# Tacho Lycos
# 2017 NASA Student Launch
# Critical Design Review


High-Powered Rocketry Team

911 Oval Drive

Raleigh NC, 27695


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# 1. Summary of CDR

## 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
TRA Certification: 05945
Certification Level: 3

James Livingston
TRA Certification: 02204
Certification Level: 3

Dr. Charles Hall
TRA Certification: 14134
Certification Level: 3

## 1.2. Launch Vehicle Summary

### 1.2.1. Size and Mass

Table 1: Size and Mass Properties

| CDR | |
|---|---|
| Length | 122.0 in |
| Diameter | 6.2 in |
| Loaded Weight | 49.6 lb |
| Center of Pressure | 89.5 in |
| Center of Gravity | 77.0 in |
| Stability | 2.0 Caliber |
| Apogee | 5305.0 ft |
| Max Velocity | 672.0 ft/s |
| Max Acceleration | 434.0 ft/s$^2$ |
| Recovery System | 1 Drogue Parachute<br>1 Main Parachute |
| Motor | L2200G |

### 1.2.2. Final Motor Choice

The team has selected the Aerotech L2200G motor for the full-scale rocket. It is a 99% L-Class motor, has a total impulse of 5104 N-s, and a burn time of 2.27 seconds. The motor and casing are 26.18 inches long and have a diameter of 2.95 inches. This motor provides the best stability and performance characteristics for carrying the launch vehicle to the target altitude of 5280 ft.

### 1.2.3. Recovery System

The vehicle will descend in three sections attached by shock cord and supported by one 2ft diameter drogue parachute and one 14ft diameter main parachute. At apogee, the launch vehicle will separate between the fin can and middle airframe (payload bay and avionics bay) thus ejecting the payload and deploying the drogue chute. At 700ft AGL the launch vehicle will separate between the nosecone and middle airframe and the main parachute will deploy. The launch vehicle will touchdown with a kinetic energy of approximately 59.4 ft-lb and velocity of 9.9 ft/s discussed in §3.3.3.

#### 1.2.4. Rail Size

Based on the motor selected and the requirement of a launch rail exit velocity no less than 52 feet per second, a 96 in (8 ft) rail will be required. A rail of this length will allow the launch vehicle to exit the rail at approximately 65 fps.

#### 1.2.5. Milestone Review Flysheet

The Milestone Review Flysheet can be found in Appendix E.

### 1.3. Payload Summary

#### 1.3.1. Payload Title

Piston Battering Ram (PBR)

#### 1.3.2. Experiment Summary

The Payload Deployment System will detach the payload from the launch vehicle using a pyrotechnically activated tether-and-release device after the payload bay and fin can have separated. After payload deployment, the Target Differentiation System (TDS), controlled by a Raspberry Pi 3 Model B microcontroller, will control all autonomous tasking for the onboard TDS. The TDS will use a Raspberry Pi Camera Module v2 to capture images of the landing zone. The microcontroller will process the images onboard, locate the targets in the landing zone, and differentiate between them. Once landed, the servo-controlled Upright Landing System (ULS) will deploy and upright the payload from its landing orientation if it is not already upright. Telemetry data from the onboard orientation sensor will confirm the upright landing.

## 2. Changes Made Since PDR

### 2.1. Vehicle Criteria

The launch vehicle presented in PDR has been refined but has not undergone any major revisions. Per NASA recommendation, all couplers are now 12 inches (increased from the proposed 8 inches) allowing for a 6 inch overlap at every connection surface. Longer couplers reduce the chance of buckling during flight and improve the separation of vehicle sections during recovery system deployment. With the added coupler length, the overall vehicle height and weight have increased requiring a motor change. The team has selected the L2200G motor which produces 5104 N-s of total impulse. The fins have also been scaled up in order to maintain a stability margin of between 2.0 and 2.1 caliber upon rail exit. The nosecone has been changed from a 5:1 Ogive shape to a Von Karman 5.5:1 shape in order to reduce drag and due to supplier availability.

Dimensions and architecture of the avionics bay and Payload Deployment system electronics and their interfaces with the launch vehicle have been adjusted. During subscale vehicle construction, the wiring for each of these components was too time consuming because the order of assembly placed components in inaccessible locations. The final design will now use four PerfectFlight StratoLogger CF altimeters, two for the recovery system in the avionics bay and two for the Payload Deployment System in the payload bay. Previously the team used the StratoLogger CF as a main altimeter and an Entacore AIM USB 3.0 as the redundant; however, the StratoLogger provides simplified switch wiring. The main and redundant StratoLoggers will be selected from different manufacturing batches in order to reduce risk a similar manufacturing defect.

### 2.2. Payload Criteria

The payload has changed in several ways since PDR. The Target Differentiation System (TDS) has been reduced from a redundant system to a single system due to spatial constraints, the material of the payload body has been changed from aluminum 6061-T6 to clear polycarbonate to allow for viewing the payload internals after complete assembly, and the Upright Landing System (ULS) has undergone a complete redesign, transitioning from a lunar module landing system to a servo-driven system.

The Payload Deployment System design has been vetted and refined. The system now includes a tether-and-release connection from the fin can to the payload, whereas the design presented in PDR exhibited a shear pin connection from the fin can to the payload. This design allows for the controlling of the payload detachment from the fin can. A time-delayed detachment will allow enough time for the payload to clear the payload bay before detaching from the fin can.

### 2.3. Project Plan

As the project moves forward, the design of the subscale rocket has been finalized. During manufacturing of the vehicle issues were encountered and a high level of problem solving was used to determine solutions that both ensured the integrity of the design while and allowed for effective fabrication. The build of the subscale helped in defining the goals and milestones of the full-scale build. The design for the payload’s Upright Orienting System has changed drastically since the PDR which is explained in detail in §5.2.9. The budget for both vehicles and payloads has been fleshed out and reflects availability of components. The updated budget, funding and timeline can be found in §7.

## 3. Vehicle Criteria

### 3.1. Design and Verification 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

Aside from the NSL competition requirements the team also will also try to successfully complete the following team derived requirements:

- Achieve an altitude within 2% (105 feet) of the goal altitude.

- Proper and complete ejection of the payload.
- Stable powered and unpowered flight.
- Maintain GPS connectivity following flight.
- Incident free launch days.
- Design, fabricate, and fly a vehicle of exceptional quality.

### 3.1.3. Final Launch Vehicle Design Selection

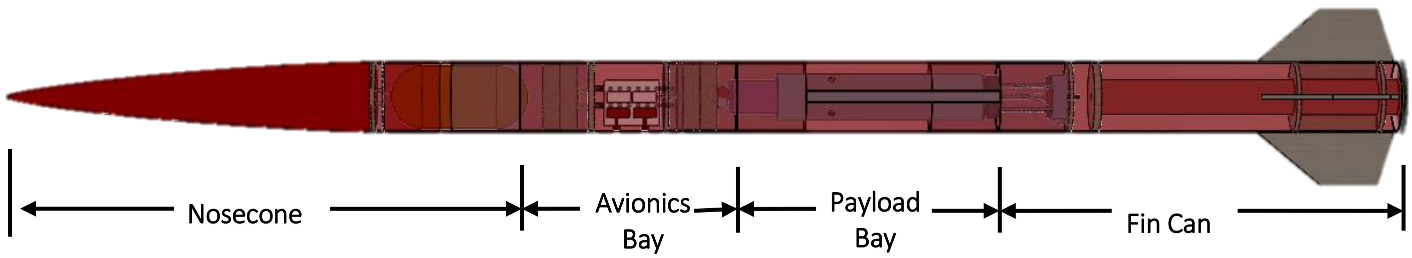



Figure 1: Assembly of complete launch vehicle

#### 3.1.3.1. Nosecone

The final nosecone assembly is shown below in Figure 2. The nosecone shape selected for the full-scale design is a 5.5:1 Von Karman with an aluminum tip (metal tip not shown in Figure 2). The team decided to switch from a 5:1 Ogive to the Von Karman because of the reduced drag characteristics that Von Karman nosecones possess. Along with this, the Von Karman was more readily available from suppliers and does not negatively impact performance when compared to the original Ogive. The metal tip is intended to reduce damage upon touch down on hard surfaces by preventing tip cracking.

Along with the change in nosecone shape, a portion of body tube will now be epoxied to the nosecone. The previous design had the nosecone coupler as the separation point for the main chute ejection event; however, the launch vehicle will now separate at the connection between the avionics (AV) bay and the upper airframe. This change was implemented in order to improve ease of access to the terminal blocks and black powder canisters attached to the AV bay bulkhead.

The bulkheads for the main parachute were selected to be 1/2" thick birch plywood and will be secured with epoxy and a coupler in the load bearing direction. The nosecone bulkhead will only act as a mounting surface for the forward connection of the main chute recovery harness.

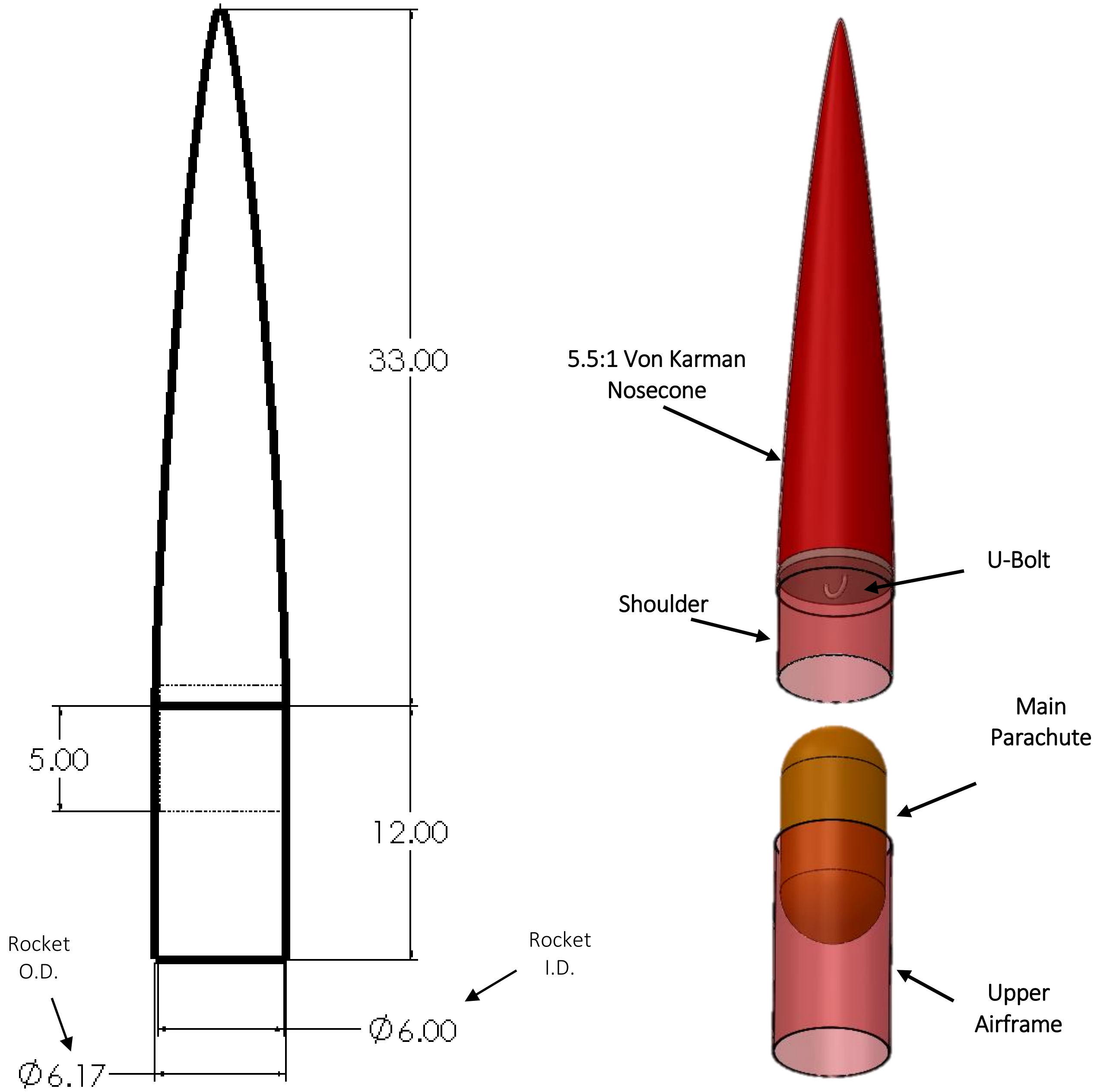



Figure 2:Nosecone Dimensional Drawing and Model View

### 3.1.3.2. Avionics Bay

The AV bay will house the electronics used to control ejection charges for both the main and drogue parachutes. During PDR, two solutions were presented in regard to accessing the avionics, the first was through a hatch cut in the wall of the body tube and the second was by way of a removable bulkhead. The final design will implement the second method of removing the aft most bulkhead. This design was used during subscale and worked well structurally; however, the length of the AV bay, along with a poorly vetted design, led to difficult and time consuming wiring.

The final AV bay design and overall dimensions are shown in Figure 3. This section of the launch vehicle will have one coupler that will act as the forward mating point between the AV bay and nosecone. This interface will be secured during launch by four #4-40 nylon shear pins and will separate during flight when the main parachute is deployed.

The forward bulkhead will be 1/2” thick and will be fixed in the body by epoxy while the aft bulkhead will be removable and is 3/8” thick. Both bulkheads are to be constructed from birch plywood. A pair of aluminum 1/4-20 rods will support the 3D printed ABS avionics sled (shown in Figure 4 and detailed below). These rods will be screwed into the aft side of the U-bolt in the fixed bulkhead via coupling nuts. These rods will run the length of the AV bay, through the aft (removable) bulkhead, and will be secured via nuts on both sides of the bulkhead.

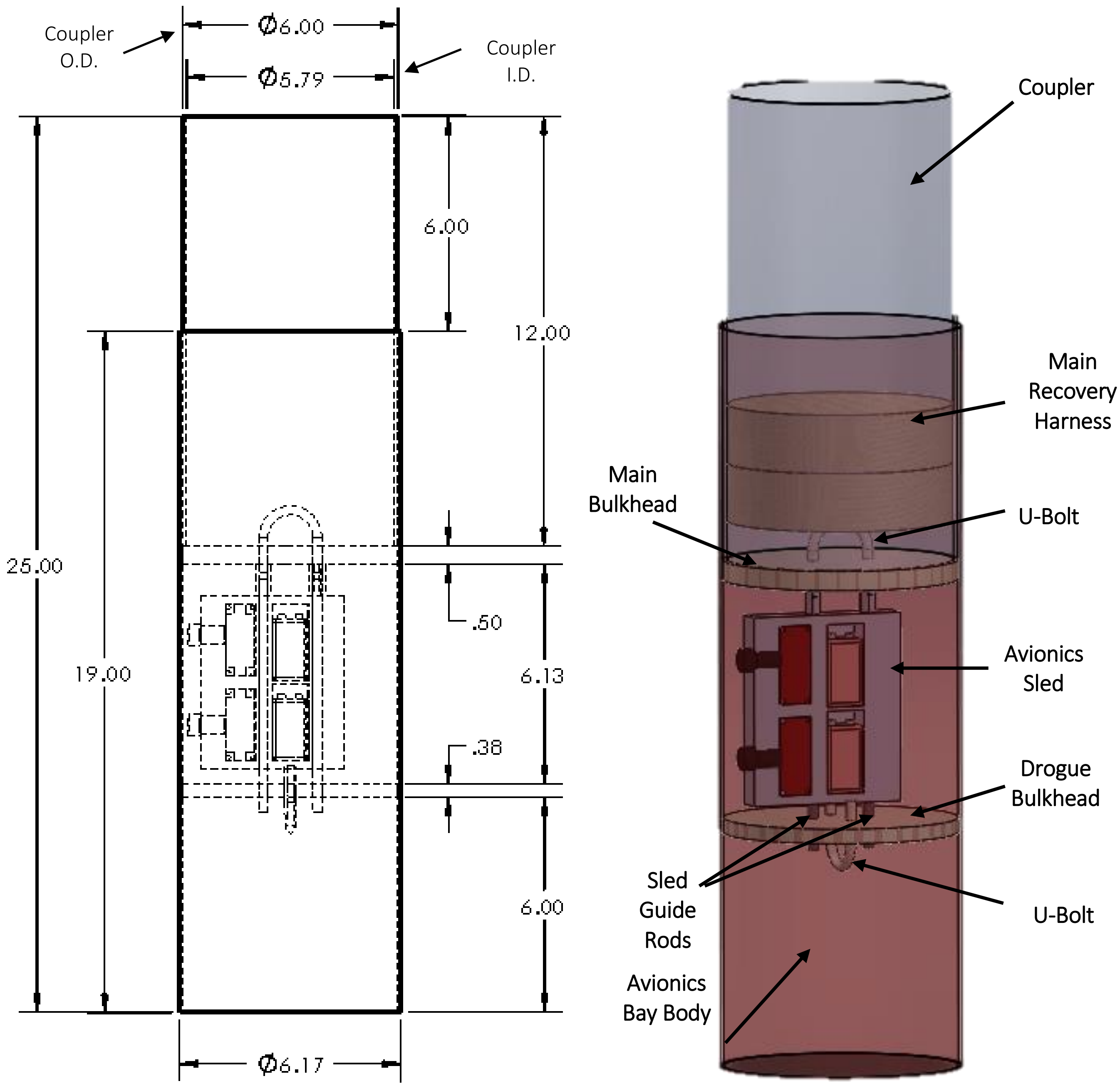



Figure 3:Avionics Bay Dimensional Drawing and Model View

The avionics bay will contain two StratoLogger CF altimeters, one main altimeter and a second redundant altimeter. In order to reduce the possibility of identical manufacturing defects, each altimeter will be taken from different production batches. The altimeters will be programmed to fire ejection charges that decouple the fin can and middle airframe at apogee, thus deploying the payload and the drogue recovery system. A redundant charge will then be fired 1 second after apogee. At 700 ft AGL, the primary altimeter will initiate the ejection charge used to separate the middle airframe and the nosecone, thus deploying the main recovery system. The redundant charge will be programmed to fire after an additional second.

Each altimeter will be independently powered by a 9 V battery and wired to its own rotary arming switch. The switches will be accessible from outside the launch vehicle and will not be armed until the launch vehicle is erected on the launch rail to prevent unscheduled ejection charge ignition. Each arming switch shall be capable of being locked in the ON position for launch. Holes will be drilled in the body tube in line with the switches to turn them on and allow the altimeters to breathe.

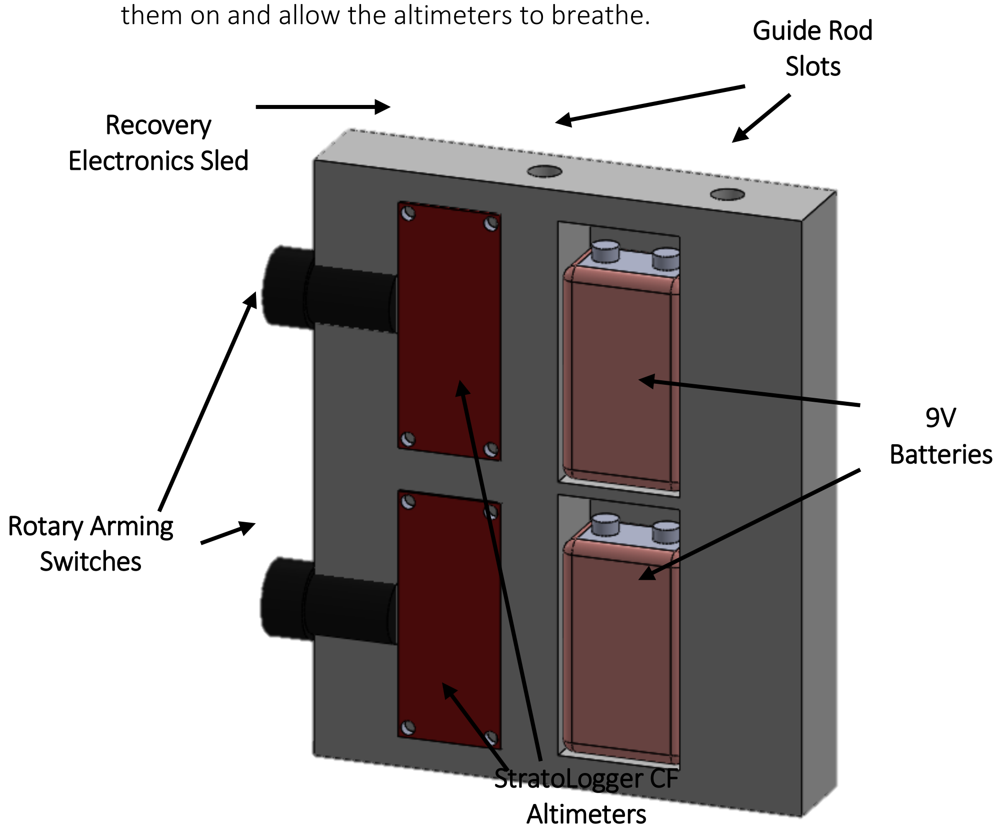



Figure 4:Payload Sled

### 3.1.3.3. Payload Bay

The payload bay will house the payload and all its subsystems along with the launch vehicle drogue parachute and shock cord. A pair of guide rails will be epoxied to the side of the fiberglass body and will assist the payload in exiting the launch vehicle along the proper path. In order to reduce binding, the rails will be aligned with a set of laser cut guides in order to confirm they are exactly 180° offset from each other. The payload has two sets of two rail buttons that will be able to freely rotate if the payload twists in flight. This system worked without flaw during the subscale launch and as such the team has confidence it will perform as intended on the final launch vehicle. A cross-section of the guide rails can be found in Figure 6.

The idea of a canister to house the drogue chute and shock cord has been scrapped and instead will simply rest inside the body of the payload bay. The canister was deemed to be unnecessary and simply added weight to the vehicle without providing any appreciable benefit. The payload itself will now be pulled from the payload bay by an ARRD attached to the fin can. For further discussion on the Payload Deployment System see §5.1.1.

The overall length of the payload bay has been increased in order to accommodate for the longer payload and couplers. The specific dimensions can be seen in Figure 5. The forward coupler will be secured to the avionics bay by a set of 4 screws that will remain intact for the duration of the flight. Screws will be used here so that the removable bulkhead in the avionics bay can be accessed.

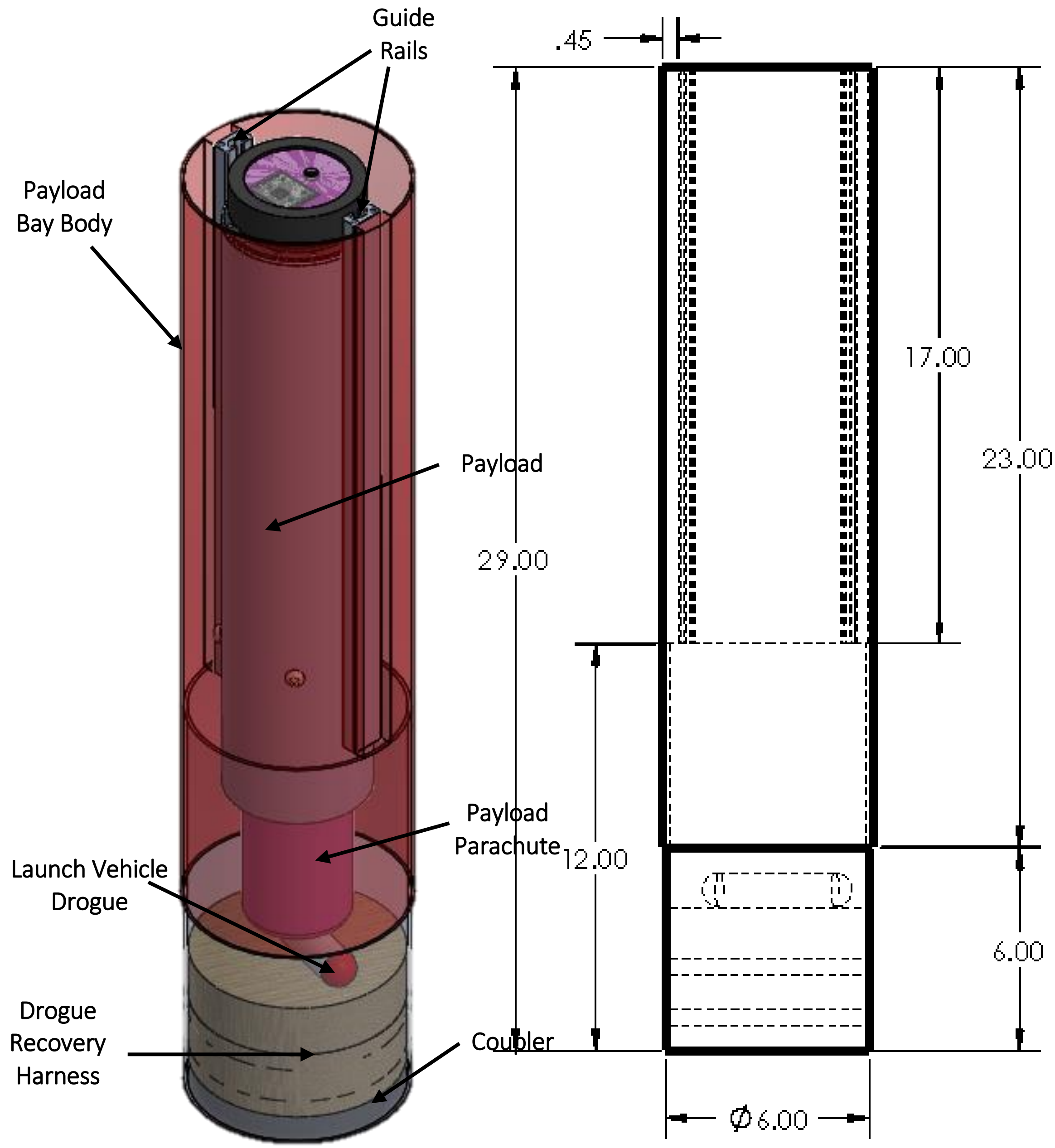



Figure 5: Payload Bay Dimensional Drawing and Model View (Shown aft end up)

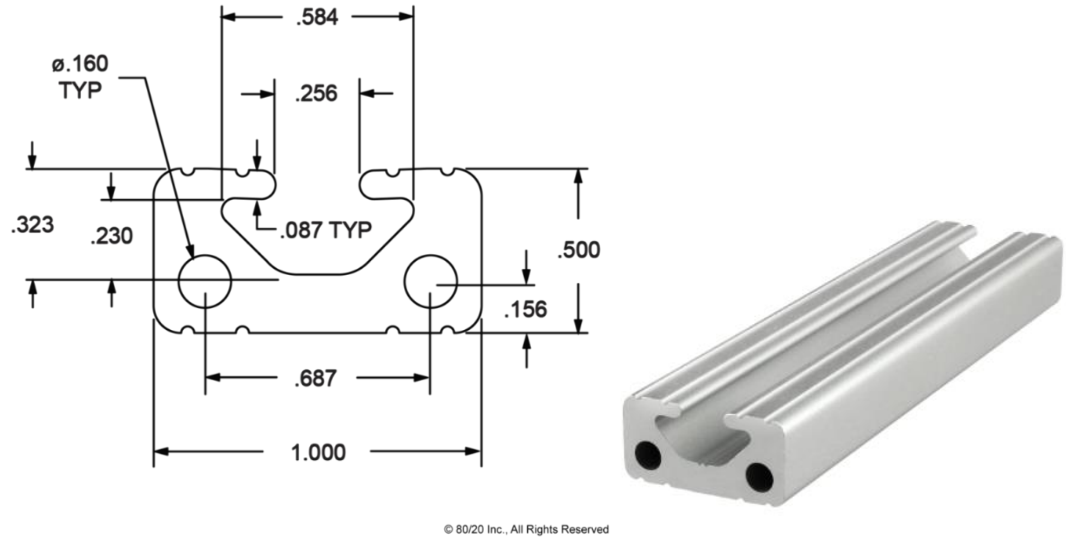



Figure 6:Payload Bay Rail Cross-Section

### 3.1.3.4. Fin Can

The fin can design has not undergone many major design revisions since PDR and major dimensions and a rendered model can be seen in Figure 7. The overall length has increased to a height of 41" (including coupler) in order to house the longer coupler. This coupler is mated against a birch plywood bulkhead of 3/8" thickness. The bulkhead will act as the aft connection point of the drogue parachute recovery harness as well as the ARRD and its accompanying altimeters. Both the coupler and bulkhead will be fixed to the body tube by epoxy. Two 1/4" diameter holes will be drilled in the body tube near the altimeters in order for accurate pressure readings to be recorded.

In order for the guide rails to lay flush against the payload bay body tube, two 1" x 6" slots will have to be cut into the coupler. This is the design that was implemented during subscale testing and no excessive stress was noted on the coupler post flight. Any cracks that did form during construction were minor, on the surface only, and were filled with epoxy prior to launch.

The design incorporates 4 trapezoidal fins contained between a pair of 3/8" birch plywood centering rings which will be epoxied to the motor tube and wall of the body. A dimensional drawing of the fins can be seen in Figure 8. Like the guide rails in the payload bay, the fins will be aligned using a laser cut plywood jig in order to ensure they are perpendicular to the body tube and equally spaced. A jig was not used when constructing the subscale fins and the process of aligning the fins took longer than it should have. Aligning the fins perpendicular to the body is paramount in ensuring symmetric stability properties of the launch vehicle. The fins will be offset from the aft end of the body tube by 0.25 inches in order to reduce impact damage on touchdown.

The motor, L2200G will be contained within an Aerotech Reloadable Motor System (RMS) 75/5120 motor casing which will be secured to the motor tube via an Aeropack 75mm engine retainer. The engine retainer will be epoxied to the aft end of the motor tube using JB weld which performs better in high temperature environments when compared to West Systems 105/206 epoxy. The motor tube will be secured to the body tube via a series of load paths including the engine block, both centering rings, and all four fins. The engine block is a 5/8" thick piece of birch plywood that will be epoxied to the motor tube and body tube.

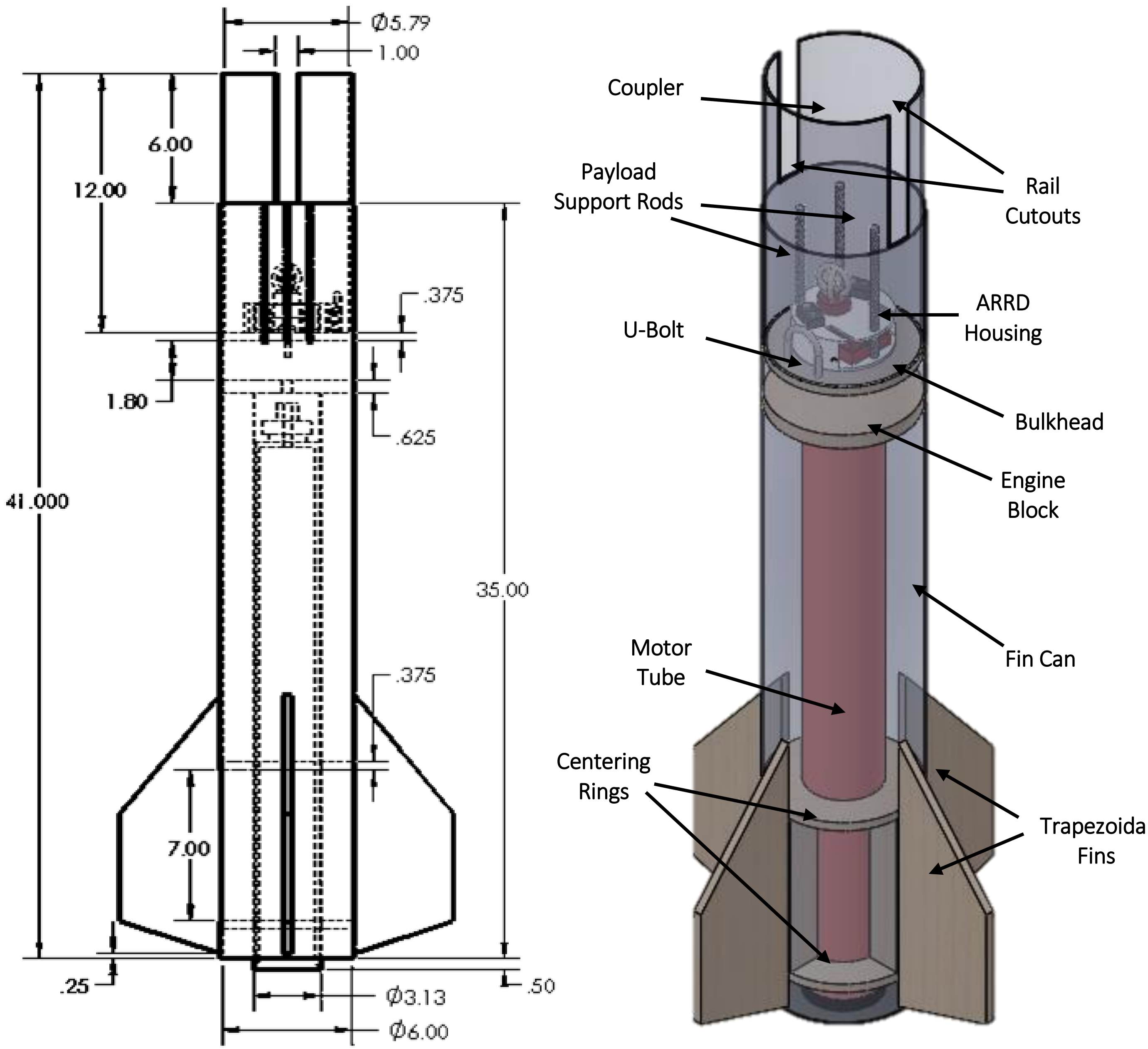



Figure 7: Fin Can Dimensional Drawing and Model View

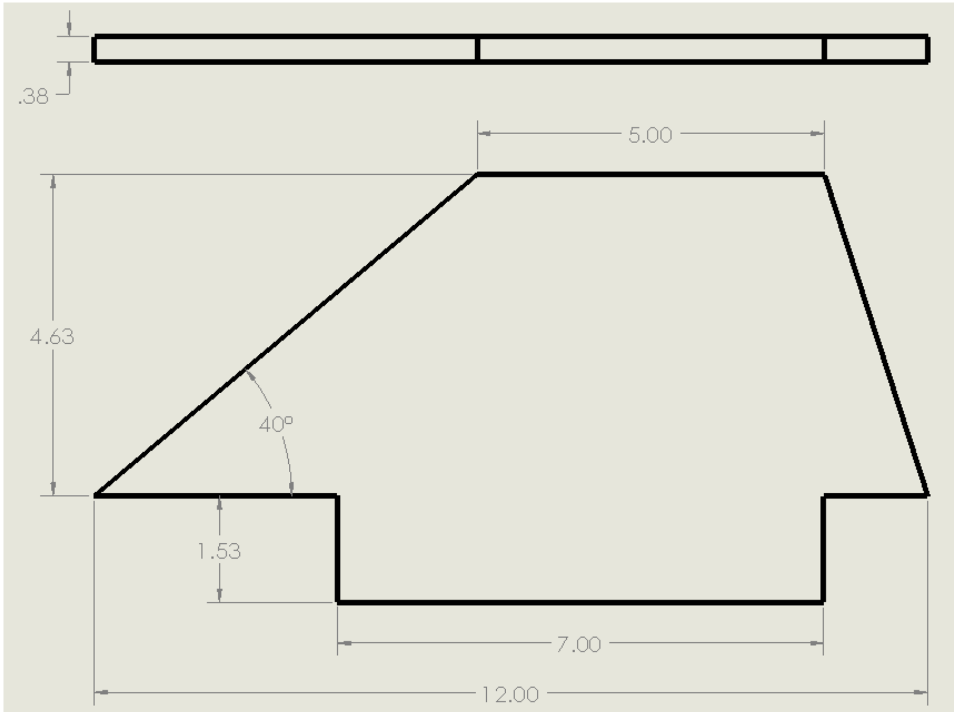


Figure 8:Fin Dimensions

Regarding the ARRD Housing, the general design presented below was implemented during the subscale launch and worked but with some flaws. The subscale's design had each altimeter placed on opposite sides of the ARRD and required the ARRD to be inserted prior to inserting the rest of the housing. These factors, along with the addition of switches, made the wiring very difficult and time consuming. To reduce time spent wiring, the new housing has a smaller diameter which coupled with the larger rocket diameter allows the ARRD and housing to be wired outside of the launch vehicle.

The updated ARRD housing (shown in Figure 9) will contain the altimeters and batteries used to control the ejection charge within the ARRD. This structure will be 3D printed out of ABS plastic. Each altimeter will be secured to the ARRD housing via adhesive backed Velcro. Along with space for the batteries, altimeters and ARRD, three threaded rods will fit through the housing and bolt into the fin can bulkhead. The threaded rods will support the payload during liftoff and will contact the payload on the retainer cap. This contact point will allow for the best transfer of load through the payload and prevent and 3D printed components from bearing the force from liftoff. Each rod will be 5/16" diameter stainless steel with an exposed length of 6 inches.

The ARRD will be bolted into the fin can bulkhead and will be removable. This will be achieved by placing a nut within one of the layers of plywood and then epoxying the other two layers around it. The same system will be implemented for the threaded rods. The U-bolt attached to the bulkhead will not be removable and will be attached to the bulkhead prior to its insertion in fin can.

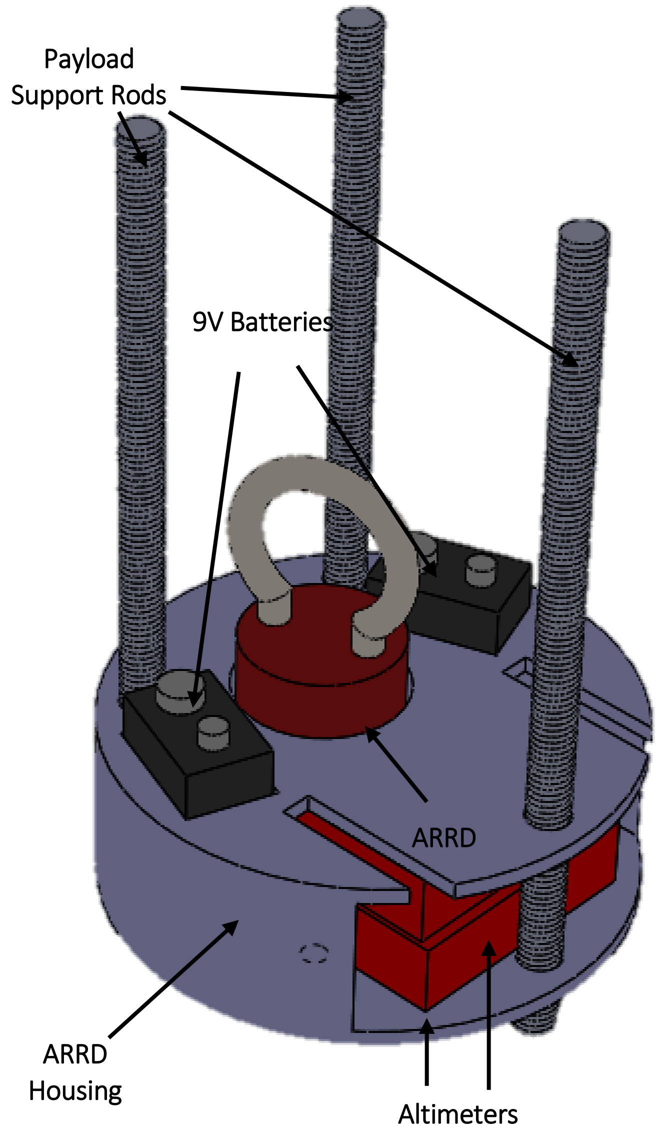



Figure 9:ARRD housing with altimeters, batteries, ARRD, and support rods

### 3.1.3.5. Motor Selection and Thrust Curve

Three motor choices were presented during PDR with varying total impulse ratings and associated altitude predictions for the stated launch vehicle. Based on the projected weight of 49.6lb, an Aerotech L2200G motor has been selected which is predicted to lift the vehicle to an apogee altitude of 5305ft in ideal conditions. The L2200G is a 75mm 99% L-Class motor which produces 5104 N-s of total impulse with a peak thrust of 3102N and a burn time of 2.27s. This is the only motor within the L-class requirement (5120 N-s max total impulse) with enough thrust to lift the launch vehicle to the target apogee of 5280 ft. Further discussion on performance can be found in §3.4.1.

Figure 10 shows the simulated thrust curve as reported by the manufacture and reproduced in OpenRocket.

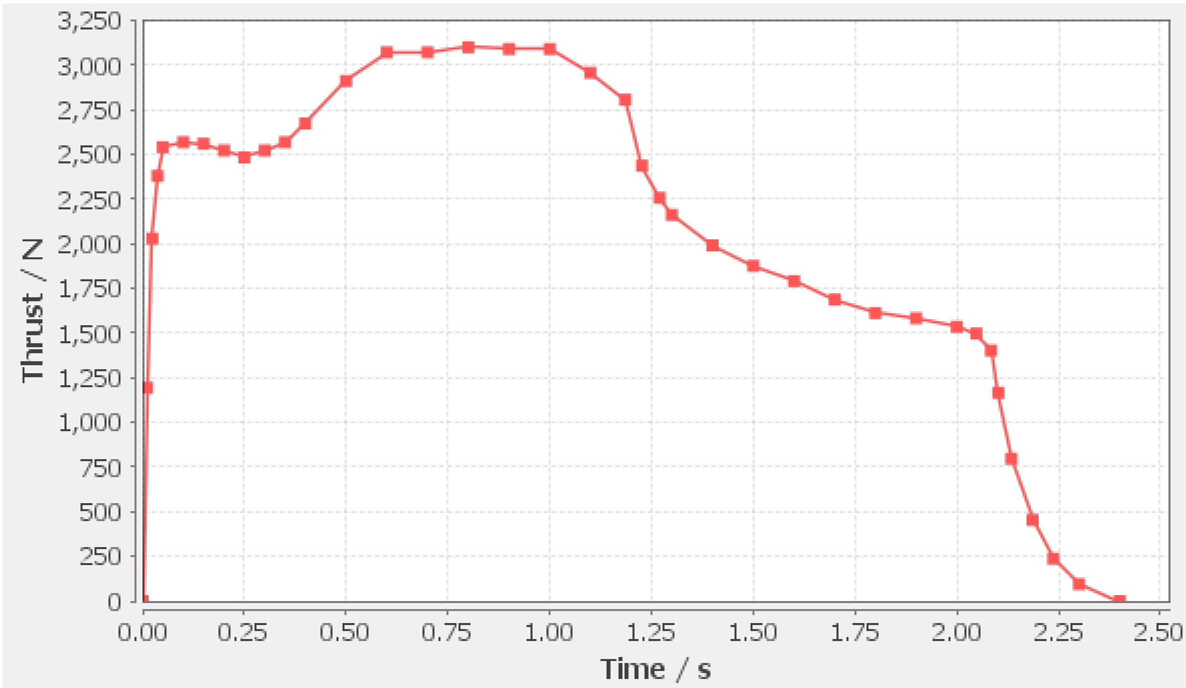



Figure 10:L2200G Motor Thrust Curve (courtesy of OpenRocket and Aerotech)

### 3.1.4. Component Mass Projections

The launch vehicle is currently projected to weigh 49.6 lb. This weight comes from OpenRocket and SolidWorks models, and thus is an accurate 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 39.3 lb. This weight approximation includes both epoxy and paint that will be applied during the construction process. Minimal weight gains, if any, are expected and the rocket will most likely lose a small portion of this weight due to 3D printed fill settings. Any weight variations will be small and should not interfere with the launch vehicle performance. Table 2 shows a detailed breakdown of the projected weight of each assembly and component.

Table 2: Predicted Component and Assembly Weight

| Assembly | Component | Weight (lb) |
|---|---|---|
| Nosecone | Nosecone (including coupler) | 3.04 |
| | Main Parachute | 3.75 |

| | | |
|---|---|---|
| | Upper Airframe | 1.30 |
| | Bulkhead (including U-Bolt) | 0.69 |
| | **Assembly Total** | **8.78** |
| Avionics Bay | Avionics Bay Body | 2.06 |
| | Coupler | 1.62 |
| | FWD Bulkhead (including U-Bolt) | 0.72 |
| | AFT Bulkhead (including U-Bolt) | 0.62 |
| | Main Recovery Harness | 1.37 |
| | Drogue Recovery Harness | 1.00 |
| | Drogue Parachute | 0.14 |
| | Avionics Sled (including electronics) | 0.57 |
| | Sled Guide Rods (includes both) | 0.12 |
| | **Assembly Total** | **8.21** |
| Payload Bay | Payload Bay Body | 2.50 |
| | Coupler | 1.62 |
| | Payload Guide Rails (includes both) | 1.20 |
| | Payload | 4.70 |
| | **Assembly Total** | **10.02** |
| Fin Can | Fin Can Body | 3.80 |
| | Coupler | 1.46 |
| | Bulkhead (includes all hardware) | 0.75 |
| | ARRD | 0.34 |
| | ARRD Housing (includes all electronics) | 0.51 |
| | Support Rods (includes all 3) | 0.32 |
| | Engine Block | 0.42 |
| | Centering Rings (includes both) | 0.35 |
| | Fins (includes all) | 1.71 |
| | Motor Tube | 1.70 |
| | Motor Casing | 4.93 |
| | Propellant | 5.57 |
| | Engine Retainer | 0.25 |
| | **Assembly Total** | **22.09** |
| Totals | **Total Epoxy** (Approximate) | **0.50** |
| | **Lift Off Weight** | **49.60** |
| | **Touchdown Weight** | **39.33** |

### 3.1.5. Understanding of Project Components

All risks defined in Appendix B, the Failure Mode Effects and Criticality Analysis, 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 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. There is currently no risk of going overbudget. 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.

## 3.2. Subscale Flight Results

### 3.2.1. Subscale title

RED Rocket

### 3.2.2. Scaling Factor

The intent of the subscale was to determine whether the payload would eject safely with the current launch vehicle design. Determining the size of the subscale launch vehicle began with deciding on what size payload was needed to have preliminary camera and leg lander system. A 3in diameter aluminum tube was decided upon as large enough for the camera and all its components. Next, the team decided that the subscale should be design to reach 2500 ft which is close to half the altitude of what the competition rocket will be design to obtain. These two parameters along with the other NASA launch vehicle safety and competition requirements were used to size the rocket rather than build an exact scaled down version. The subscale rocket fabrication resulted in a launch vehicle that was 95in long with a 5.15in diameter and weighing a total of 28.1lb. The full-scale launch vehicle will be 122in long, 6.17in in diameter and will weight 49.6lb. The full scales increase in size is a product of using a larger diameter payload body.

### 3.2.3. RED Rocket Launch

The launch of RED Rocket took place in Bayboro, North Carolina on December 17, 2016 which had an approximate temperature of 60 degrees Fahrenheit. The day began with low visibility fog and strong winds gusts, but during the time leading up to the launch the skies cleared and wind was minimal with gusts no more than 5 miles per hour. The rocket was mounted on the 80/20 rail via two rail buttons secured to the fin can. The launch vehicle rested upon a small block of wood to allow space of the propellant to exit. A black and white painted PVC pipe was placed next to the rocket for later calculation of rail exit velocity. Figure 11 displays the rocket mounted on the rail before main motor ignition.

Figure 11:RED Rocket Loaded on Rail

Following ignition, the rocket accelerated off the rails rapidly resulting in all the propellant burning out within 2-3 seconds. The rocket followed a vertical flight path, indicating proper spacing and angling of fins. Figure 12 shows the rocket directly after motor ignition.

Figure 12:Main Ignition

The launch vehicle successfully decoupled at apogee with a good release of the fin can section which then guided the payload and tethered drogue parachute out without impedance. During the descent towards the ground, the AARD failed to disconnect the payload from the rocket body. This caused the payload to remained bound to the launch vehicle the entire duration of the flight. The main parachute was programmed to eject from the nose cone section, but neither the main or backup charges ignited for the main parachute. This indicated improper wiring or altimeter malfunction. However, the Jolly Logic controlled payload parachute deployed at a pre-programmed altitude of 700 ft slowing the descent of the launch vehicle. Figure 13 below shows the payload still attached to the fin can and how the fin can is tethered to the upper airframe.

Figure 13:RED Rocket descent

Unfortunately, due to the main parachute failing to deploy the rocket came down with more force than predicted. The impact resulted in the loss of one of the fins and two of the four payload legs coming detached from the payload body. However, all detached components were reclaimed during retrieval.

### 3.2.4. Subscale Simulation

The subscale vehicle was designed using OpenRocket, which produced flight simulations of a vehicle 93.5 inches long with a 5.15-inch diameter and weighed 28.6 lb. The OpenRocket model had the CG 58.30 inches aft of nose tip and the CP at 68.56 inches aft of the nose tip, giving it a stability of 2.00 caliber. For the simulation, an L1103X motor was used. Standard atmospheric conditions were applied with an average wind of 3 mph. The following are the predicted flight characteristics from the simulation: apogee at 2479 ft, maximum velocity of 415 ft/s ,maximum acceleration of 375 ft/s$^2$, time to apogee of 12.6 seconds, and total flight time of 75 seconds. These values are illustrated in Figure 14.

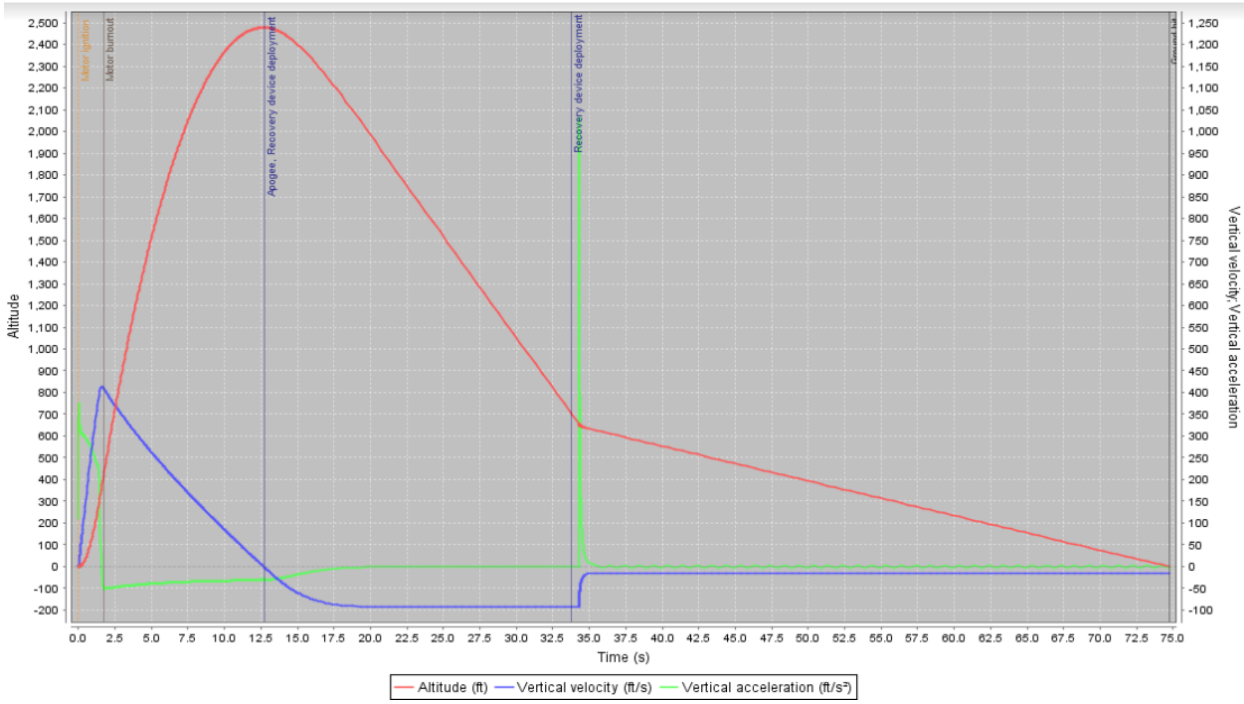



Figure 14:OpenRocket Subscale Simulation

### 3.2.5. Subscale Flight Data

Fabrication of the actual subscale resulted in slightly varying specifications. The actual rocket was lighter and weighted 28.1lb compared to the simulated 28.6lb. The final length of the rocket was 94 inches, which is 0.5 inches longer than the SOLIDWORKS model. In addition, the actual CP was found to be 69.23 inches aft of the nose tip and CG was located 59.5 inches aft of nose tip.

There were four altimeters on board during the subscale. The StratoLogger controlling the apogee event was the only altimeter that produced usable data. The StratoLogger obtained altitude and velocity data for the RED Rocket launch shown below in Figure 15.

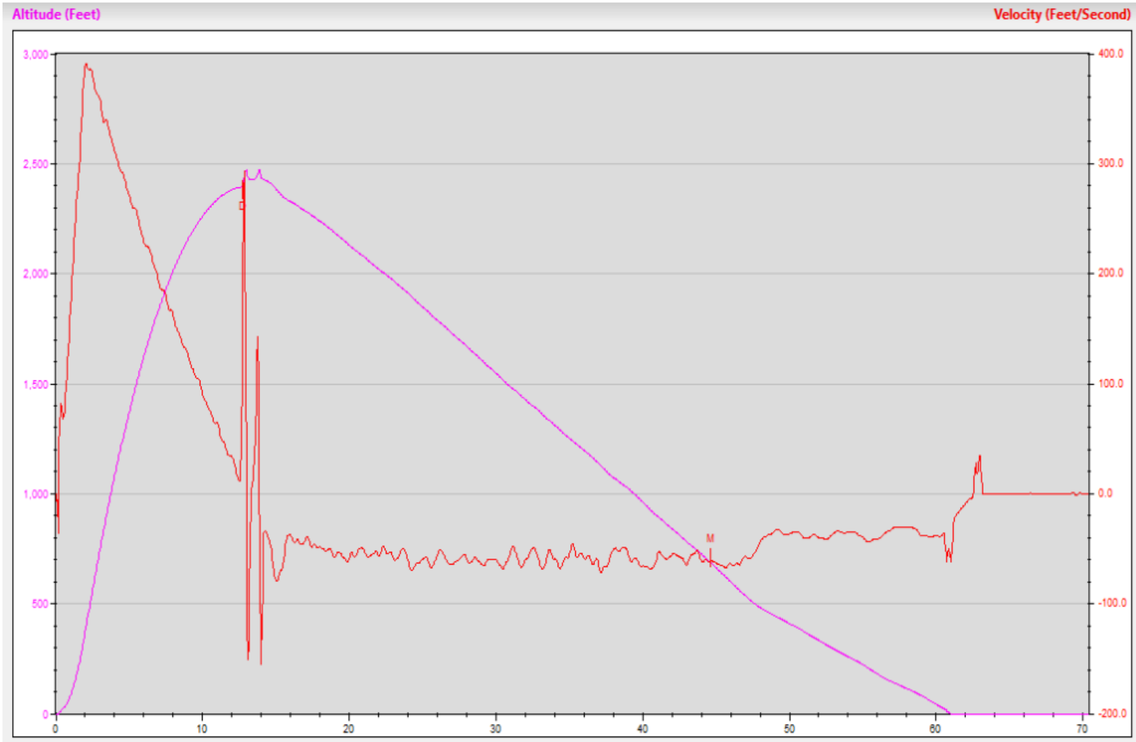


Figure 15:Onboard Altimeter Flight Data

From Figure 15 above, Red Rocket performed similar to the simulation. The maximum velocity was approximately 380ft/s and reached an altitude of 2438ft resulting in a 41ft difference from the simulation. Time to apogee was almost an exact match, but since the main parachute did not deploy the total flight time was significantly shorter. Figure 16 below shows the altimeter voltage levels throughout the duration of the flight.

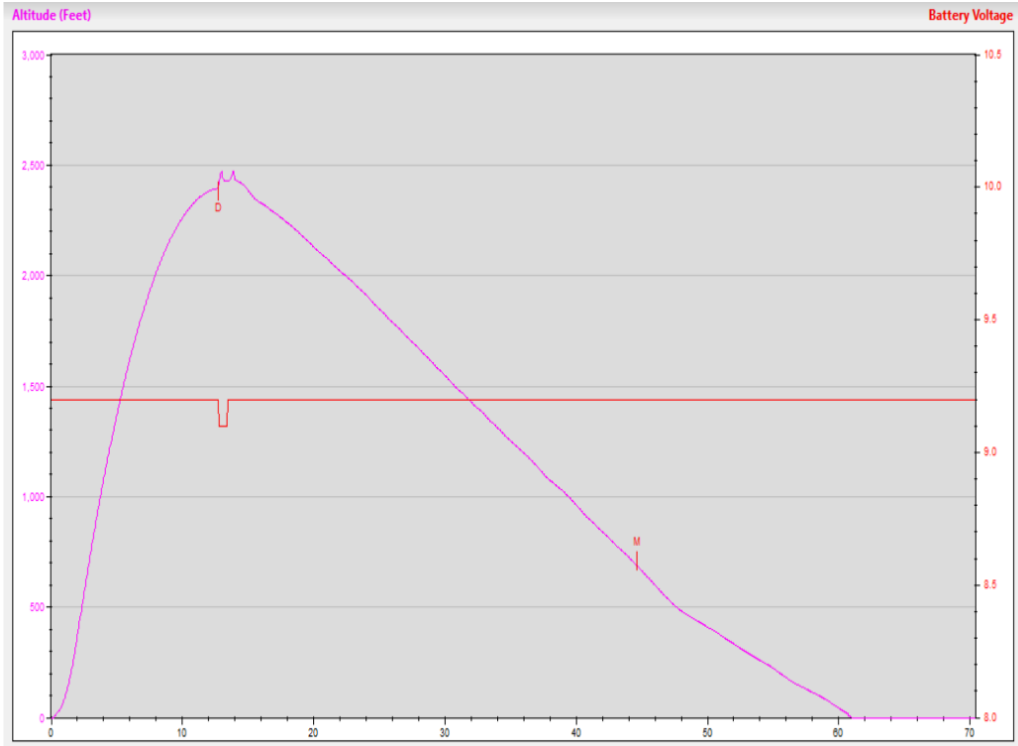



Figure 16:Onboard Altimeter Voltage Plot

From Figure 16, the drogue parachute open at the appropriate apogee, but no voltage change is seen when the main parachute was supposed to open. The altitude gradient only changes below 500ft due to the payload still attached and its parachute deploying from the Jolly Logic Release system.

### 3.2.6. Projected Full-Scale Drag Coefficient

Due to the lack of data available from the sub-scale launch, an estimation of the drag coefficient for the sub-scale rocket is not available. However, based on OpenRocket simulations, the subscale drag coefficient at operational Mach numbers was found to be 0.55.

### 3.2.7. How Subscale Impacted Full-Scale Design

During construction, some issues arose due to accessibility of the inner components. Most of these issues were due to the subscales smaller diameter, but small redesigns to the ARRD housing and the forward avionics bay were made to make the altimeters, batteries and wires more accessible. Because one of the fins broke off upon impact, thicker fins will be used for the full-scale flight to mitigate the risk of this happening again. Lastly, to avoid any programming errors with altimeters the same brand of altimeter will be used. The StratoLogger CF was selected as the brand of altimeter to use due to it being the only altimeter that produced usable data. The team has access to older StratoLogger CF altimeters and will purchase newer ones to avoid any manufacturing defects that may be present.

## 3.3. Recovery Subsystem

At apogee, the 2ft 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 CF programmed to fire the primary charge at apogee and the redundant StratoLogger programmed to fire the redundant charge 1 second later.

At 700ft, the 14ft 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 CF and the secondary charges controlled by the redundant altimeter. Secondary charges are to be detonated 1 second after primary charges.

### 3.3.1. System Design

The design was chosen because of its simplicity towards the competition requirements. The launch vehicle is essentially designed around the payload. Alternative designs required having too many sections and dedicated avionics. The chosen design has one avionics bay for the launch vehicle which simultaneously reduces weight and allows the launch vehicle to descend altogether under one drogue parachute and one main parachute.

### 3.3.2. Parachutes, Bulkheads, and Attachment Hardware

The parachutes selected for the launch vehicle recovery are a 2ft or 24in drogue and a 14ft or 168in main parachute. Both parachutes will be purchased from Fruity Chutes webstore. The specifications can be seen below in Table 3.

Table 3: Parachute Characteristics

| | Drogue Parachute | Main Parachute |
|---|---|---|
| Type | Elliptical | Ultra-Compact |
| Size | 24in | 168in |
| $C_d$ | 1.6 | 2.2 |
| Parachute Material | 1.1oz Rip-Stop | Standard Nylon Toroidal |
| Line Material | 220lb Nylon | 400lb Spectra |
| Swivel Rating | 1000lb | None |
| Weight | 2.2oz | 60oz |
| Packing Volume | 12.2in$^3$ | 245.15in$^3$ |

The bulkheads separating the sections of the rocket will be constructed from 1/8$^{th}$ in plywood epoxied and pulled under vacuum to ensure adhesion. The bulkhead for the main parachute will be 0.5in thick and the bulkheads that the drogue will be tethered to will have a thickness of 0.375in. U-bolts will be threaded through each bulkhead and secured on each side and will have 1/4" thickness.

The parachutes will be tethered to the bulkheads by 1in, flat, woven Kevlar tethers rated at 2000lb. The parachutes will be connected to the Kevlar tethers via a looped knot in the tether and 0.25in steel quick links. These same quick links will be used to attach the tethers to the U-Bolts.

Because black powder will be used to decouple the launch vehicle, each parachute will rest with in fire resistant Kevlar sheets.

### 3.3.3. Ejection Method

Black powder charges will be used to decouple the rocket sections to allow parachutes to unfurl and sizes were calculated with the following formula:

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

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 2.0 grams of black powder and will therefore have a 2.25-gram redundant charge. The drogue parachute cavity will require 2.25 grams of black powder and will have a 2.5-gram redundant charge. There will be four 4-40 nylon shear pins at each separation point to hold the rocket together until decoupling.

The black powder charges will be placed in PVC caps and taped over prior to assembling the rocket once the black powder has been measured out and distributed. The PVC caps will be screwed into the corresponding bulkheads. The caps for the apogee drogue release ejection will be placed at the forward most part of the payload bay section and face the back of the rocket. The caps for the main parachute ejection will be attached to the top of the avionics bulkhead facing the nose. Essentially the charges are located directly outside the forward avionics bay on both sides. The placement of the black powder charges allows the rocket to work with only one avionics bay and remain fully tethered together after both decoupling events.

### 3.3.4. Recovery System Electronics

All recovery system ejection events will be powered by StratoLogger CF altimeters and can be seen below in Figure 17.

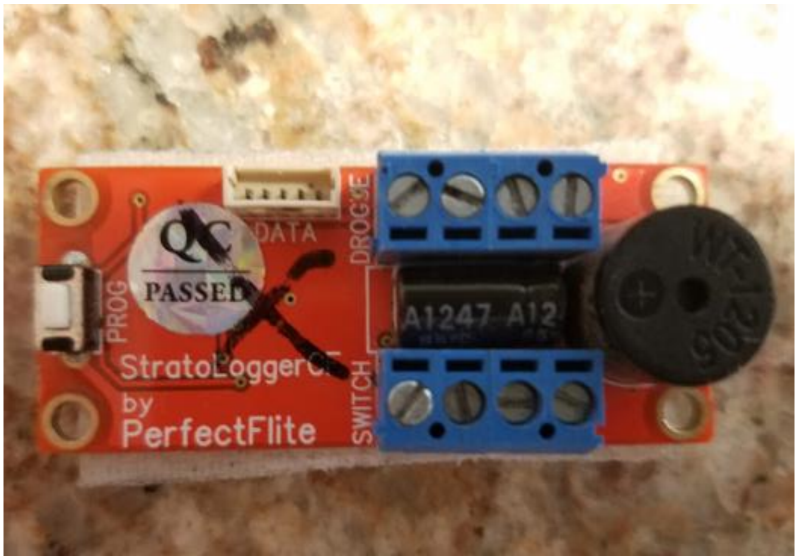


Figure 17:PerfectFlite StratoLogger CF Altimeter

To ensure parachute ejection, each altimeter will be independently powered by its own 9V battery and have its own rotary switch. The rotary switch can be seen below in Figure 18.


Figure 18:Rotary Switch for altimeter priming

The rotary switches will be accessible from the outside of the launch vehicle so that they may be turned on as the rocket is resting on the launch rail.

### 3.3.5. Electrical Schematic for Recovery System

A block diagram of the recovery system is presented in Figure 19. The recovery system will be responsible for the deployment of the drogue and main parachutes.

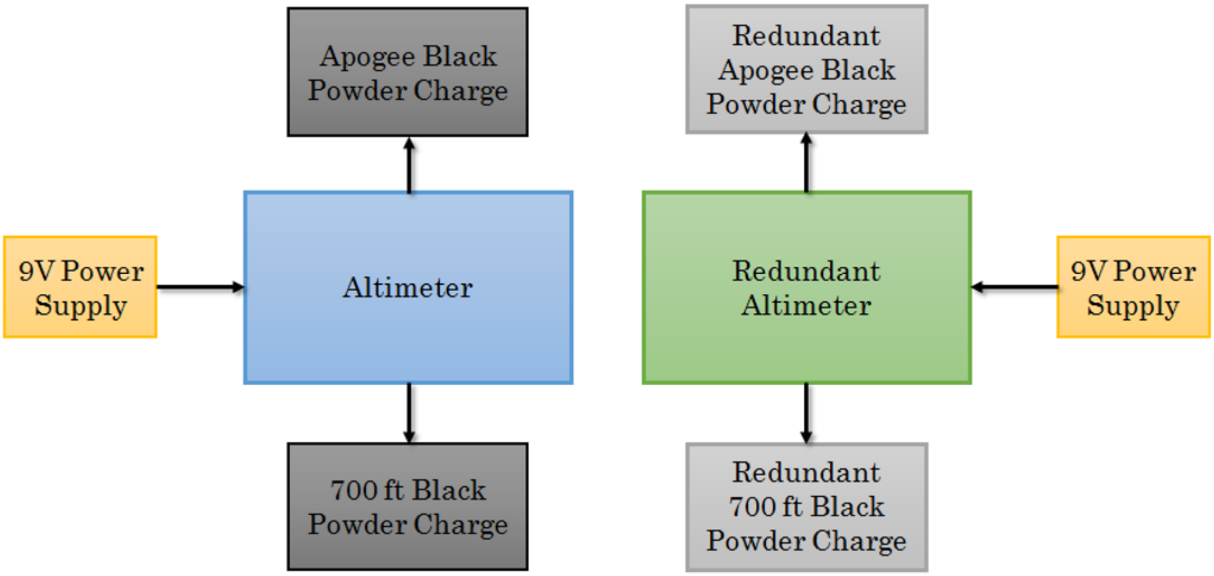



Figure 19:Rocket Parachute Deployment

### 3.3.6. Launch Vehicle and Ground Station

The launch vehicle will contain a GPS unit to ensure recovery of the launch vehicle. The GPS will be a BigRedBee (BRB) 900 MHz GPS transmitter that comes with its own power source and will be housed in the nose cone section of the rocket. The GPS units have provided the team with reliable location information in the past and has allowed for recovery of the launch vehicle. This GPS unit 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. The BRB GPS can be seen below in Figure 20.

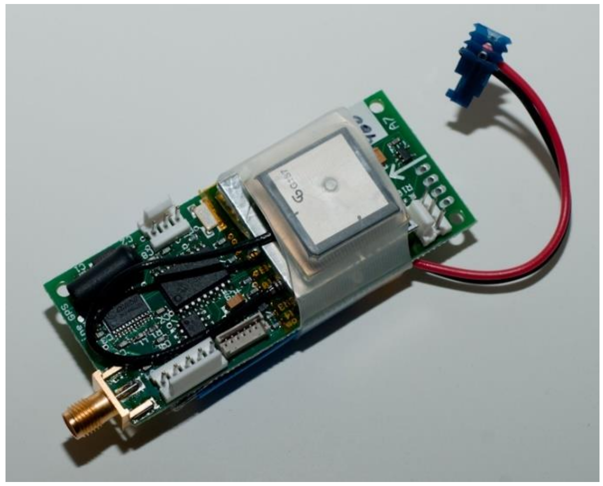


Figure 20:Big Red Bee Tracker

## 3.4. Mission Performance Predictions

### 3.4.1. Flight Profile Simulations

Figure 21, below, shows a flight profile simulation from OpenRocket using the AeroTeck L2200G 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 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 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.

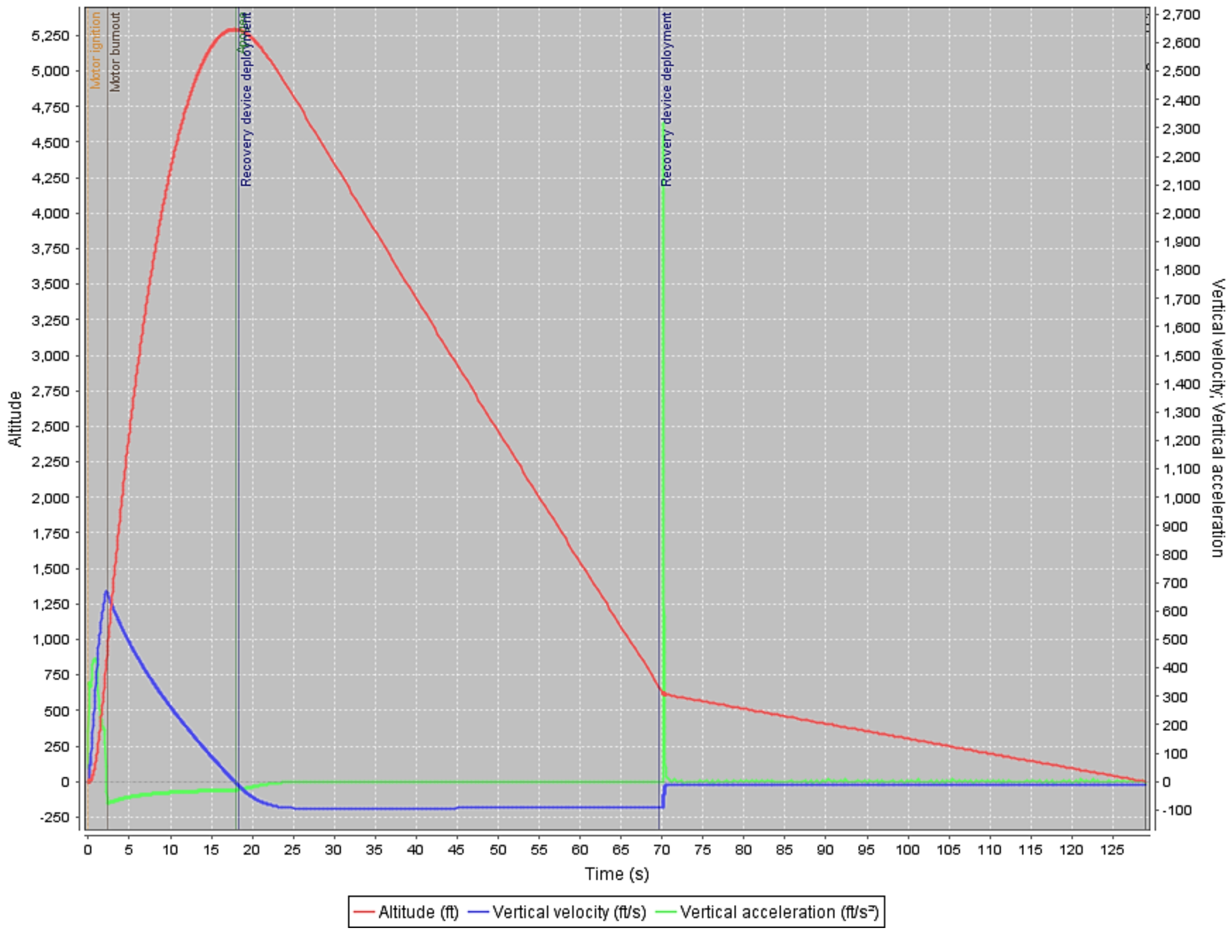



Figure 21:OpenRocket Flight Performance Predictions Plot

With the current design and no wind, the apogee can be expected to be 5347 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 miles per hour winds are shown in Table 4 and come from OpenRocket simulations of the same parameters as listed above. From the altitude simulations, it is seen that over the range of possible wind velocities the apogee of the rocket is within 1% of the target altitude. The average wind speed in Huntsville is approximately 10 mph which puts the predicted altitude to within 15 ft of nominal.

Table 4:Predicted Altitude with Various Wind Conditions

| Wind Speed (mph) | Predicted Altitude (feet) |
|---|---|
| 0 | 5347 |
| 5 | 5320 |
| 10 | 5295 |
| 15 | 5265 |
| 20 | 5240 |

### 3.4.2. Stability Margin, Center of Pressure, Center of Gravity

Due to the correlation found in PDR between OpenRocket and the Barrowman method of solving for center of pressure (CP), OpenRocket was used exclusively for predicting center of gravity (CG), CP, and stability margin. The datum for CG and CP were taken from the forward most point of the nosecone. For a Mach number of 0.0 and fully loaded vehicle (representing rail exit), OpenRocket gives a static margin of 2.00 cal. with the CG located 77.0 inches aft of datum and the CP located 89.3 inches aft of datum. For a Mach number of 0.3 and weight excluding propellant (post motor burn), OpenRocket gives a static margin of 2.67 caliber with a CG location of 73.0 inches and a CP location of 89.5. The center of pressure for an ogive nosecone is 46.6 percent of the length, measured from the tip of the nose. CG and CP will be physically determined by weight and balance once the vehicle is constructed. Figure 22 shows the location of the center of gravity (blue and white cross) and the center of pressure (red circle with red dot) for the launch vehicle at rail exit and post motor burn out.

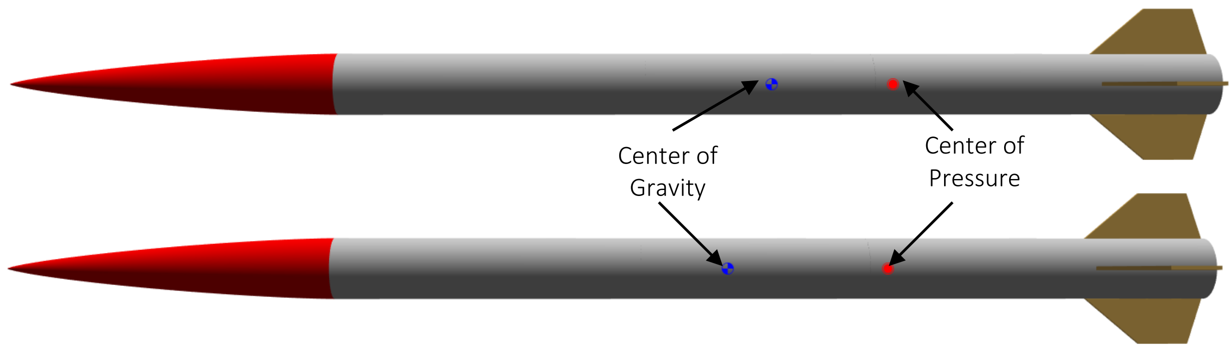



Figure 22: Launch vehicle showing CG and CP locations for rail exit (top) and post motor burn (bottom)

Launch rail exit velocity is crucial to the vehicle's stability. Per the 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 27 inches from the bottom of the rocket, the rail button will travel 69 inches for an 8-foot rail or 117 inches for a 12-foot rail before leaving the rail. For the L2200G motor and a 96-inch launch rail, it was found that the vehicle's top rail button would leave the rail at 65.3 feet per second. If a 12-foot rail were used, the vehicle's top rail button would leave the rail 85.0 feet per second. Based on this data, the 8-foot rail will be sufficient to allow the launch vehicle to accelerate to a velocity great enough to have a stability margin greater than 2.

Equation 2 was used to calculate this velocity and 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 and drag were neglected due to the low velocities being considered.

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

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 560lb and is the L2200G 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).

### 3.4.3. 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.

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

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 44.2lb and 4.8lb respectively. Solving Equation 3 yields a maximum impact velocity of 10.64 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 23 below shows the speed in which the rocket body will fall under different sized drogue parachutes.

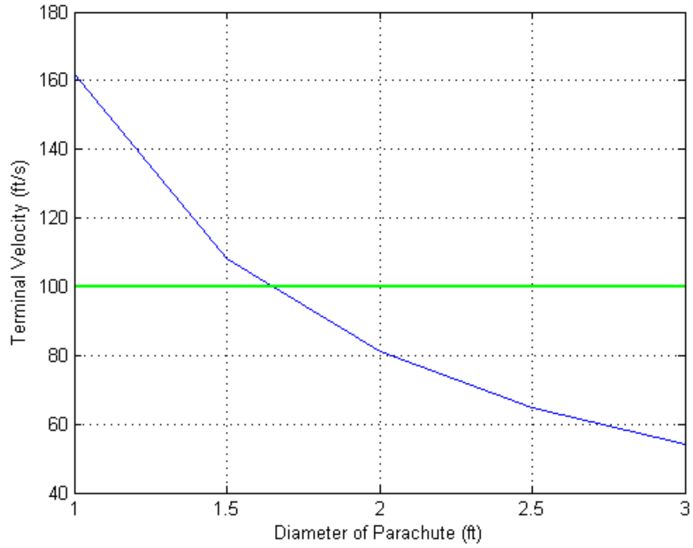



Figure 23: Vehicle Under Drogue Velocity

For the drogue sizing, 100ft/s was chosen as the maximum velocity at which the vehicle will fall. Based on figure 19, a 2ft drogue parachute was chosen to deploy at apogee slowing the rocket body to 81.0ft/s.

At 700ft, 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 75ft-lbf threshold. As calculated above the rocket needs to be slowed to a velocity of less than 10.64ft/s. Figure 24 below shows the impact speed compared to different diameter parachutes.

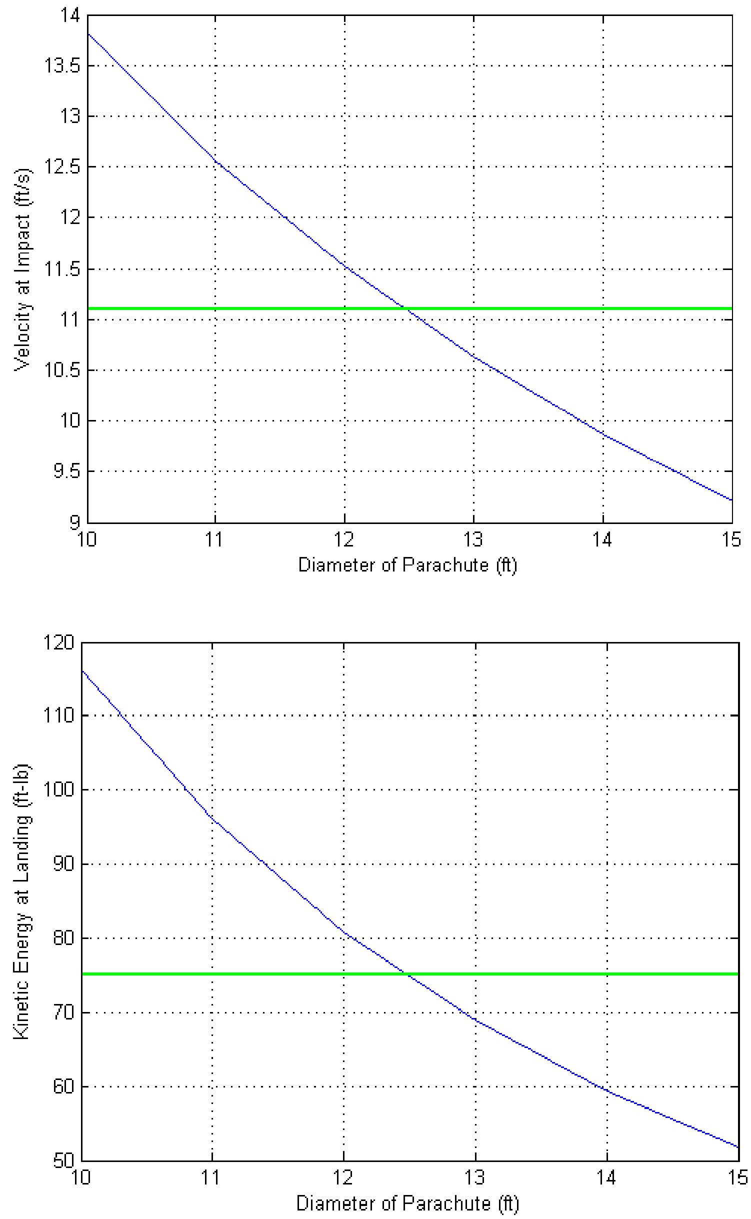



Figure 24:Main Parachute Descent Plot

From Figure 24, it was determined that a parachute of greater than 13ft is necessary to bring the impact force under the allowable threshold. To account for projected weight gains involved with fabrication of the rocket a 14ft parachute will be used as the main parachute for the rocket so that fabrication will have a factor of safety with regard to the recovery system. The 14ft parachute will slow that rocket body down to an impact velocity of 9.87ft/s and a kinetic energy of 59.4ft-lbf.

The payload will require a parachute deployment to complete the data collection and still fall under the impact force limits. Figure 25 shows the maximum velocity at which the payload will fall.

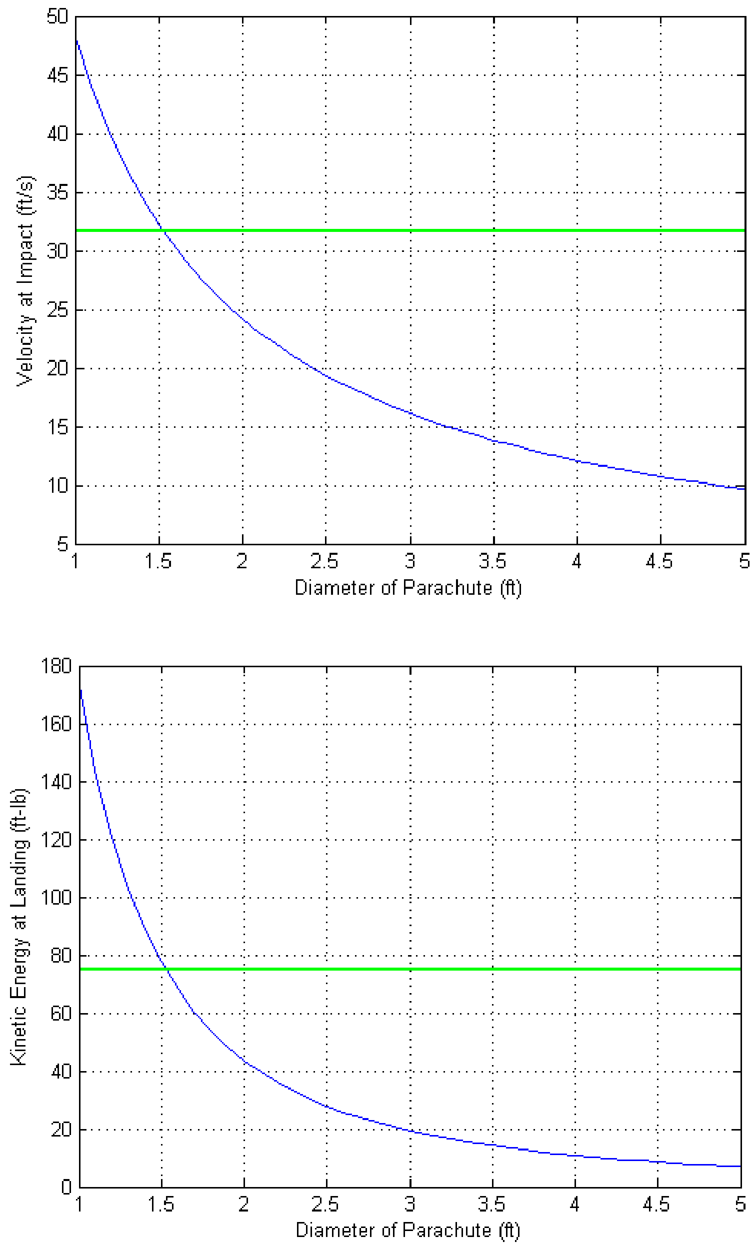



**Figure 25: Payload Parachute Controlled Descent Calculations**

From Figure 25, it was determined that a parachute with a 4ft 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 12.1 ft/s and a kinetic energy of 10.9 ft-lbf. 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.

### 3.4.4. 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. Knowing how long the rocket takes to reach the ground allows for the calculation of horizontal drift. A perpendicular launch is a safe assumption and simplifies the calculations involved with wind drift and yields an approximate distance that the team would have to walk to retrieve the launch vehicle and payload. Table 5 below shows the predicted wind drift for five different wind cases with Figure 26 showing corresponding radius of potential drift.

Table 5: Wind Drift Predictions

| Wind (mph) | Rocket Airframe (ft) | Payload (ft) |
|---|---|---|
| **0 (blue)** | 0 | 0 |
| **5 (green)** | 933 | 424 |
| **10 (brown)** | 1866 | 849 |
| **15 (yellow)** | 2799 | 1273 |
| **20 (red)** | 3733 | 1697 |

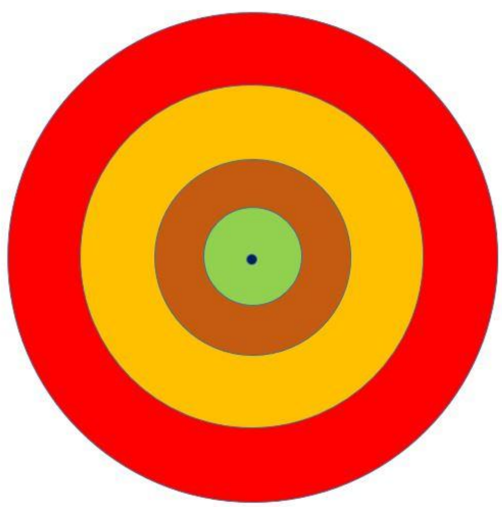


Figure 26: Wind Drift Diagram

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 parachute 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.

# 4. Safety

## 4.1. Launch Concerns and Operation Procedures

The operations for assembly and launch can be found in Section 6.

## 4.2. Safety

### 4.2.1. Safety Officer

The team safety officer has been identified as William Martz. His responsibilities are included in Appendix D: Compliance Matrix, section 4.

### 4.2.2. Personnel Hazard Analysis

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.

Table 6: Launch Hazard Analysis

| Procedure | Concern | Risk | Mitigation | Confidence |
|---|---|---|---|---|
| Launch | 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 our 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 closer than regulations allow will be a simple task by giving warnings prior to launch. | Having set distances specified by launch officials mitigates this concern. 300 ft for an L-class motor |
| | 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: Construction Hazard Analysis

| Procedure | Concern | Risk | Mitigation | Confidence |
|---|---|---|---|---|
| Construction Hazard | Drill Press | Physical harm to extremities. Damage to lungs, eyes, and ears of the user and of others. | 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 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. | 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. | 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. |
| | Manual Mill | 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 | 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. | 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. | 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. |
| | 3D Printer | Burns. Electric shock hazard. | 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. |

| | | | | |
|---|---|---|---|---|
| | Power Supply | Electric shock hazard. | Power supplies are left unplugged when not in use. They are not used near water and cords are inspected for wear and breakage 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. | 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 misplacement of the heat source. Keeping these two risks in check ensures the safety of the equipment operation. |

### 4.2.3. Misfires

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

### 4.2.4. Launch Safety

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

### 4.2.5. 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. Minimum Personnel Distance ft. 300 for L motor type.

### 4.2.6. Certification

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

### 4.2.7. Materials

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

### 4.2.8. Motor

I will use only certified, commercially made rocket motors, and will not tamper with these motors or use them for any purposes except those recommended by the manufacturer. I will not allow smoking, open flames, nor heat sources within 25 feet of these motors.

### 4.2.9. Ignition System

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

### 4.2.10. Size

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

### 4.2.11. 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.

### 4.2.12. Failure Mode Effects and Criticality Analysis

The complete FMECAs for the launch vehicle and payload can be found in Appendix A and B. These appendices have been updated to reflect robustness of design.

## 4.3. Environmental Hazard Analysis

The primary goal of the Environmental Hazard Analysis (EHA) process is the identification of environmentally critical systems. An environmentally critical system is one which poses a reasonable threat to the environment, can result in violation of applicable permits, or can incur substantial monetary expenses as the result of regulatory fines and cleanup costs in the event of a catastrophic failure, system malfunction, and/or losses during standard operations.

The EHA will be addressed in three separate parts below, the NAR requirements and compliance, the effect of the vehicle on the environment, and payload on the environment.

Table 8:Environmental Hazard Analysis Scale

| | |
|---|---|
| 1 | Normal system operation, or system malfunction results in violation of air/water permits, or contamination of soils with an impact greater than one week for cleanup. Regulatory penalties are possible. |
| 2 | Normal system operation, or system malfunction results in violation of air/water permits, or contamination of soils with an impact greater than one day but less than one week for cleanup. No regulatory penalties are involved. |
| 3 | Normal system operation or system malfunction results in no impact to air/water permits and minimal contamination to soils requiring one day or less for cleanup. No regulatory penalties are involved. |

### 4.3.1. NAR High Power Rocket Environmental Safety Code

#### 4.3.1.1. Launcher

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

#### 4.3.1.2. 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.

#### 4.3.1.3. Launch Site

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

#### 4.3.1.4. Launcher Location

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

### 4.3.2. Vehicles Environmental Impact

The rocket has the potential to impact the environment in multiple ways. The most unavoidable impact would be the pollution caused by the combustion products of the motor. This impact cannot be mitigated without entirely scrubbing the launch. Another environmental impact would occur if there was any debris caused by a failed or damaged rocket. If not all collected/recovered after the completion of the launch, any material would become litter. Fire is a possible environmental impact that could occur if either the motor casing (being hot after full burn of the motor) encounters something flammable or if the rocket impacts something while still under power. This risk is being mitigated by choosing a long enough descent and by ensuring that the rocket leaves the launch pad at a velocity high enough to prevent it from going off course. The final possible environmental impact would be any damage caused by collision with the rocket. This risk is being mitigated by using redundant charges for each parachute as well as redundant altimeters to lower the risk of the parachutes not deploying.

Table 9: Launch Vehicle Environmental Hazards

| System | Component | Hazard | Cause | Effect | Recommendation |
|---|---|---|---|---|---|
| Launch Vehicle | Black Powder Charges | 3 | Unscheduled spill | Black powder integrates with the soil | No recommendation - black powder is not regulated unless 1lb or greater |
| | Avionics | 3 | Normal and/or abnormal operation | No effect | No recommendation |
| | Airframe | 2 | Catastrophic Failure of launch vehicle | Fiberglass shards integrate with soil | Retrieve shrapnel to best ability - may take more than one day |
| | Bulkhead and fins | 2 | Failure or bulkhead or fin | Aircraft grade birch plywood integrates with soil | Retrieve shrapnel to best ability - may take more than one day |
| | Shear Pins | 3 | Normal and/or abnormal operation | Shear pins lost into the void | retrieve shear pins if possible |
| | Nosecone | 2 | Catastrophic Failure of launch vehicle | Fiberglass shards integrate with soil | Retrieve shrapnel to best ability - may take more than one day |
| | Parachutes | 3 | Normal and/or abnormal operation | No effect | No recommendation |
| | Motor | 2 | Catastrophic failure of motor | Rapid, unscheduled disassembly of the launch vehicle | Retrieve shrapnel to best ability - may take more than one day |

| System | Component | Hazard | Cause | Effect | Recommendation |
|---|---|---|---|---|---|
| | Rail Buttons | 3 | Normal and/or abnormal operation | No effect | No recommendation |
| | Shock Cord | 3 | Normal and/or abnormal operation | No effect | No recommendation |
| | ARRD | 2 | Catastrophic failure of ARRD | Payload separation failure and payload structural failure | Retrieve shrapnel to best ability - may take more than one day |

### 4.3.3. Payload Environmental Impact

Table 10: Payload Environmental Hazards

| System | Component | Hazard | Cause | Effect | Recommendation |
|---|---|---|---|---|---|
| Payload | Raspberry Pi Camera Module v2 | 3 | Normal and/or abnormal operation | No effect | No recommendation |
| | Raspberry Pi 3 Model B microcontroller | 3 | Normal and/or abnormal operation | No effect | No recommendation |
| | Jolly Logic Chute Release | 3 | Jolly Logic is not tethered properly | The Jolly Logic will separate from the system and become litter | Ensure proper attachment of Jolly Logic Chute Release to parachute cords |

| System | Component | Hazard | Cause | Effect | Recommendation |
| --- | --- | --- | --- | --- | --- |
| | Venom 20C 2S 5000mAh LiPo Battery | 3 | Normal and/or abnormal operation | No effect | No recommendation |
| | Polycarbonate Viewing Surface | 3 | Normal and/or abnormal operation | No effect | No recommendation |
| | ABS Mounting Surface | 3 | Normal and/or abnormal operation | No effect | No recommendation |
| | Electronics Subassembly | 3 | Normal and/or abnormal operation | No effect | No recommendation |
| | Polycarbonate Payload Body | 3 | Normal and/or abnormal operation | No effect | No recommendation |
| | Big Red Bee BRB900 GPS | 2 | GPS Fails to transmit Payload location | Payload becomes unrecoverable debris on launch day | Recover payload after launch day |
| | 80/20 Rail Guide System | 3 | Normal and/or abnormal operation | No effect | No recommendation |
| | Servos | 3 | Normal and/or abnormal operation | No effect | No recommendation |

| System | Component | Hazard | Cause | Effect | Recommendation |
|---|---|---|---|---|---|
| | Aluminum Rods (legs) | 3 | Break before payload reaches touchdown | Rods become debris | Recover broken payload legs |
| | | 3 | Break upon ground impact | | |
| | Cables | 3 | Normal and/or abnormal operation | No effect | No recommendation |

# 5. Payload Criteria

## 5.1. Design of Payload Equipment

### 5.1.1. Payload Deployment System

The best alternative design for the Payload Deployment System was determined to be a design created after submission of the PDR. The design will be explained below, followed by an explanation of why this alternative design is the best choice.

The payload will deploy from the payload bay within the launch vehicle. A black powder charge will separate the payload bay and fin can, which are tethered together. The tether will run along the inner wall of the payload bay, clear of the payload. The launch vehicle drogue chute will be packed forward of the payload in the payload bay, and will deploy upon separation from the fin can after the payload is pulled out.

The payload will be contained within the payload bay on a rail system comprised of two 0.5”-by-1” rails, epoxied to the inner wall of the payload bay. The payload will have four rail buttons, two for each rail spaced approximately 8” away from the other, to greatly decrease the possibility of binding. The rail buttons will have 360° freedom about their fastening hardware but will be tightly secured to the payload body. This will be done by placing a hex nut on both the inner and outer wall of the payload body to the fastening bolt with a locking glue and leaving space between the outer hex nut and the rail button.

An Advance Retention Release Device (ARRD), connecting the payload to the fin can, will pull the payload out of the payload bay. The ARRD can be seen below in Figure 27.


Figure 27: ARRD (Advanced Retention Release Device) [0]

The ARRD is a pyrotechnically actuated recovery device which utilizes a tether-and-release system. A charge contained inside the ARRD (held within the black and red components) will be actuated to separate the chrome subassembly from the ARRD body, which will separate the payload from the fin can. The ARRD body will stay connected to the fin can and the subassembly will be attached to the payload via an internally connected shock cord.

The Payload Deployment System was tested and confirmed to work in the subscale launch. The charge activated to separate the payload bay and fin can succeeded, and the payload was pulled out by the ARRD. However, the payload was not released from the fin can due to an altimeter programming error—the ARRD charge was not activated. Continuity from the altimeter to the ARRD was confirmed. The ARRD was disconnected from the system without disassembling the separating components and tested to verify the ARRD did not fail. A signal was sent to the ARRD and the unit separated. Thus, upon inspecting the altimeter code, it was confirmed to be a coding problem.

A system has been put in place to mitigate the possibility of an altimeter code problem happening in the future. At least two team members will review and confirm the code will produce the desired result, and a functionality test of the altimeter in a vacuum chamber will be performed to verify the team members' confirmation.

This alternative design was determined to be the best because it features a payload-fin can connection that is not separable until the connection undergoes an active, controlled separation. The ARRD will keep the payload connected to the fin can until the internal charge is activated, thus ensuring the payload will be pulled out of the launch vehicle when the payload bay and fin can separate. Prior alternative designs featured a shear pin to connect the payload to the fin can. A variety of problems could be present depending on when the payload deployed if the connection was broken late or not broken at all. The launch vehicle drogue chute may be unable to deploy or the payload chute may deploy inside the payload bay and get caught on the launch vehicle before the payload is a safe proximity away from the launch vehicle (assuming the payload deploys randomly because of the shear pin connection performing unexpectedly).

The connection of the payload to the launch vehicle is aft of the payload (attached to the fin can instead of the payload bay) in this design. This method of attachment is more desirable than a connection forward of the payload because the shock cord connecting the payload bay to the fin can will not be pulled out around the payload after the payload has completed its motion along the rail system (which may be still attached to the payload bay in the event of a malfunction). Rather, the payload will be pulled out with the fin can shock cord. This greatly decreases the length of shock cord that must deploy from the payload bay around any obstruction caused by the payload not deploying. Thus, regardless of whether the payload separates from the fin can, all the shock cord and the launch vehicle drogue chute will deploy.

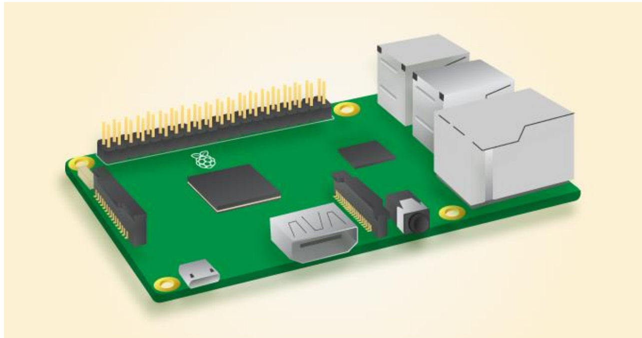
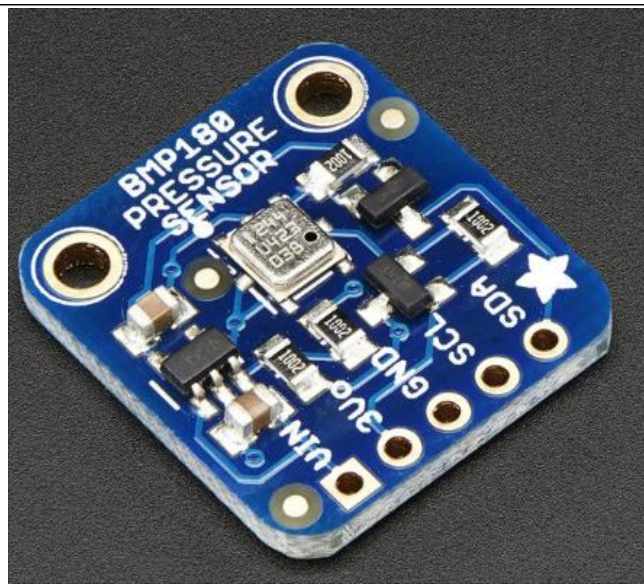
### 5.1.2. Target Differentiation System (TDS)

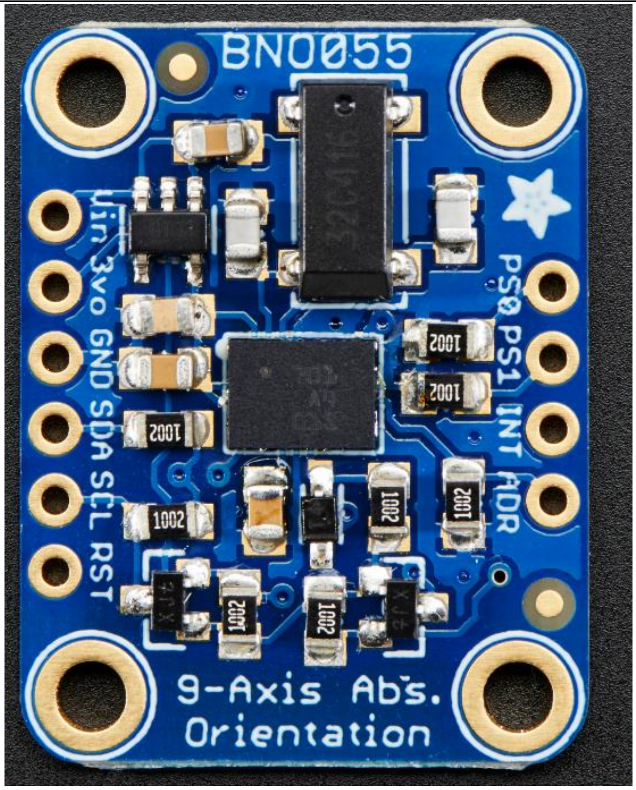
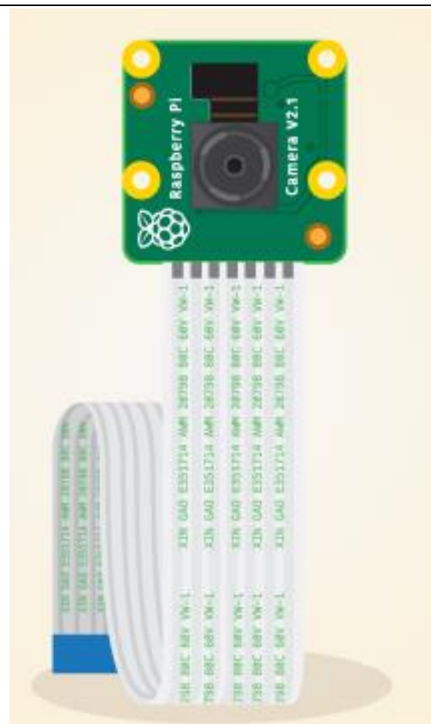
#### 5.1.2.1. TDS Hardware

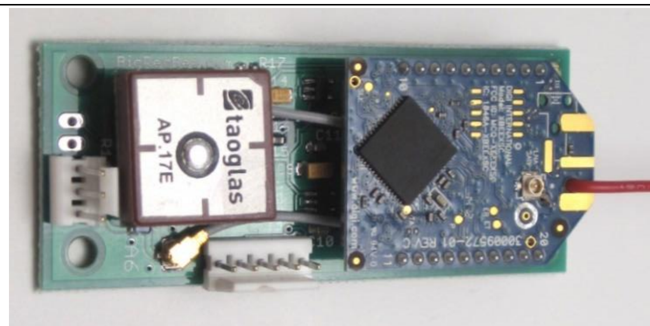
Due to the change in design of the ULS, the best alternate design for the TDS was determined to be a design created after submission of the PDR. The TDS was changed from a redundant, two-unit camera system to a single system between PDR and CDR due to space constraints within the payload and launch vehicle. If the two-unit system was to be used with the current launch vehicle and payload body dimensions the payload would be over 30 inches in height and the launch vehicle would require a motor outside the scope of this project.

The TDS will be a single camera system controlled by a Raspberry Pi 3 Model B microcontroller. The system will include Adafruit BMP180 Sensor, which will function as an altimeter to log telemetry data, the Adafruit BNO055 Absolute Orientation Sensor, a 9-axis Absolute Orientation Sensor used to confirm an upright landing, a Raspberry Pi Camera Module v2, the DROK LM2596 Voltage Regulator, which will step the 7.4V supplied from the battery, the Venom 20C 2S 5000mAh LiPo, down to 5V for all other components in the system. The system will also include the Big Reg Bee BRB900 GPS unit for locating the payload upon landing. The TDS can be seen below at the component level in Table 11.

Table 11:TDS Components

| Description | Image |
|---|---|
| Raspberry Pi 3 Model B |  [1] |
| Adafruit BMP 180 Sensor |  [2] |

| Description | Image |
| --- | --- |
| Adafruit BNO055 Absolute Orientation Sensor |   [3] |
| Raspberry Pi Camera Module 2 |   [4] |

| Description | Image |
|---|---|
| DROK LM2596 Voltage Regulator |  [5] |
| Venom 20C 2S 5000mAh LiPo Battery |   [6] |
| Big Red Bee BRB900 |   [7] |

All the components listed above will be secured to the electronics sled in the payload body except the BRB900 and Pi Camera Module. The BRB900 will be secured to the ID of the payload body to accommodate the antenna length. The Pi Camera Module will be secured to the aft face of the payload for image capturing.

#### 5.1.2.2. TDS Software

Once the images are captured using the Raspberry Pi Camera System, they are stored in a folder on the on-board memory card. They will be analyzed using a computer vision function written in Python using the open-source libraries NumPy and OpenCV. After the images are analyzed, they are stored in a new folder. The function currently uses the three RGB values given by NASA to create a mask of the image, which will then be used to identify the largest region of each specific color. For reference, the targets have been numbered using the same convention given by NASA. The convention is as follows:

Target 1 – RGB = 0, 32, 91 Pantone = 281C (Blue)

Target 2 – RGB = 255, 209, 0 Pantone = 109C (Yellow)
Target 3 – RGB = 166, 9, 61 Pantone = 1945C (Red)

After the largest region of each tarp color is identified, the program will overlay a rectangle of the same color targeted which binds the region. Above the rectangle, text will be inserted that portrays the number and color of the target identified, e.g. "Target 2 – Yellow."

Since the tarp samples provided by NASA were received within a week of CDR, outdoor testing with the actual samples has not been conducted yet. However, image simulations of three 40'x40' tarps at various altitudes within a 300ft radius at a field near the MSFC launch site were created and analyzed (GoogleEarth). The results are shown below.

Figure 28: Original Simulation Image (Altitude: 2500ft)


Figure 29:Image After Python Function

### 5.1.3. Body Material

The payload body material is changing from aluminum 6061-T6 to clear polycarbonate/Lexan. This change is being made due to complications during the subscale build of minimal visibility of the inside of the payload body during assembly and of the payload internals once the payload was assembled. It is desirable to make the internals visible from the payload exterior to witness feedback from the TDS from LEDs and/or switches, to observe the effects of any drop or shake test on the payload internals before disassembly, and to observe the ULS components as it uprights the payload during tests.

There will be a decrease in the payload body weight by switching to polycarbonate/Lexan because it is less dense than aluminum 6061-T6. The average yield strength of polycarbonate is 8120 psi [8]. The lower yield strength (when compared to aluminum 6061-T6) is anticipated to be negligible because both yield strengths are far outside the scope of this project. In the subscale payload, the flange was welded to the payload body because both were aluminum 6061-T6. The flange will be epoxied to the payload body in the full-scale.

### 5.2. System Level Design

A rendering of the full assembly in SolidWorks can be seen below in Figure 30.

Figure 30: Payload assembly

This rendering includes every component that will be in the payload except for the ARRD shock cord, rail button hardware, all wiring, and parachute components. The parachute is modeled as a tube to give a sense of the space it will require in the payload and launch vehicle based on the subscale payload. Aside from the rail buttons and ARRD shock cord, the parachute is the only component of the payload that will be exposed on all sides.

The payload will weigh approximately 4.70 lb, has an OD of 4.25”, and will be approximately 23.5” long.

The components of the payload will now be listed, specifications described, and the interactions with other components in the payload discussed.

### 5.2.1. Body

The payload body will protect the internal components of the payload. It will be made of clear polycarbonate to provide visibility of payload internals. A drawing of the payload body can be seen below in Figure 31.

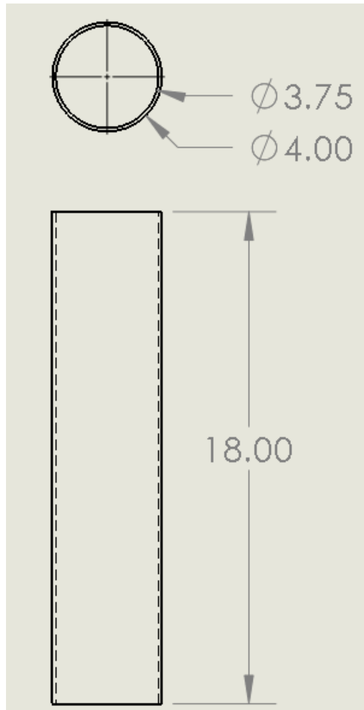



Figure 31:Payload Body Drawing

The body will be attached to the internals via the flange, which connects to the retainer, and the bulkhead tabs, which hold the bulkhead in place.

### 5.2.2. Flange

The flange will be epoxied to the aft face of the payload body and connect to the retainer body with fastening hardware. A drawing of the flange is shown below in Figure 32.

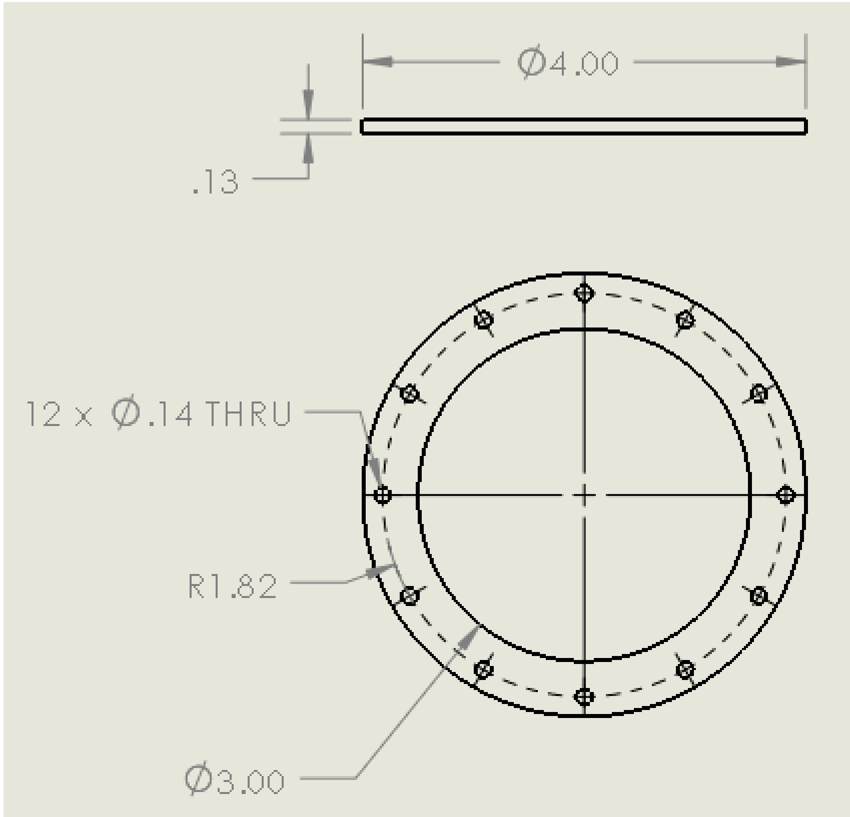



Figure 32: Flange Drawing

The flange will be cut with a waterjet from an aluminum 6061-T6 sheet. The purpose of the flange is to provide fastening hardware holes for the body-retainer connection.

### 5.2.3. Retainer Body

The Apogee Components AeroPack 75mm Retainer Body will connect to the flange via the fastening hardware provided with the part. A drawing of the retainer body is shown below in Figure 33.

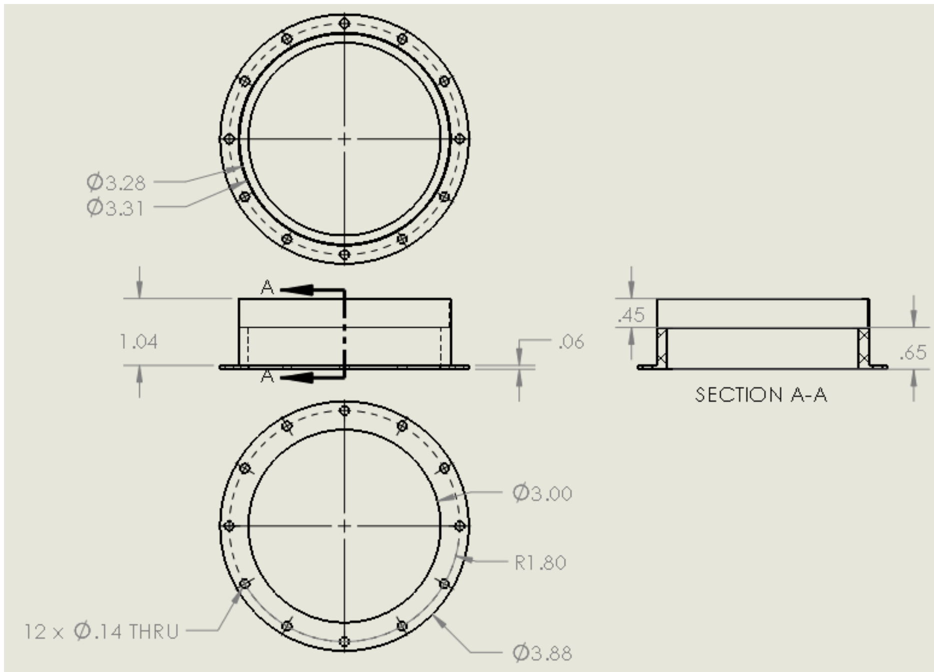



Figure 33: Retainer Body Drawing

A picture of the Apogee Components AeroPack 75mm Retainer Body can be seen below in Figure 34.

Figure 34:Apogee Components AeroPack 75mm Retainer Body

The retainer body's purpose is to contain the mounting surface and viewing surface when paired with the retainer cap. The retainer body and cap also provide access to the payload internals from the aft face of the payload.

### 5.2.4. Retainer Cap

The Apogee Components AeroPack 75mm Retainer Cap will screw onto the retainer body and provide aft access to the payload internals. A drawing of the retainer cap is shown below in Figure 35.

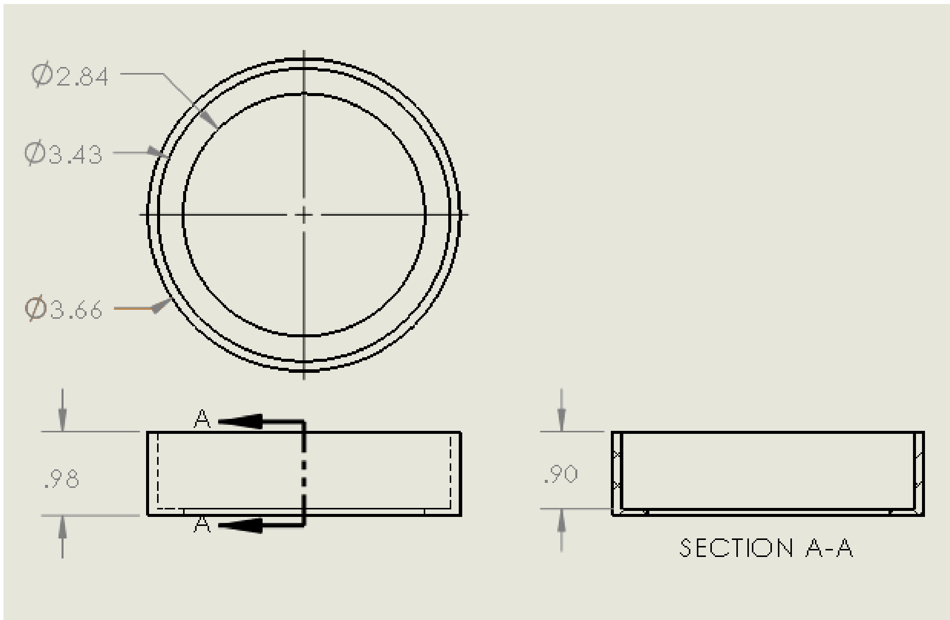



Figure 35: Retainer Cap Drawing

A picture of the Apogee Components AeroPack 75mm Retainer Cap can be seen below in Figure 36.

Figure 36:Apogee Components AeroPack 75mm Retainer Cap

Aft access to the internals will be especially useful when assembling the camera subassembly and mounting surface. The retainer cap will house the viewing surface and hold the mounting surface in place when connected to the retainer body. The retainer cap restricts the payload internals' ability to translate in the aft direction.

### 5.2.5. Viewing Surface

The viewing surface is a 0.125" thick polycarbonate sheet laser cut to a circle with a cutout for the shock cord connecting the ARRD Connector to the ARRD. A drawing of the viewing surface can be seen below in Figure 37.

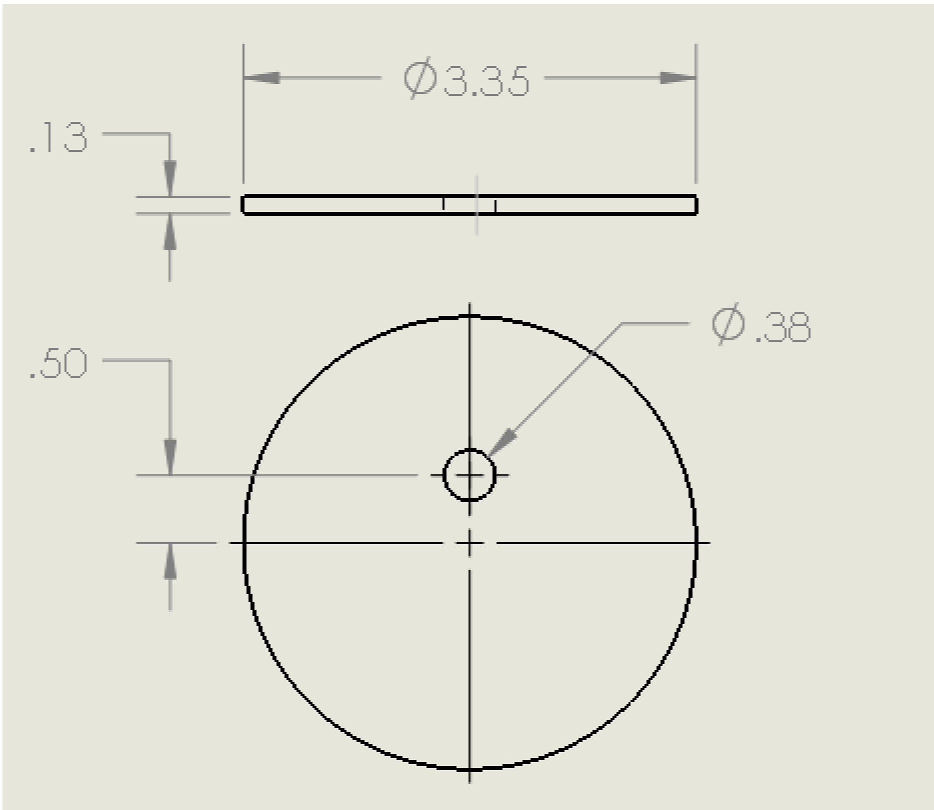



Figure 37: Viewing Surface Drawing

Its purpose is to protect the camera and payload internals while not obstructing the camera's image capturing capability. The viewing surface will be held within between retainer cap and mounting surface in the assembly.

### 5.2.6. Mounting Surface

The mounting surface is a custom-designed, 3D printed ABS plastic component used to mount the camera subassembly and orient it with respect to the electronics subassembly. Figure 38 below, shows a drawing of the mounting surface.

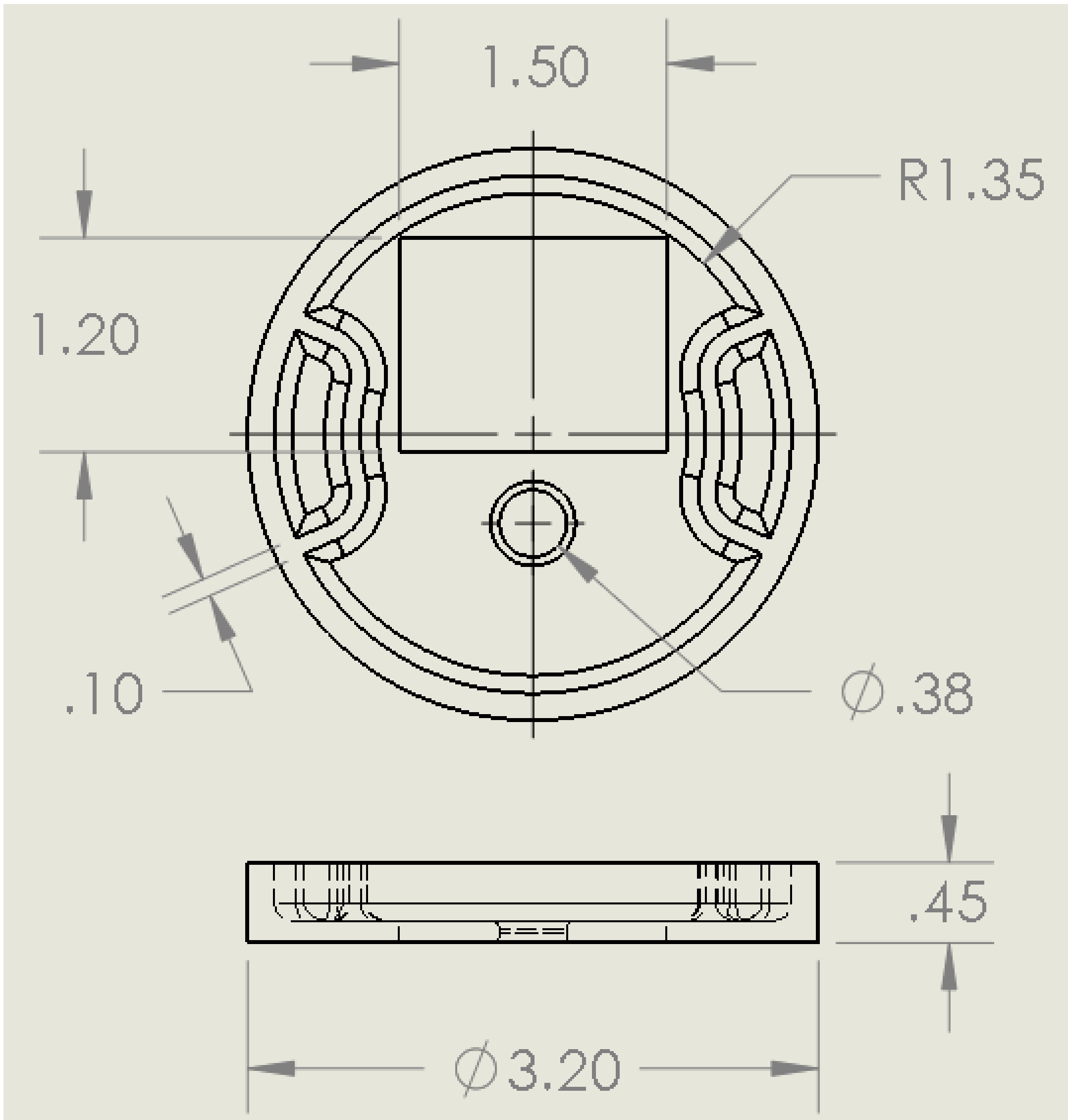



Figure 38:Mounting Surface Drawing

The ribbon cable running from the Raspberry Pi to the Camera Module may become disconnected if it experiences any forces during flight. The mounting surface greatly reduces the possibility of uncontrolled motion of the payload internals by securing the electronics rods' orientation within a 30° channel. The cutouts in the mounting surface are for the camera subassembly (rectangular cutout) and the ARRD shock cord (circular cutout). An isometric image and further discussion of the mounting surface can be found in §V.i.c.i.

### 5.2.7. Camera Subassembly

The camera subassembly consists of the Raspberry Pi Camera Module v2 and the camera mount. The camera is connected to the mount to provide protection for the rear face of the camera. The camera subassembly can be seen below in Figure 39.


Figure 39:Camera Subassembly

The camera is assembled to the camera mount via fastening hardware provided with the Camera Module and will drop into its designated cutout in the mounting surface after assembly. The camera subassembly will be secured in the mounting surface cutout with electrical tape to assist in keeping the ribbon cable connection unharmed during assembly and flight.

### 5.2.8. ARRD Connector

The mounting surface is a custom-designed, 3D printed ABS plastic component created to be an anchor for one side of the ARRD shock cord. It has two holes for the electronics rods and one for the ARRD shock cord. The ARRD connector can be see below in Figure 40.

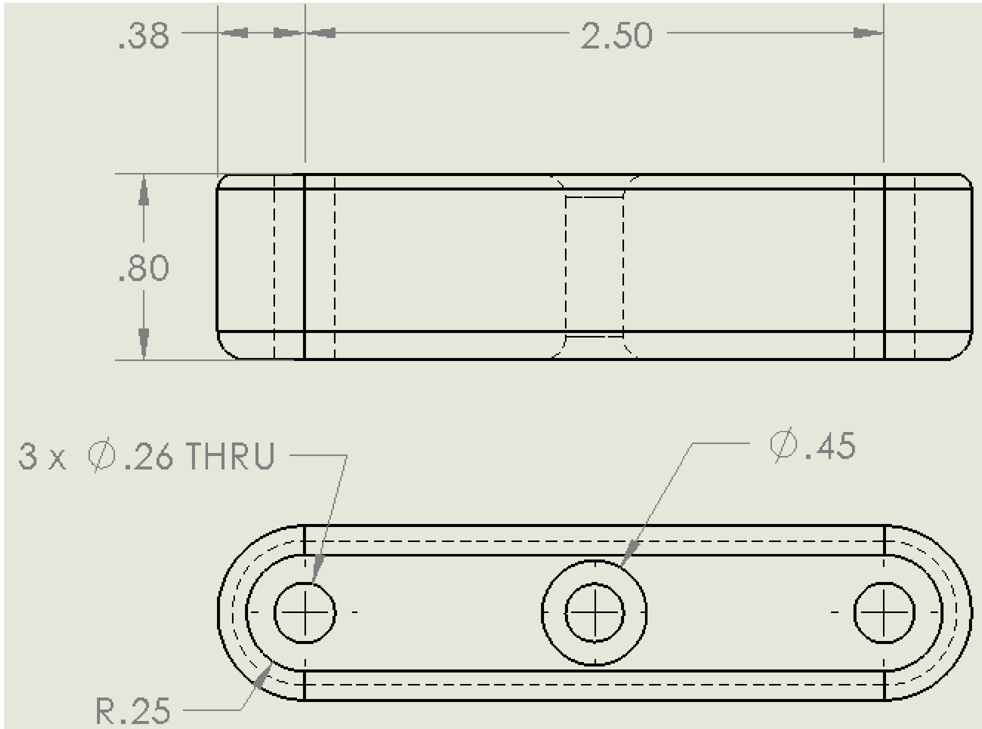



Figure 40: ARRD Connector Drawing

The ARRD connector will be secured on the electronics rods with hex nuts on each side. The ARRD shock cord will be securely wrapped around the connector. This method was tested during the subscale launch and was still intact upon landing of the fin can-payload system.

### 5.2.9. Upright Orientation System

The final design of the ULS is an active system that automatically uprights the payload upon ground impact. The original design was abandoned due to the difficulty of manufacturing, dimension restraints within the payload and general desire for alternative design. This design was chosen because of its robustness in achieving the upright landing objective set forth by NASA.

The final design uses a high-torque continuous-rotation servo as a winch system to retract cables that are attached to four legs. Once the Raspberry Pi system detects ground impact (based on altitude and orientation), the servo will rotate a spool in order to retract the leg cables. The cables are fed through the payload walls and attach to a sliding mechanism (ULS Leg Sliding Tabs) on the outside of each leg that will allow the linear motion of the cables being retracted to translate to the legs rotating to their final deployed position. The ULS Leg Sliding Tabs hold the legs in their upright (flight) position using appropriately sized Velcro. When the servo begins rotating, the Velcro is sheared apart from the Sliding Tabs so the legs will rotate to their deployed position. This will bring the payload to the same orientation it began with inside the rocket body on the launch pad. The four legs are semi-circular in shape and rest on the outer diameter of the payload.

The single servo is powered by an independent 6V NiMH battery and controlled by the Raspberry Pi. The battery will be attached to the bottom of the servo. This unit will have a dedicated 3D printed sled that will secure the servo and battery in the bottom portion of the payload using nuts and the electronics rods. Figure 41 and Table 12 below show the leg assembly and components.

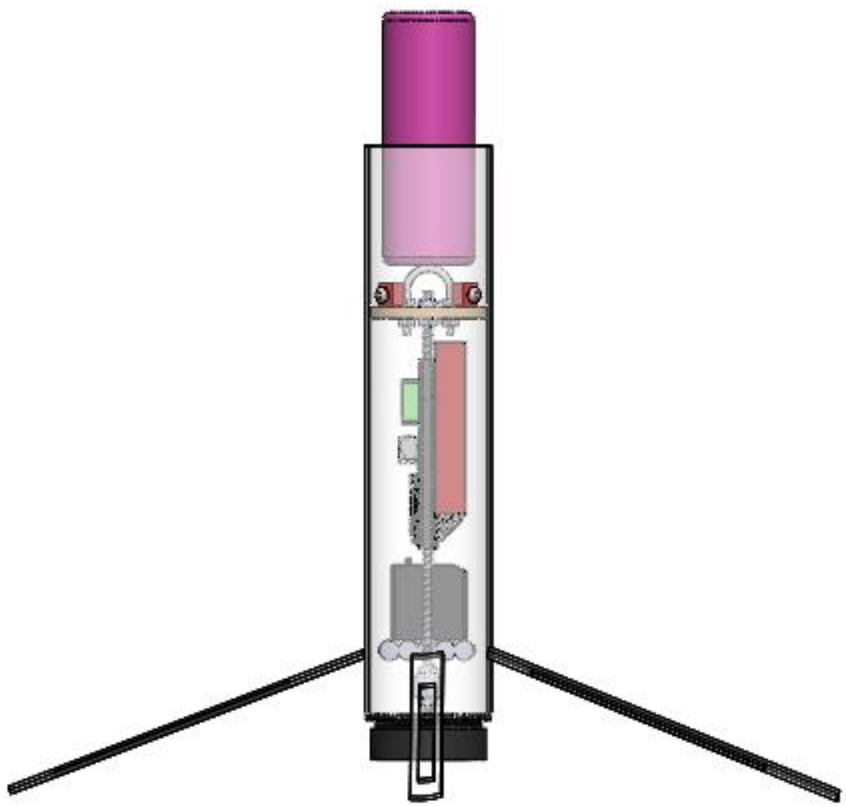


Figure 41: ULS Assembly

Table 12: ULS Hardware

| Description | Image |
| --- | --- |
| **SpringRCSM-S8166R Continuous Rotation Servo (pictured without Spool Attachment)** |  |
| **Tenergy6V 2000mAh NiMH Battery Pack** |  |

| Description | Image |
|---|---|
| **Red 200lb Synthetic Model Winch Line** |  |

### 5.2.10. Electronic Rods

The electronics rods are 14" long ¼"-20 aluminum rods used to align and secure the electronics subassembly, ARRD connector, and mounting surface. An image of the rods can be seen below in Figure 42.

Figure 42: Electronics Rods

The electronics rods will be secured on the bulkhead with hex nuts on the forward side and by the mounting surface on the aft side.

### 5.2.11. Electronic Subassembly

The electronics subassembly is comprised of the electronics sled, devices on the sled, and battery platform. The electronics subassembly will be positioned on the electronics rods 1" aft of the payload bulkhead and 3.5" forward of the ARRD connector. It is secured along the electronics rods by four hex nuts. A solid model of the electronics subassembly is shown below in Figure 43.

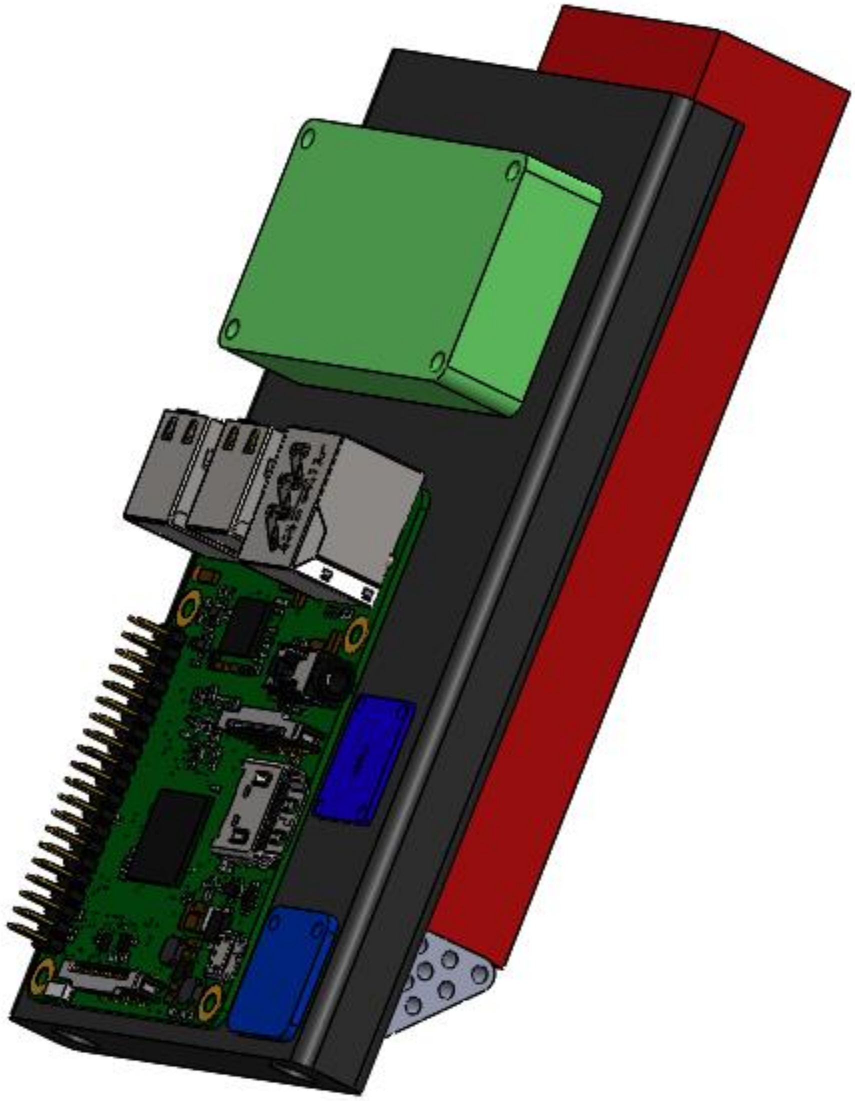


Figure 43: Electronics Subassembly

The Raspberry Pi is shown on the front face. The model was found on the GrabCAD solid model database, modeled by “trinityscsp” [9]. The Adafruit BMP180 is the aft blue device to the right of the Raspberry Pi, and the BNO055 is forward of the BMP180. The DROK LM2596 is forward of the Raspberry Pi. The Venom Battery is the red item on the rear face of the electronics sled and the battery platform is directly aft of it. The models show the space encompassed by each component without cables or connectors. The battery platform will be printed separately from the electronics sled and bonded to the sled with acetone. The specifications of the battery platform can be seen below in Figure 44.

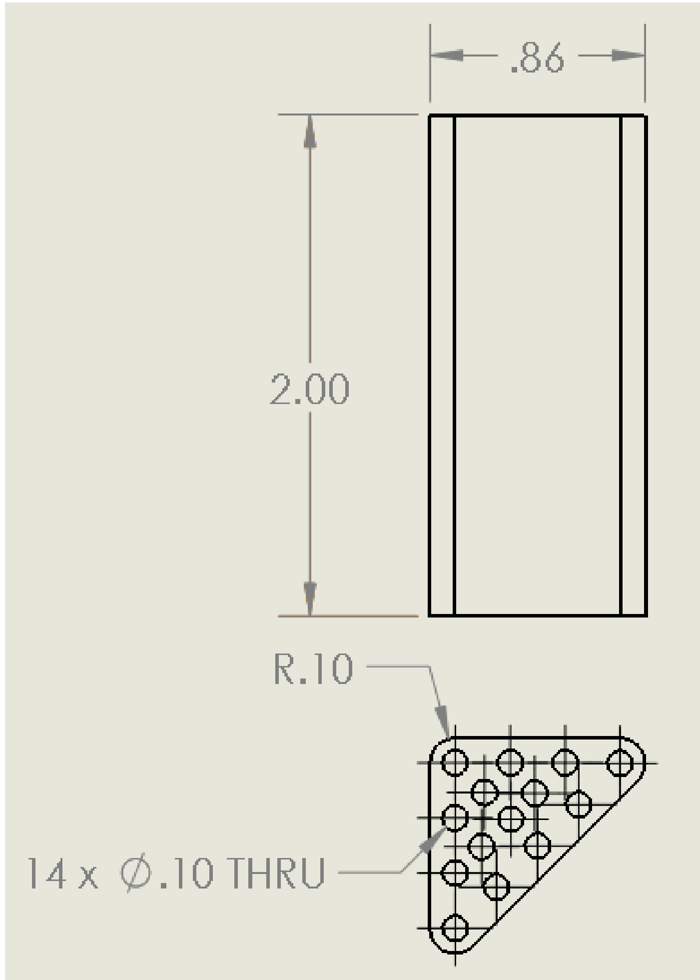



Figure 44: Battery Platform Drawing

The cutouts featured throughout the battery platform have been incorporated to decrease material usage and reduce print time.

### 5.2.12. Rail Buttons

Four Apogee Components Standard Airfoiled Rail Buttons will attach the payload to the rails of the Payload Deployment System in the payload bay. Two views of the rail buttons can be seen below in Figure 45.

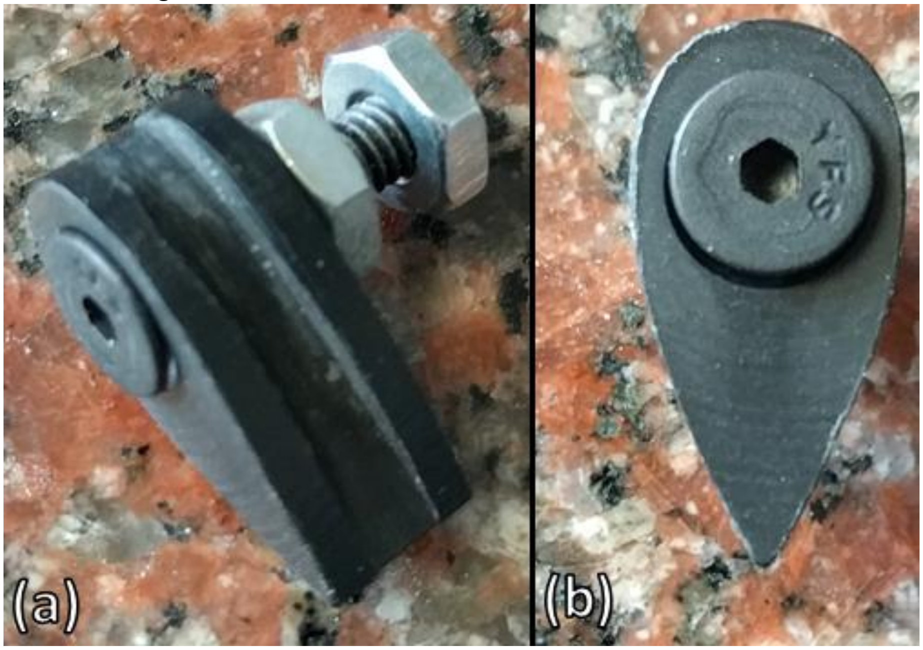



Figure 45: Rail Button

Figure 45(a) shows the hardware that will be used to secure the rail buttons to the payload body. A locking glue will be used on the hex nuts and fastening hardware (8-32 x 3/4" socket flat screws) while allowing the rail button to remain free to rotate. Figure 45(b) shows the airfoiled profile of the rail buttons.

### 5.2.13. Payload Bulkhead

The payload bulkhead is a 3/8" thick bulkhead comprised of three 1/8" birch plywood bulkheads epoxied together. The payload bulkhead specifications are shown below in Figure 46.

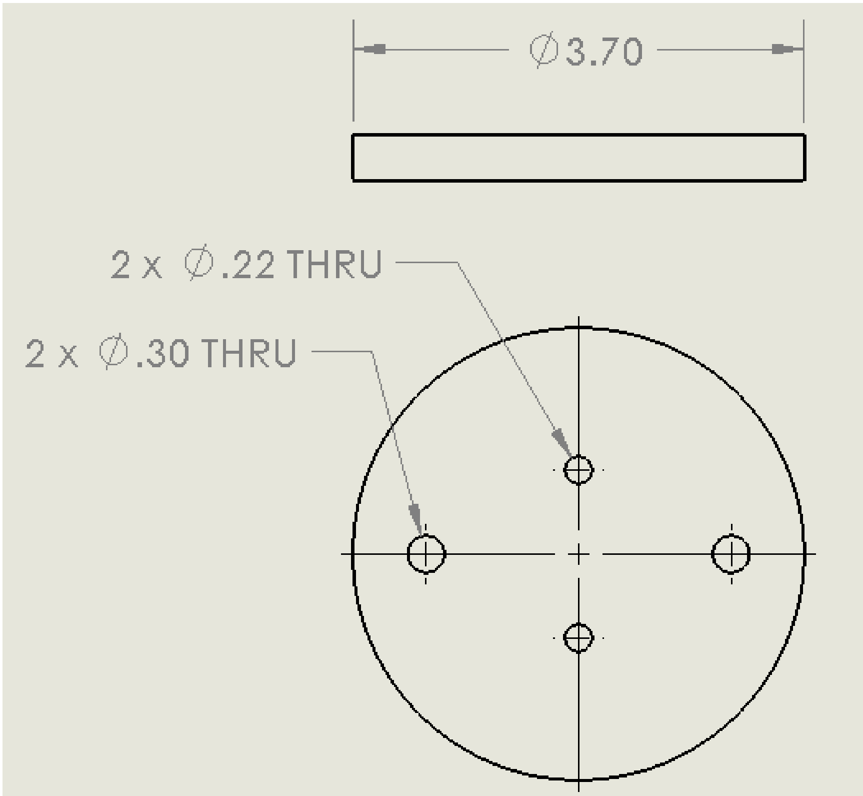



Figure 46:Payload Bulkhead Drawing

The 0.30" diameter holes in the payload bulkhead are for the electronics rods, while the 0.22" diameter holes are designated for the U-bolt. The 0.05" difference between the bulkhead diameter and the payload body inner diameter has been incorporated as a result of payload assembly during the subscale test.

### 5.2.14. U-Bolt

A standard U-bolt will be used to connect the parachute recovery system to the payload. The U-bolt to be used in the payload is shown below in Figure 47.

Figure 47:U-Bolt

The payload bulkhead will be between the U-bolt washers and will have a hex nut on both sides. After the electronics rods and U-bolt have been attached to the bulkhead and the electronics subassembly has been assembled on the rods, the U-bolt will provide a "handle" to place the payload internals into the payload body for completing the assembly.

### 5.2.15. Bulkhead Tab

The bulkhead tabs are custom-designed, 3D printed ABS plastic component used to restrict the forward motion of the payload internals after assembly. The bulkhead tab can be seen below in Figure 48.

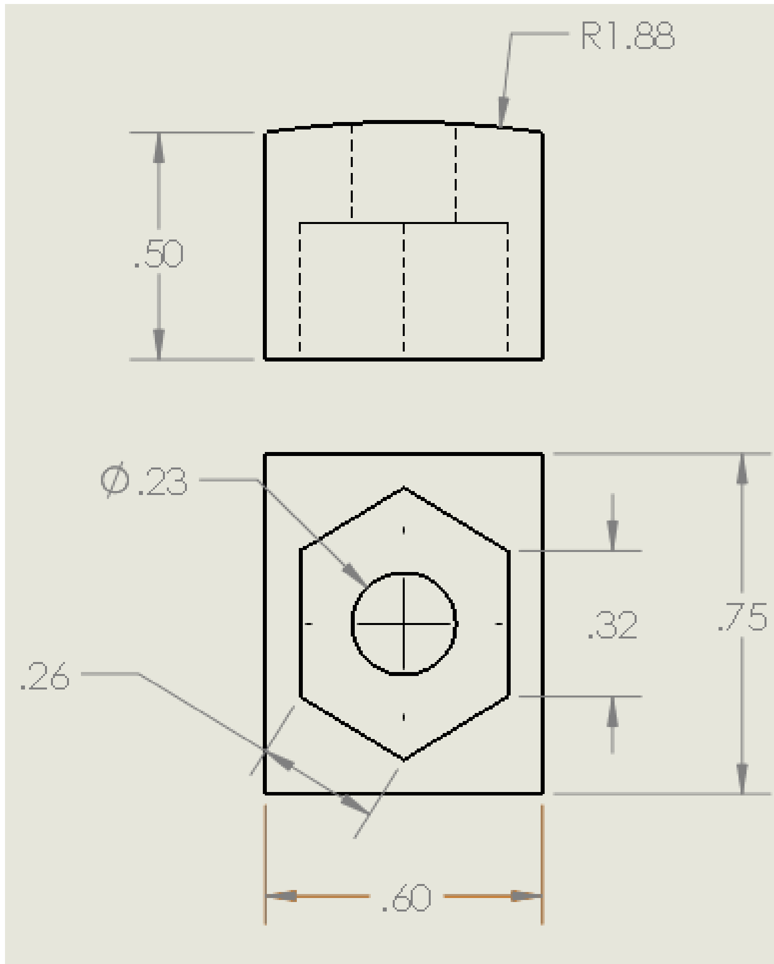



Figure 48:Bulkhead Tab Drawing

The bulkhead tab features a cutout for a ¼"-20 hex nut on one face and a radius to match the payload body inner diameter on the face opposite. A through-hole for the fastening hardware is also seen on the front face. Four bulkhead tabs will be used in the payload, each separated 90° from the next. Bulkhead tabs were used in the subscale launch and were confirmed to have functioned correctly.

### 5.2.16. Recovery System

To slow the payloads descent and to allow the TDS enough time to identify targets a 48in Iris Ultra Compact Parachute was selected. The parachute will be deployed using the Jolly Logic Parachute Release. It will be purchased from Fruity Chutes and the specifications can be seen below in Table 13.

Table 13:Payload Parachute Characteristics

| | |
|---|---|
| **Type** | Iris Ultra Compact Toroidal |
| **Size** | 48in |
| **$C_d$** | 2.2 |
| **Parachute Material** | 1.1oz Rip-Stop Nylon |
| **Line Material** | 400lb Spectra |
| **Swivel Rating** | None |
| **Weight** | 4.3oz |
| **Packing Volume** | 26in$^3$ |

The subscale flight used the same recovery system that will be featured in the full scale. The Jolly Logic Release is a self-contained system that uses a rubber band surrounding the rolled parachuted and can be programmed to release in increments of 100ft. Both the parachute and Jolly Logic can be seen below in Figures 49 and 50.

Figure 49: Payload 48in Diameter Parachute

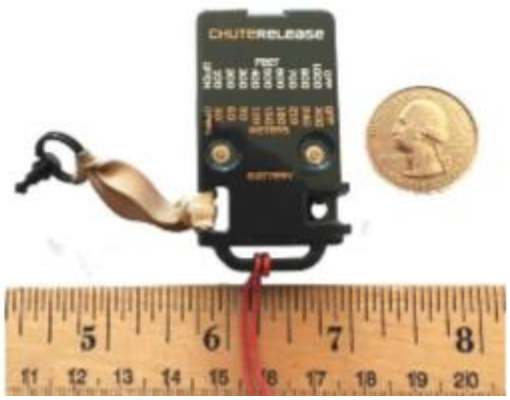


Figure 50: Jolly Logic Parachute Release

The Jolly Logic uses a small tether to attach to a parachute line and the parachute will be attached to the U-bolt on top of the bulkhead of the payload via a ¼” steel quick link.

### 5.2.17. Hardware

All components along the electronics rods except the mounting surface will be secured between ¼”-20 hex nuts on both rods. The hex nuts will assist in retaining the components’ position within the payload during assembly and flight.

## 5.3. Changes Made from Subscale

The subscale mounting surface (MS) had two cutouts for the electronics rods to drop into for the payload internals to remain in the correct orientation. It was found upon assembling the subscale payload that the electronics rods did not remain in a perfectly straight orientation down the system, thus making it impossible to connect the rods to their cutouts in the MS. This issue has been fixed by creating 30° channels instead of circular cutouts in the MS for the rods. Both MSs can be seen below in Figure 51.

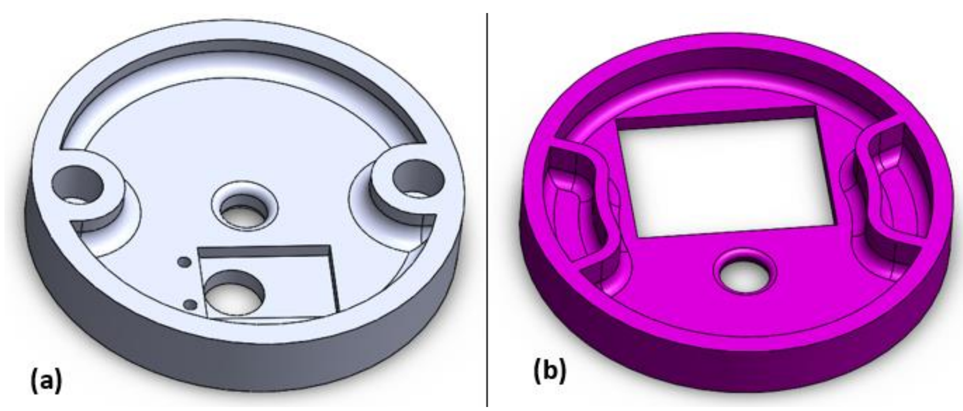


Figure 51: Subscale (a) and Full-Scale (b) Mounting Surface

Regardless of whether the rods become misaligned in the payload (w.r.t. the forward and aft connections), the chance they will fit in the channels in the full-scale MS is greater than the subscale MS. The 30° channels will allow for the misalignment of either or both rods in either radial direction. Once attached to the electronics rods, the MS will be fully inserted into the retainer body. The viewing surface will be inserted into the retainer cap and screwed on to the retainer body, thus locking the MS in place.

## 5.4. Team Derived Functional Requirements

The team derived requirements for the payload functional performance can be found in §7.2.2.

## 5.5. Payload Electronics

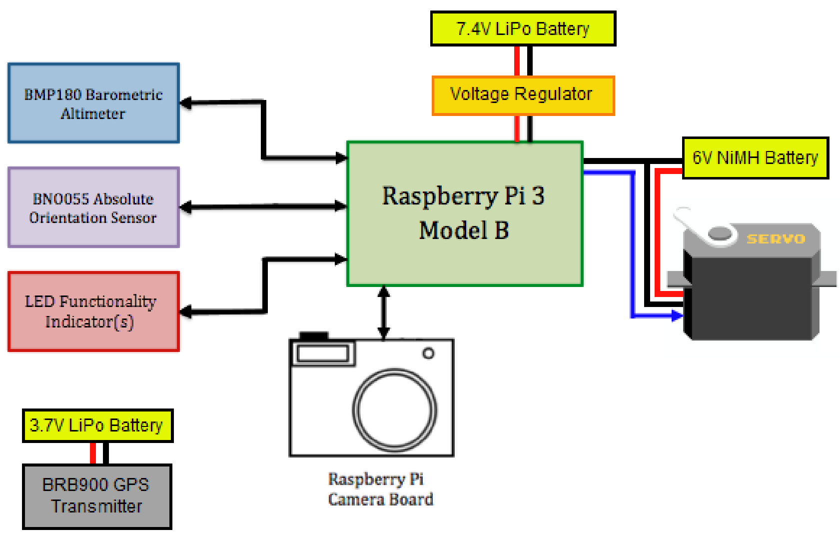



Figure 52: Payload Electronics Block Diagram

a. All payload electronics in the block diagram above, Figure 52, have been discussed in §5.1.2.1, TDS Hardware and §5.2.9, Upright Orientation System.

b. A 7.4V LiPo Battery supplies power to the Raspberry Pi, payload sensors and LED indicators at 5V with the assistance of a voltage regulator. This battery was chosen due to its appropriate capacity, sizing, and previous team success. The BRB900 GPS transmitter comes with a rechargeable 3.7V LiPo battery. This GPS unit was chosen due to its ease of use, independent battery configuration and previous team success using it. The ULS uses a 6V NiMH battery to supply power to the servo. This battery was chosen because the servo can handle a maximum voltage of 6V and the size dimensions of the battery allow it to fit in between the electronics rods. An independent battery was chosen to power this servo due to the servo's power consumption and criticality of its proper operation. All batteries will be charged properly before launches.

c. There are no switches for the payload electronics. The payload electronics were designed to be plugged into their batteries and assembled into the payload body in less than five minutes. The small amount of power consumed by the payload electronics while on standby with battery power does not necessitate having one or more switches on the outside of the payload body to avoid potential loss of battery power. In addition, the only sources of potential hazard come from bad connections between electronics. Extreme caution will be taken to ensure the electrical connections are properly made during payload assembly.

d. LED indicators will be attached to the Raspberry Pi to show functionality before payload assembly. The altimeter and orientation sensors will have one dedicated LED, and the servo system will have another. Each LED will light up for five seconds to indicate its system is functioning properly.

# 6. Launch Operations Procedures

## 6.1. Preliminary Procedure and Checklist

### 6.1.1. PBR Assembly

1. Retrieve the following:
   a. PBR Body (if not assembled)
      i. Payload body (flange should be connected)
      ii. Retainer cap
      iii. Retainer body
      iv. Retainer hardware (twelve screws)
      v. Viewing surface
      vi. Mounting surface
      vii. Raspberry Pi Camera Module v2
      viii. Camera Mount and mounting hardware
      ix. Rail buttons
      x. Four 8-32 x ¾” socket flat screws
      xi. Eight 8-32 x ¾” hex nuts
      xii. U-bolt
      xiii. Four U-bolt washers
      xiv. Four U-bolt hex nuts
   b. PBR Internals (if not assembled)
      i. Two  electronics rods
      ii. Electronics Sled (battery platform should be connected)
      iii. Bulkhead
      iv. Raspberry Pi Microcontroller

v. Voltage Regulator
vi. BNO055
vii. BMP180
viii. Venom 20C 2S Battery
ix. Raspberry Pi Camera Module v2 ribbon cable
x. ARRD Connector
xi. ARRD Shock Cord
xii. Twelve ¼" x 20 hex nuts
xiii. Wires for electronics subassembly
xiv. Hardware for electronics subassembly

c. Bulkhead Tabs (if not assembled)
   i. Four bulkhead tabs
   ii. Four ¼" x 20 0.75" long screws
   iii. Four ¼" x 20 hex nuts
d. Parachute Recovery System
   i. Parachute
   ii. Jolly Logic
   iii. Quick link
   iv. Kevlar sheet
e. Big Red Bee BRB900
f. ULS (if not assembled to PBR already)
   i. Four ULS leg hinges
   ii. Four ULS legs
   iii. Four synthetic model winch lines
   iv. Spring RC Servo
   v. Tenergy Battery

2. Remove any restrictive device that may be holding the ULS to the PBR body.
   CAUTION: the ULS may attempt to deploy (or the legs may detach entirely if not connected to the servo subassembly). Be wary when removing any restrictive devices and allow the legs to deploy/detach carefully for the time being.
3. Ensure the rail buttons are connected to the PBR body.
4. Connect the retainer body to the PBR body with the fastening hardware that came with the retainer.
5. Connect the electronics rods into the bulkhead and secure it on both sides of each rod with hex nuts.
6. Connect the U-bolt onto the bulkhead and secure it by placing a washer and hex nut on both sides of each post.
7. Assembly the electronics subassembly and wire it, but do not connect the battery to the Raspberry Pi.
8. Connect the ribbon cable to the Raspberry Pi (it is not connected to the camera now).
9. Secure any free wires to the electronics sled with electrical tape (the battery and Raspberry Pi are still unconnected).

10. Screw two hex nuts onto the electronics rods.
11. Connect ground wire of servo to its 6V NiMH battery as well as a ground pin on the Raspberry Pi.
12. Connect servo power (red) wire to battery and servo signal wire to Raspberry Pi GPIO pin.
13. Attach four ULS cables to the servo spool.
14. Slide servo into its 3D printed sled and secure it to the electronics rods using two hex nuts.
15. Slide the electronics subassembly onto the electronics rods and secure it with a hex nut on each rod.
16. Screw two hex nuts onto the electronics rods.
17. Attach the ARRD shock cord to the ARRD connector.
18. Secure the BRB900 to the electronics subassembly.
19. Connect the Raspberry Pi to the battery.
20. Slide the ARRD connector onto the electronics rods and secure it with a hex nut on each rod.

NOTE: The payload internals have now been assembled.

21. Put the viewing surface into the retainer cap.
22. Connect the mounting surface and the camera subassembly.
23. Secure the camera subassembly with electrical tape.
24. Slide the payload internals into the payload body.
25. Push the ARRD shock cord through its cutout in the mounting surface and viewing surface.
26. Connect the camera subassembly to the ribbon cable.
27. Secure the mounting surface onto the electronics rods.
28. Screw the retainer cap (with viewing surface) onto the retainer body (which has the mounting surface on it).
29. Wrap the parachute.
30. Connect the parachute and Kevlar sheet to the quick link.
31. Wrap the Kevlar sheet around the parachute.
32. Connect the quick link to the U-bolt.
33. Attach the ULS Legs to the payload body at the designated location using hinges.
34. Insert the ULS Slider Tabs into the ULS Leg Slide Channel.
35. Making sure the Slider Tabs are at the highest position (furthest forward) within the ULS Leg Slide Channel, attach the Slider Tabs to the outside of the payload body using one square inch of Velcro.
36. Feed the four ULS cables through the walls of the payload (one for each 90 degrees around circumference of payload) and attach them to ULS Slider Tabs.

NOTE: The PBR is now assembled.

### 6.1.2. Avionics

1. Retrieve the following:
    a. Avionics airframe

   b. Avionics sled with altimeters
   c. Battery sled and two 9V batteries & 4 zip ties
   d. Small flathead screwdriver
   e. Ten ¼ x 20 nuts
   f. Removable bulkhead
   g. Two e-matches
   h. Painters tape
   i. Wire cutters/strippers
2. Begin with the removable bulkhead – this bulkhead will separate the payload airframe and the avionics airframe. It will be referred to as the aft bulkhead.
3. Thread an e-match through the drilled holes in the blast caps – the blast caps are attached to the forward bulkhead of the avionics airframe
4. Tape the e-match wire to the outside of the blast cap, ensuring the drilled hole is covered
5. Using wire cutters, cut the e-match wires to the appropriate length
6. Strip the wires and attach them to the terminal blocks
7. Empty contents of the primary main black powder charge into the primary blast cap and cover with painter's tape - Primary is denoted as blackened speaker wire
   a. If there is excess room between the black powder and where the rim of the blast cap, pack small amounts of tissue paper before taping
8. Empty contents of the secondary main black powder charge into the secondary blast cap and cover with painter's tape - Secondary is denoted as unmarked speaker wire
   a. If there is excess room between the black powder and where the rim of the blast cap, pack small amounts of tissue paper before taping
9. Set aft bulkhead aside
10. Ensure rotary switches on the surface of the avionics airframe are in the OFF (0) position
11. Attach 9V batteries to the 9V direct output lines
12. Zip tie each battery onto the sled in the appropriate position, ensuring no wires are under the zip ties
13. Connect the speaker wire protruding from the forward bulkhead to Main StratoLogger terminal blocks - use the speaker wire with the blackened ends
14. Connect the speaker wire protruding from the forward bulkhead to the Entacore terminal blocks - use the speaker wire with the unmarked ends.
15. Connect the speaker wire protruding from the aft end of the aft bulkhead to the Drogue StratoLogger terminal blocks – use the speaker wire with the blackened ends
16. Connect the speaker wire protruding from the aft end of the aft bulkhead to the Drogue Entacore terminal blocks – use the speaker wire with the unmarked ends.
17. Use ¼ x 20 nuts to set the stop for the altimeter sled
18. Slide altimeter sled and battery sled down the two threaded rods of the avionics airframe
   a. Use ¼ x 20 nuts to separate the two sleds

19. Use ¼ x 20 nuts to secure the avionics and battery sleds
20. Connect the "Switch" wires from each altimeter to each rotary switch – red to red and nothing to nothing
21. Use one ¼ x 20 nut per rail as the backstop for the aft bulkhead. Make sure they are screwed below the blue line
22. Slide the aft bulkhead down the alignment rods so that the blue line is just aft of the bulkhead
23. Secure bulkhead with two ¼ x 20 nuts.

### 6.1.3. Nosecone

1.Retrieve the following:

- b. Nosecone airframe
- c. Avionics airframe
- d. Main parachute **[80 inches]**
- e. Four quick links
- f. One swivel
- g. One Kevlar sheet **[LARGE]**
- h. Main shock cord
- i. Rubber bands
- j. Four shear pins
- k. Painters tape
- l. Two e-matches
- m. Small flathead screw driver
- n. Wire cutters/strippers
- o. Black powder for main chute **[2.0 grams]** and **[2.1 grams]**
- p. Tissue paper

2. Using one quick link, attach the portion of the shock cord labeled NOSE to the U-bolt located in the nose cone.
3. Fold the shock cord in a zig-zag pattern and pack it into the forward section of the nosecone – using rubber bands if necessary
4. Using one quick link attach the open loop in the middle of the shock cord to the swivel.
5. Using a second quick link, attach the open end of the swivel to a quick link at the end of the parachute
6. Attach the large Kevlar sheet to the quick link closest to the parachute
7. Cover the parachute with the Kevlar sheet and pack into open space in the Nose
8. Continue packing the remainder of the Kevlar shock cord into the nose
9. Thread an e-match through the drilled hole in the blast caps – the blast caps are attached to the forward bulkhead of the avionics airframe

10. Tape the e-match wire to the outside of the blast cap, ensuring the drilled hole is covered
11. Using wire cutters, cut the e-match wires to the appropriate length
12. Strip the wires and attach them to the terminal blocks
13. Empty contents of the primary main black powder charge **[2.0 grams]** into the primary blast cap and cover with painters' tape
    a. If there is excess room between the black powder and where the rim of the blast cap, pack small amounts of tissue paper before taping
14. Empty contents of the secondary main black powder charge **[2.1 grams]** into the secondary blast cap and cover with painters' tape
    a. If there is excess room between the black powder and where the rim of the blast cap, pack small amounts of tissue paper before taping
15. Join the nosecone airframe to the avionics airframe, ensuring the arrows are aligned
16. Insert four shear pins into the appropriate holes coupling the two airframes

#### 6.1.4. Fin Can

1. Retrieve the following:
   - 1.1 Fin can
   - 1.2 ARRD
   - 1.3 Four quick links
   - 1.4 Drogue shock cord
   - 1.5 Kevlar sheet
   - 1.6 Tissue paper
   - 1.7 Black powder charges for drogue chute and ARRD **[0.1 grams]**
   - 1.8 Rubber bands
   - 1.9 Wire cutter/strippers
   - 1.10 Two e-matches
   - 1.11 Small flathead screw driver
   - 1.12 One swivel
   - 1.13 Painters tape
   - 1.14 PBR
   - 1.15 Rocket forward of the fin can
2. IMPORTANT NOTE FOR FINCAN: When testing continuity for the ARRD Altimeters, the StratoLogger will not beep normally. The beeps should be as follows: Start up beep: nine beeps right after each other. Transition beep. Three beeps, space, two beeps, space, one beep. This will indicate the start of the custom programming. If it does not beep like that, then you have a major problem (bug John to finish this on how to troubleshoot it)
   - 2.1 Troubleshooting: if the beep pattern is not followed, take the StratoLogger out and turn it off. Hold down the program button and turn it on. There should be an extended beep that cuts out when you release the program switch. Immediately following that, hit the program button nine times in a row in quick succession to select program nine.

Verify this program with the same beeps as above after cycling (turning on and off) the StratoLogger

2.2 If that fails, then do not use the StratoLogger, just use the Entacore with the A wiring.

3. ARRD Assembly:

3.1 Ensure the switches are set to the "0" or "OFF" position.

3.2 Load the black powder **[0.1 grams]** and e-matches into the ARRD. The e-matches will be easier to do if the wire end is sent from the forward side of the ARRD through the component.

3.3 Screw the ARRD together. Ensure the ARRD I-bolt is not attached.

3.4 Screw the ARRD into the fin can.

3.5 Run the e-match wires through the lower ARRD housing. The wires need to run through the middle "core" section of the housing.

3.5.3 NOTE: the lower ARRD housing is thinner than the upper.

3.6 Assemble the lower ARRD housing to the fin can using two #4-½" screws into predrilled holes. The e-match wires should not be below the lower ARRD housing.

3.7 Wire e-matches, switches, and batteries.

3.7.3 NOTE: The Entacore switch must be wired with the battery in the loop. Ensure connections are solid. The e-match needs to be wired into the "A" and "+" terminals, and the battery switch assembly needs to be in the "V+" and "V-" terminals.

3.7.4 NOTE: The StratoLogger switch and battery go straight into the altimeter. The e-match needs to go into the "Drogue" slot, the switch goes in "Switch," and the battery goes with the negative/ground on the "neg" slot.

3.8 Put the Entacore on the larger Velcro slot.

3.9 Assemble the upper ARRD housing onto the assembly. The component is attached via at least a 1" screw driven through the predrilled hole.

3.10 Install batteries and StratoLogger in the appropriate slots in the ARRD housing.

3.10.3 NOTE: The batteries are fully installed once electrical tape has been used to secure them into the ARRD housing.

3.10.4 NOTE: Tape the wiring in such a way that it is not obstructing any subsystem within the fin can.

3.11 NOTE: The connection of the shock cord to the ARRD I-bolt will leave the payload in a very unsteady condition. It is imperative that at least two people perform the following steps.

3.12 Tie a Cinch Knot from the shock cord protruding from the PBR onto the ARRD I-bolt.

3.12.3 Loop through bolt, bring excess over other rope, wrap so you see 5 coils, on final turn bring excess under loop and back over through new loop. Pull tight and cinch.

3.13 Connect the ARRD I-bolt to the ARRD.

3.14 Cinch the PBR down onto the ARRD housing tabs so there is minimal excess shock cord between the ARRD and the PBR.

3.14.3 NOTE: Because of the length of the coupler, the ARRD I-bolt will be almost touching the PBR VS.

4. Assembly of fin can and PBR to Payload Airframe:
   4.1 Stow the ULS in its upright position.
   4.2 Slide the Payload airframe over the fin can and PBR, ensuring the PBR rail buttons are on the rail tracks.
   4.3 Screw shear pins into the payload airframe.

### 6.1.5. Payload Airframe

1. Retrieve the following
   a. Payload airframe
   b. Avionics airframe
   c. Drogue parachute **[36 inches]**
   d. Drogue shock cord
   e. Four Quick links
   f. One Swivel
   g. Four Philips head screws with sanded tips
   h. Small Philips head screw driver
   i. Two e-matches
   j. Wire cutters/strippers
   k. Small flat head screw driver
   l. Black powder for drogue chute
2. Thread an e-match through the drilled hole in the blast caps – the blast caps are attached to the forward bulkhead of the avionics airframe
3. Tape the e-match wire to the outside of the blast cap, ensuring the drilled hole is covered
4. Using wire cutters, cut the e-match wires to the appropriate length
5. Strip the wires and attach them to the terminal blocks
6. Empty contents of the primary drogue black powder charge into the primary blast cap and cover with painters' tape
   a. If there is excess room between the black powder and where the rim of the blast cap, pack small amounts of tissue paper before taping
7. Empty contents of the secondary drogue black powder charge into the secondary blast cap and cover with painters' tape
   a. If there is excess room between the black powder and where the rim of the blast cap, pack small amounts of tissue paper before taping
8. Couple the payload airframe and the avionics airframe
9. Using 4 Philips head screws with sanded tips, secure the connection between the two portions
10. Connect a quick link to the forward loop of the drogue shock cord
11. Connect the same quick link to the exposed U-bolt of the forward most bulkhead

12. Close the quick link and begin packing the shock cord in a zig-zag fashion
13. Connect a quick link to the middle loop of the shock cord and one end of the swivel
14. Connect a quick link to the opposite end of the swivel and the end of the parachute
15. Before closing the parachute quick link, attach a Kevlar protection sheet
16. Pack the parachute tightly into the forward portion of the payload airframe

### 6.1.6. Engine

1. Obtain Aerotech L2200G package and motor casing
2. Open the L2200G package and verify that all listed contents are present
3. Using Synco ™ Super Lube ™ or other grease, apply a light coat of grease to all threads and O-rings.
4. Hold the forward closure (black) in a vertical position, smoke charge cavity facing up. Insert the smoke charge insulator into the smoke charge cavity until it is seated against the forward end of the cavity.
5. Apply a liberal amount of grease to one end of the smoke charge element. Insert the greased end of the smoke charge element into the smoke charge cavity until it is seated against the end of the cavity. Set the completed forward closure assembly aside.
6. Using a fingernail, carefully deburr both inside edges of the liner tube (2-3/4” O.D. black plastic tube).
7. Insert the larger diameter portion of the nozzle into one end of the liner, with the nozzle liner flange seated against the liner.
8. Install the propellant grains into the liner, placing the three grain spacer O-rings between each propellant grain. The aft grain should be seated against the nozzle grain flange.
9. Place the greased forward seal disk O-ring into the groove in the forward seal disk.
10. Insert the smaller end of the seal disk into the open end of the liner tube until the seal disk flange is seated against the end of the liner.
11. Push the linger assembly into the motor case until the nozzle protrudes approximately 1-3/4” from the end of the case.
12. Place the greased forward O-ring into the forward end of the case until it is seated against the forward seal disk.
13. Thread the previously-completed forward closure assembly into the forward end of the motor case by hand until it is seated against the case.
14. Place the greased aft O-ring into the groove in the nozzle.
15. Thread the aft closure into the aft end of the motor case by hand until it is seated against the case.
16. Install the motor into the rocket’s motor mount tube. Ensure that the motor is securely retained in the rocket by using positive mechanical means to prevent it from being ejected during recovery system deployment.

### 6.1.7. Launch

1. Fill out launch card
2. Transport the small, red handled flat head screwdriver and [NAME] to the launch pad

3. Slide rocket onto launch rail by aligning the two large launch buttons onto the 1515 rail
4. Verify that the launch platform is at the correct orientation and is stable
5. Insert the coated end of a Firestar ™ or other igniter through the nozzle throat until it stops against the smoke charge element.
6. Secure the igniter to the nozzle with a piece of masking tape
7. Arm first altimeter and confirm the appropriate continuity beeps
8. Arm second altimeter and confirm the appropriate continuity beeps
9. Return to the safe viewing area, 300 ft or more away from launch pad
10. Launch

#### 6.1.8. Post Flight Inspection

1. Account for all pieces of the rocket.
2. Ensure all ejection charges have fired, leaving no hazardous remaining black powder.
3. If any charges are still live, disable the electronics that could still fire them before the rocket is moved. Failure to complete this step could result in charges firing at any time.
4. Disable all electronics.
5. Reassemble the rocket.
6. Clean all components.

# 7. Project Plan

## 7.1. Testing

The Launch vehicle verification plans are currently being updated. All tests listed below have/will be completed but the specifics have changed. A series of experiments will be conducted to ensure the viability of the launch vehicle subsystems and verify that they are ready for flight.

### 7.1.1. Altimeter Pressure Test

In order to verify the programing of the altimeters for the deployment of the recovery systems and control of the ARRD, each altimeter will be tested inside a clear vacuum chamber. The altimeters will be powered via a 9V battery and a resistor and LED light will be wired to the ejection terminals to signal current flow. The pressure in the vacuum chamber will then be adjusted to simulate a full flight cycle to an apogee altitude of 5280 ft. The LED's will be observed to confirm they fire at the appropriate times (apogee, apogee delay, or 700 ft AGL depending on the altimeter being tested). The observed illuminations will be compared to the programmed values in order to confirm each altimeter's operation.

### 7.1.2. GPS Transmitter Experiment

To ensure that all transmitting devices function properly, the team will perform tests using each BigRedBee GPS unit. The units will be powered on and taken by a team member on the NC State bus system which can be tracked using a GPS based cell phone app. The BigRedBee units will then be synced to Google maps and compared to the tracking of the bus tracking app.

### 7.1.3. Stage Separation

Black powder ejection charge testing will take place to confirm calculations performed in §3.2. These calculations rely on a constant, which converts cubic inches of pressurized volume to grams of black powder, to find the ideal pressure for a certain separation force. Testing for the main recovery system will be conducted using the completed nosecone and avionics bay sections. Testing for the drogue chute will be conducted using the deployment rig described below. Successive ejection tests will be performed based on the performance of the initial tests.

### 7.1.4. Payload Deployment System

In order to validate the Payload Deployment System a test rig has been constructed which allows the launch vehicle to separate in a similar way to the conditions experienced at apogee. The Payload Deployment system is a critical subsystem to allow the mission criteria to be met successfully and this rig will aid in ground testing in a safe environment. The goals of testing this subsystem are to confirm the payload will be pulled from the payload bay without binding on the rails, the ARRD will release the payload without damaging the body tube, ejection charges are sized such that the payload clears the payload bay in less than 2 seconds, and to confirm the recovery harness will not get tangled in the payload or guide rails. Figure 53, shows an isometric model of the test rig while Figure 54, shows the overall dimensions.

Figure 53:Deployment test rig with complete vehicle assembly (no supporting straps shown)

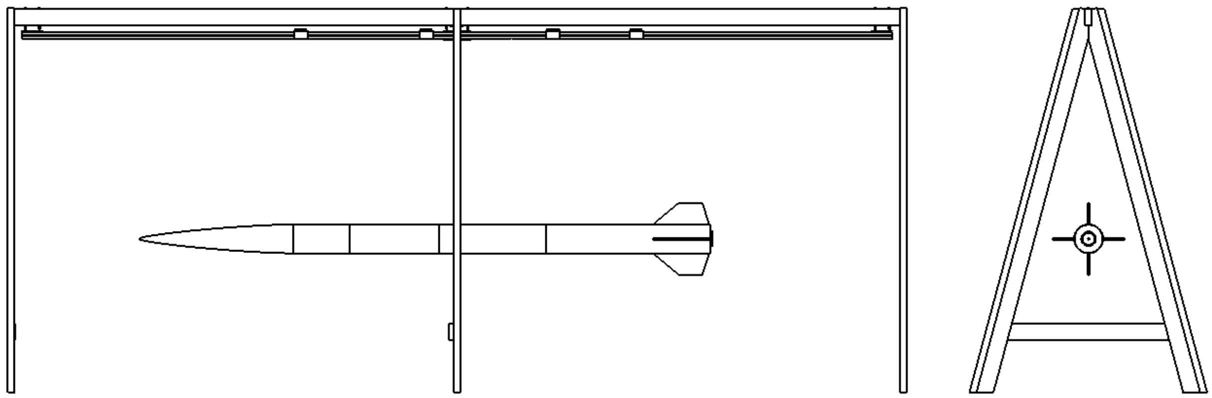


Figure 54:Deployment test rig dimensional drawing

The frame of the rig is constructed out of standard dimensional lumber which supports two lengths of 7.75 ft long 8020 aluminum guide rail. The guide rail cross sectional dimensions can be found in Figure 55. Each section of the rocket will be supported by 2 aluminum linear bearings that will glide along the rail. The test rig will provide approximately 15 feet of total track for the rocket sections to slide along. The rocket will be support by straps that connect to U-bolts on the linear bearings. These straps will be connected to adhesive backed Velcro strips that will stick to the body of the rocket during testing. The adhesive back Velcro will prevent the sections from slipping out of the straps during the forces experienced upon ejection. Since the rocket sections are largely bound to move in a linear direction, the fins will have sufficient clearance to fit through the end support legs without contact.

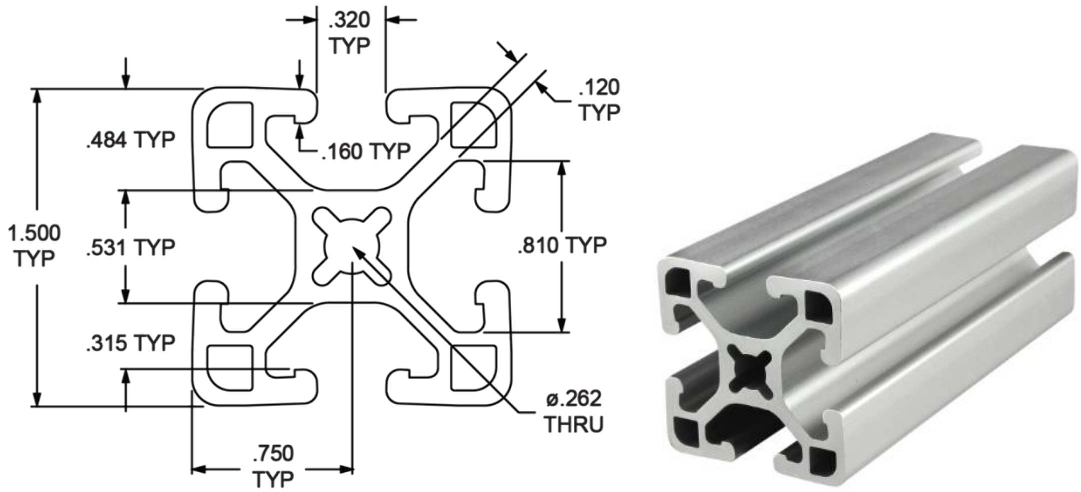



Figure 55: Payload deployment system test rig rail

Figure 56:Standard 3-slot linear bearing with UHMW polyethylene pads

### 7.1.5. Payload Electronics Testing

Payload electronics testing will be conducted and completed prior to full-scale testing; it is comprised of 4 parts. The two objectives of the payload are to 1) identify and differentiate among the three targets and 2) be oriented upright upon payload recovery. These two objectives are imperative to the success of the mission and the payload will be tested for them as follows:

### 7.1.6. Identify and Differentiate Targets

Test 1: The tarp samples provided will be placed on the ground during various outdoor weather conditions (sunny, mostly sunny, overcast, etc.). Pictures will be taken of the targets on the ground using an iPhone and the Python TDS code will analyze the images to determine if targets were detected. Success criteria includes if the targets are successfully identified in all the images. If targets are not detected for all outdoor conditions, the function will be modified until desired results are achieved. This test objective is to demonstrate the integrity of the Python TDS code.

Test 2: This test will have the same conditions as Test 1, but the assembled payload will be used to acquire images using the Raspberry Pi Camera System. Subsequently, the %Python TDS Code% will analyze the images. Success criteria includes if the targets are successfully identified in all the images. Once again, if targets are not detected for all outdoor conditions, the function will be modified until desired results are achieved. This test objective is to demonstrate the integrity of the camera system as well as the Python TDS code.

#### 7.1.7. Upright Landing

Test 1: Using a fully assembled payload, the payload will be placed on the ground, horizontally, and programmed to upright itself after ten seconds of zero motion. Success criteria includes if the payload successfully uprights itself within 60 seconds of being placed on the ground. If the system fails to orient itself upright, different servos and/or different leg configurations will be investigated. This test objective is to demonstrate the integrity of the servo ULS.

Test 2: Using a fully assembled payload, the payload will be allowed to descend with its parachute deployed. The payload will be programmed to upright itself after ground impact in order to emulate launch day expectations. This test will be conducted at night to ensure the safety of all team members and possible bystanders. Success criteria includes if the payload successfully uprights itself within 60 seconds of ground impact. In addition, the objective of this test is to demonstrate the integrity of the payload recovery system and servo ULS.

### 7.2. Requirements Compliance

#### 7.2.1. NSL Competition Requirements Verification Plan

The NASA compliance matrix can be found in Appendix D.

#### 7.2.2. Team Requirements Verification Plan

The team derived functional requirements focus that go beyond the NSL requirements are centered around the payload and the difficulty and are listed below:

a. TDS Differentiates Targets by Color and Number (e.g., Target #1 – Red)
   To prove the TDS has successfully differentiated the targets, a number and color must be assigned to each target.

   Target detection simulations have proved the software package can complete the task within the requirements and poses no risks to the system.

b. Software Package is Custom
   The team has decided to use a team-member-made software package for all code execution on the payload. This functional requirement was decided upon after the CDR teleconference, when it was stated that “code could be used from another source” for the target detection and upright landing challenge.

   Target detection simulations have proved the software package can complete the task within the requirements and poses no risks to the system.

c. ULS Self-Uprights Within 60 Seconds of Landing

This functional requirement gives a baseline for the ULS code execution and up righting process. It was determined that any if the system takes over 60 seconds to upright the payload the recovery team may reach the payload before it has up righted itself.

Due to the ULS system having an independent battery system to power the servo, the only risk associated with this team derived requirement is the capability of the servo or insufficient battery power to complete the task. The battery selected is a 6V, 2000 mAh battery pack which has more than enough electric charge to remain on standby for several hours and to actively power the system for the 60 second limit upon ground contact. In addition, the maximum operational voltage of the servo is 6V. At the maximum operational voltage, the servo is capable of rotating at 47 RPM; preliminary estimates have shown that less than ten revolutions will fully deploy the ULS Legs. The battery and servo selected will accomplish this team-derived requirement well within acceptable levels of risk for this system.

## 7.3. Budget Plan

The total projected budget for the NASA SL 2017 is $10,992.45. The budget is broken down in further detail in the following sections.

### 7.3.1. Subscale Vehicle Budget

| | Subscale | | |
|---|---|---|---|
| | Item | Quantity | Price |
| Vehicle | 54 mm 1706 Aeroteck Motor Casing | 1 | $ 152.00 |
| | 5" 5:1 Ogive Nosecone | 1 | $ 90.00 |
| | Aeroteck K1103X Motor | 2 | $ 319.92 |
| | Fiberglass Body Tube 5" | 72" | $ 182.00 |
| | Fiberglass Coupler 5" | 24" | $ 104.00 |
| | 1/8" Aircraft Birch Plywood 3-Ply | 15 | $ - |
| | Wet System Epoxy & Hardener | In House | |
| | Fibre Glast Glass Microspheres | In House | |
| | PVC 3/4" Blast Cap | 4 | $ 3.92 |
| | 1/4" U-Bolt | 4 | $ 20.88 |
| | 54 mm Retention Tube | 1 | $ 57.60 |
| | 1515 Rail Buttons | 2 | $ - |
| | Shear Pins | 8 | $ - |
| | Kevlar Shock Cord | 2 | $ - |
| | Fruity Chute 84" Iris Ultra Compact | 1 | $ 345.00 |
| | Fruity Chute 18" Iris Ultra Compact | 1 | $ 60.00 |
| | Speaker Wire | In House | |
| | Black Powder | 5 grams | $ - |
| | Electronics Rotary Switches | 4 | $ - |
| | 1/8" Threaded Rods | 2 | $ - |
| | Aero Pack 54 mm Retainer (Flanged) | 1 | $ 40.66 |
| | Duracel 9V Battery | 4 | $ 11.31 |
| | Entacore 1000 Altimeter | 2 | $ - |
| | GPS | 1 | $ - |
| | Stratologger CF Altimeter | 2 | $ - |
| | RATTworks ARRD | 1 | $ - |
| | Coupling Nut | 2 | $ 2.48 |
| | | | **$ 1,389.77** |

### 7.3.2. Subscale Payload Budget

| | Subscale | | |
|---|---|---|---|
| | **Item** | **Quantity** | **Price** |
| Payload | 3D Printed Mounting Sheet 54 mm | 1 | $ - |
| | 6061-T6 Aluminum Bare Drawn Tube (3"OD x 0.065") | 1 | $ 51.43 |
| | ALUMINUM BARE SHEET 6061 T6 - 0.125" thickness | 1 | $ 15.35 |
| | Alloy 5356 MIG Welding Wire | 1 | $ 9.92 |
| | 1010 Rail Buttons | 2 | $ 14.00 |
| | 1/2" Threaded Rod | 2 | $ 33.39 |
| | Hex Nut 1/2"-13 | 25 | $ 5.45 |
| | 3D Printed Electronics Sled | 1 | $ - |
| | BMP180 Altimeters | 4 | $ 39.80 |
| | BNO055 Orientation Sensors | 2 | $ 34.95 |
| | 7.4V 2700mAh Lithium Polymer Batteries | 1 | $ 34.99 |
| | Big Red Bee BRB900 GPS Module | 1 | $ - |
| | 5V 1.5A Linear Voltage Regulator - 780 | 2 | $ 1.50 |
| | TO-220 Clip-On Heatsink | 2 | $ 1.50 |
| | 10uF 50V Electrolytic Capacitors - Pac | 1 | $ 1.95 |
| | Raspberry Pi 3 Model B Microcontroller with Camera System | 1 | $ 89.99 |
| | Jolly Logic Parachute System | 1 | $ 130.00 |
| | Fruity Chutes 48" Iris Ultra Compact | 1 | $ - |
| | 3D Printed Acrylic Grazing Sheet | 0 | $ - |
| | 1"x1/2"T-Slot Rails -14" | 2 | $ 8.38 |
| | | | **$ 472.60** |

### 7.3.3. Full-scale Launch Vehicle Budget

| | Fullscale | | |
|---|---|---|---|
| | **Item** | **Quantity** | **Price** |
| Vehicle | 75 mm 5120 Aeroteck Motor Casing | 1 | $ 440.00 |
| | 6" 5.5:1 Von Karman Nosecone | 1 | $ 132.00 |
| | Aeroteck L2200G Motor | 2 | $ 499.98 |
| | Fiberglass Body Tube 6" | 414.86 | $ 326.00 |
| | Fiberglass Coupler 6" | 207.39 | $ 176.10 |
| | 1/8" Aicraft Birch Plywood 3-Ply | 20 | $ 113.00 |
| | Wet System Epoxy & Hardener | In House | |
| | Fibre Glast Glass Microspheres | In House | |
| | PVC 3/4" Blast Cap | 4 | $ 3.92 |
| | 1/4" U-Bolt | 4 | $ 20.88 |
| | 75mm Retention Tube | 1 | $ 20.00 |
| | 1515 Rail Buttons | 2 | $ 9.30 |
| | Shear Pins | 8 | $ - |
| | Kevlar Shock Cord | 2 | $ - |
| | Drogue Parachute | 1 | $ - |
| | Main Parachute | 1 | $ - |
| | Speaker Wire | In House | |
| | Black Powder | 5 grams | $ - |
| | Electronics Rotary Switch | 4 | $ 49.65 |
| | 1/8" Threaded Rods | 2 | $ - |
| | Aero Pack 75 mm Retainer (Flanged) | 2 | $ 53.50 |
| | Duracel 9V Battery | 4 | $ 11.31 |
| | Entacore 1000 Altimeter | 1 | $ - |
| | Big Red Bee GPS | 1 | $ 309.00 |
| | Stratologger CF Altimeter | 3 | $ 176.40 |
| | RATTworks ARRD | 1 | $ 95.00 |
| | Coupling Nut | 2 | $ 2.48 |
| | | | **$ 2,438.52** |

### 7.3.4. Full-scale Payload Budget

| | Fullscale | | |
|---|---|---|---|
| | **Item** | **Quantity** | **Price** |
| Payload | 3D Printed Mounting Sheet 75 mm | 1 | $ - |
| | Polycarbonate Body Tube | 2 | $ 169.48 |
| | Aero Pack 75 mm Retainer (Flanged) | 1 | $ 53.50 |
| | 1010 Rail Buttons | 2 | $ 14.00 |
| | | | |
| | 1/2" Threaded Rod | 2 | $ 33.39 |
| | Hex Nut 1/2"-13 | 25 | $ 5.45 |
| | 3D Printed Electronics Sled | 1 | $ - |
| | BMP180 Altimeters | 4 | $ 39.80 |
| | BNO055 Orientation Sensors | 2 | $ 34.95 |
| | 7.4V 5000mAh Lithium Polymer Batteries | 1 | $ 46.97 |
| | Big Red Bee BRB900 GPS Module | 1 | $ 309.00 |
| | 5V 1.5A Linear Voltage Regulator - 780 | 2 | $ 1.50 |
| | TO-220 Clip-On Heatsink | 2 | $ 1.50 |
| | 10uF 50V Electrolytic Capacitors - Pac | 1 | $ 1.95 |
| | Raspberry Pi 3 Model B Microcontroller with Camera System | 1 | $ 89.99 |
| | Jolly Logic Parachute System | 1 | $ 130.00 |
| | Fruity Chutes 48" Iris Ultra Compact | 1 | $ - |
| | 3D Printed Acrylic Grazing Sheet | 0 | $ - |
| | 1"x1/2"T-Slot Rails -14" | 2 | $ 8.38 |
| | | | **$ 939.86** |

### 7.3.5. Travel Budget

| Travel | | |
|---|---|---|
| Event | Item | Price |
| Huntsville | Hotel | $3,820.80 |
| | Gas | $1,300.00 |
| | Van Rental | $ 511.20 |
| Bayboro | Van Rental | $ 119.70 |
| | | **$5,751.70** |

### 7.4. 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** | $ 14,229.86 | | |
| **Requested Total** | $ 14,229.86 | $ 5,000.00 | $ 19,229.86 |

### 7.5. Timeline

### 7.5.1. Fall Timeline

| Fall 2016 | | | | |
|---|---|---|---|---|
| | **Event / Task** | **Start Date** | **End Date** | |
| | Request for Proposal Released | 8/15/17 | | Proposal Writing |
| | Fall FDOC | 8/17/16 | | |
| | **Proposal Submitted** | **9/30/16** | | |
| | Awarded Proposals Announced | 10/14/16 | | |
| | Senior Meeting | 10/14/16 | | |
| | Fall Open House | 10/15/16 | | |
| | Senior Meeting | 10/18/16 | | |
| | PDR Checkin | 10/20/16 | | PDR Writing |
| | Outreach Meeting | 10/26/16 | | |
| | Web Presence Established | 10/31/16 | | |
| | All Content In PDR | 11/1/16 | | |
| | PDR Editing | 11/1/16 | 11/3/16 | |
| | **Completed PDR Submission** | **11/4/16** | | |
| Subscale Build | PDR Teleconference | 11/14/16 | | |
| | Thanksgiving Break | 11/23/16 | 11/25/16 | |
| | Salem Elementary Outreach | 12/2/16 | | CDR Writing |
| | Fall LDOC | 12/6/16 | | |
| | Building Access Ends | 12/16/16 | 1/9/17 | |
| | **Subscale Launch** | **12/17/16** | | |

### 7.5.2. Spring Timeline

| Phase | Spring 2017 Event / Tast | Start Date | End Date | Writing |
|---|---|---|---|---|
| | Building Acess Resumes Spring FDOC | 1/9/17 | | CDR Writing |
| | CDR Editing | 1/9/17 | 1/12/17 | |
| Fullscale Build | **Completed CDR Submission** | **1/13/17** | | |
| | CDR Teleconference | 1/18/17 | | FRR Writing |
| | Math and Science Night | 1/19/2017 | | |
| | Lacy Elemtary STEM Night | 1/19/17 | | |
| | weatherstone Elementary STEM Expo | 1/21/17 | | |
| | **Subscale Launch #2** | **1/21/17** | | |
| | Astronomy Days | 1/28/2017 | | |
| | FRR Q&A | 2/8/17 | | |
| | **Full Scale Launch** | **2/25/17** | **2/26/17** | |
| | All Content in FRR | 2/27/17 | | |
| | FRR Editing | 2/27/17 | 3/5/17 | |
| | **Completed FRR Submission** | **3/6/17** | | |
| | FRR Teleconference | 3/8/17 | 3/24/17 | |
| | Team Travels to Huntsville, AL | 4/5/17 | | |
| | LRR | 4/5/17 | | |
| | NASA Safety Briefing | 4/6/17 | | |
| | Rocket Fair & Tour of MSFC | 4/7/17 | | |
| | **Launch Day & Banquet** | **4/8/17** | | |
| | Backup Launch Day | 4/9/17 | | |
| | Return to NCSU | 4/17/17 | | PLAR Writing |
| | PLAR Editing | 4/17/2017 | 4/23/2017 | |
| | **Completed PLAR Submission** | **4/24/17** | | |
| | **Winning Team Announced by NASA** | **5/12/17** | | |
| | Spring Commencement | 5/13/17 | | |

## 7.6. Educational Engagement Plan and Status

### 7.6.1. Previous Educational Engagement

Salem Elementary School Outreach

Where: Salem Elementary School, Apex, NC 27523

When: Friday December 2, 2016 from 2:30-4:30

Several members from the High-Powered Rocketry Club travelled to Salem Elementary School to visit an afterschool program run by the YMCA. The team gave a prepared presentation on what STEM is, example STEM careers, the engineering design cycle, and introductory water bottle physics. In addition to the presentation, the team brought a couple of subscale rockets from previous years. At the end of the presentation, the floor was open to questions and members of the club were able to answer the various questions asked. Following the presentation, there was a hands-on experiment with water bottle rockets where the students got to choose varying amounts of water and predict the amount of water that would lead to the rocket going the highest.

### 7.6.2. Planned Educational Engagements

#### Lacy Elementary School's STEM Night

Location: Lacy Elementary School, Raleigh, NC 27607
When: Thursday January 19, 2017, 5pm – 8pm
Members of the High-Powered Rocketry Club will attend the Lacy Elementary School STEM night to give a presentation on high-powered rocketry, NASA SLI, and engineering at NC State. The team will also bring a collection of previous years' rockets to have on static display and answer questions on the various components of the rockets. In addition, weather permitting, the club will be launching water bottle rockets with assistance from the students.

#### Weatherstone Elementary STEM Expo

Location: Weatherstone Elementary School, Cary, 27513
When: Saturday January 21, 2017 10am-2pm
The High-Powered Rocketry Club will have a booth at the Weatherstone Elementary STEM Expo to give a presentation on NASA SLI, high-powered rocketry, water bottle rockets, and engineering at NC State. The team will bring a small collection of previous rockets from previous years to show to the students. In addition, weather permitting, the team will have a water bottle rocket workshop where students can design and build their own water bottle rocket to launch with some coaching from the team members.

#### Astronomy Days

Location: North Carolina Museum of Natural Sciences, Raleigh NC 27601
When: Saturday January 28, 9:00am-5:00pm and Sunday January 29 12:00pm-5:00pm, 2017
The High-Powered Rocketry Club will be continuing 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. The booth will feature static displays of rockets both from the club and from the Tripoli Rocket Association plus posters describing high-powered rocketry designs and flights.

# 8. References

[0] “RATTworks ARRD Advanced Retention Release Device,” Aerocon Systems, http://aeroconsystems.com/cart/launch-recovery/rattworks-aard-advanced-retention-release-device/ [retrieved 10 January 2017].

[1] “Raspberry Pi Model B,” Raspberry Pi, https://www.raspberrypi.org/products/raspberry-pi-3-model-b/ [retrieved 9 January 2017].

[2] “BMP180 Barometric Pressure/Temperature/Altitude Sensor- 5V ready,” Adafruit, https://www.adafruit.com/product/1603 [retrieved 9 January 2017].

[3] “Adafruit BNO055 Absolute Orientation Sensor,” Adafruit, https://learn.adafruit.com/adafruit-bno055-absolute-orientation-sensor/overview [retrieved 9 January 2017].

[4] “Camera Module v2,” Raspberry Pi, https://www.raspberrypi.org/products/camera-module-v2/ [retrieved 9 January 2017].

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[6] “Venom 20C 2S 5000mAh 7.4V Hard Case LiPo Battery with Universal Plug System,” Venom, https://www.venompower.com/products/venom-20c-2s-5000mah-7-4v-hard-case-lipo-battery-with-universal-plug-system [retrieved 9 January 2017].

[7] “BRB900,” Big Red Bee, http://www.bigredbee.com/brb900.htm [retrieved 9 January 2017].

[8] “Overview of materials for Polycarbonate/ABS Alloy, Unreinforced,” MatWeb, http://www.matweb.com/search/DataSheet.aspx?MatGUID=d16a64a389df424f8e53ed481e77477b [retrieved 10 January 2017]

[9] “Raspberry Pi Model B+,” GrabCAD, https://grabcad.com/library/raspberry-pi-model-b-2 [retrieved 15 November 2016].

# Appendix A: Launch Vehicle FMECA

| System | Function / Component | Failure Mode | Causal Factors | Failure Effects | | Hazard | Recommendations |
|---|---|---|---|---|---|---|---|
| | | | | Subsystem | System | | |
| 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 | |
| | | Charge causes damage to any components other than shear pins | 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 (no more than 3 grams) of black powder using pre-flight checklists |
| | Avionics (Altimeters) | Main parachuate deploys at wrong altitude | Altimeter detects inccorect altitude | Altitude between apogee and 750 ft detected | Excessive drift | 4 | Verify each altimeter chirps the appropriate program at the launch site. |
| | | | | Altitude between 600ft and 200ft detected | Kinetic energy will exceed 75 ft-lb | 2 | |
| | | | | Altitude below 200ft detected | | 1 | |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | | No power to avionics or charges | Wiring Short | Loss of real-time altitude data | Ejection charge never ignites and parachutes don't deploy | 1 | Ensure that there all wire is properly insulated and that all wires are securely contained in their respective terminals |
| | | | Battery becomes disconnected from altimeters | | | 1 | Ensure that altimeters are properly wired and that wires are secure prior to launch. Listen for appropriate altimeter chips when powering on |
| | | | Low battery voltage | Insufficient voltage to ignite e-match | | 1 | Install new/unopened (Duracell) batteries prior to launch |
| | | | Low battery charge | Loss of power to altimeter during flight | | 1 | |
| | | No launch detect | Faulty altimeter | Lack of flight data | | 1 | Test altimeters in vacuum chamber prior to launch and listen for fault codes at launch site. |
| | | False apogee detected | | Premature/ late ejection of drogue parahutes | Increased load on drogue recovery hardware | 2 | Ensure that pressure ports are sized correctly and listen for fault codes at launch site |
| | BigRedBee (GPS) | Ground System Failure | Loss of power to ground receiver or the laptop | Inability receive data from the GPS | Inability to track and recover the rocket in less than an hour | 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 |
| | Fiberglass Airframe | Cracks or Breaks | Manufacturing Defect | Structural integrity of fiberglass sections at risk | 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. Fill cracks with epoxy |
| | | | Improper maintenance | | | 1 | Thorough pre- and post-launch inspections of body tubing |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | Bulkheads | Separation of bulkhead from airframe during flight | Manufacturing Defect | Recovery harness has only 1 attachment point | Kinetic energy will exceed 75 ft-lb and launch vehicle will fall in multiple sections | 2 | Visual inspection after completing construction before any implementation |
| | | | Loads beyond design specifications | | | 2 | Based on subscale flight data, factor of safety is sufficient |
| | | | Damaged during handling | | | 2 | Replace damaged bulkhead |
| | | U-Bolt separates from bulkhead | Loads beyond design specifications | | | 2 | Ensure prior to launch that all U-Bolts are correctly installed and implement checklist steps to verify |
| | Fins | Severe weather-cocking | Fin dimensions are not cut according to design | N/A | Decreased flight stability, and possible damage to other components | 2 | Laser cut fins to increase manufacturing precision |
| | | | Fins not Evenly Spaced (90 degrees) | N/A | | 2 | Create a laser-cut wooden frame for fin placement to ensure proper placement |
| | | Fin separation | Loads beyond design specifications | N/A | Fin failure during flight will decrease stability of rocket and will likely cause a catastrophic failure | 1 | Based on subscale flight data, factor of safety is sufficient |
| | | | Damaged during handling | | | 1 | Inspect for cracks and other defects during assembly. Replace if damaged |
| | | | Fin Flutter | | | 3 | Unlikely max velocity will reach speeds necessary to induce flutter |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | | Ground impact | | | 4 | Implement a recovery system design that ensures a low speed surface impact |
| Shear Pins | All pins break before charge detonation | Manufacturing Defect | Loose assembly of compartment | Premature recovery system deployment | 2 | Visual inspection after shipping before any implementation |
| | | Loads beyond design specifications | | | 2 | Maintain vehicle within design specifications |
| | 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 | Cracks or Breaks | 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 | | | 2 | Team members will be taught proper handling and installation procedures for the nosecone |
| | | Ground impact | | N/A | 4 | Metal tip will mitigate hard surface impact damage |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | | 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 |
| | | | Epoxy doesn't cure properly | | | 2 | Follow proper procedures for applying epoxy |
| | Parachutes | Tears | Manufacturing Defect | Reduced drag coefficient | Kinetic energy of components above 75 ft-lb | 1 | Inspect for tears and other defects prior to installation |
| | | | Loads beyond design specifications | | | 1 | Scale parachutes to any weight increase/decrease that the rocket sees during construction. |
| | | | Damaged during handling | | | 1 | Team members will be taught proper handling and installation procedures for the parachutes, and each parachute will be inspected carefully prior to launch |
| | | Improper deployment | Parachutes Get Caught Inside Rocket Body | Parachute doesn't unravel | 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 to 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 checklist 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 ignitors 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 | Ensure all connection points between motor tube, centering rings, and fins are properly joined. Inspect prior to launch. |
| | Rail Buttons/ Launch Rail | Vehicle does not leave launch rail as intended | Rail Buttons Separate from Launch Vehicle | Vehicle leaves rail at an angle greater than | Possible mission failure and hazard to | 1 | Rail buttons will be epoxied into body to ensure they don't separate |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | | | Rail Buttons Break | 5 degrees from vertical | ground crew and spectators | 1 | 2 standard rail buttons for a 15 inch rail will be installed and inspected for defects prior to launch |
| | | Vehicle does not leave launch rail at all | Rail Buttons Stick | N/A | Mission objectives not met as the flight does not take place | 2 | Lubricate the launch rail and rail buttons prior to launch and ensure that the vehicle moves smoothly on the rail. |
| | | | Rail Breaks | | | 2 | 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. Shock cord is tubular Kevlar with a breaking strength greater than 1500 lb |
| | | | 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 |
| | ARRD | Early Separation | Altimeter misfire | Payload might not fully deploy or will get tangled in shock cord | Drogue will be prevented from deploying | 2 | Review altimeter checklist and ensure altimeters are properly programed and that all wiring is secured |
| | | | Altimeter programmed incorrectly | | | 2 | |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | | | Connecting bolt breaks | | | 2 | Inspect connection points prior to launch for defects and follow pre-launch checklist |
| | | Late Separation | Altimeter programmed incorrectly | Payload may tangle in drogue | Drogue will be compromised and increase loads on main parachute | 2 | Review altimeter checklist and ensure altimeters are properly programed |
| | | No Separation | See "Altimeter" section | Payload camera will not get a clear view of targets | Major mission requirements will not be met | 4 | Review altimeter checklist and ensure altimeters are properly programed. Listen for fault codes prior to launch |

# Appendix B: Payload FMECA

| System | Function / Component | Failure Mode | Causal Factors | Failure Effects | | Hazard | Recommendations |
|---|---|---|---|---|---|---|---|
| | | | | Subsystem | System | | |
| Payload | Raspberry Pi Camera Module v2 | Damaged lens/camera | Manufacturer defect | Raspberry Pi unable to acquire | Payload fails to identify and differentiate targets | 4 | Thoroughly check camera systems prior to launch |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | | | Broken lens during flight | meaningful data | | 4 | Test recovery system effect on uncontrolled motion |
| | | Obstructed view | Camera Module dislodged from mount | | | 4 | Thoroughly check integrity of connection |
| | | | Payload tangled in launch vehicle drogue parachute | | | 4 | Ensure both payload chute and launch vehicle drogue chute are packed tightly with no loose strings |
| | | | Payload does not detach from fin can | | | 4 | Thoroughly test ARRD functionality and employ altimeter code check procedure |
| | | Loose wiring | Electrical system Hardware integrity compromised during flight | | | 4 | Post-assembly functionality check |
| | | | Improper assembly | | | 4 | |
| | | Software issue | Hardware and software not compatible | | | 4 | Test full TDS system functionality before launch |
| | | | Code not debugged/ tested thoroughly prior to launch | | | 4 | Debug and test camera system |
| | Raspberry Pi 3 Model B microcontroller | Manufacturer defect | Manufacturer defect | Raspberry Pi unable to acquire data | Payload fails to identify and differentiate targets | 4 | Thoroughly check Raspberry Pi prior to launch |
| | | Poor attachment to electronics sled | Improper assembly | | | 4 | Post-assembly functionality check |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | | Compatibility issues with hardware | TDS system not tested for functionality | | | 4 | Test full TDS system functionality before launch |
| | | Damages surrounding components | Improper assembly | | | 4 | Post-assembly shake test |
| | | Detaches from sled during flight | Improper assembly | | | 4 | Post-assembly shake test |
| | | | Violent uncontrolled motion during flight | | | 4 | Test recovery system effect on uncontrolled motion |
| | Jolly Logic Chute Release | Not tethered to parachute | Improper attachment to parachute cords | Loss of Jolly Logic Chute Release | Negligible--parachute still properly deploys | 4 | Ensure proper attachment of Jolly Logic Chute Release to parachute cords |
| | | No release or response | Manufacturer defect | Payload recovery system fails to deploy | Payload descent becomes uncontrolled | 1 | Thoroughly check Jolly Logic Chute Release and proper assembly to parachute prior to launch |
| | | | Not enough tension in rubber band | | | 1 | |
| | | | Too much tension in rubber band / rubber band breaks (parachute may be too large) | | | 1 | |
| | | | Dead battery | | | 1 | |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | | | Improper altitude selection | | | 1 | |
| | | Partial deploy | Some parachute strings tangled in Jolly Logic Chute Release | Payload recovery system partially deploys | Payload does not land within kinetic energy requirement of 75 ft-lb | 2 | |
| | Venom 20C 2S 5000mAh LiPo Battery | No power available | Power loss prior to launch | Raspberry Pi unable to acquire data | Payload fails to identify and differentiate targets | 4 | Perform battery life testing |
| | | | Improper wiring | | | 4 | Visual inspection after assembly |
| | | | Improper system design | | | 4 | System performance testing |
| | | Disconnected | Uncontrolled motion during flight | | | 4 | Test recovery system effect on uncontrolled motion |
| | | | Improper wiring | | | 4 | Visual inspection after assembly |
| | Polycarbonate Viewing Surface | Cracks, scratches or breaks | Loads beyond design specifications | N/A | Payload fails to identify and differentiate targets | 4 | Verification of subscale test results through further testing |
| | | | Damaged during handling | | | 4 | Visual inspection prior to assembly |
| | | Obstructed view | Uncontrolled motion during flight | | | 4 | Testing of payload deployment system |
| | ABS Mounting Surface | Fracture during flight | Uncontrolled motion during flight | Cameras unsecured | Payload fails to identify and differentiate targets | 4 | Verification of subscale test results through further testing |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | | | Loads beyond design specifications | | | 4 | |
| | Electronics Subassembly | Separation from electronics rods | Uncontrolled motion during flight | Electronics unsecured | Potential for payload to be unable to identify and differentiate targets | 4 | Post-assembly shake test |
| | | Separation from electronics sled | Improper assembly | | | 4 | Post-assembly shake test |
| | | Fracture during flight | Loads beyond design specifications | | | 4 | Structural testing |
| | | Improper assembly | Loose/Improper connections | | | 4 | Post-assembly functionality check |
| | | Shorting out | Incorrect amount of power supplied to device(s) | Electronics unusable | | 4 | Ensure proper power is supplied to device |
| | | Manufacturing defect | Manufacturing defect | | | 4 | Inspection prior to assembly |
| | Polycarbonate Payload Body | Material failure due to assembly | Improper assembly | Payload may experience rapid unscheduled disassembly | Drogue chute may be unable to deploy | 3 | Structural testing |
| | | | Loads beyond design specifications | | | 3 | Structural testing |
| | | Impact with rocket frame | Rail buttons fail | Payload bound in launch vehicle | Drogue chute may be unable to deploy | 3 | Rail button and payload deployment system testing |
| | | | Improper payload deployment | Payload experiences rapid unscheduled disassembly | Drogue chute may be unable to deploy, launch vehicle shock cord may be damaged | 1 | Payload deployment system testing, make sure rail system is clear of FOD |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | Big Red Bee BRB900 GPS | Ground system failure | Loss of power to ground receiver/laptop | Inability to receive data from the BRB900 | 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 BRB900 | 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 BRB900 to disconnect from power supply | | | 4 | Use simulations to test max load before failure |
| | | | Improper wiring | | | 4 | Post-assembly functionality check |
| | 80/20 Guide Rail System | Obstructions Along Rails | FOD in Payload Compartment | Potential to fail payload requirements, potential for payload recovery system to be undeployable | Mistimed/No payload deployment | 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 |
| ULS | Servos | Not enough torque to erect payload | Weak servo selection | ULS fails to erect payload | Payload fails upright landing requirement | 4 | Ensure servo has necessary torque |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | | | Electrical pull on battery too large, drains battery too quickly | to desired orientation | | 4 | Test servo prior to complete system integration |
| | | | Weak/dead battery | | | 4 | Verify new batteries on launch day |
| | Aluminum rod legs | Break before payload reaches touchdown | Legs impact inside of rocket body | ULS has no way to support and maintain an upright landing | Payload fails upright landing requirement | 3 | Verify strength of leg connection |
| | | | Tangle in shock cord | | | 3 | Properly load shock cord around payload |
| | | | Structural support not thick enough to handle load | | | 3 | Verify strength of leg connection |
| | | Break upon impact with ground | Connection to payload too weak | Legs cannot upright payload | Payload fails upright landing requirement | 4 | Descent and landing testing prior to launch |
| | | | Payload lands on payload leg connection | | | 4 | Descent and landing testing prior to launch |
| | | Wind pulls parachute enough to tip over | Legs not strong enough to hold upright | Legs cannot upright payload | Payload fails upright landing requirement | 4 | Static ground testing with varying wind speeds |
| | Cables | Legs do not extend out fully | Cables not long enough | Payload not fully upright | Payload fails upright landing requirement | 4 | Range of motion testing |
| | | | Cables not strong enough | | | 4 | Static ground testing with varying payload orientations |
| | | Cables tangle with wires | Cables not far enough away from electronics | Electronics interference and payload legs get stuck | | 4 | Ensure wire spools properly |
| | | Cables snap | Cables not strong enough | Payload cannot upright itself | | 4 | Cable strength testing |

# 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 |

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| 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 |

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| 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 |

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| 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 |

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| 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 |

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| 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 |

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|---|---|---|---|---|
| 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 |

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| 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 |

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|---|---|---|---|---|
| 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 |

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| 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 |

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| 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 |

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|---|---|---|---|---|
| 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 |

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|---|---|---|---|---|
| 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 |

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| 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 |

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| 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 |

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|---|---|---|---|---|
| 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 |

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| 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 |

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| 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 |

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|---|---|---|---|---|
| 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 |

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| 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 |

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|---|---|---|---|---|
| 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 |

NC STATE UNIVERSITY

# Appendix E: Milestone Review Flysheet

## Milestone Review Flysheet

| Institution | NC State | Milestone | Critical Design Review |
|---|---|---|---|

| Vehicle Properties | |
|---|---|
| Total Length (in) | 122 |
| Diameter (in) | 6.2 |
| Gross Lift Off Weigh (lb) | 49.6 |
| Airframe Material | Fiberglass |
| Fin Material | Aircraft-Grade Birch Plywood |
| Coupler Length | 12 in |

| Motor Properties | |
|---|---|
| Motor Designation | L2200G |
| Max/Average Thrust (lb) | 697 / 504 |
| Total Impulse (lbf-s) | 1147 |
| Mass Before/After Burn | 10.5 / 4.9 |
| Liftoff Thrust (lb) | 562 |
| Motor Retention | Retainer, engine block, centering ring |

| Stability Analysis | |
|---|---|
| Center of Pressure (in from nose) | 89.5 |
| Center of Gravity (in from nose) | 77 |
| Static Stability Margin | 2.01 |
| Static Stability Margin (off launch rail) | 2.1 |
| MaxThrust-to-Weight Ratio | 14:1 |
| Rail Size and Length (in) | 1.5 x 1.5 x 96 |
| Rail Exit Velocity | 65.3 ft/s |

| Ascent Analysis | |
|---|---|
| Maximum Veloxity (ft/s) | 672 |
| Maximum Mach Number | 0.61 |
| Maximum Acceleration (ft/s^2) | 434 |
| Target Apogee (From Simulations) | 5305 |
| Stable Velocity (ft/s) | 65.3 |
| Distance to Stable Velocity (ft) | 5.75 |

| Recovery System Properties | |
|---|---|
| Dogue Parachute | |
| Manufacturer/Model | Fruity Chutes / Classic Elliptical |
| Size | 24 in |
| Altitude at Deployment (ft) | apogee |
| Velocity at Deployment (ft/s) | 0 |
| Terminal Velocity (ft/s) | 81 |
| Recovery Harness Material | Kevlar |
| Harness Size/Thickness (in) | 1 |
| Recovery Harness Length (ft) | 25 ft |
| Harness/Airframe Interfaces | Tubluar Kevlar Shock Cord / U-bolt with quick link |

| Recovery System Properties | |
|---|---|
| Main Parachute | |
| Manufacturer/Model | Fruity Chutes / Iris Ultra Toroidal |
| Size | 168 in |
| Altitude at Deployment (ft) | 700 |
| Velocity at Deployment (ft/s) | 81 |
| Terminal Velocity (ft/s) | 9.9 |
| Recovery Harness Material | Kevlar |
| Harness Size/Thickness (in) | 1 |
| Recovery Harness Length (ft) | 25 ft |
| Harness/Airframe Interfaces | Tubluar Kevlar Shock Cord / U-bolt with quick link |

| | | | | |
|---|---|---|---|---|
| Kinetic Energy of Each Section (Ft-lb) | Section 1 | Section 2 | Section 3 | Section 4 |
| | 4000 | | | |

| Kinetic Energy of Each Section (Ft-lb) | Section 1 | Section 2 | Section 3 | Section 4 |
|---|---|---|---|---|
| | 59.4 | 10.9 | | |

| Recovery Electonics | |
|---|---|
| Altimeter(s)/Timer(s) (Make/Model) | 2 x StratoLogger SL100 |
| Redundancy Plan | Redundant charge fired 1 second after apogee |
| Pad Stay Time (Launch Configuration) | 1 hour |

| Recovery Electonics | |
|---|---|
| Rocket Locators (Make/Model) | Big Red Bee 900 MHz GPS |
| Transmitting Frequencies | 900 MHz |
| Black Powder Mass Drogue Chute (grams) | 2.25 |
| Black Powder Mass Main Chute (grams) | 2.00 |

## Milestone Review Flysheet

| Institution | NC State | Milestone | Critical Design Review |
|---|---|---|---|

| Autonomous Ground Support Equipment (MAV Teams Only) | |
|---|---|
| Capture Mechanism | Overview |
| | N/A |
| Container Mechanism | Overview |
| | N/A |
| Launch Rail Mechanism | Overview |
| | ***Include Description of rail locking mechanism*** |

| | |
|---|---|
| Igniter Installation Mechanism | Overview<br><br>N/A |

| Payload | |
|---|---|
| Payload 1 | Overview<br><br>The Payload Deployment System will detach the payload from the launch vehicle using a pyrotechnically activated tether-and-release device after the payload bay and fin can have separated. After payload deployment, the Target Differentiation System (TDS), controlled by a Raspberry Pi 3 Model B microcontroller, will control all autonomous tasking for the onboard TDS. The TDS will use a Raspberry Pi Camera Module v2 to capture images of the landing zone. The microcontroller will process the images onboard, locate the targets in the landing zone, and differentiate between them. Once landed, the servo-controlled Upright Landing System (ULS) will deploy and upright the payload from its landing orientation if it is not already upright. Telemetry data from the onboard orientation sensor will confirm the upright landing. |
| Payload 2 | Overview<br><br>N/A |

| Test Plans, Status, and Results | |
|---|---|
| Ejection Charge Tests | Black powder ejection charge testing will take place to confirm calculations. These calculations rely on a constant, which converts cubic inches of pressurized volume to grams of black powder, to find the ideal pressure for a certain separation force. Testing for the main recovery system will be conducted using the completed nosecone and avionics bay sections. Testing for the drogue chute will be conducted using the deployment test rig. Successive ejection tests will be performed based on the performance of the initial tests. |
| Sub-scale Test Flights | The launch vehicle successfully decoupled at apogee with a good release of the fin can section which then guided the payload and tethered drogue parachute out without impedance. During the descent, back towards the ground the ARRD failed to disconnect the payload from the rocket body. This caused the payload to remained bound to the launch vehicle the entire duration of the flight. The main parachute was programmed to eject from the nose cone section, but neither the main or backup charges ignited for the main parachute. This indicated improper wiring or altimeter malfunction. However, the Jolly Logic controlled payload parachute deployed at a pre-programmed altitude of 700 ft slowing the descent of the launch vehicle. Unfortunately, due to the main parachute failing to deploy, the rocket came down with more force than predicted. Impact resulted in the loss of one of the fins breaking off and two of the four payload legs coming detached from the payload body. However, all detached components were reclaimed during retrieval. |
| Full-scale Test Flights | The full-scale test flight will take place on February 25 or 26, 2017. The test will validate all launch vehicle and payload systems and provide complete confidence in mission success prior to FRR. The payload will implement a target differentiation system, parachute recovery system, and upright landing system. The launch vehicle recovery system timing and sizing wil lbe confirmed. Target apogee and altimeter accuracy will be tested and necessary weight adjustments will be made in the weeks preceeding FRR. |

NC STATE UNIVERSITY

# Milestone Review Flysheet

| Institution | NC State |
|---|---|

| Milestone | Critical Design Review |
|---|---|

| Additional Comments |
|---|
| |