Section 1.8, include "the launch vehicle shall be capable of remaining in launch-ready configuration at the pad for a minimum of 1 hour without losing the functionality of any critical on-board component." The battery life will need to be sufficient to endure launch preparation times, the minimum one hour in launch-ready configuration, and for the duration of its flight.

To ensure the battery life will be sufficient to pass the criteria above, power consumption testing will be performed in the lab. The BeagleBone Black and Raspberry Pi microcontrollers are expected to use about 300-400milliamps during idle operations, which will go up during data acquisition/processing. A DC current sensor will be connected to each of the microcontrollers while a bench test is performed emulating the launch preparation, one hour launch-ready configuration and flight in order to determine battery power needs.

5.3.3. Uncontrolled Motion

The purpose of this test is to determine if the payload will experience any uncontrolled motion during its descent. Uncontrolled motion is defined as any force acting on the payload which results in the TDS unsuccessfully processing images to differentiate between the targets. This test will be performed during the subscale launch. It should be noted, however, that this does not mean the TDS must process images during the subscale launch—it is possible images may only be captured and saved on the on-board computer and processed later or quantitatively determined to be unfit for processing.

5.4. Scientific Value

The requirements of the Target Detection and Upright Landing Challenge are meant to simulate the current problems facing the space industry. The questions that need answering in this project directly correlate to what scientist and engineers are working on. This project is a learning experience for all team members involved, to further their understanding of rockets, aerodynamics, electronics, and the design process from start to finish. The experiments conducted and recorded throughout this project will not provide help for the team's success but will also help future team members.

5.4.1. Payload Objectives

The objectives of the payload are to:

- Successfully separate from the launch vehicle
- Capture and process images of the targets in order to differentiate between them
- Land upright in the same orientation as on the launch pad in a reusable manner

5.4.2. Payload Constraints

The payload will perform within the following constraints:

- Include a custom on-board software package
- Analyze data taken from the image processing system in real time

5.4.3. Payload Success Criteria

The payload will be successful if it is deployed, captures images of the targets, identifies and differentiates among the three targets and lands upright upon ground contact in a reusable manner. Success for the payload will only be obtained if these tasks are completed. Success with the payload will prove the viability of the system as a whole to be implemented in other tasks, such as rapidly reusable rocket system.

5.4.4. Experimental Logic, Approach, and Method of Investigation

All of the experiments described above are physical tasks that will need to be completed by the team. By testing each of the crucial subsystems (deployment, target differentiation, recovery, and ULS), overall success of the project can be ensured. It is important that all modes of failure are analyzed to account for any means of failure. Therefore, each test will be performed several times in order to collect sufficient data and prove the repeatability of the processes. It is important that viable data be obtained from each experiment so that the real system will work correctly. As such, each experiment will be approached as if the test were for the actual competition. Improper testing would lead to inaccurate data and failure of the mission, detracting from the scientific value of the project.

5.4.5. Test and Measurement, Variables, and Controls

The data will be collected using accurate measuring devices, such as digital calipers and a gram scale. As described above, the variables to be tested are payload deployment sequence success, image processing and target differentiation success, payload recovery system parameters, and ULS success. Since all of the tests are experimental in nature and are rated on a success/failure scale, control tests cannot be used to establish a baseline for the experiments.

5.4.6. Relevance of Expected Data

The data collected during the experiments will show if the current leading design will work. The data is critical to the success of the project, and is thus relevant to the tasks at hand.

5.4.7. Preliminary Experiment Process Procedure

The experiments described in both §3.1.4. and §5.3. will be carefully conducted so accurate results can be obtained. Careful experimentation preserves the scientific value of the experiment and keeps the results indicative of the project. Each experiment will follow the general guidelines of any scientific study. First, a problem is present which needs to be investigated or solved. Next, an experiment is formed that will test possible solutions to the problem or provide more insight into the issue. The experiments will be designed to account for any issues that may arise and to test the capabilities of the design. The experiments will be carefully conducted to not corrupt the results and to preserve their legitimacy. The results will then be analyzed to make sure the initial requirements were met and the data received is accurate. The process of experimentation is valid for any scientific study, and thus the experimental process procedures have scientific value.

6. Project Plan

6.1. Budget Plan

Table 9: Payload Budget

	Item	Unit Price	Quantity	Price
Viewing Surface	Aero Pack 75 mm Retainer (Flanged)	$53.50	1	$53.50
	Aero Pack 54 mm Retainer (Flanged)	$40.66	1	$40.66
	Acrylic Grazing Sheet	IN HOUSE	1	$0.00
	Mounting Sheet	IN HOUSE	1	$0.00
Payload Body	6061-T6 Aluminum Bare Drawn Tube - Wall 0.065" (4"OD x 0.065")	$87.32	1	$87.32
	6061-T6 Aluminum Bare Drawn Tube (3"OD x 0.065")	$51.43	1	$51.43
	ALUMINUM BARE SHEET 6061 T6 - 0.125" thickness	$15.35	1	$15.35
	Alloy 5356 MIG Welding Wire	$9.92	1	$9.92
	Standard Airfoil Rail Buttons (fits 1" Rail - 1010)	$7.00	1	$7.00
	0.5" X #13 THREADED ALUMINUM 6061 ROD COARSE 72" - PACK OF 2 BARS	$33.39	1	$33.39
	Carbon Steel Hex Nut with 1/2"-13 Dia./Thread Size; PK25	$5.45	1	$5.45
	Electronics Board	IN HOUSE	1	$0.00

Electronics	BeagleBone Black Computers	$45.00	2	$90.00
	USB accessible HD camera	$45.00	2	$90.00
	BMP180 Altimeters	$9.95	4	$39.80
	BNO055 Orientation Sensors	$34.95	2	$34.95
	7.2V 5000mAh Lithium Polymer Batteries	$50.00	2	$100.00
	GPS Module	$39.95	2	$79.90
	5V 1.5A Linear Voltage Regulator - 7805 TO-220	$0.75	2	$1.50
	TO-220 Clip-On Heatsink	$0.75	2	$1.50
	10uF 50V Electrolytic Capacitors - Pack of 10	$1.95	1	$1.95
	One-Way Radio			$0.00
	Raspberry Pi 3 Model B Microcontroller with Camera System	$89.99	1	$89.99
Recovery	Jolly Logic Parachute System			$130.00
	Streamer			
	Payload Chute (Fruity, Iris Ultra 48")			
			Total	$963.61

Table 10: Preliminary Rocket Budget

	Item	Quantity	Price
Subscale	Motor casing	1	$ 65.00
	Nosecone	1	$ 65.00
	I motor	2	$ 100.00
	Fiberglass Body Tube 5" (by the foot)	5	$ 164.05
	Fiberglass Coupler (15")	1	$ 40.78
Full-Scale	Motor casing	1	$ 65.00
	Nosecone	1	$ 115.00
	L motor	2	$ 360.00
	Fiberglass Body Tube 6" (48" tubes)	2	$ 414.86
	Fiberglass Coupler 6" (12" tubes)	3	$ 207.39
General	Aircraft Spruce Domestic Birch Plywood ¼" x 4 x 4	1	$ 120.00
	Aircraft Spruce Domestic Birch Plywood⅜" x 4 x 4	1	$ 140.00
	Epoxy and hardener	1	$ 50.00
	Paint	--	$ 30.00
	Rail buttons	4	$ 10.00
	StratoLogger Altimeter	4	$ 320.00
	GPS Bee	3	$ 95.00
	Wires	--	$ 30.00
	Connectors	--	$ 20.00
	Kevlar shock cord (ft)	60	$ 60.00
	Parachute materials		$ 500.00
	Black powder (lb)	1	$ 20.00
	RATTworks ARRD	1	$ 95.00
		Total	$ 3,087.08

Table 11: Travel Budget

	Item	Cost
Butner Launch #1	Gas	$50
Butner Launch #2	Gas	$50
Bayboro Subscale Launch #1 (December 17-18)	Gas	$160
Bayboro Subscale Launch #2 (January)	Gas	$160
Bayboro Full-scale Launch #1 (February)	Gas	$160
Bayboro Full-scale Launch #2 (March)	Only if needed	
Huntsville, AL Competition Launch (April 6-9)	Van Rental (2)	$1,200
	Gas	$800
	Meals	$400
	Hotel (3 rooms, 5 nights)	$1,000
		$3,980

6.2. Funding Plan

The original budget for the 2016-2017 year was largely based off the NASA SL requirements from the previous year and previous awards from various sources. The current budget is a more refined version of the original budget, with more specific information on what funds the team will receive from NC State student organizations as well as more specific line items. The total budget from Figures 8, 9, 10 is currently $8040 including the full-scale competition rocket, sub scale rocket and estimated travel expenses. Table 11 shows the projected funding plan for the entire duration of the competition.

Table 12: Funding Plan

	Fall	Spring	
Engineering Council	$ 2,829.86	$ 3,000.00	
Space Grant	$ 3,000.00		
	$ 5,000.00		
Student Government Association (SGA)	$ 1,400.00	$ 2,000.00	
Engineering Technology Fund	$ 2,000.00		
Firm Total	$ 6,229.86		
Requested Total	$ 14,229.86	$ 5,000.00	$ 19,229.86

In Table 11 the grey areas represent funding that is awarded at a single instance and will not duplicate in the spring. The blue areas represent projected funds.

6.3. Timeline

Table 13: Projected Timeline

	Event/Task	Start Date	Finish Date	
	Request for Proposal (RFP) Released)	8/15/2016		Aug
Proposal Writing	RFP Writing	8/15/2016	9/29/2016	Sep
	Completed RFP Submission	**9/30/2016**		
	Awarded Proposals Announced	10/14/2016		Oct
	Fall Open House	10/15/2016		
Preliminary Design Review (PDR) Writing	Meeting w/ Senior Design Team (MSDT)	10/14/2016		
	MSDT	10/18/2016		
	PDR Checking	10/20/2016		
	Meeting with Outreach Lead	10/26/2016		
	Web Presence Established	10/31/2016		
	All Content In	11/1/2016		Nov
	Editing	11/1/2016	11/3/2016	

		Completed PDR Submission	**11/4/2016**		
		PDR Teleconference	11/14/2016		
Subscale & Payload Build	Critical Design Review (CDR)	Black powder & bulkhead testing	11/7/2016	11/11/2016	
		Begin designing subscale, expand test program, & order subscale, full-scale & payload components	11/7/2016	11/23/2016	
		Thanksgiving Break	11/23/2016	11/25/2016	
		CDR Q&A	11/30/2016		
Full-scale & Payload Build		Building Access Ends	12/16/2016		Dec
		Subscale Launch	**12/17/2016**	**12/18/2016**	
		All Content In	1/2/2017		Jan
		Building Access Resumes	1/9/2017		
		Completed PDR Submission	**1/13/2017**		
		CDR Teleconference	1/17/2017	1/31/2017	
		FRR Q&A	2/8/2017		Feb
		Full Scale Launch	February		
		All Content In	2/27/2017		
		Editing	2/27/2017	3/5/2017	Mar
		Completed FRR Submission	**3/6/2017**		
		FRR Teleconference	3/8/2017	3/24/2017	
		Team Travel to Huntsville, Alabama	4/5/2017		Apr
		Launch Readiness Review (LRR)	4/5/2017		
		NASA Safety Briefing	4/6/2017		
		Rocket Fair & Tours of MSFC	4/7/2017		
		Launch Day & Banquet	4/8/2017		
		Backup Launch Day	4/9/2017		
	Post-Launch Assessment Review (PLAR)	All Content In	4/17/2017		
		Editing	4/17/2017	4/23/2017	
		Completed PLAR Submission	**4/24/2017**		
		Winning Team Announced by NASA	5/12/2017		May

6.4. Educational Engagement Plan and Status

Weatherstone Elementary STEM Expo 2016-2017

The High-Powered Rocketry Club will be continuing its outreach to inspire elementary school kids to pursue careers in STEM. The Club will be taking over a classroom and set up a presentation to do an overview of the Club and STEM related careers. In addition to the classroom and the presentation, weather permitting the team will be launching water bottle rockets in an open field near the school. Previous times with this event, there have been more than 500 families in attendance.

Location: Weatherstone Elementary School 1000 Olde Weatherstone Way Cary, NC 27513

Time: January 21st 10:00 AM to 2:00 PM

Astronomy Days at the North Carolina Museum of Natural Science

The High-Powered Rocketry Club is planning to continue its support of the Tripoli Rocket Association and help at their booth at Astronomy Days. At Astronomy Days. The team will be talking to thousands of individuals about rockets and the club itself. As the time get closer, the team will be getting more details on the times when the event occurs.

Location: North Carolina Museum of Natural Science, 11 W Jones St, Raleigh, NC 27601

Time: TBD

As for future events beyond the two listed above, the club is awaiting email replies from several different potential outreach events and there are further places to be contacted for future events. These events will be added to future documentation.

7. References

[1] "Aluminum 6061-T6; 6061-T651," MatWeb Material Property Data, http://www.matweb.com/search/DataSheet.aspx?MatGUID=16bda8c8d9b24a54 ade5de2ebe5fb082 [retrieved 23 September 2016].

[2] "Quantum Composites QC-2150LD NT 25% Fiberglass Reinforced Phenolic SMC," MatWeb Material Property Data, http://www.matweb.com/search/DataSheet.aspx?MatGUID=1b8c06d0ca7c456694c7777d9e10be5b&ck ck=1 [retrieved 23 September 2016].

[3] "DRAWN ALUMINUM BARE TUBE 6061 T6," Online Metals, http://www.onlinemetals.com/merchant.cfm?pid=4744 [retrieved September 25, 2016].

[4] "4" G12 FIBERGLASS FILAMENT WOUND TUBE 48" LONG," Apogee Components, https://www.apogeerockets.com/Building_Supplies/Body_Tubes/Fiberglass_Tubes/4in_G12_Fiberglass _Filament_Wound_Tube_48in_Long?cPath=42_43_285& [retrieved September 25, 2016].

[5] Lentink, D., "DNA of Maple Seed Flight," Science Magazine [online database], published June 12, 2009. [retrieved October 25, 2016]. [6] "Chute Release – Jolly Logic," Jolly Logic, https://www.jollylogic.com/ products/chuterelease/ [retrieved October 25, 2016].

[7] "Iris Ultra 48 Compact Parachute," Fruity Chutes, http://fruitychutes.com/buyachute/iris-ultra-compact-chutes-c-18/iris-ultra-48-compact-parachute-125lbs-20fps-7lbs-15fps-p-141.html [retrieved 25 October 2016].

Appendix A: Launch Vehicle FMECA

System	Function / Component	Failure Mode	Causal Factors	Failure Effects: Subsystem	Failure Effects: System	Hazard	Recommendations
Launch Vehicle	Black Powder Charges	Failure to Ignite	E-Match doesn't light	First ejection charge does not ignite	Rocket fails to separate and deploy parachute(s)	4	Conduct ground tests to ensure that enough black powder will be used for proper separation. Thoroughly check redundant systems prior to launch
			Altimeter Malfunction			4	
			Improper Programming			4	
		Redundant black powder fails to ignite	E-Match doesn't light	Failure of both ejection charges		1	
			Altimeter Malfunction			1	
			Improper Programming			1	
		Violent ejection causes accidental separation	Charge is too big	Causes violent separation and/or damage to surrounding area	Could cause damage to bulkheads or shock-cord, resulting in a possible failure of parachute deployment	1	Verify that charges are sealed properly and the correct amount of black powder using pre-flight checklists
	Avionics (altimeters)	Parachutes Deployed at Wrong Altitude	Altimeter Detects Incorrect Altitude	No ejection or premature/late ejection of the parachutes	Failure of proper parachute deployment	1	Set the launch altitude on altimeters at launch site the day of launch, or purchase altimeters that zero themselves at power-on
		No power to avionics or charges	Wiring Short	Loss of real-time altitude data		1	Ensure that there aren't any exposed wires and that all wires are securely

							contained in their respective terminals
			Power Loss			1	Ensure that altimeters are properly wired and that wires are secure prior to launch. Determine that altimeters are powered prior to launch
			Dead Battery			1	Buy fresh (Duracell) batteries prior to launch and do not unpackaged
		False Apogee Detected	Sudden decrease in static pressure in avionics section	Premature ejection of drogue parachutes		1	Ensure that pressure ports are sized correctly and use only altimeters with false apogee verification
		Faulty Altimeter	Manufacturer defect	No ejection or premature/late ejection of the parachutes		1	Test altimeters on the ground in vacuum chamber to simulate firing of drogue and main charges

	BigRedBee (GPS)	Ground System Failure	Loss of power to ground receiver or the laptop	In ability receive data from the GPS	Inability to track and recover the rocket (in a reasonable amount of time)	3	Make sure that the receiver and laptop are fully charged at least 6 hours prior to flight
		Loss of signal	Environment or rocket materials blocking signal			3	Perform range tests to ensure reliability of the system at simulated altitudes and ground distances
		Radio Interference	Multiple radio devices on the same local frequency and channel			3	Make sure that all transmitting devices are on separate channels and confirm with other teams and launch officials that no frequency conflict exists
		Loss of power	Flight forces cause GPS to disconnect from power supply			3	Make sure all GPS units are fully charged and use simulated load tests to determine the necessary procedures to secure the units

		Vehicle is Over/Under Stable	Manufacturing Defect or Mass miscalculation	Flight Stability at risk	Possible transition from vertical to horizontal powered flight, and possible break up of vehicle during powered ascent	1	Perform mass analysis on each component and assembly and build accurately to ensure that rocket is has a stability margin above 2
	Fiberglass Airframe	Cracks or Breaks	Manufacturing Defect	Structural integrity of fiberglass sections at risk	Possible premature separation of rocket segments or rapid unscheduled disassembly during flight	1	Visual inspection after shipping before any structural implementation
			Experienced loads beyond design specifications			1	Implement a safety factor greater than 1.0 to ensure that flight conditions do not exceed design specifications
			Damaged during handling			1	Team members will be taught proper handling procedures for body tubing and the assembled rockets
			Improper maintenance			1	Thorough pre- and post-launch inspections of body tubing
	Bulkheads	Separation of bulkhead from airframe	Manufacturing Defect	Structural integrity of rocket segments at risk	Possible premature separation of rocket segments, rapid	1	Visual inspection after completing construction before any

		during flight			disassembly of rocket, or recovery system failure during descent		implementation
			Loads beyond design specifications			1	Implement a safety factor to ensure that flight conditions do not exceed design specifications
			Damaged during handling			1	Team members will be taught proper handling and installation procedures for bulkheads
			Improper maintenance			1	Thorough pre- and post-launch inspections of bulkheads
		Parachute and/or bulkhead separation from vehicle during flight	U-bolt comes un-attached	Without an attached parachute, a rocket segment could be free to free fall	Loss of recovery system will result in mission failure and can cause harm to ground crew	1	Ensure prior to launch that all U-bolts are correctly installed and implement checklist steps to verify
			Loads beyond design specifications			1	Implement a safety factor to ensure that flight conditions do not exceed design specifications
			Improper maintenance			1	Thorough pre- and post-launch inspections of bulkheads

		Non-compromising cracks	Loads beyond design specifications	Present potential for further damage to bulkhead	If left unnoticed, a small crack can expand during flight which may result in bulkhead failure	3	Implement a safety factor to ensure that flight conditions do not exceed design specifications
			Damaged during handling			3	Adhere to proper handling procedure
			Improper maintenance			3	Thorough pre- and post-launch inspections of bulkheads
	Fins	Improper construction	Fins not Evenly Spaced (90 degrees)	Incorrect fin placement will necessitate a rebuild of the fin section	Decreased flight stability, and possible damage to other components	3	Create a laser-cut wooden frame for fin placement to ensure proper placement
		Surface damage	Loads beyond design specifications	Damage to fin will necessitate its replacement before any future launches	Fin failure during flight will decrease stability of rocket and will likely cause a catastrophic failure	1	Implement a safety factor to ensure that flight conditions do not exceed design specifications
			Damaged during handling			1	Team members will be taught proper handling procedures for fins and fin section
			Improper maintenance			1	Pre- and post-launch thorough inspections of the fins
			Ground impact			2	Implement a recovery system design that

							ensures a low speed surface impact
		Fin flutter	Loads beyond design specifications	Loss of fin subsystem effectiveness	Decreased flight stability, and possible damage to other components	4	Maintain operations within design specifications
			Damaged during handling			4	Adhere to proper handling procedure
			Improper maintenance			4	Pre- and post-launch thorough inspections of the fins
	Shear Pins	Pins break before charge detonation	Manufacturing Defect	Loose assembly of compartment	Separation of vehicle compartments	2	Visual inspection after shipping before any implementati on
			Loads beyond design specifications			2	Maintain vehicle within design specifications
			Improper maintenance			2	Use of new pins after each launch
		Pins don't break at charge detonation	Manufacturing Defect	Failure to separate	Loss of safe and effective recovery system	1	Pre-launch visual inspection of shear pins
			Poor Design			1	Proper calculation of the force exerted on the pins during detonation
	Avionics Sled	Detaches from secured position	Loads beyond design specifications	Damage to/loose wiring of avionics components	Loss of recovery system initiation	1	Use simulations to test max load before failure

			Damaged during handling			1	Team members will be taught proper handling and installation procedures for the avionics sled
			Improper maintenance			1	Pre- and post-launch thorough inspections of the avionics sled
	Nosecone	Non-compromising cracks	Loads beyond design specifications	Potential for future damage	If left unattended this could lead to catastrophic failure of the entire system	3	Use simulations to test max load before failure
			Damaged during handling			3	Team members will be taught proper handling and installation procedures for nosecone
			Improper maintenance			3	Pre- and post-launch thorough inspections of the nosecone
		Damage from impact	Object in flight path	Loss of future nosecone use	Loss of controlled and stabilized flight	2	Ensure that skies are clear of any foreign objects as per NAR standard operations
			Damaged during handling		If left unattended this could lead to catastrophic failure of the entire system	2	Team members will be taught proper handling and installation procedures for the nosecone

			Improper maintenance			2	Pre- and post-launch thorough inspections of airbrakes
		Premature separation from other structural members	Damaged during handling	Potential for structural damage	Loss of controlled and stabilized flight	2	Team members will be taught proper handling and installation procedures for the nosecone
			Improper maintenance			2	Pre- and post-launch thorough inspections of the nosecone
	Parachutes	Non-compromising Tears	Loads beyond design specifications	Potential for future damage	If left unattended this could lead to partial or complete parachute failure	3	Determine likely airspeed at which the parachutes will be deployed, and determine the load that the parachutes can safely withstand
			Damaged during handling			3	Team members will be taught proper handling and installation procedures for the parachutes, and each parachute will be inspected carefully prior to launch

		Parachute Not Unraveling / Unfolding	Parachutes Get Caught Inside Rocket Body	Failure for parachute to properly deploy	Loss of safe and effective recovery system	1	Design and build the rocket in such a way that each parachute has a clear and open ejection path
			Improper folding and/or packing of the parachute			1	Team members will be taught proper folding and packing methods of the parachutes, and each parachute will be folded and packed according to steps on the launch-day checklist
	Motor	Motor Does Not Ignite	Igniter Not Inserted Correctly	Failure of Vehicle Launch	Team Member/RSO must insert new igniter and re-start launch sequence	4	Prior to launch, individual inserting the igniter will be instructed on how to insert igniter. Said individual will follow the launch-day and be guided by a team mentor
			Motor Assembled Incorrectly			4	Team member assembling the motor will be assisted in the assembly by a team mentor

			Faulty Igniter			4	Test the batch of igniters prior to launch day to ensure quality
		Catastrophic Motor Failure	Damage to motor components prior to launch	Possible Destruction of Launch Vehicle	Complete Failure of Mission and hazard to ground crew and spectators	1	Perform careful inspection of each motor component prior to launch and during construction
			Motor Assembled Incorrectly			1	Team member assembling the motor will be assisted in the assembly by a team mentor
			Motor Casing Becomes Dislodged During Motor Burn			1	Design and build the motor tube housing with a high safety margin supported with FEA models of predicted loads
	Rail Buttons/ Launch Rail	Incorrect or Partial Separation of Vehicle from Launch Rail	Rail Buttons Separate from Launch Vehicle	Early or improper separation of Launch Vehicle from Launch Rail	Possible Mission Failure and Hazard to ground crew and Spectators	1	Design the rail button mounts on the rocket with a factor of safety over 1.5 to ensure rail buttons are secured on the vehicle

			Rail Buttons Break			1	Purchase proper rail buttons for the mass and rail exit velocity of the vehicle, inspect for damage prior to launch
			Rail Buttons Stick	Launch Vehicle Fails to Separate from the Rail	Possible Damage to airframe, loss of motor	3	Lubricate the launch rail and rail buttons prior to launch and ensure that the vehicle moves smoothly on the rail.
			Rail Breaks			3	Ensure that the rail is constructed solidly prior to launch
	Shock Cord	Incorrect or Partial Deployment of Shock Cord	Tears During Ejection	Parachute is no longer connected to entirety of airframe	Loss of safe and effective recovery system	1	Inspect shock chord for damage prior to launch, use a large enough gage shock chord, and use only the necessary amount of black powder for separation
			Becomes Disconnected from Airframe or parachutes			1	Ensure that the connections from the shock cords to the vehicle and parachutes are secure, and have step in the launch day

							checklist to verify secure connection
			Gets Caught Inside Vehicle Airframe	Parachute isn't deployed entirely		1	Ensure that there is nothing inside the vehicle body that can catch or snag the shock cord as it exits/unwinds

Appendix B: Payload FMECA

System	Function / Component	Failure Mode	Causal Factors	Failure Effects		Hazard	Recommendations
				Subsystem	System		
Payload	Camera	Damaged Lens/Camera	Manufacturer Defect	Micro-controllers unable to acquire data	Payload fails to identify and differentiate targets	4	Thoroughly check camera systems prior to launch
			Broken Lens Due to Uncontrolled Motion			4	Test recovery system effect on uncontrolled motion
		Loose Wiring	Electrical System Hardware Integrity Compromised During Flight			4	Post-assembly functionality check
			Improper Assembly			4	
		Software Issue	Code not debugged/ tested thoroughly prior to launch			4	Debug and test camera system
	Micro-controllers	Manufacturer Defect	Manufacturer Defect	Micro-controllers unable to acquire data	Payload fails to identify and differentiate targets	4	Thoroughly check microcontrollers prior to launch
		Poor Attachment to Electronics Board	Improper Assembly			4	Post-Assembly functionality check
		Movement During Flight	Uncontrolled Motion During Flight			4	Test recovery system effect on uncontrolled motion

Parachute Release Mechanism	No Release or Response	Manufacturer Defect	Payload recovery system fails to deploy	Payload descent becomes uncontrolled	1	Thoroughly check recovery system prior to launch
		Improper Wiring			1	
	Dislodged in Flight	Improper Assembly			1	
	Partial Deploy	Manufacturer Defect			1	
ULS	Cracks or Breaks	Manufacturing Defect		Failure to meet mission criteria for upright landing	3	Visual inspection prior to assembly
		Damaged During Assembly			3	Visual inspection during/after assembly and testing
	Failure to Deploy	Improper Design			3	Testing during sub-scale and full-scale phases
	Poor Attachment to Payload Body	Improper Assembly			3	Visual inspection during/after assembly and testing

	Failure to Remain Upright Upon Landing	Improper Design			3	Testing during sub-scale and full-scale phases
Batteries	No Power Available	Power loss prior to launch	Micro-controllers unable to acquire data	Payload fails to identify and differentiate targets	4	Perform battery life testing
		Improper Wiring			4	Visual inspection after assembly
		Improper Design			4	Testing during sub-scale and full-scale phases
	Disconnected	Uncontrolled Motion During Flight			4	Test recovery system effect on uncontrolled motion
		Improper Wiring			4	Visual inspection after assembly
Viewing Surface	Cracks or Breaks	Loads Beyond Design Specifications		Payload fails to identify and differentiate targets	4	Testing during sub-scale and full-scale phases
		Damaged During Handling			4	Visual inspection prior to assembly
	Obstructed View	Uncontrolled Motion During Flight			4	Testing during sub-scale and full-scale phases
Mounting Surface	Fracture During Flight	Uncontrolled Motion During Flight	Cameras unsecured	Payload fails to identify and differentiate targets	4	Testing during sub-scale and full-scale phases
		Loads Beyond Design Specifications			4	
Electronics Board	Separation from Electronics Rods	Uncontrolled Motion During Flight	Electronics unsecured	Potential for payload to be unable to identify and	4	Testing during sub-scale and full-scale phases

	Fracture During Flight	Loads Beyond Design Specifications		differentiate targets	4	
	Manufacturing Defect	Manufacturing Defect			4	Inspection prior to assembly
Payload Body	Material Failure Due to Assembly	Improper Assembly	Uncontrolled Motion of Payload	Potential for payload to be unable to identify and differentiate targets and land upright	3	Visual inspection during/after assembly and testing
		Loads Beyond Design Specifications			3	Testing during sub-scale and full-scale phases
	Impact with Rocket Frame	Improper Payload Deployment	Uncontrolled Motion of Payload	Potential for payload to be unable to identify and differentiate targets	4	Testing during sub-scale and full-scale phases
GPS	Ground System Failure	Loss of Power to Ground Receiver/Laptop	Inability to receive data from the GPS	Inability to track and recover the payload in a reasonable amount of time	4	Make sure that receiver and laptop are fully charged at least six (6) hours prior to flight
	Broken GPS	Manufacturer Defect			4	Testing prior to assembly
	Loss of Signal	Environment or Rocket Materials Blocking Signal			4	Perform range testing to ensure reliability of system
	Radio Interference	Multiple Radio Devices on the Same Local Frequency and Channel			4	Ensure all transmitting devices are on separate channels
	Loss of Power	Flight Forces Cause GPS to Disconnect from Power Supply			4	Use simulations to test max load before failure

		Improper Wiring			4	Post-assembly functionality check
Wiring	Improper Assembly	Loose/Improper Connections	Nonfunctional electronics and avionics	Payload fails to identify and differentiate targets and deploy recovery system	1	Post-assembly functionality check
	Shorting Out	Incorrect Amount of Power Supplied to Device(s)			1	Ensure proper power is supplied to device
Rail System	Obstructions Along Rails	FOD in Payload Compartment		Mistimed/No payload deployment and potential to fail upright landing	2	Pre-flight system check
	Broken Rail Buttons	Loads Beyond Design Specifications			2	Testing during sub-scale and full-scale phases
	Dislodged from Track	Improper Assembly			2	Post-assembly inspection
Altimeter	No power	Dead Battery	Loss of real-time altitude data	Failure of recovery system deployment	1	Ensure batteries have adequate power before flight
	Manufacturer Defect	Manufacturer Defect	Mistimed/No recovery system deployment		1	Testing prior to assembly
Accelerometer	No power	Dead Battery	Loss of real-time orientation data and false apogee indicated	Payload fails to deploy at desired altitude/does not deploy	1	Ensure batteries have adequate power before flight
	Manufacturer Defect	Manufacturer Defect			1	Testing prior to assembly

Appendix C: MSDS for Hazardous Materials

A. **GOEX Black Powder**

https://www.epa.gov/sites/production/files/2015-05/documents/9530608.pdf

B. **Klean-Strip Acetone**

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

C. **West Systems 105 Epoxy Resin**

http://www.westsystem.com/ss/assets/MSDS/MSDS105.pdf

D. **West Systems 206 Slow Hardener**

http://www.westsystem.com/ss/assets/MSDS/MSDS206.pdf

E. **Fiberglass Fabric**

http://web.mit.edu/rocketteam/www/usli/MSDS/Fiberglass%20(differnt%20supplier).pdf

F. **Batteries**

http://www1.mscdirect.com/MSDS/MSDS00024/00338228-20151101.PDF

G. **Electronic Matches**

http://aiaaocrocketry.org/wp-content/uploads/2010/11/electrical-matches-msds.pdf

H. **Cotton Flock**

http://www.westsystem.com/ss/assets/MSDS/MSDS403.pdf

I. **Baby Wipes**

http://westhurleylibrary.org/CircBlog/MSDS/Pampers_Wipes.pdf

J. **Motor Ignitors**

https://www.apogeerockets.com/downloads/MSDS/Aerotech/Igniters.pdf

K. **Liquid Nails**

http://www.liquidnails.com/LNDatasheets/MSDS/LN-901_LNP-901

L. **Glass Microspheres**

http://cdn.fibreglast.com/downloads/PDCT-MSDS-00003.pdf

M. **Turtle Wax**

https://www.turtlewax.com/docs/default-source/msds-english/msds-consumer/turtle-wax-super-hard-shell-carnauba-paste-wax

N. WD-40

https://wd40.com/files/pdf/msds-wd482671453.pdfd

Appendix D: Compliance Matrix

Section	Description of Requirement	Method of Compliance (MOC)	Description of MOC	Document Section(s)
1.1	The vehicle shall deliver the science or engineering payload to an apogee altitude of 5,280 feet above ground level (AGL).	Test	An OpenRocket simulation will determine the approximate apogee. Apogee will be recorded during subscale and full-scale tests and adjustments will be made as required.	1.2.1
1.2	The vehicle shall carry one commercially available, barometric altimeter for recording the official altitude.	Identification	The vehicle shall carry two commercially available barometric altimeters for the sake of redundancy, the Stratologger SL100 and the Entacore AIM 3.0.	3.1.3.6
1.2.1	The official scoring altimeter shall report the official competition altitude via a series of beeps to be checked after the competition flight.	Demonstration	Altimeters used in the launch vehicle will report the official competition altitude.	N/A

1.2.5	At the launch field, to aid in determination of the vehicle's apogee, all audible electronics, except for the official altitude-determining altimeter shall be capable of being turned off.	Demonstration	All electronic systems will be capable of being turned off.	N/A
1.3	All recovery electronics shall be powered by commercially available batteries.	Identification	All electronics will be powered by commercially available 9V batteries.	3.1.3.6
1.4	The launch vehicle shall be designed to be recoverable and reusable. Reusable is defined as being able to launch again on the same day without repairs or modifications.	Demonstration	It shall be demonstrated that the launch vehicle is reusable after subscale testing, full-scale testing, and upon recovery from competition launch.	N/A
1.5	The launch vehicle shall have a maximum of four (4) independent sections. An independent section is defined as a section that is either tethered to the main vehicle or is recovered separately from the main vehicle using its own parachute.	Design Review	The launch vehicle has been designed such that there will be less than four (4) independent sections.	1.2.3
1.6	The launch vehicle shall be limited to a single stage.	Design Review	The launch vehicle has been designed such that there will only be one (1) stage.	1.2.2

1.7	The launch vehicle shall be capable of being prepared for flight at the launch site within 4 hours, from the time the Federal Aviation Administration flight waiver opens.	Test	The preparation sequence will be performed and timed during the subscale and full-scale tests in its entirety.	N/A
1.8	The launch vehicle shall be capable of remaining in launch-ready configuration at the pad for a minimum of 1 hour without losing the functionality of any critical on-board component.	Test	Power consumption of both microcontrollers will be tested to determine power draw, to ensure batteries will be able to support components for the length of launch and up to an additional hour beforehand.	5.3.2
1.9	The launch vehicle shall be capable of being launched by a standard 12 volt direct current firing system.	Test	The launch vehicle capability will be tested during subscale and full-scale tests.	N/A
1.10	The launch vehicle shall require no external circuitry or special ground support equipment to initiate launch (other than what is provided by Range Services).	Design Review	The launch vehicle has been designed in such a way that no external circuitry or special ground support will be required.	N/A

1.11	The launch vehicle shall use a commercially available solid motor propulsion system using ammonium perchlorate composite propellant (APCP) which is approved and certified by the National Association of Rocketry (NAR), Tripoli Rocketry Association (TRA), and/or the Canadian Association of Rocketry (CAR).	Design Review	An Aerotech L1120W motor is being used for the full-scale launch vehicle.	1.2.3
1.12	Pressure vessels on the vehicle shall be approved by the RSO	Design Review	The vehicle contains no pressure vessels	N/A
1.14	The launch vehicle shall have a minimum static stability margin of 2.0 at the point of rail exit	Design Review	OpenRocket gives a static margin of 2.12, while Barrowman's equations gave a stability margin of 2.10, both of which are well above 2.0.	3.3.2
1.15	The launch vehicle shall accelerate to a minimum velocity of 52 fps at rail exit.	Design Review	The top rail button will leave the rail at 59.2 fps not accounting for drag, rail friction, non-constant thrust, and propellant burn-off, which leaves a margin of error.	3.3.2

1.16	All teams shall successfully launch and recover a subscale model of their rocket prior to CDR	Test	Subscale Launch shall occur on December 17-18.	6.3
1.16.1	The subscale model should resemble and perform as similarly as possible to the full-scale model, however, the full-scale shall not be used as the subscale model.	Design Review	The subscale model shall contain a reduced payload system (single camera system) and have smaller dimensions than the full-scale model.	N/A
1.16.2	The subscale model shall carry an altimeter capable of reporting the model's apogee altitude	Design Review	Subscale model telemetry will be as close to identical as the full-scale model as possible.	N/A
1.17	All teams shall successfully launch and recover their full-scale rocket prior to FRR in its final flight configuration.	Test	Full-scale launch will take place in February. FRR will be submitted by March 6.	6.3
1.17.1	The vehicle and recovery system shall have functioned as designed.	Test	Subscale and full-scale testing will be performed to ensure functionality.	N/A

1.17.6	After successfully completing the full-scale demonstration flight, the launch vehicle or any of its components shall not be modified without the concurrence of the NASA Range Safety Officer (RSO).	Identification	Concurrence with the NASA RSO will be sought if any modifications to the launch vehicle or any of its components is to take place after successfully completing the full-scale test.	N/A
1.17.7	Full scale flights must be completed by March 6th.	Test	Full-scale launch will take place in February.	6.3
1.18	Any structural protuberance on the rocket shall be located aft of the burnout center of gravity.	Design Review	The launch vehicle shall contain no structural protuberances.	3.1.3

1.19.1	The launch vehicle shall not utilize forward canards	Design Review	The vehicle will not utilize forward canards	3.1.3.5
1.19.2	The launch vehicle shall not utilize forward firing motors.	Design Review	The full-scale vehicle will use an Aerotech L1120W motor.	1.2.2
1.19.3	The launch vehicle shall not utilize motors that expel titanium sponges (Sparky, Skidmark, MetalStorm, etc.)	Design Review	The full-scale vehicle will use an Aerotech L1120W motor.	1.2.2
1.19.4	The launch vehicle shall not utilize hybrid motors.	Design Review	The full-scale vehicle will use an Aerotech L1120W motor.	1.2.2

1.19.5	The launch vehicle shall not utilize a cluster of motors.	Design Review	The full-scale vehicle will use an Aerotech L1120W motor.	1.2.2
1.19.6	The launch vehicle shall not utilize friction fitting for motors	Design Review	No friction fitting will be utilized in motor installation.	N/A
1.19.7	The launch vehicle shall not exceed Mach 1 at any point during flight.	Test	The vehicle will be shown to only under subsonic conditions during full-scale testing.	N/A
1.19.8	Vehicle ballast shall not exceed 10% of the total weight of the rocket.	Demonstration	Vehicle ballast shall be shown to not exceed 10% of the total weight of the rocket.	N/A

2.1	The launch vehicle shall stage the deployment of its recovery devices, where a drogue parachute is deployed at apogee and a main parachute is deployed at a much lower altitude. Tumble recovery or streamer recovery from apogee to main parachute deployment is also permissible, provided that kinetic energy during drogue-stage descent is reasonable, as deemed by the Range Safety Officer.	Design Review	The vehicle is equipped with a shock cord supported with a 2-foot diameter drogue parachute that is released from between the fin can and payload bay. Once the launch vehicle descends to 700 feet above the ground level the main parachute will be released from between the upper airframe and the nosecone. The launch vehicle is expected to land with 55 ft-lb at 8.5 ft/s.	3.2
2.2	Each team must perform a successful ground ejection test for both the drogue and main parachutes. This must be done prior to the initial subscale and full scale launches.	Test	Testing will start with the calculated amount of black powder loaded into a mock-up of each section that is weighted and connected appropriately. Further tests will be performed until the sections separate by the appropriate amount.	3.1.4.3

2.3	At landing, each independent sections of the launch vehicle shall have a maximum kinetic energy of 75 ft-lbf.	Analysis	A MATLAB program was generated to find the parachute sizes necessary to keep the landing velocity and kinetic energy within the requirements. A drogue parachute with a diameter of 2 feet and a main parachute with a diameter of 15 feet were chosen and fit the requirements according to calculations.	3.3.3
2.4	The recovery system electrical circuits shall be completely independent of any payload electrical circuits.	Design Review	The payload will have a self-contained avionics attachment to deploy its own parachute.	3.1.3.6
2.5	The recovery system shall contain redundant, commercially available altimeters. The term “altimeters” includes both simple altimeters and more sophisticated flight computers.	Design Review	One Stratologger SL100 and one Entacore AIM 3.0 will be used to fire the black powder charges that decouple the rocket sections and release the payload and parachutes.	3.1.3.6

2.6	Motor ejection is not a permissible form of primary or secondary deployment.	Design Review	The motor is secured by two 0.375-inch-thick centering rings made from aircraft grade birch plywood. Additionally, the motor is set against a 1 inch engine block to further secure it and ensuring the motor will not be ejected.	3.1.3.5
2.7	Each altimeter shall be armed by a dedicated arming switch that is accessible from the exterior of the rocket airframe when the rocket is in the launch configuration on the launch pad.	Demonstration	All onboard altimeters shall be shown to have dedicated arming switches accessible from the exterior of the rocket while in launch configuration.	N/A
2.8	Each altimeter shall have a dedicated power supply	Design Review	Each altimeter will be powered individually by nine volt batteries.	3.1.3.6
2.9	Each arming switch shall be capable of being locked in the ON position for launch.	Demonstration	The team will demonstrate the capability for the arming switch to be locked in the ON position before launch.	N/A

2.10	Removable shear pins shall be used for both the main parachute compartment and the drogue parachute compartment.	Design Review	There will be four 4-40 nylon shear pins at each separation point to hold the rocket together until decoupling.	3.2
2.11	An electronic tracking device shall be installed in the launch vehicle and shall transmit the position of the tethered vehicle or any independent section to a ground receiver.	Design Review	The main launch vehicle will permanently house a Digi XTend 900 MHz radio to communicate the location of the vehicle to the ground before and after the payload separation.	3.4.2
2.11.1	Any rocket section, or payload component, which lands untethered to the launch vehicle, shall also carry an active electronic tracking device.	Design Review	The payload will hold two BigRedBee GPS transmitters to redundantly communicate the location of the payload to the ground	3.4.1
2.11.2	The electronic tracking device shall be fully functional during the official flight on launch day.	Demonstration	Multiple onboard GPS units will be shown to be fully functional prior to final assembly on launch day.	N/A

2.12	The recovery system electronics shall not be adversely affected by any other on-board electronic devices during flight (from launch until landing).	Testing	Recovery system electronics shall be housed separately in the vehicle to shield them from other onboard devices which may adversely affect their proper operation.	3.1.3.6
2.12.1	The recovery system altimeters shall be physically located in a separate compartment within the vehicle from any other radio frequency transmitting device and/or magnetic wave producing device.	Design Review	The recovery system altimeters will be located in a prefabricated mount or custom fitted 3D printed avionics sleds in which the only components are two batteries and altimeters.	3.1.3.6
2.12.2	The recovery system electronics shall be shielded from all onboard transmitting devices, to avoid inadvertent excitation of the recovery system electronics.	Design Review	Recovery system electronics shall be housed separately in the vehicle to shield them from other onboard devices which may adversely affect their proper operation.	3.1.3.6

2.12.3	The recovery system electronics shall be shielded from all onboard devices which may generate magnetic waves (such as generators, solenoid valves, and Tesla coils) to avoid inadvertent excitation of the recovery system.	Design Review	Recovery system electronics shall be housed separately in the vehicle to shield them from other onboard devices which may adversely affect their proper operation.	3.1.3.6
2.12.4	The recovery system electronics shall be shielded from any other onboard devices which may adversely affect the proper operation of the recovery system electronics.	Design Review	Recovery system electronics shall be housed separately in the vehicle to shield them from other onboard devices which may adversely affect their proper operation.	3.1.3.6
3.1.1	Each team shall choose one design experiment option from the list.	Inspection	Landing detection and controlled landing was chosen as the experiment.	3.1.1

3.2.1	Teams shall design an onboard camera system capable of identifying and differentiating between 3 randomly placed targets.	Demonstration	An explanation of the Target Differentiation System, integration plan, and electrical schematic are provided.	5.1.2.2
3.2.2	After identifying and differentiating between the three targets, the launch vehicle section housing the cameras shall land upright, and provide proof of a successful controlled landing.	Demonstration	A successful ULS will land the payload upright. Telemetry data from the payload will provide proof of a successful upright landing.	5.4.3
3.2.3	Data from the camera system shall be analyzed in real time by a custom designed on-board software package that shall identify and differentiate between the three targets.	Analysis	Visual validation of recorded telemetry data, images, and locations of targets detected.	5.4.3

4.1	Each team shall use a launch and safety checklist	Demonstration	A checklist will be used on launch days that will include a complete step by step list of procedures and safety measures to ensure a safe and efficient launch.	N/A
4.2	Each team must identify a student safety officer who shall be responsible for all items in section 4 of the NASA SL 2017 Handbook	Identification	The team's student safety officer has been identified as William Martz.	N/A
4.3.1.1	The student safety officer shall monitor design of vehicle.	Analysis	The safety officer will be made aware of changes to the design of the launch vehicle to re-analyze safety criteria.	N/A
4.3.1.2	The student safety officer shall monitor construction of vehicle	Inspection	The safety officer will be present for construction of the launch vehicle to ensure that team members utilize proper safety measures and proper construction methods.	N/A

4.3.1.3	The student safety officer shall monitor assembly of vehicle	Inspection	The safety officer will be present during assembly of the launch vehicle to ensure it assembled properly and safely.	N/A
4.3.1.4	The student safety officer shall monitor ground testing of vehicle	Inspection	The safety officer will be present during all launch vehicle testing.	N/A
4.3.1.5	The student safety officer shall monitor Subscale launch test(s).	Inspection	The safety officer will be present for the subscale launch test(s) to maintain safety of team members and others present.	N/A
4.3.1.6	The student safety officer shall monitor full-scale launch test(s)	Inspection	The safety officer will be present for the full-scale launch test(s) to maintain safety of team members and others present.	N/A

4.3.1.7	The student safety officer shall monitor Launch day	Inspection	The safety officer will be present for the full-scale launch to maintain safety of team members and others present.	N/A
4.3.1.8	The student safety officer shall monitor recovery activities	Inspection	The safety officer will accompany the team members retrieving the rocket sections to verify that the ejection charges have blown and that it is safe to retrieve the vehicle.	N/A
4.3.1.9	The student safety officer shall monitor Educational Engagement Activities	Inspection	The safety officer will accompany the team members on educational engagement activities to make sure that all involved stay continually safe.	N/A
4.3.2	The student safety officer shall implement procedures developed by the team for construction, assembly, launch, and recovery activities	Demonstration	The safety officer will reference the failure mode, effects and criticality analyses (FMECA)s as well as MSDSs and team launch checklists to make sure that the team uses proper and safe procedures during construction, assembly, launch, and recovery activities	N/A

4.3.3	The student safety officer shall Manage and maintain current revisions of the team's hazard analyses, failure modes analyses, procedures, and MSDS/chemical inventory data	Analysis	In the event of a design change or a material change, the safety officer will update and manage the FMECAs, MSDSs, and any other checklists/procedural documentation that the team references and uses.	N/A
4.3.4	The student safety officer shall assist in the writing and development of the team's hazard analyses, failure modes analyses, and procedures.	Analysis	The safety officer will analyze the design of the launch vehicle and will aid the team members in the proper design and writing of the FMECAs and checklists, as well as the selection of the MSDSs	N/A
4.4	Each team shall identify a "mentor."	Identification	The team's student mentor has been identified.	N/A
4.5	During test flights, teams shall abide by the rules and guidance of the local rocketry club's RSO.	Demonstration	The team safety officer will ensure that all team members abide by the rules and guidance of the local rocketry club's RSO.	N/A

4.6	Teams shall abide by all rules set forth by the FAA.	Demonstration	The entire team will comply with all FAA regulations to include the stipulations regarding launch wind speed.	N/A
5.1	Students on the team shall do 100% of the project, including design, construction, written reports, presentations, and flight preparation except for assembling the motors and handling black powder or any variant of ejection charges, or preparing and installing electric matches (to be done by the team's mentor).	Inspection	Students will do the entirety of the project.	N/A
5.2	The team shall provide and maintain a project plan to include, but not limited to the following items: project milestones, budget and community support, checklists, personnel assigned, educational engagement events, and risks and mitigations.	Demonstration	Project milestones, budget, community support, checklists, personnel assigned, educational engagement events, and risk mitigation have been identified and expanded on in the Proposal or PDR.	6.0

5.3	Foreign National (FN) team members shall be identified by the Preliminary Design Review (PDR) and may or may not have access to certain activities during launch week due to security restrictions. In addition, FN's may be separated from their team during these activities.	Identification	A list of FN team members has been compiled.	N/A (no FN team members)
5.4	The team shall identify all team members attending launch week activities by the Critical Design Review (CDR).	Identification	A list of all team members attending launch week activities will be compiled by the CDR.	N/A
5.5	The team shall engage a minimum of 200 participants in educational, hands-on science, technology, engineering, and mathematics (STEM) activities, as defined in the Educational Engagement Activity Report, by FRR	Demonstration	The participant requirement will be met and demonstrated by FRR.	N/A
5.6	The team shall develop and host a Web site for project documentation.	Demonstration	The website has been created and web presence has been established.	http://www.ncsurocketry.com/

5.7	Teams shall post, and make available for download, the required deliverables to the team Web site by the due dates specified in the project timeline	Demonstration	Deliverables will be made available for download by the due dates.	http://www.ncsurocketry.com/
5.8	All deliverables must be in PDF format	Demonstration	All deliverables will be saved in PDF format.	N/A
5.9	In every report, teams shall provide a table of contents including major sections and their respective subsections.	Demonstration	A table of contents will be provided.	Table of Contents (pg. 2)
5.10	In every report, the team shall include the page number at the bottom of the page.	Demonstration	Page number will be included.	N/A
5.11	The team shall provide any computer equipment necessary to perform a video teleconference with the review board	Demonstration	Proper equipment will be provided.	N/A
5.12	All teams will be required to use the launch pads provided by Student Launch's launch service provider.	Identification	Launch pads provided by the Tripoli Rocketry Association.	N/A

5.13	Teams must implement the Architectural and Transportation Barriers Compliance Board Electronic and Information Technology (EIT) Accessibility Standards (36 CFR Part 1194) Subpart B- Technical Standards (http://www.section508.gov): § 1194.21 Software applications and operating systems. § 1194.22 Web-based intranet and Internet information and applications.	Identification	Standards have been identified and will be implemented.	N/A