NC STATE UNIVERSITY

Tacho Lycos
2017 NASA Student Launch
Flight Readiness Review

High-Powered Rocketry Team

911 Oval Drive

Raleigh NC, 27695

March 6, 2017

Table of Contents

Table of Tables

Table of Figures

Table of Appendices

Summary of FRR

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

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

1.2. Launch Vehicle Summary

1.2.1. Size and Mass

Table 1: Size and Mass Properties

FRR	
Length	125.0 in
Diameter	6.2 in
Loaded Weight	52.6 lb
Center of Pressure	91.8 in
Center of Gravity	78.0 in
Stability	2.25 Caliber
Apogee	5170 ft
Max Velocity	640 ft/s
Max Acceleration	411 ft/s^2
Recovery System	1 Drogue Parachute 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. It is 26.2 in. long and has a diameter of 2.95 in. The motor uses 4 propellant grains and is housed within an Aerotech 75mm/5120 casing. This motor provides the best stability and performance characteristics for carrying the launch vehicle to the target altitude.

1.2.3. Recovery System

The vehicle will descend in three sections attached by shock cord and supported by one 2 ft. diameter drogue parachute and one 14 ft. diameter main parachute. At apogee, the launch vehicle will separate between the fin can and payload bay thus ejecting the payload and deploying the drogue chute. At 1100 ft. AGL the launch vehicle will separate between the nosecone and upper airframe and the main parachute will deploy. The launch vehicle will touchdown with a kinetic energy of approximately 67.8 ft-lb and velocity of 9.87 ft/s, which will be discussed in §3.3.5.

1.2.4. Rail Size

Based on the motor selected, the launch weight of 52.6 lb., and the requirement of a launch rail exit velocity no less than 52 feet per second (fps), a 144 in. (12 ft.) rail will be required. A rail of this length will allow the launch vehicle to exit the rail at no less than 65 fps, based on results in §3.3.4.

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 an advanced retention release device (ARRD) 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.

2. Changes Made Since CDR

2.1. Vehicle Criteria

No major revisions have been made to the launch vehicle since CDR. All changes are based on the differences between the actual component dimensions and those estimated during CDR. The vehicle has gained approximately 3 pounds of mass based on actual component weights being greater than estimated during CDR. The stability margin has also increased by 10 percent from 2.07 cal. based on estimations to 2.25 cal. after vehicle construction. The significant increase is a result of the nosecone being heavier than predicted and the fin leading edges being rounded as opposed to flat. The vehicle also gained 3 in. during construction due to the nosecone being 2 in. longer than predicted and the fin can body being extended 1 in. to aid construction. All bulkheads are now 0.5 in. thick in order to increase structural rigidity at drogue recovery harness connection points. This change was also made to promote uniformity and prevent construction mishaps.

2.2. Payload Criteria

The payload body features an interface to connect the body tube to the retainer, known as the flange. The flange material as presented in the CDR was aluminum 6061-T6; however, the body tube material was polycarbonate. It was determined that the material of the flange and body tube should match to improve the connection. Documentation was submitted to NASA to substantiate the change request, and the change was approved.

2.3. Project Plan

Following a less than successful launch, the team will be repairing the vehicle and preparing for a relaunch. There are two open launch windows, March 18th 2017 and March 25th 2017. The need to relaunch not only extends the vehicle testing timeline but also adjusts the full-scale budget to reflect the need for three total launches. An additional L2200G reload must be purchased increasing the cost allocated for motor reloads from $500.00 to $750.00.

Additionally, E-Council and Student Government Association have made their decisions regarding funding. Cumulatively, the NC State High-Powered Rocketry Club has received $1,950, reducing our projected budget from $19,300.00 to $16,200.00.

3. Vehicle Criteria

3.1. Design and Construction of Launch Vehicle

3.1.1. Changes Made to Vehicle since CDR

As stated in §2.1, no significant changes were made to the launch vehicle between CDR and the full-scale test flight. Only minor revisions were made to component length and weight based on actual dimensions as opposed to those stated by manufactures.

The bulkheads that support the drogue recovery harnesses – at the aft. avionics bay and fin can – were increased from 3/8 in. to 1/2 in. thick to promote uniformity between all bulkheads and increase structural rigidity at those locations.

3.1.2. Safe Launch and Recovery Features

3.1.2.1. Structural Elements

The vehicle body and couplers are constructed out of 6 in. diameter G12 garolite filament-wound fiberglass tube. This tubing provides tensile strength in the range of 35,000 psi and is on the same order as 6061-T6 aluminum. Along with the improved strength properties, fiberglass offers greater wear resistance and waterproofing compared to other body tube components such as phenolic or Blue Tube.

Bulkheads, centering rings, and the engine block are comprised of 1/8 in. thick 3-ply aircraft. grade birch plywood sheets epoxied together using West Systems 105/206 epoxy/hardener resin system. Note that all future references to epoxy, bonding, or joining imply use of the epoxy system stated above, unless otherwise noted. Bulkheads are constructed from 4 sheets, totaling 1/2 in. thickness, centering rings from 3 sheets, totaling 3/8 in. thickness and the engine block uses 5 sheets, totaling 5/8 in. thick. All plywood structural components are epoxied to the fiberglass body tube and/or couplers. Bulkheads provide the connection point from the recovery hardware to the vehicle body tube while the engine block and centering rings retain the motor tube, and thus the motor, during launch.

The fins are constructed from the same birch plywood using 3 sheets for a total thickness of 3/8 in. and are laminated using the same West Systems combination. The fins provide added retention of the motor tube during launch as they are joined to the motor tube and slotted through the body tube.

All bulkheads are fit in the body tube such that the load they experience from the recovery harnesses pulls them towards the coupler they are mated against. All couplers are epoxied in place and provide an extra form of retention during descent. The only bulkhead that is not epoxied to the body is the aft. bulkhead in the avionics bay and it is joined to the forward AV bay bulkhead during flight using 2, 5/16 in. diameter threaded rods of 6 in. in length. These rods secure the bulkhead in place and primarily prevent rotation and forward translation within the AV bay during flight.

The aft. side of the coupler joining the AV bay and payload bay is permanently connected to the payload bay using epoxy. The forward side of this coupler is attached to the AV bay during flight using 4, #8 stainless steel machine screws backed with nuts.

Three, 5/16 in. threaded rods are screwed into hex nuts that are fixed within the fin can bulkhead. These threaded rods are used to support the payload during the forces experienced during launch and prevent it from translating aft. and crushing the altimeters used to detach the payload from the fin can.

3.1.2.2. Electrical Elements

Figure 1 shows a schematic of the electrical elements in the avionics bay of the launch vehicle. Black powder charges are discharged using StratoLogger CF altimeters powered by 9V batteries and armed with a rotary switch.

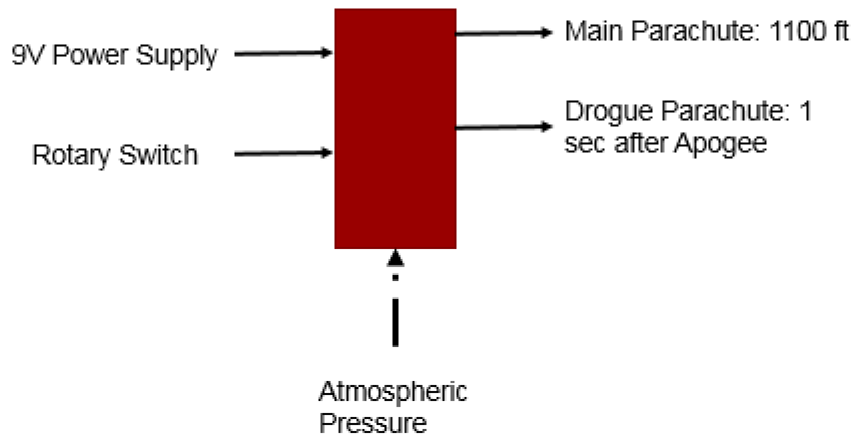


Figure 1: Electrical Elements of Launch Vehicle

3.1.2.3. Drawings and Schematics

As stated in §3.1.1, there were minimal design changes made to the launch vehicle between CDR and the full-scale flight. The vehicle is broken in 4 main sections during assembly and 3 during flight. As seen in **Figure 2**, from forward to aft, the sections are Nosecone, Avionics Bay (AV), Payload Bay (PB), and Fin Can. During flight, the AV Bay and PB will remain connected while the PB and fin can will separate releasing the PBR and the drogue chute. The nosecone and AV Bay will separate at a controlled altitude of 1100 ft. releasing the main chute.

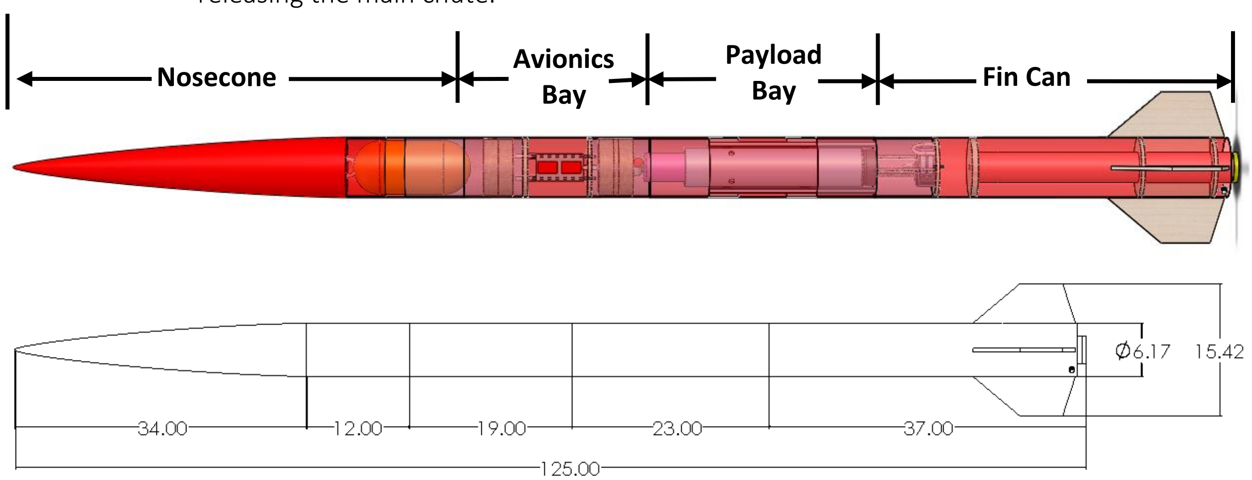


Figure 2: Full-Scale Vehicle Assembly

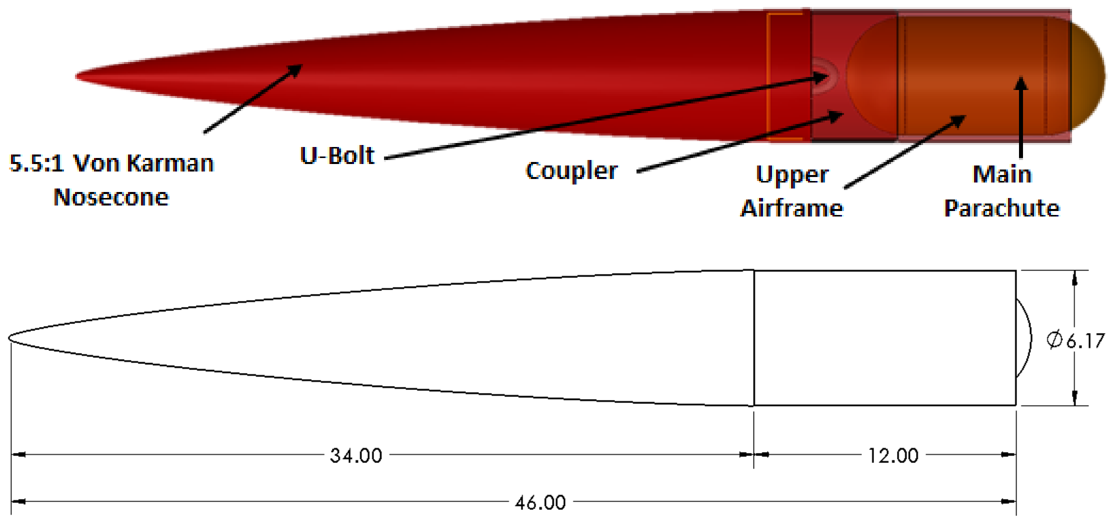


Figure 3: Nosecone Assembly and Drawing

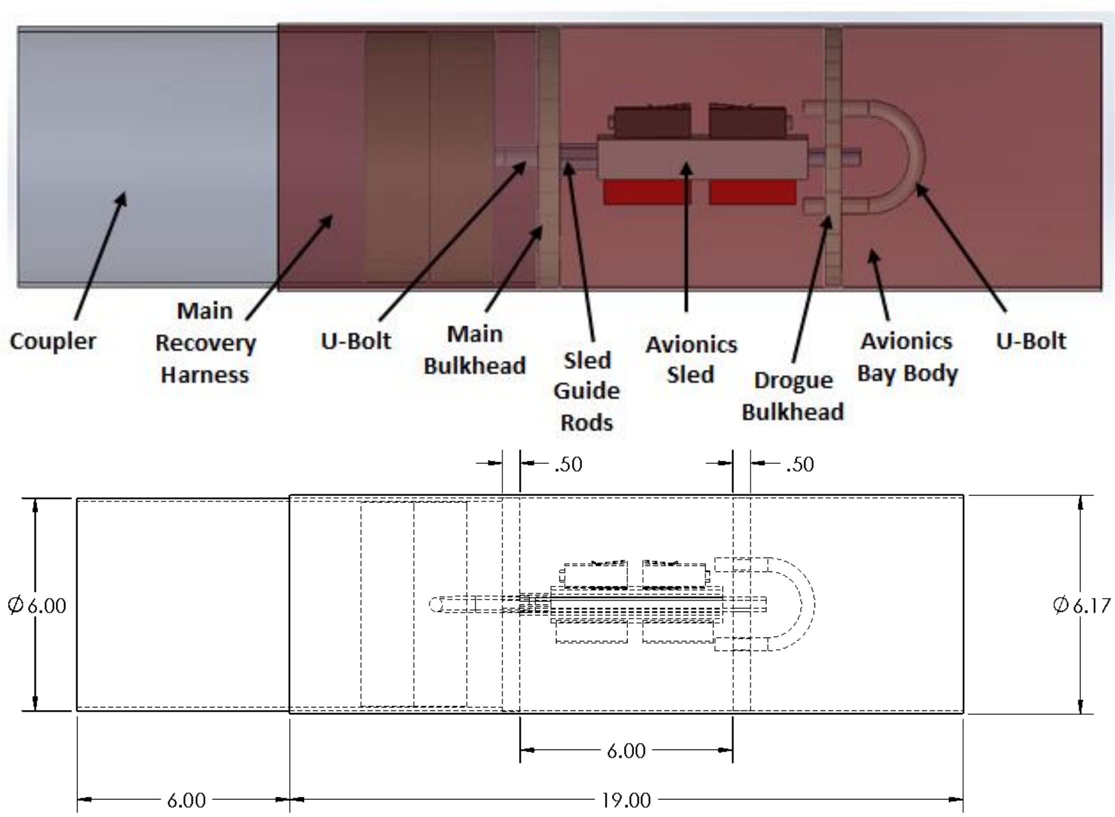


Figure 4: Avionics Bay Assembly and Drawing

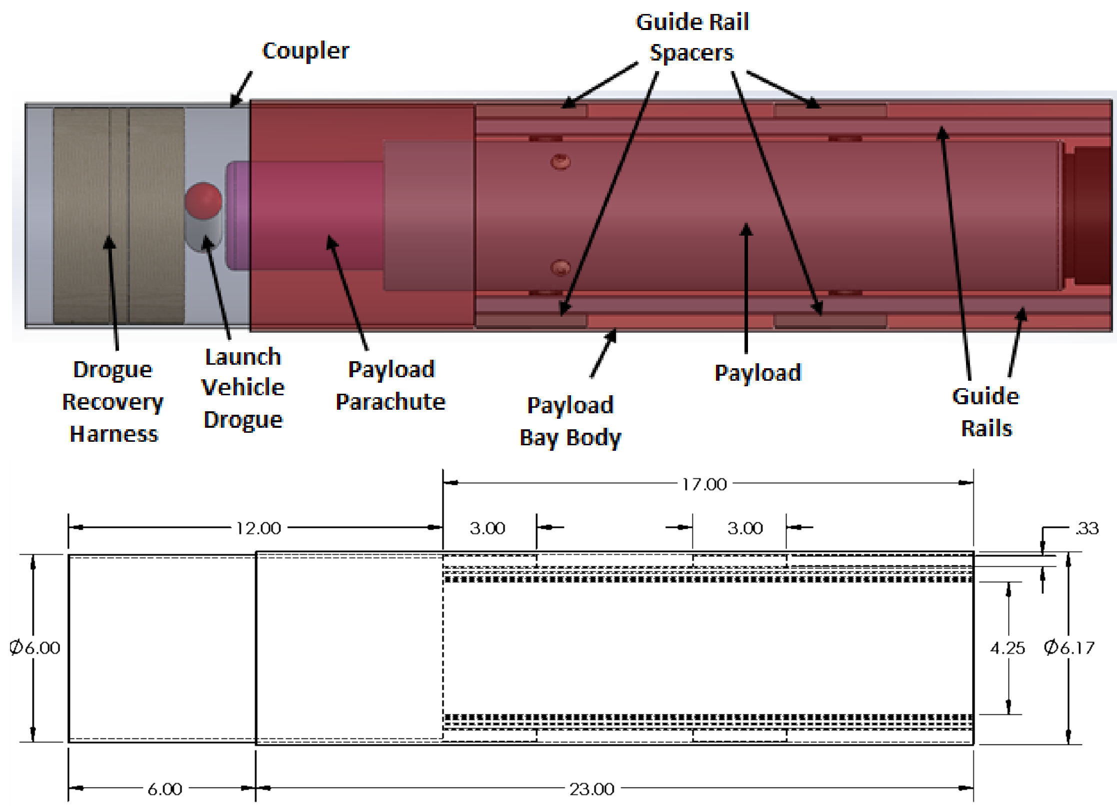


Figure 5: Payload Bay Assembly and Drawing

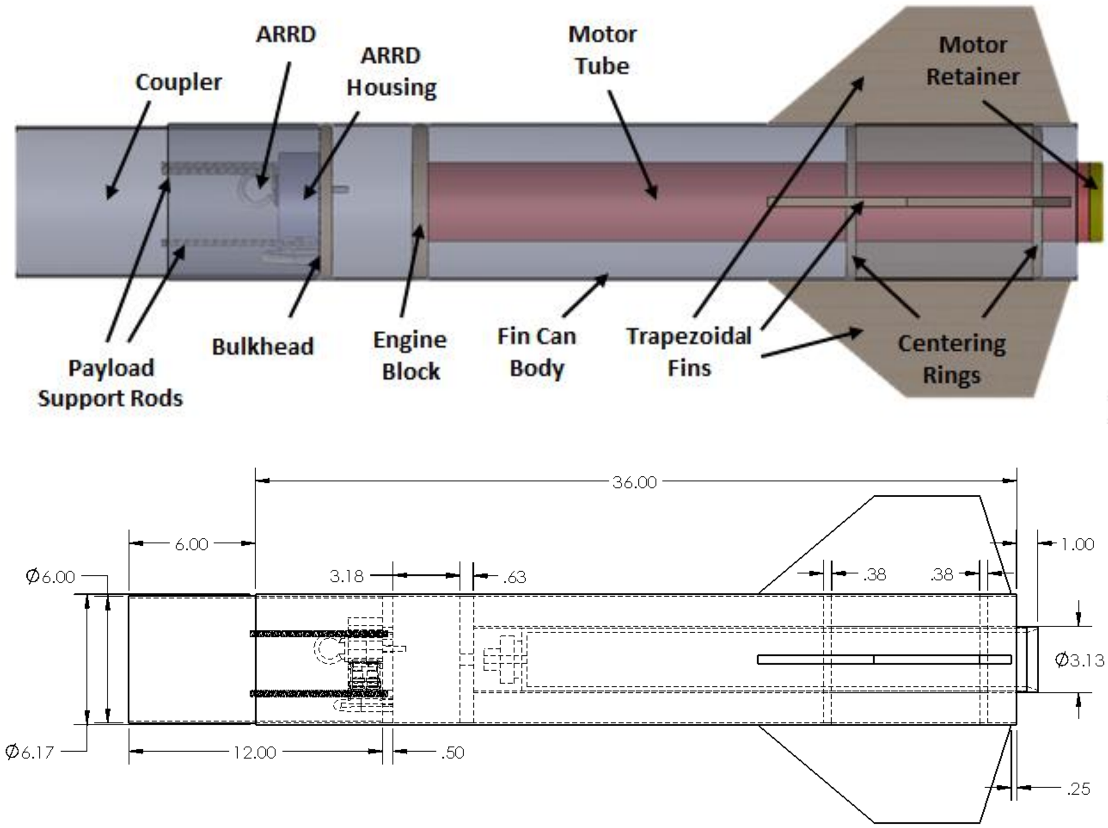


Figure 6: Fin Can Assembly and Drawing

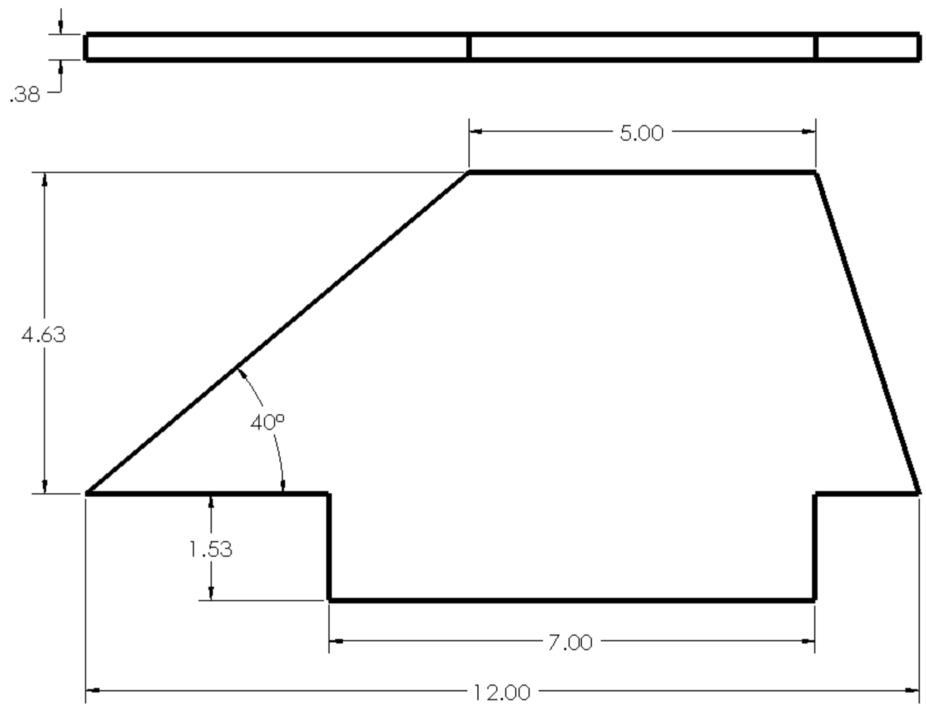


Figure 7: Fin Dimensions

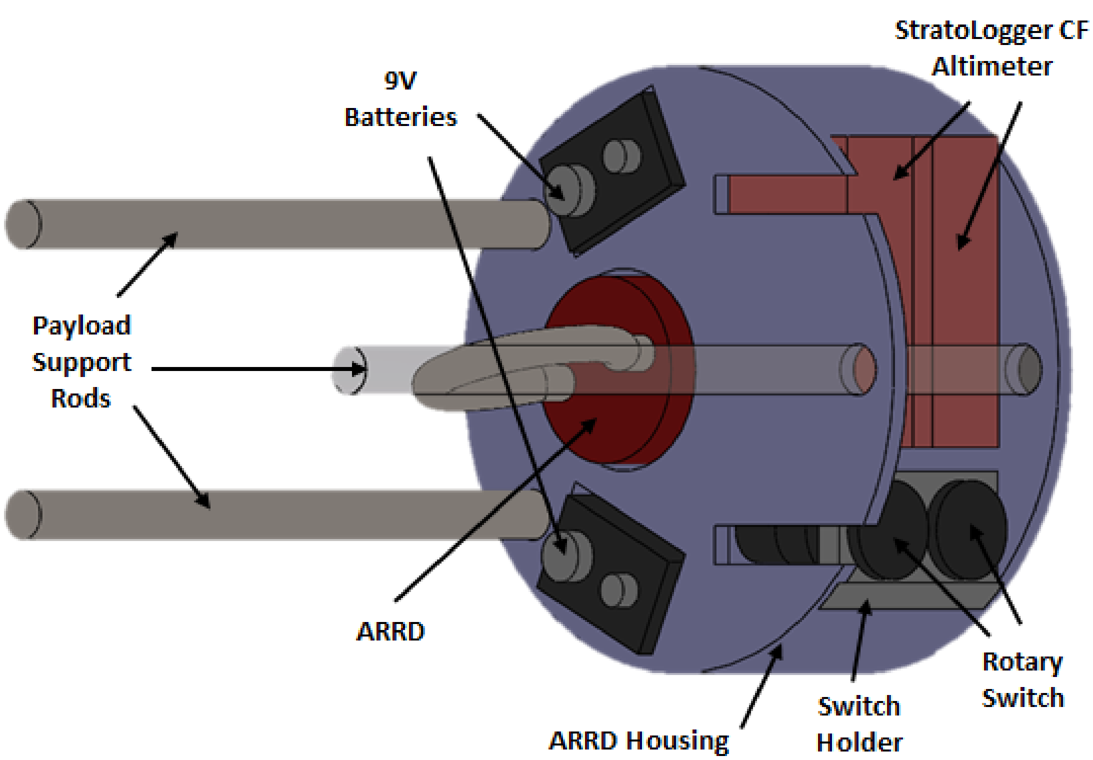


Figure 8: ARRD Housing Assembly

3.1.3. Flight Reliability Confidence

Testing was conducted on the altimeters, black powder charges, and parachutes prior to the scheduled launch of the full-scale vehicle. Along with these tests, two subscale flights and one full scale flight have proven the design worthiness. Some set-backs were encountered on the first subscale and first full scale flight but they were based in the construction of the vehicle not the design itself. The second subscale launch went as planned, that is, all ejection charges fired and separated the vehicle as planned and the ARRD released the payload at apogee. During this flight, there were no anomalies and all sections of the vehicle were recovered without harm.

The team is confident that the full-scale launch vehicle will meet the mission success criteria because the launch vehicle has performed well and reached the projected altitude for both the subscale and full-scale vehicles. Full information about the full-scale launch can be found in § 3.4.

3.1.4. Construction Process

Fiberglass body tube was purchased in lengths of 12 in., 36 in., and 48 in. Along with this a 36 in. fiberglass tube for the motor was purchased. The 12 in. (upper airframe) and 36 in. (fin can) body tubes did not require cutting as they were already at length. The 48 in. tube was cut in two segments of 19 in. and 23 in. for the avionics bay and payload bay respectively. The 36 in. motor tube was cut one time to a length of 26.5 in. Two fiberglass couplers were purchased with lengths of 12 in. and required no modifications. One coupler had to be purchased in a length of 14 in. due to supplier availability, and was cut to size using the same saw as used on the body tube. Figure 9 shows the pre-cut segments of body tube while Figure 10 shows the drop saw used to cut the pieces.

Figure 9: As-Purchased Body Tube and Coupler
(from left. to right: 12 in. body, 36 in. body, 48in. body, coupler)

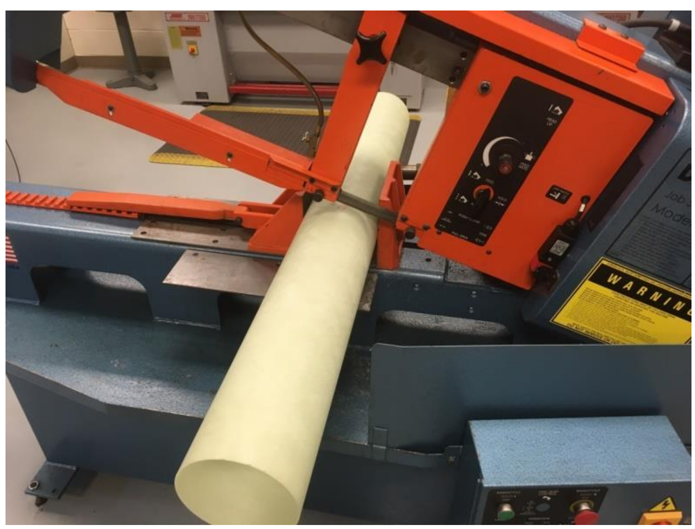


Figure 10: Drop saw cutting body tube to length

Bulkheads, centering rings, the engine block, and fins were constructed from laminating sheets of 3-ply 1/8" birch plywood using West Systems 105/206 resin system. For reference, all future mentions of epoxy or West Systems will be in regard to the 105/206 combination unless otherwise stated. These items were cut out using a Universal Laser Systems VLS 6.60 Laser Table shown in Figure 11. The fins used 3 layers of plywood, all bulkheads used 4 layers, all centering rings used 3 layers, and the engine block used 5 layers. Once the layers were cut out, epoxy was liberally applied and the layups were vacuum packed in batches for no less than 8 hours each. Figure 12 shows an example of the vacuuming packing while Figure 13 shows examples of the finished bulkheads and fins. The bulkhead used in the fin can required special hexagon shaped holes be cut into 2 of the layers in order to accommodate 4, 5/16” hex nuts. These hex nuts retain the threaded rods used to support the payload and ARRD during flight and are permanently contained within the bulkhead. This bulkhead was laminated in the same way as other bulkheads but with special care such that no epoxy filled the nut holes by placing small strips of blue painter’s tape over them during the vacuum stage. This tape was drill out following the epoxy cure stage of construction. Figure 14 shows this bulkhead during the stages of its construction.

Figure 11: Universal Laser Systems VLS 6.60 Laser Table

Figure 12: Lamination and vacuum seal process

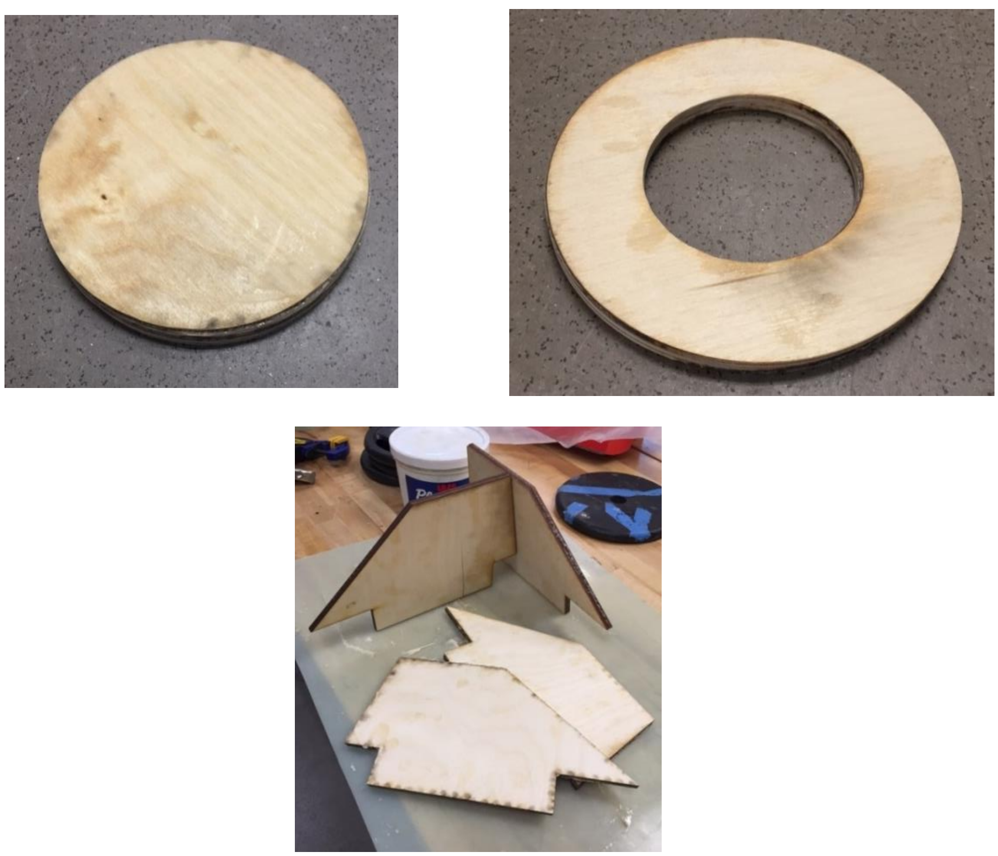


Figure 13: Finished plywood laminations
(Clockwise from upper right: centering ring, fins, bulkhead)

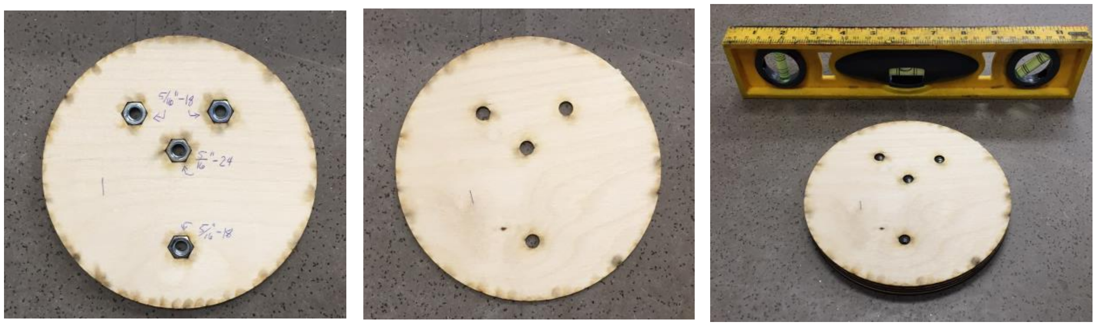


Figure 14: Fin Can Bulkhead (from left. to right): Layer with hex nuts inserted, layer with laser cut holes for rods, completed bulkhead

Following plywood lamination, all pieces were sanded on the edges to remove excess epoxy. The fins were further sanded on the leading and trailing edges to achieve a rounded shape for reduced drag during flight, shown in Figure 15. After sanding was completed, 5/16 in. thick zinc-plated steel U-bolts were connected to the nosecone and two avionics bay bulkheads, all of which implemented backing plates. A galvanized, cast steel eye-bolt rated for 1200 lb with backing nut and washer was connected to the fin can bulkhead. An eye-bolt was used here due to limited space taken up by the ARRD housing. Once the bolts were installed, two terminal blocks and two PVC blast caps were installed – using epoxy – on one side of each avionics bay bulkhead. An example of a completed bulkhead can be seen in Figure 16.

Figure 15: Comparison of fin pre-sanding and post-sanding.

Figure 16: Aft. (left) and forward (right) view of the completed AV bay bulkheads

Once the plywood pieces were constructed and the body tube was prepared, the components could be connected to form each section assembly. The nosecone, shown in Figure 17, and its shoulder were shipped in two pieces. The nosecone shoulder is 9 in. and required slight sanding of the forward edges to fit. The nosecone bulkhead was sanded to fit forward of and flush with the shoulder once installed. This shoulder was inserted 3 in. into the nosecone and secured by placing epoxy around all contact surfaces between the coupler, bulkhead, and nosecone. Once this epoxy was cured, the upper airframe was fit over the remaining 6 in. of the shoulder and the two were epoxied in place. The finished nosecone assembly can be seen in Figure 18.

Figure 17: As-Purchase 5.5:1 Von Nosecone

Figure 18: Completed Nosecone Assembly

The AV sled is constructed from two sheets of 3.00” x 4.25” x 0.25" Lexan, two aluminum 0.5 in. tubes with 5/16 in. through holes, and epoxy to join all surfaces. From here, two aluminum 9V battery clips are epoxied to one side to support the batteries in the radial direction. Velcro straps were then installed to support in the axial direction. The altimeters used to control the recovery ejection charges are then bolted to the opposite side of the AV sled with #4-40 machine screws and nuts. The completed AV sled can be seen in Figure 19.

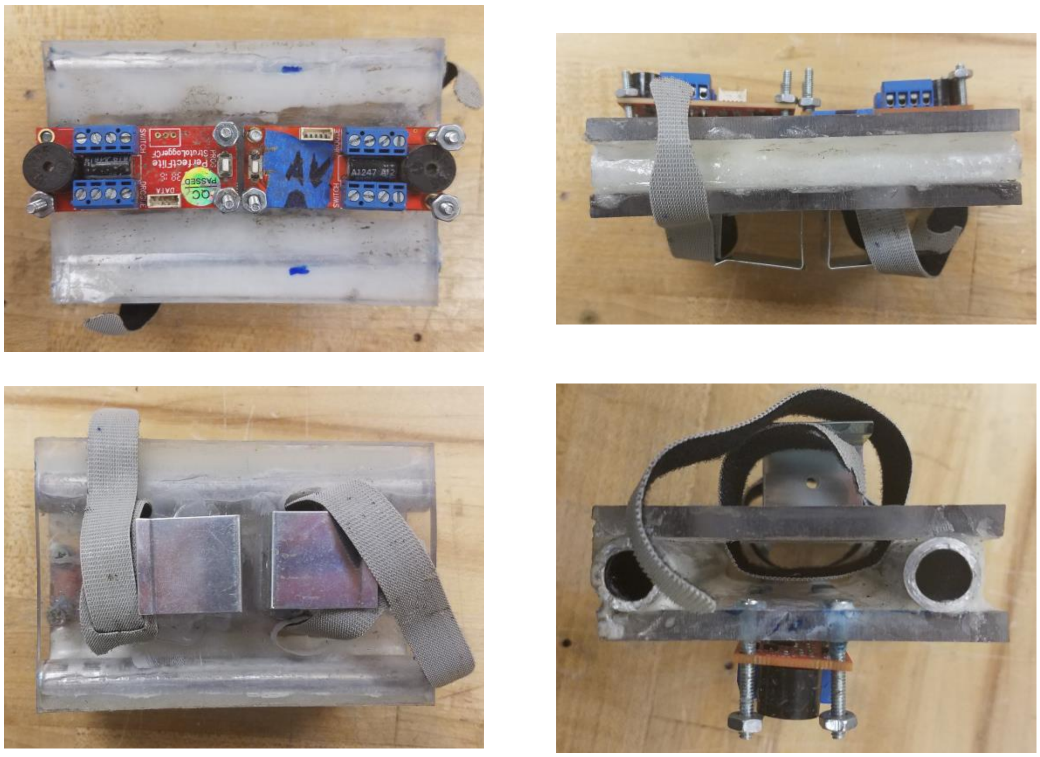


Figure 19: AV Sled Assembly

The construction of the AV bay assembly started by connecting the forward, fixed AV bay bulkhead and coupler to the AV bay body tube (19 in.). The bulkhead and coupler were bonded to the body tube using epoxy and all connection surfaces. Four 1/4 in. holes were drilled for the altimeters to breathe and two 1/2 in. holes were drilled for the switches to connect through. Examples of which can be seen in Figure 20. This completes the connection of all fixed components on the AV bay. The assembly of the removable portions of the avionics bay begins by connecting one 5/16 in. coupling nut on each end of the forward bulkhead U-bolt such that half the length is over the U-bolt with the rest reserved for the threaded rods. Once the threaded rods are inserted, the fully assembled AV sled can slide into the AV bay. Figure 21 shows the forward and aft. views of the AV bay at this point. Once the sled is inserted and all wiring is completed, the aft. avionics bulkhead slides over the ends of the threaded rods and is secured using hex nuts on either side. This completed assembly of the AV bay can be seen in Figure 22.

Figure 20: AV Bay Breather and Rotary Switch Holes

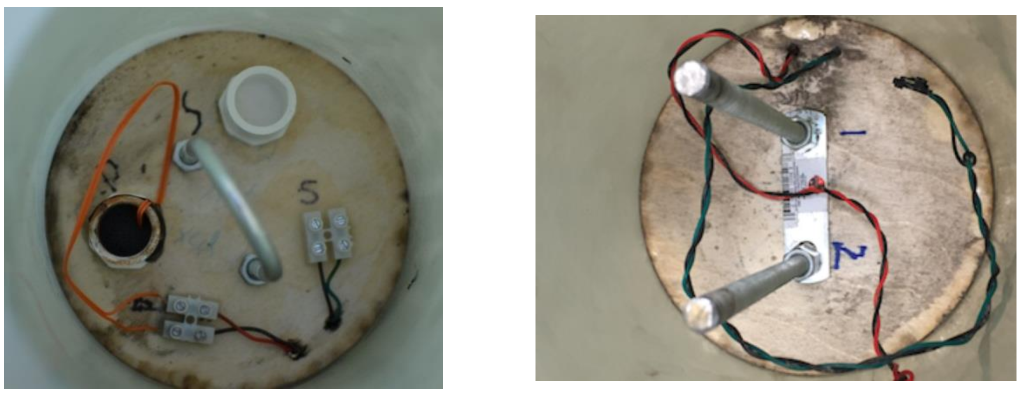


Figure 21: Forward (left) and aft. (right) view of AV assembly prior to AV sled insertion

Figure 22: Aft. view of AV bay assembly with AV sled installed (left) and final aft. bulkhead installed (right)

Construction of the Payload Bay began with bonding the payload bay body tube and a coupler by placing epoxy on all connection surfaces and inserting the coupler 6 in. into one end of the body tube. Next, spacers, as seen in Figure 23, for the 0.50” x 1.00” x 17.00” 1010 guide rails were 3D printed out of ABS plastic. These spacers were prepared to be epoxied to the wall of the payload bay body tube and the guide rails by sanding and flame treating per West Systems recommendation for bonding hard plastics. Two spacers of 3.00” x 1.00” x 0.31” were used on each rail with one placed 6 in. from the aft. end of the body tube and the other mated against the coupler. The rail alignment jig, shown in Figure 23, was used to ensure both rails were exactly 180° offset from each other prior to the application of epoxy. The aft. end of the completed payload bay assembly can be seen in Figure 24

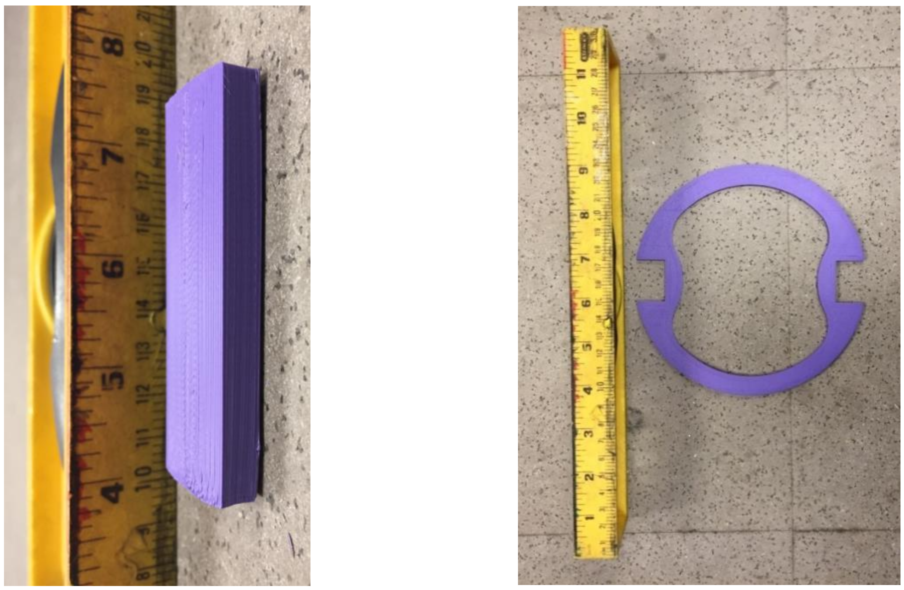


Figure 23: Rail spacer (left) and rail alignment jig (right)

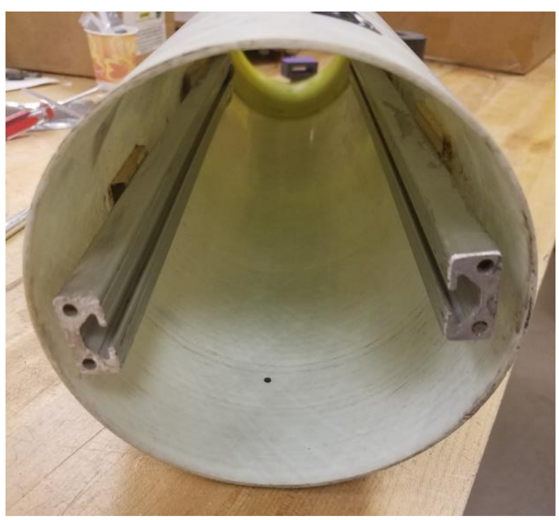


Figure 24: Aft. end of payload bay showing rails and spacers

Construction of the Fin Can begins by cutting slots into which the tabs of the fins can be inserted. This was done using the oscillatory multi-purpose saw seen in Figure 25. Next the forward centering ring was bonded to the fiberglass motor tube, shown in Figure 26 such that the aft. surface would mate flush with the forward surface of the fin tabs. (A measurement error was made such that the motor tube protrudes an extra inch from the aft. end of the body tube.) The motor tube with forward centering ring attached was then inserted into the body of the fin can and epoxy was applied to the forward and aft. connection points of the centering ring and body tube, as seen in Figure 26. Using the 3D printed fin alignment jig, all four fins were inserted into the slots and epoxy was used to bond all connection points between the fin tabs, motor tube, centering ring, and body tube. Cotton flock was added to the epoxy in order to increase viscosity and prevent dripping during the curing cycle. Figure 27 shows the application of epoxy in this section of the fin can. The final centering ring was pressed against the aft. side of the fin tabs and epoxy was applied to all mating surfaces, as shown in Figure 28. Once the final centering ring was installed, a 75 mm motor retainer was bonded to the motor tube. The last step in ensuring full motor retention was to insert the engine block at the forward end of the motor tube and apply epoxy to all surfaces. Once all of the components had cured, the fin can bulkhead and coupler were bonded to the forward side of the body tube in the same manner as with the forward AV bay bulkhead. Lastly, fillets between the fins and the outside of the body tube were created using epoxy impregnated with micro balloons to increase strength and viscosity.

Figure 25: Rigid JobMax Multi-Saw

Figure 26: Motor tube and forward centering ring before and after (left. and right) being bonded to the fin can

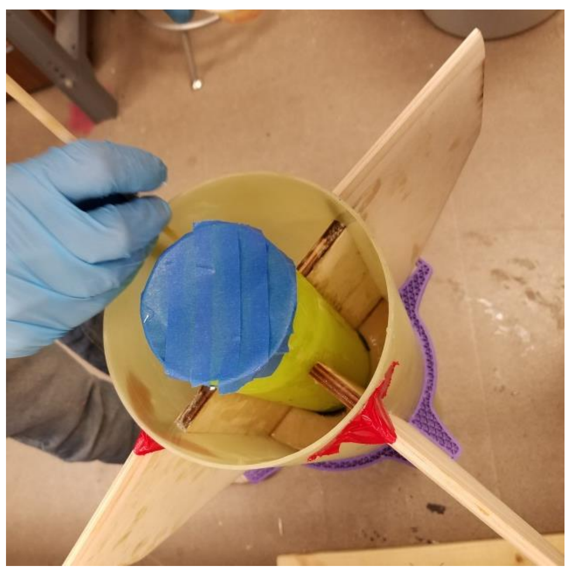


Figure 27: Aft. view of the fin can prior to final centering ring being installed

Figure 28: Aft. view of fin can, following final centering ring installation

Rail buttons were improperly installed during the initial construction of the vehicle. They were simply epoxied on without the installation of backing nuts. Prior to full scale flight testing the rail buttons were removed and placed back on the body in locations that would allow back nuts to be accessed. One rail button is aft. of the aft. centering ring on the fin can and the other is located at the CG on the payload bay. Loctite was used to secure the threads. This completes the construction phase of the launch vehicle. For further information on how the components are assembled leading up to launch please refer to the launch procedure in §6.1.

Table 2: Vehicle as-constructed weights broken down by assembly

Assembly	Weight (lbs)
Nosecone	**10.4**
Avionics Bay	**9.2**
Payload Bay	**10.4**
Fin Can	**22.5**
Lift. Off Weight	**52.6**
Touchdown Weight	**42.9**

3.2. Recovery Subsystem

3.2.1. Robustness

3.2.1.1. Structural Elements

The parachutes for the recovery system are sized per the kinetic energy guidelines from the competition requirement discussed in further detail in §3.3.5. The parachutes selected for launch vehicle recovery are a 2 ft. (24 in.) drogue and a 14 ft. (168 in.) main parachute.

Both parachutes were 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	N/A
Weight	2.2oz	60oz
Packing Volume	12.2in^3	245.15in^3

Separating the sections of the launch vehicle are ½ in. thick bulkheads. Out of the two recovery devices, the drogue parachute is deployed first at apogee and is connected to the fin can and payload bay sections of the launch vehicle. It is attached via a 25 ft. harness comprised of 3/4 in. tubular woven Kevlar shock chord. Its length is over twice the length of the launch vehicle to discourage any collision of decoupled sections. A 5/16 in. U-bolt is threaded through the avionics bay bulkhead and is attached with nuts on both sides, while the fin can is connected via a 3/8 in. galvanized cast steel eye bolt. Both the U-bolt and eye bolt are connected to the shock chord via a 5/16 in. zinc-plated steel quick link.

The main parachute is connected to the nosecone and forward avionics bay bulkheads by 5/16 in. inch U-bolts that are threaded through the bulkheads. They are secured with the same 5/16 in. steel quick links as the drogue. The main parachute is harnessed with a 25 ft. long 1 in. tubular woven Kevlar shock chord.

The recovery system is only as strong as its weakest component, so all hardware was chosen to raise the factor of safety. In terms of strengths of materials, the eye bolt has a working load limit of 1200 lb. and the quick links have a working load limit rated at 1760lb and a breaking strength of 5280 lb. The 3/4 in. and 1 in. Kevlar shock cords have strength ratings of 1500 lb. and 2000 lb., respectively.

Woven Kevlar fire resistant square wraps protect the parachutes from the black powder charges. A 12 in. square Kevlar wrap will protect the drogue and a 24 in. square Kevlar wrap will protect the main parachutes.

The fin can coupler and forward avionics bay coupler will be held to their respective mating sections using four #4-40 shear pins (i.e. each of the locations that will be separated during flight). These shear pins were tested during ground ejection tests and full-scale flight to ensure that they would yield, thus allowing the rocket to decouple and deploy parachutes.

3.2.1.2. Electrical Elements

The launch vehicle has one avionics bay with two StratoLogger CF altimeters, shown in Figure 29, that will each be powered by one 9V Duracell battery. Each altimeter will have its own dedicated rotary switch, as seen in Figure 30, that will be activated when the launch vehicle is placed up on the rails. These altimeters will be wired to terminal blocks epoxied onto the bulkheads and connected with 20-guage wire. The terminal blocks serve as a relay between the wires from the altimeters to the wires of the e-matches. The e-match connects from the terminal block into 3/4in PVC blast caps that are responsible for holding the black powder during flight.

The StratoLogger CF has proven to be a robust and reliable altimeter with intuitive wiring to the batteries and charges. The rotary switches are the preferred switch since they are difficult to turn off through bumping or any forces caused by a launch.

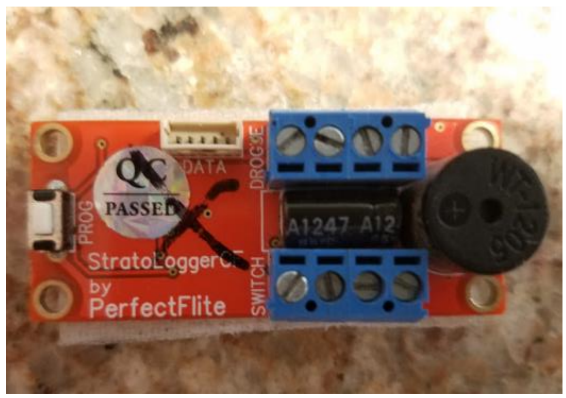


Figure 29: StratoLogger CF altimeter

Figure 30: Rotary Switch for Altimeter Activation

3.2.1.3. Redundancy Features

Using multiple black powder charges to decouple the rocket allows for sufficient redundancy. We began with Eq. *1* to give a baseline estimate of the amount of black powder to be used to separate each section.

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

Where L is the length of the section in inches, D is the diameter in inches, and 0.006 is a constant used to convert cubic inches to grams of black powder. This equation gives a charge that assumes empty volume which yielded 4.75 grams for the payload bay and 3.5 for the main cavity. This equation assumes empty volume so smaller charges were tested to begin with and ground testing yielded the sizes that were used in the full-scale launch.

There are three main ejection events each with a redundant system. Each redundant black powder charge is larger than the primary charge to ensure decoupling. At apogee, the 2 ft. drogue parachute will deploy between the middle and aft. rocket sections. The StratoLogger CF is programmed to fire the primary drogue charge of 4.0 g black powder at apogee and the redundant StratoLogger CF programmed to fire the 4.2 g black powder redundant charge 1 second later. At 1100 ft. AGL, the 14 ft. main parachute will deploy via a 3.0 g black powder charge between the nosecone and avionics bay. One second later a 4.2 g charge will fire. Both events will be controlled by the avionics bay, with the primary charges controlled by the StratoLogger CF and the secondary charges controlled by the redundant StratoLogger CF altimeter.

Controlling the ARRD event are two more StratoLogger CF altimeters that will wire directly from the altimeters into the e-match housing. The ARRD has only one area for black powder and has a recommended charge of 0.1 grams so the secondary altimeter serves as merely as insurance against one of the altimeters not working properly.

These charge sizes have been tested multiple times and were confirmed by the full-scale flight.

3.2.1.4. Drawings and Schematics

Figure 31 below shows a block diagram of the recovery system that will be responsible for the deployment of the drogue and main parachutes.

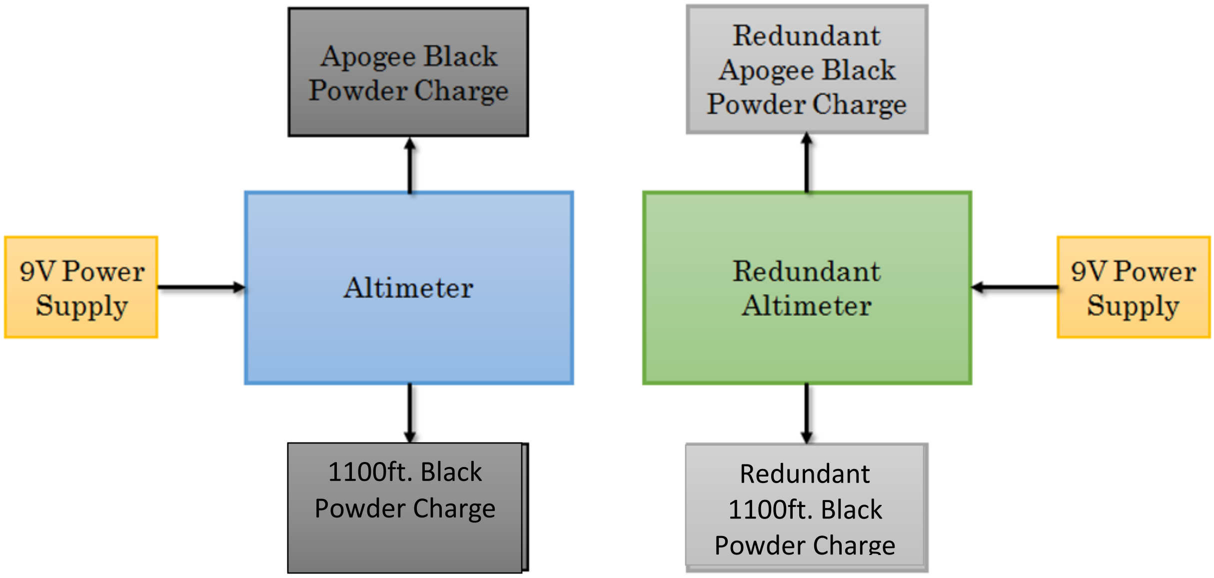


Figure 31: Avionics Electrical Schematic

3.2.1.5. Rocket Locating Transmitters

The launch vehicle will contain a BigRedBee GPS unit in order to track the descent. The GPS will be fitted and mounted on the nose cone section due to the entire launch vehicle falling as a single tethered unit. It has its own rechargeable battery and the GPS transmits at 900 MHz to a ground receiver which feeds telemetry data to Google Earth. If line of sight is lost, the location can be overlaid on a Google Earth map providing enough information to find the launch vehicle. Google Earth does not require a live internet connection therefore can provide GPS data at the launch site. An image of the BigRedBee GPS unit and receiver is shown below in Figure 32.

Figure 32: BigRedBee 900 Mhz GPS Unit and Receiver

3.2.1.6. Electromagnetic Field Sensitivity

The BigRedBee unit will be the only device on the launch vehicle which transmits high-frequency EM waves. In order to prevent any interference between the vehicle avionics and the GPS unit, the GPS will be housed within the nosecone section of the rocket which is separated from the Avionics bay by a bulkhead. Also, as additional insurance an aluminum foil barrier will be placed in the avionics section. The barrier will isolate the GPS from the altimeters used to deploy the launch vehicle parachutes. Finally, tests will be performed to ensure that the powered altimeters react in no way to the GPS' electromagnetic field.

3.3. Mission Performance Predictions

3.3.1. Mission Performance Criteria

Aside from the NSL competition requirements the team also will aim 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 throughout the flight.
- Incident free launch days.
- Design, fabricate, and fly a vehicle of exceptional quality.

3.3.2. Predictive Analysis and Flight Profile Simulation

Figure 33, below, shows a flight profile simulation from OpenRocket using an AeroTech L2200G motor. The drogue parachute is deployed at apogee and the main parachute deploys at 1100 ft. AGL. This simulation does not account for the fact that the payload mass is ejected at apogee. Therefore, the descent rates are an over estimate as the reduced mass will decrease the descent velocity of the launch vehicle. These simulations could be considered a worst-case scenario if the payload does not detach from the launch vehicle at apogee. The simulation shown was performed using a launch altitude of 600 ft. above sea level (approximate altitude in Huntsville, AL), 10 mph wind, 5° from vertical launch angle, and standard atmosphere conditions.

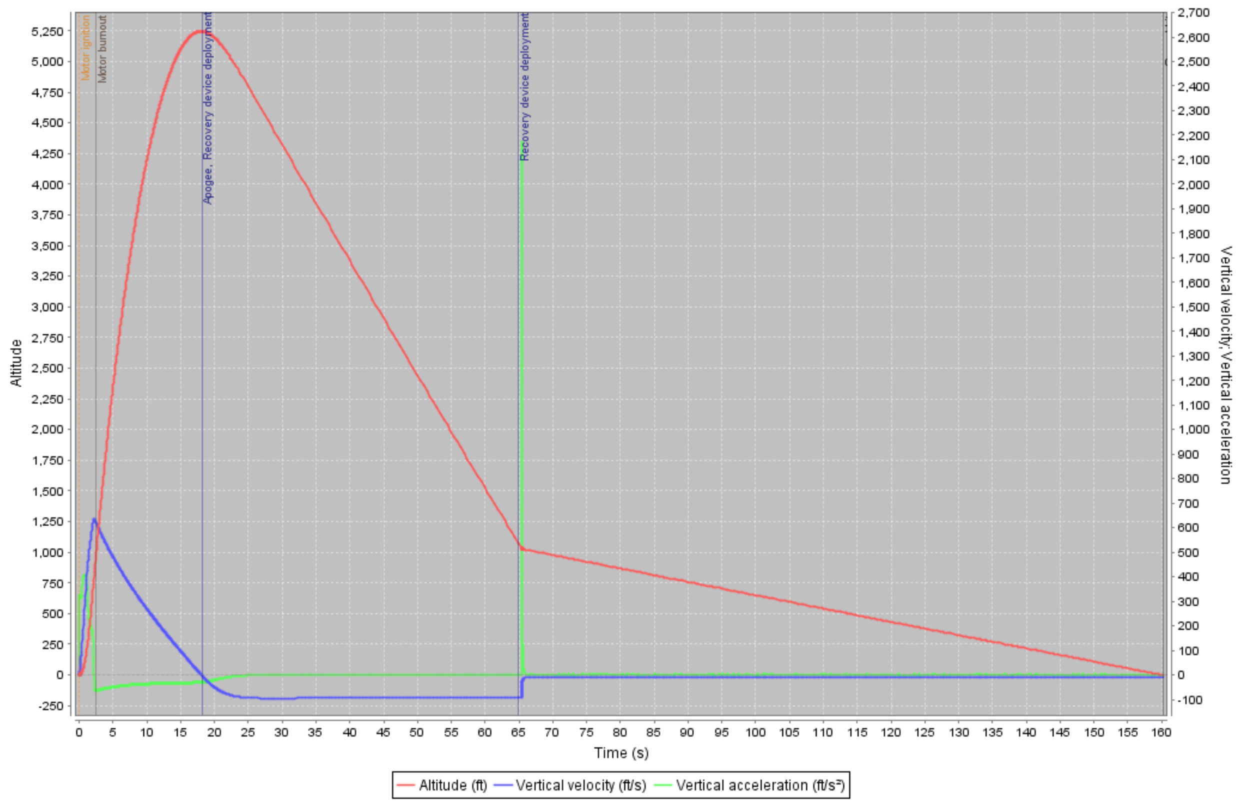


Figure 33: OpenRocket Flight Profile Simulation (Assuming steady 10 mph wind and no payload deployment)

A list of predicted apogee altitudes at various wind conditions can be found in Table 4. The predictions also take into account the percent error between the simulation and the measured flight data as discussed in §3.3.3. Based on allowable wind conditions, all predicted apogee altitudes are within 3% of the target altitude of 5280 ft. with a deviation of no more than 175 ft. The apogee altitude during competition is predicted to be 5169 ft. AGL based on an average wind speed of 10 mph in Huntsville, AL.

Table 4: Predicted Apogee Altitudes for Various Wind Conditions

Wind Speed (mph)	Simulation Altitude (feet)	Predicted Altitude (feet)
0	5306	5226
5	5276	5197
10	5248	5169
15	5229	5151
20	5195	5117

Figure 34 shows the simulated thrust curve as reported by the manufacture and reproduced in OpenRocket's library of motors.

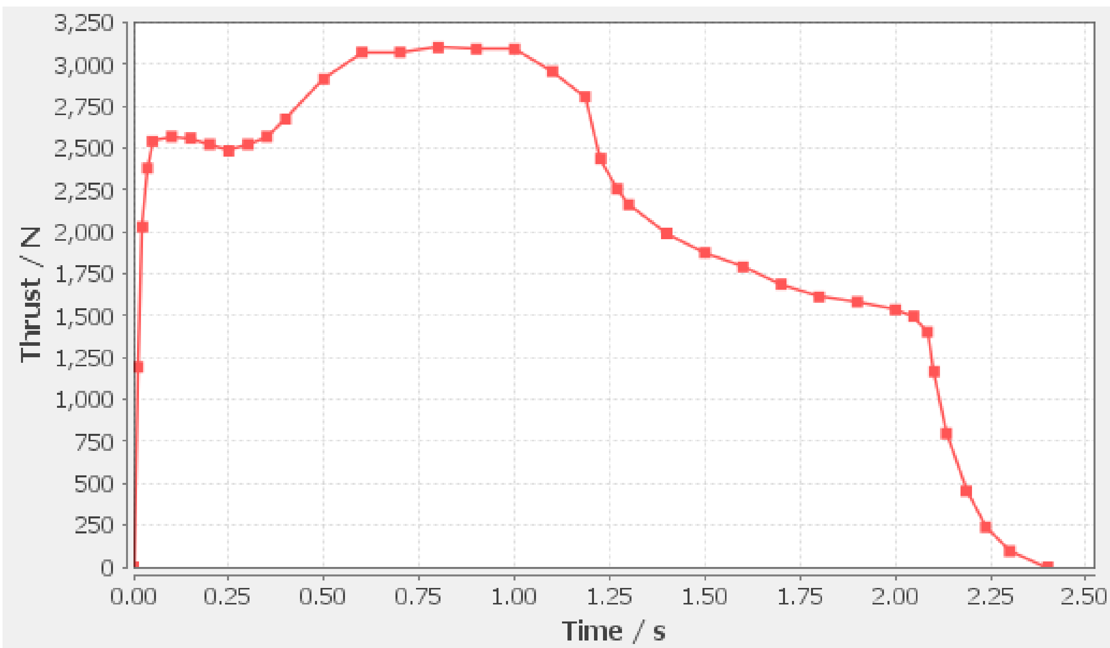


Figure 34: L2200G Motor Thrust Curve (courtesy of OpenRocket and Aerotech)

3.3.3. Comparison to Measured Values

OpenRocket was used for all flight profile simulations during the design life cycle and showed good correlation to actual flight data. During the first subscale flight OpenRocket predicted an apogee altitude of 2479 ft. and the measured altitude for the simulated flight was 2438 ft. resulting in a margin of error of 1.7%. For the second subscale flight, OpenRocket predicted an apogee altitude of 2777 ft. and the average measured altitude was 2714 ft. resulting in a margin of error of 2.3%. As stated above, the predicted altitude for wind conditions around 15 mph is 5229 ft. and the measured altitude during the full-scale test flight was averaged at 5150 ft. This results in an error of 1.5 %.

With these experimental data points, it can be seen that OpenRocket predicts an altitude of approximately 1.5 – 2 percent higher than the value measured using StratoLogger CF altimeters.

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

OpenRocket was used for estimating center of pressure (CP). The center of gravity (CG) was determined by balancing the fully constructed vehicle (launch ready) and measuring the equilibrium point. The OpenRocket model was updated to reflect this CG value by tweaking weights and adding values for epoxy. From here the stability margin could be calculated.

The datum for CG and CP were taken from the forward most point of the nosecone. For the vehicle in launch-ready configuration, OpenRocket gives a static margin of 2.25 caliber with the CG located 78.0 in. aft. of datum and the CP located 91.7 in. aft. of datum. For a Mach number of 0.6 and weight excluding propellant (post motor burn), OpenRocket gives a static margin of 2.95 cal. with a CG location of 73.9 in. and a CP location of 92.2 in. aft. of datum. The center of pressure for a Von Karman nosecone is approximately 50 percent of the length, measured from the tip of the nose.

Figure 35 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.

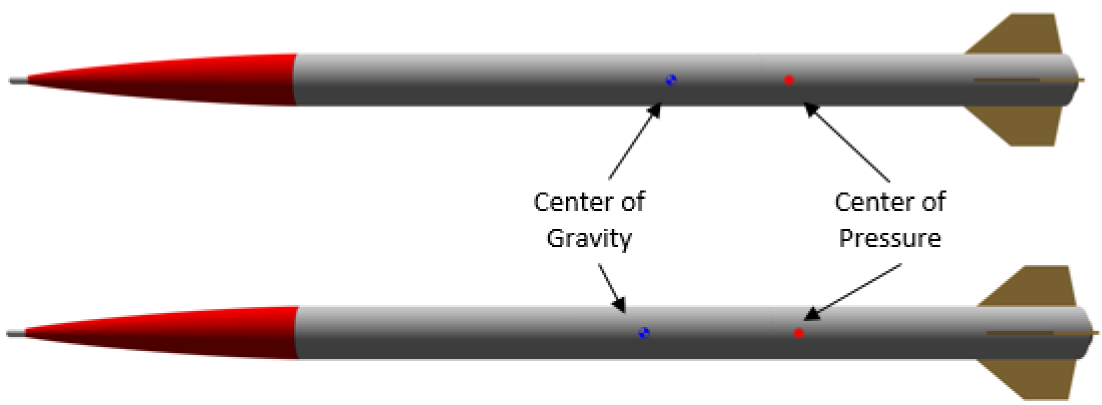


Figure 35: CG and CP locations for rail exit (top) and post motor burn (bottom)

Launch rail exit velocity is crucial to the vehicle's stability. Per 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." With the top rail button located at the CG, the rail button will travel 49 in. for an 8 ft. rail or 97 in. for a 12 ft. rail before leaving the rail. For the L2200G motor and a 96 in. launch rail, it was found that the vehicle's top rail button would leave the rail at 50.4 feet per second. If a 12 ft. rail were used, the vehicle's top rail button would leave the rail 70.9 feet per second. Based on this data, the 12 ft. rail must be used in order to allow the launch vehicle to accelerate to a velocity great enough to ensure stability.

Eq. 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. Based on these assumptions, the actual rail exit velocity will be marginally lower. These assumptions are also validated by data presented in §3.4.2, in which the rail exit velocity was found to be approximately 48 fps.

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

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 560 lb. 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).

3.3.5. Management of Kinetic Energy

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 Eq. *3* below, the velocity can be calculated to determine the speed at which the payload and rocket body can fall.

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

Knowing the mass of the body, m, and the maximum kinetic energy, KE, the maximum descent velocity, V, can be determined.

Using simulated velocity off the rails from the current design and launch rail length discussed in further detail in §3.2, the launch vehicle will be traveling at approximately 65 ft/s and will have a weight of approximately 52.6 lb. Converting the weight to slugs and solving for Kinetic energy yields 3450 ft-lb off the rails. Kinetic energy will continue increasing until full motor burn. When it reaches apogee, it will have minimum KE and being its descent back towards the ground. Kinetic energy on descent is critical in allowing the rocket body and components to be recoverable.

The current weight estimation of the rocket after burn and payload are 41.9 lb. and 4.8 lb. respectively. Solving Eq. 3 yields a maximum impact velocity of 10.73 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 Eq. *4*.

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

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

Figure 36 below shows the speed in which the rocket body will fall under different sized drogue parachutes.

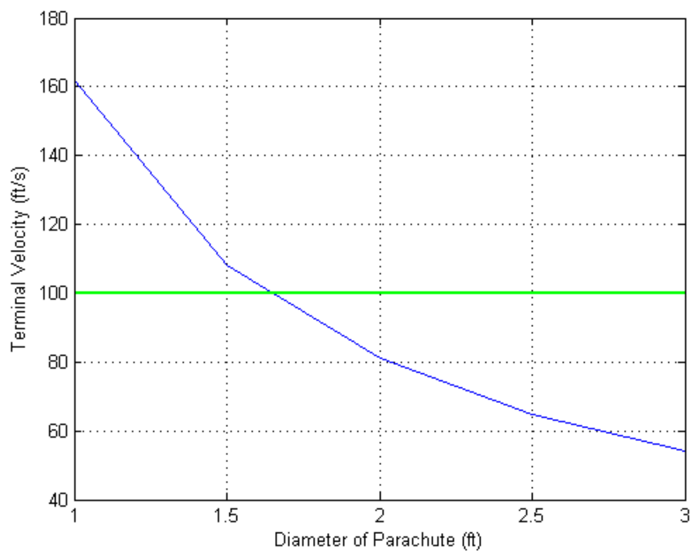


Figure 36: Vehicle under Drogue Velocity

For the drogue sizing, 100 ft/s was chosen as the maximum velocity at which the vehicle will fall. Based on Figure 36, a 2 ft. drogue parachute was chosen to deploy at apogee slowing the rocket body to 81.0 ft/s.

At 1100 ft., the main parachute will deploy between the nose cone and body tube connection. The entire main rocket will be tethered together with shock chords meaning the entire weight of the rocket will rely upon the main parachute slowing the velocity of the rocket enough to get the kinetic energy under the 75 ft-lbf threshold. As calculated above the rocket needs to be slowed to a velocity of less than 10.7 ft/s. Figure 37 below shows the impact speed compared to different diameter parachutes.

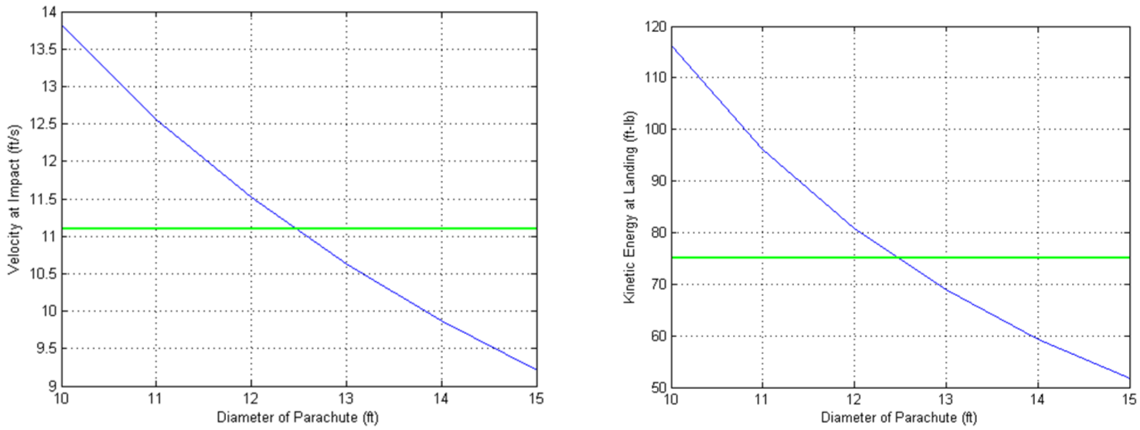


Figure 37: Main Parachute Descent Plot

From Figure 37, it was determined that a parachute of greater than 13 ft. is necessary to bring the impact force under the allowable threshold. To account for projected weight gains involved with fabrication of the rocket, a 14 ft. parachute will be used as the main parachute for the rocket so that fabrication will have some factor of safety with regard to the recovery system. The 14 ft. parachute will slow that rocket body down to an impact velocity of 9.87 ft/s and a kinetic energy of 67.8 ft-lbf.

The payload will also require a parachute deployment to complete the data collection and still fall under the impact force limits. Figure 38 shows the maximum velocity at which the payload can fall.

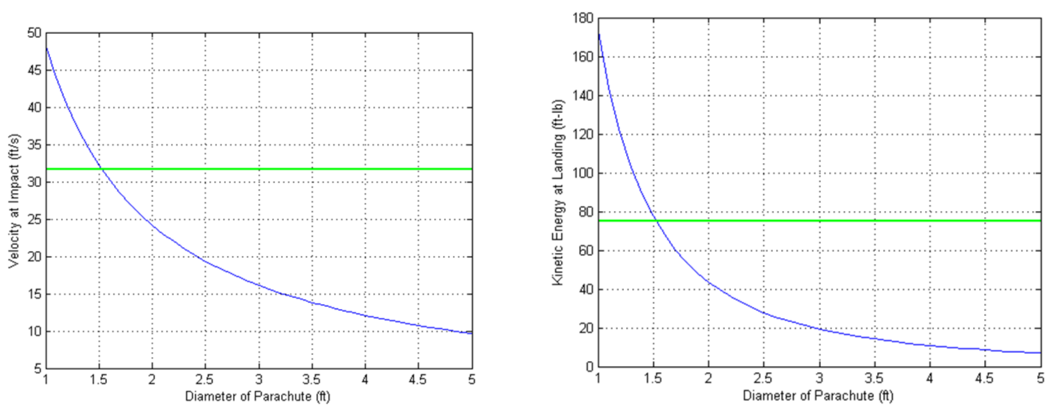


Figure 38: Payload Parachute Controlled Descent Calculations

From Figure 38, it was determined that a parachute with a 4 ft. diameter would provide enough drag to complete the mission and fall well under the maximum velocity from the requirements. The calculated impact velocity will be 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.

3.3.6. 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 at an 85° angle with the ground. Assuming an apogee of 5280 ft. and a 5° launch angle the total for each falling section is increased by a roughly 460 ft. than if launched at an angle of 90°. 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 39 showing corresponding radius of potential drift.

Table 5: Wind Drift. Predictions

Wind (mph)	Rocket Airframe (ft)	Payload (ft)
0 (blue)	460	460
5 (green)	1656	884
10 (brown)	2852	1309
15 (yellow)	4047	1733
20 (red)	5242	2157

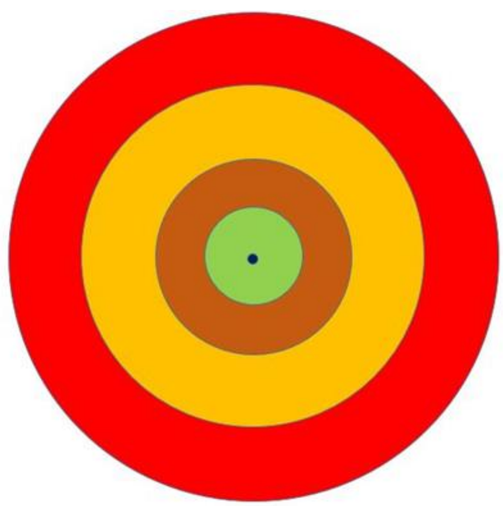


Figure 39: Wind Drift. Diagram

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. Also, note that these calculations are assuming that the parachutes fully unfurl as soon as they are deployed which is not the case in a real launch scenario. This means that actual drift. should be less than the calculated.

3.4. Full-Scale Flight

The first launch of the full-scale launch vehicle Vesuvius took place in Bayboro North Carolina on February 25th, 2016. The temperature was approximately 74 °F. The visibility was high leading up to and during launch. During launch, wind speeds were 11 mph with gust up to 15 mph. The rocket was mounted on an 8 ft., 1515 launch rail. The aft. most body tube rested upon a small 2x4 piece of wood to allow some space between the bottom platform and the propellant exit nozzle. A black and white painted PVC pipe was placed next to the rocket to determine rail exit velocity. Figure 40 below shows the rocket mounted on the rail just before motor ignition and Figure 40 shows the rocket being loaded by two team members and the club mentors.

Figure 40: Vesuvius Pre-Launch

Once the motor igniter fired, the rocket accelerated off the rails rapidly resulting in full propellant burn in less than 5 seconds. The launch vehicle maintained a slight weathercock from high stability margin and wind gusts. Figure 41 shows the rocket directly after motor ignition up until it was several hundred feet in the air.

Figure 41: 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. Also, the ARRD successfully decoupled the payload from the fin section and its descent under parachute can be seen from Figure 42 below.

Figure 42: Payload Descent

The main parachute was programmed to eject from the nose cone section at 1100 ft. The black powder charge successfully decoupled the nose and aft. sections of the launch vehicle and can be seen below in Figure 43.

Figure 43: Main Parachute Deployment

From Figure 43, the main parachute did not open fully right when the sections decoupled indicating improper folding of the parachute. It did however fully unfurl when it was closer to the ground. Also from Figure 43, only two sections of the rocket are attached and falling under parachute.

During the descent, back towards the ground, the fin can section fully detached from the tether allowing it to fall without parachute. This caused the fin can to fall in a ballistic manner until it hit the ground imbedding itself into the field. No one was hurt as all personnel were alert during the flight and a safe distance away from the descending vehicle. Figure 44 below shows the fin can imbedded into the field.

Figure 44: Fin Section Impact

Upon inspection, it was determined that the nut that held the eyebolt into the fin can bulkhead had come unscrewed thus resulting in the fin can becoming disconnected from the Kevlar harness. Since the fin section did not come down under parachute the dual deployment and recovery stage were considered unsuccessful. However, all the launch vehicle body components were recoverable with irreparable damage done to the electrical components and bulkheads within the fin section. Mitigation and design changes are discussed in further detail in §3.4.2.3. The body tube of the fin section received minimal structural damage due to the way it fell but the inner components, seen in Figure 45 below, shows the damage to insides of the fin section.

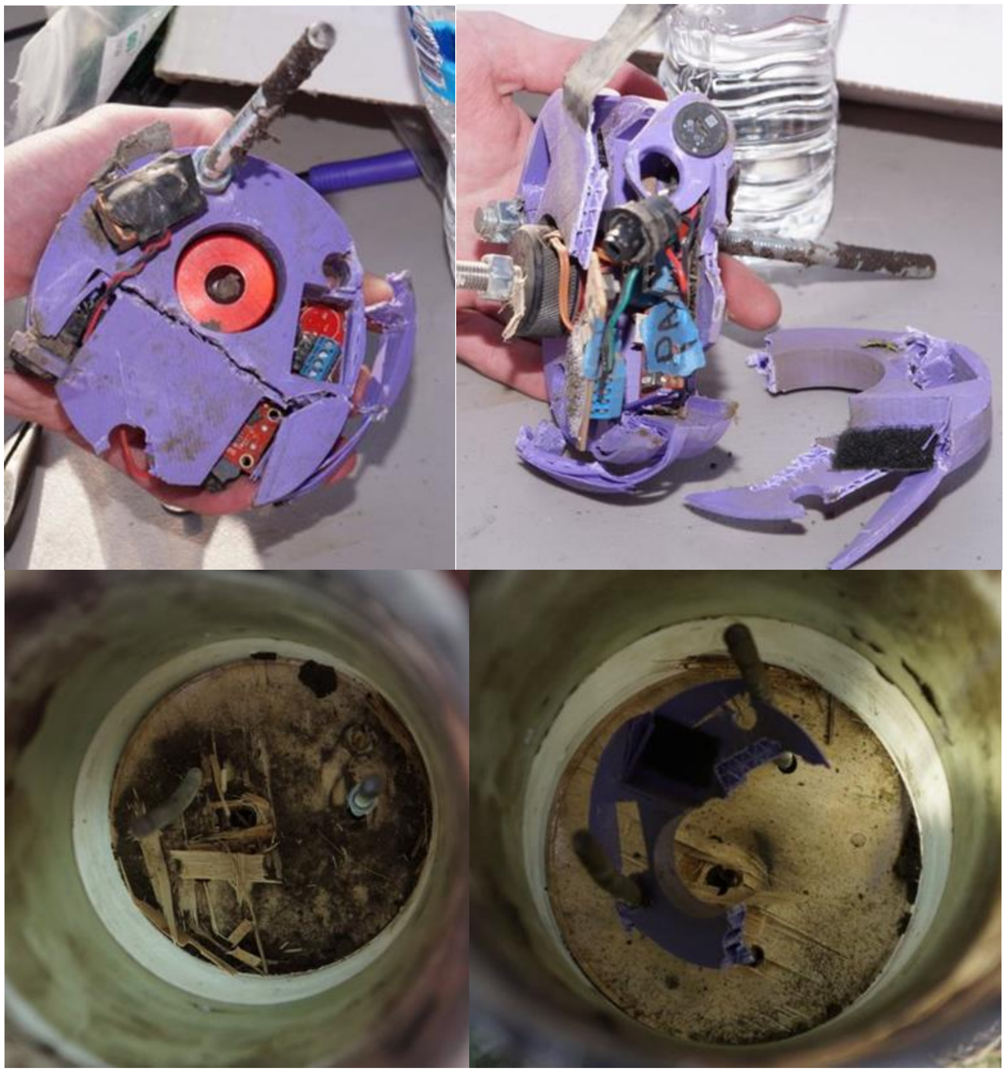


Figure 45: Fin Section Damage

Damage was sustained to the bulkhead from the ground pushing the bulkhead aft. of its position on the rocket. Also, the engine forced its way forward punching through the engine block.

Figure 46 below also shows apparent damage to one of the fins. It was possible that the payload or another part of the launch vehicle managed to impact the fin and dent it in such a way, but no other evidence of impact was found.

Figure 46: Fin Damage

3.4.1. Launch Day Conditions and Simulation

Conditions of full-scale launch were recorded to determine the accuracy of the simulation to the data provided by the onboard altimeters. The launch vehicle was built based on OpenRocket's apogee approximation along with the NASA specifications towards stability and safety parameters. Figure 47 below is a simulation run after the full-scale launch and adjusted for differences in mass that occurred through fabrication of the launch vehicle and the weather and atmospheric conditions experience during the launch.

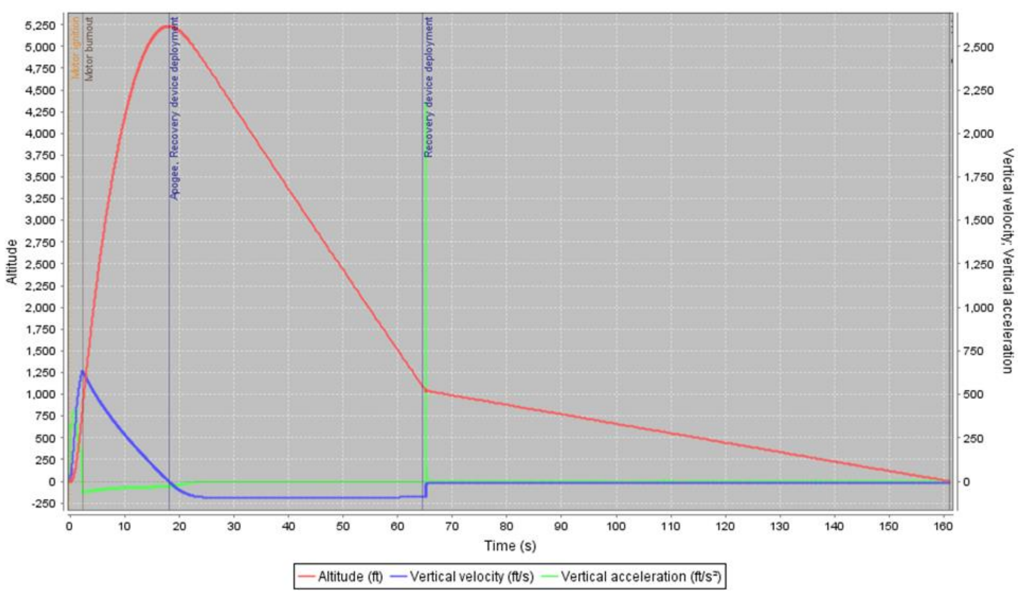


Figure 47: Open Rocket Full-Scale Simulation

From this simulation, using the same L2200G motor, the velocity off the rod is 71.8 ft/s with an apogee of 5254 ft. The maximum simulated velocity is 641 ft/s and shows the vehicle falling under drogue parachute at 91.3 ft/s.

3.4.2. Flight Analysis

There were four altimeters onboard the full-scale launch vehicle. The payload was housed within the rocket itself and deployed as expected but did not complete its mission. It was concluded that the code responsible for the target differentiation was not debugged properly and failed to run any data collection so no usable flight data was returned for the payload. Also, due to the fin section falling without parachute, the data from the two altimeters in the fin section was unable to be recovered due to damage sustained on impact. However, both altimeters that were housed within the avionics bay produced usable data. Figure 48 shows the data logged from the primary StratoLogger CF altimeter.

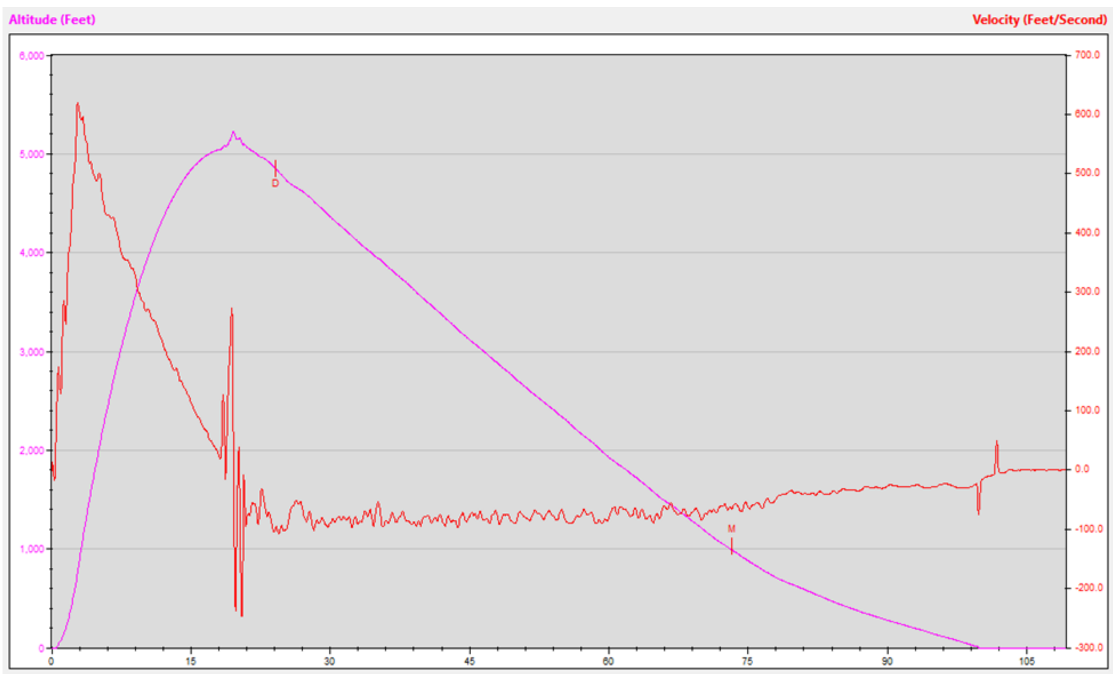


Figure 48: Primary Altimeter Data (5091ft. Recorded Apogee)

The Primary StratoLogger CF produced data similar to what was provided by the OpenRocket simulation. An apogee of 5091 ft. was recorded and a maximum velocity of approximately 650 ft/s was also recorded. Figure 49 below shows data obtained from the secondary StratoLogger CF. An apogee of 5233 ft. was recorded with approximately 650 ft/s maximum velocity, similar to the primary altimeter.

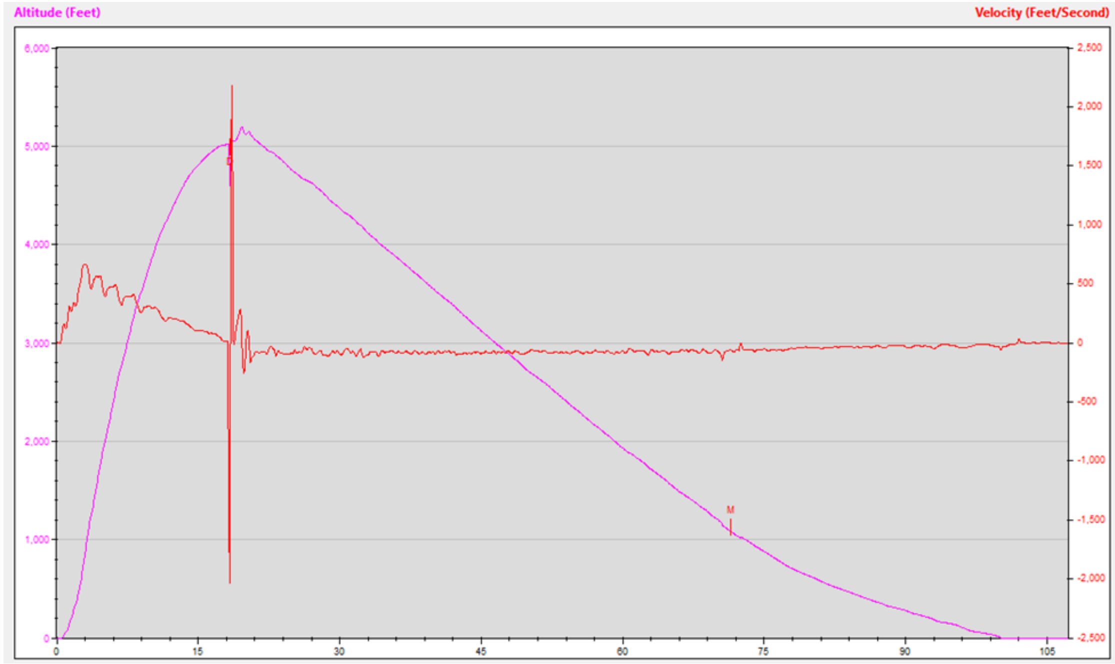


Figure 49: Secondary Altimeter Data (5233 Recorded Apogee)

A video was recorded of the launch vehicle during ignition. A black and white PVC tube was placed beside the rail to determine what the rail exit velocity was for comparison to the simulation rail exit velocity. The video recorded at a speed of 240 frames per second. At rail exit the launch vehicle moved 1 ft. in five frames. This resulted in a calculated rail exit velocity of 48 ft/s compared to the predicted 71 ft/s rail exit velocity from the OpenRocket simulation in Section 3.4.1. This is below the NASA guideline parameter due to the relocation of a rail button on launch day to straighten out a rail button that was attached at an improper angle.

3.4.2.1. Comparison to Predicted Flight Model

Comparing the simulated and actual flight data presented in the previous sections shows the discrepancies between simulated and real-time launch conditions. The simulation predicted an apogee of 5254 ft. which is lower than the competition goal, but the launch conditions were higher than desirable wind conditions. Even the two on board altimeters recorded different apogee altitudes with 5233 ft. and 5091 ft. Since wind conditions were higher than normal, a lower apogee was expected. Also, the weather cocking due to over stabilization of the rocket may have slightly lowered the apogee.

Despite these sources of error, OpenRocket continues to prove itself as a reliable simulation for determining characteristics of the actual rocket because taking the lowest value only results in a 3% difference to the simulation.

3.4.2.2. How Full-scale Flight Impacted Final Design

Unfortunately, the first full-scale launch was not a complete success. However, the subscale design was flown again after CDR and confirmed that the launch vehicle and the payload deployment method does work. Each failed launch is an opportunity to improve and move forward with a more robust and safe design. Since the unsuccessful full-scale flight, re-evaluation of the fin section eyebolt was needed. No huge design changes were deemed necessary but to ensure that during the next flight the fin section falls under the parachute, a 5/16 in. U-bolt will be used rather than the 3/8 in. eyebolt. This eyebolt was determined to be the weakness that allowed the fin section to separate midflight by unscrewing itself. Also, since the bulkhead and engine block were both damaged all debris was removed and current work is being done to install another bulkhead. Luckily the centering rings and motor tube were both salvageable, but due to the condition of the forward end of the motor tube which has fraying only the bulkhead will be reinstalled. Discussion with team mentors validates the absence of the engine block as a non-issue as the motor is well retained by the centering rings and fins. Finally, the fin with the dent on its leading edge will be replaced by fully removing the current fin and installing a new one.

3.4.2.3. Drag Coefficient Estimation

Based on strong correlation between simulated and measured altitude presented in §3.3.3, the drag coefficient used in OpenRocket is an accurate estimation of the total full-scale vehicle drag. Total drag coefficient is estimated at $C_D = 0.46$ and is composed of 67% drag from skin friction, 29% from base component drag, and 4% from pressure drag.

The total drag coefficient estimated during CDR was incorrectly reported as $C_D = 0.55$. It was found that the OpenRocket simulation was assuming a square or flat faced fin for all 4 fins. This is not congruent with the actual fins which utilize a rounded and sanded leading edge. This change was made to the simulation and the resulting value of $C_D = 0.45$ was used in the simulation used to correlate altimeter data. This difference new difference of 0.01 is most likely due to a slight increase in leading edge planform area on the full-scale fins.

4. Payload Criteria

4.1. Changes Made to Payload Since CDR

Since CDR, a change in the material of a component within the payload system was discussed and approved by NASA. The reason for this material change request is due to the change in material of the payload body from the PDR to CDR: the payload body is of polycarbonate and the flange (the component which was changed changed) was of aluminum 6061-T6 in the CDR. The flange was originally made of aluminum 6061-T6 because the payload body was the same material; however, that changed from the PDR to CDR. It was proposed to change the flange material to polycarbonate for better bonding ability to the payload body. Figure 50***: Flange to Payload Body Connection in CDR*** , below, shows an image of the flange and payload body as it was in CDR.

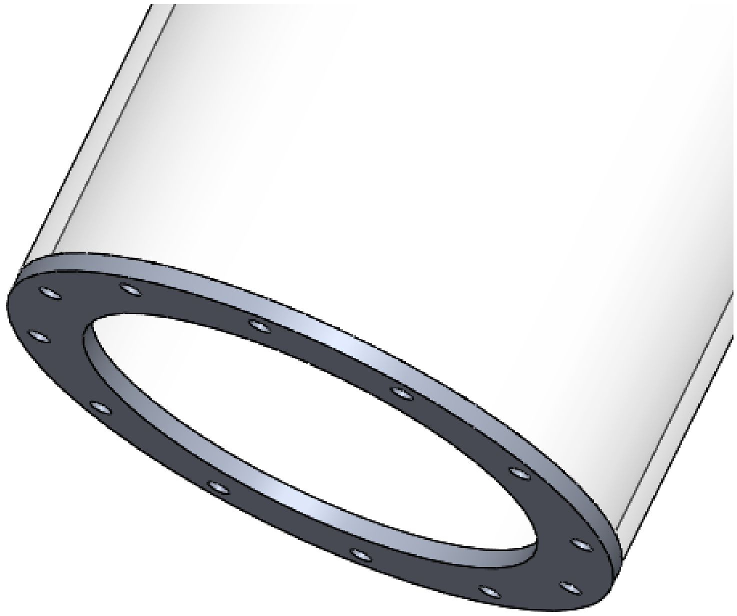


Figure 50: Flange to Payload Body Connection in CDR

In the subscale payload, the flange and body were welded together. In the full-scale, if the flange were to remain aluminum and the body polycarbonate, the two components would be connected via epoxy. Since the change request was approved, both components are now polycarbonate and they will be solvent welded similar to the way acetone bonds ABS plastic. The change had a negligible impact on the weight of the payload, on the order of fractions of ounces.

The flange is responsible for the structural integrity of just the payload. It does not contact the launch vehicle at any time; it is just used to provide a better connection for the payload body to the payload retainer. Below is Figure 51***: Full-Scale Body-Flange-Retainer Assembly***, which shows the assembled full-scale body-flange-retainer system which includes the polycarbonate flange, solvent welded to the body tube.

Figure 51: Full-Scale Body-Flange-Retainer Assembly

In addition to the change above, the ULS Legs are now rectangular in shape. This change became necessary when cutting semi-circular legs did not work as planned. After cutting the legs from excess polycarbonate tubing, the legs curled up in an unusable fashion. The attempt at cutting semi-circular legs is shown below in Figure 52***: Attempt at Cutting Semi-Circular Legs***.

Figure 52: Attempt at Cutting Semi-Circular Legs

The ULS Legs (as deployed on the full-scale flight test) are shown in Figure 53***: Rectangular Legs as Deployed on Full-Scale Flight Test*** below.

Figure 53: Rectangular Legs as Deployed on Full-Scale Flight Test

In addition, there are no ULS Slider Tabs on the Legs. The tabs proved to be unnecessary; therefore, the servo cables will be rigidly connected to legs. The attach point for the servo cables can also be seen in Figure 53 above.

A metal guide was installed below the leg hinges to provide additional moment arm (0.75”) so the ULS legs rotate properly. See Figure 54***: Metal Guide*** below.

Figure 54: Metal Guide

4.2. Payload Mission Requirements

As stated in the NASA SL College and University Handbook, the mission requirements for the target detection and upright landing challenge are as follows:

- Teams shall design an onboard camera system capable of identifying and differentiating between 3 randomly placed targets.
  - Each target shall be represented by a different colored ground tarp located on the field.
  - Target samples shall be provided to teams upon acceptance and prior to PDR.
  - All targets shall be approximately 40’X40’ in size.
  - The three targets will be adjacent to each other, and that group shall be within 300 ft. of the launch pads.
- 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.

- 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.

In addition to the mission requirements listed above, team derived mission success criteria for the payload structure, TDS, and ULS must also be met in order to consider the mission a success.

4.2.1. Mission Success Criteria

4.2.1.1. Structure

The payload body and internal components must have incurred no appreciable damage during flight and must be fully functional upon recovery. Cosmetic damage is acceptable if there are no punctures in the body tube or viewing surface. The bulkhead must not be cracked or split.

4.2.1.2. TDS & ULS

Criteria for a successful system test:

- Recording of altitude telemetry data
- Capturing of images (for use in target detection testing) beginning following vehicle launch and continuing throughout descent, landing, and recovery
    - The TDS will identify and differentiate between the three targets as described by NASA.
    - The payload will acquire images of the ground, analyze them for target detection and differentiation, and subsequently store the processed images in a designated, on-board folder.
- Extension of the ULS legs following payload descent and landing
    - The ULS will orient the payload upright upon landing, per NASA Mission Success Criteria.
    - Once the payload has landed, a servo will retract cables attached to four legs and orient it the payload so that it has the same configuration as it did inside the launch vehicle.

4.3. Payload Design

4.3.1. Structural Elements

Payload construction began with cutting the body tube with an oscillating saw and laser cutting the flange. The two components were then solvent welded using a Loctite Plastics Bonding System. The connection set for 48 hours under compressive force to increase the stability of the solvent bond.

The retainer body was then screwed into the flange-body assembly and Loctite Threadlocker Blue was used to increase the strength of the connection.

The bulkhead was laser cut from three eighth-inch aircraft-grade birch plywood sheets epoxied together and the holes for the U-bolt and electronics rods were drilled out.

The electronics rods are ¼”-20 threaded rods. All components along the electronics rods have ¼”-20 hex nuts both forward and aft. to retain the components’ relative position within the payload.

The bulkhead tabs are components which restrict the forward movement of the bulkhead and payload internals. The bulkhead tabs are 3D printed ABS components printed at maximum infill. Inside each bulkhead tab is a cutout which houses a ¼”-20 hex nut and a through-hole. This hex nut receives a ¼”-20 ¾”-length machine screw which goes through the payload body tube and its respective bulkhead tab through-hole. The position of the bulkhead on the electronics rods can be changed (by repositioning the hex nuts on either side of the bulkhead) to decrease the amount of space between it and the bulkhead tabs.

The mounting surface is the component which holds the camera and restricts aft. movement of the bulkhead and payload internals. The mounting surface is a 3D printed ABS component at 60% (heavy) infill. The mounting surface is contained between the viewing surface and retainer body. The retainer cap holds both the mounting surface and viewing surface on the payload—if either the mounting surface or viewing surface were to break, the other would still be connected to the payload by the retainer cap and body.

The payload airfoiled rail buttons fit 0.5”-by-1” rails, two for each rail inside the payload bay. The rail buttons are 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 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. The outer hex nut will be glued such that the screw head will not interact with the rail if the rail button were to slide away from its intended position. Figure 55 shows the screw-head-rail interaction (a) and the intended position of the rail button (b).

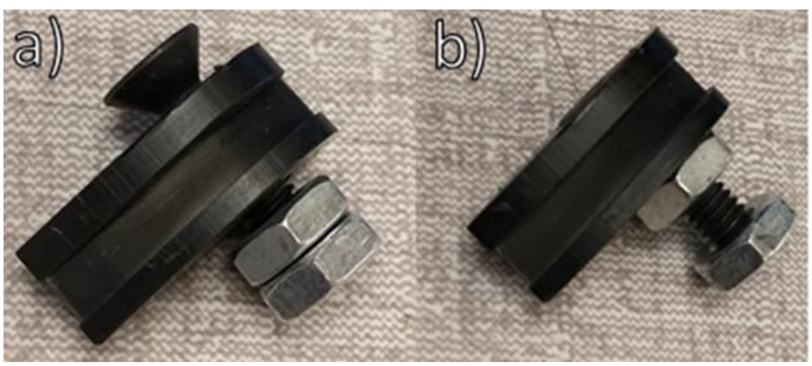


Figure 55: Positions of the Rail Button

The rails are shaped in such a way that if a screw were to protrude too far from the rail button it would effectively lock itself into its position at time of protrusion. To combat the position in Figure 55a, one hex nut is threaded more, as shown in Figure 55b. The payload body tube will be between the two hex nuts in Figure 55b.

4.3.2. Drawing and Schematics

Figure 56 shows the payload structure and ULS legs after construction. The lower rail buttons, ULS legs, and ULS flywheels are connected to the payload structure.

Figure 56: Payload Structure

The mounting surface (purple in Figure 56) and viewing surface are contained and secured within the retainer cap and body. After the payload structure assembly was completed, the payload internals were assembled and wired. Figure 56, below, shows the payload internals.

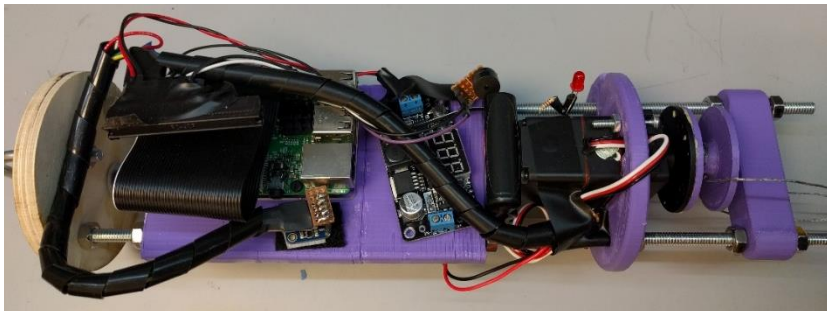


Figure 57: Payload Internals

The payload internals include all the components on the electronics rods and bulkhead. The ARRD connector (the rightmost purple component) and ULS servo system (all components between the ARRD Connector and the electronics sled) are also on the payload internals. The cables for the ULS are wired onto the spool and will be connected to the legs upon completion of assembly. The payload internals are then slid into the body tube, the ULS cables connected to the legs, the TDS camera connected to the mounting surface and secured, the ARRD cable wrapped onto the connector, the bulkhead tabs and upper rail buttons attached, and the parachute recovery system connected to the system. The completed payload system is shown below in Figure 58.

Figure 58: The Payload System

4.4. TDS

4.4.1. Precision of Instrumentation and Repeatability of Measurement

The TDS Image Processing Software has been evaluated and verified to be functional on numerous accounts. In various lighting conditions, pictures of the tarp samples were taken and analyzed. However, experimentation with text overlay (specifically, color and font) is still in the testing phase. The results of images analyses are shown below in Figure 59, Figure 60, Figure 61, and Figure 62.

Figure 59: Processed Image Sample 1

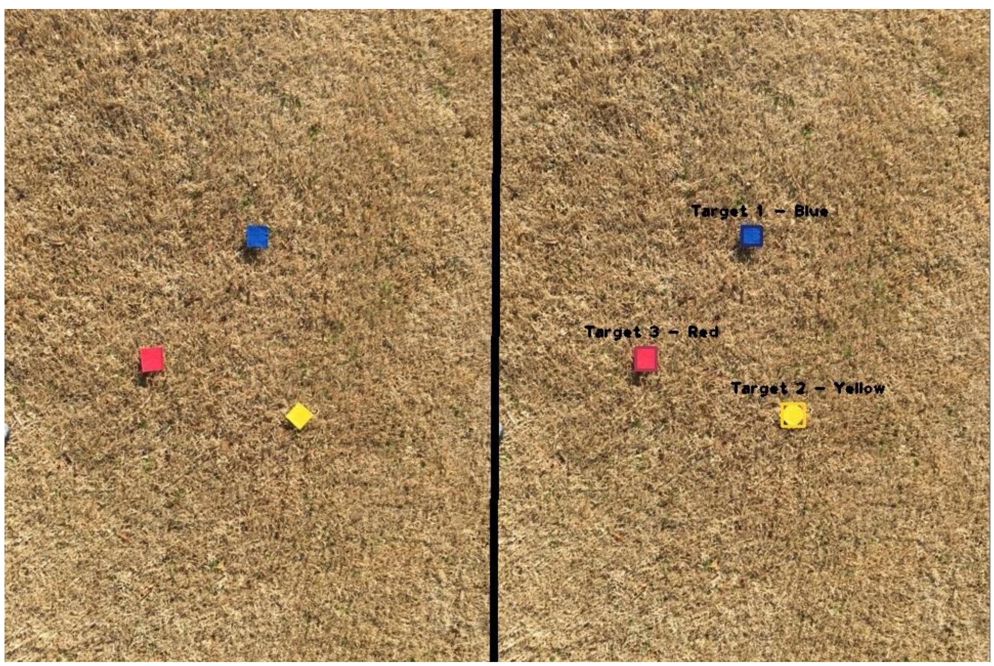


Figure 60: Processed Image Sample 2

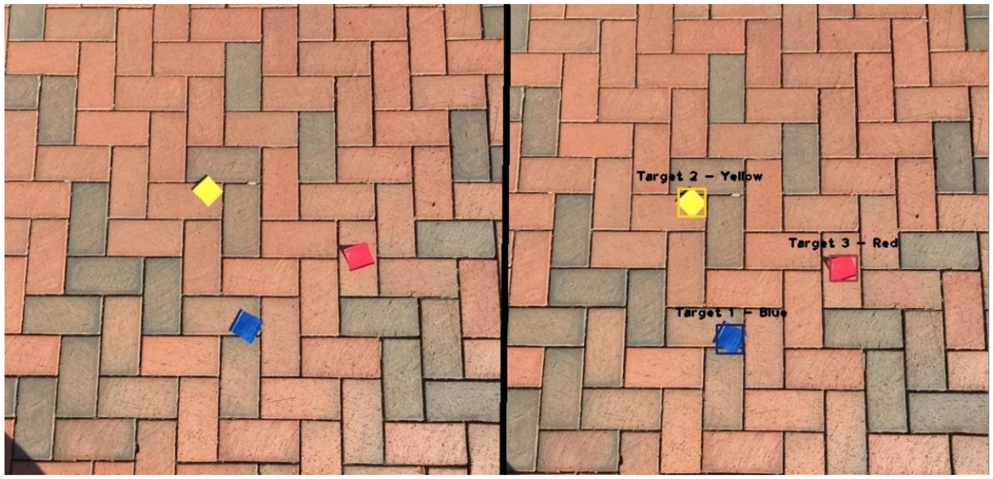


Figure 61: Processed Image Sample 3

Figure 62: Processed Image Sample 4

4.4.2. Electronics

All payload electronics will be discussed in §4.4.7, TDS Hardware, and §4.4.8, ULS Hardware.

4.4.3. Drawings and Schematics

Figure 63 shows an annotated diagram of the payload internals.

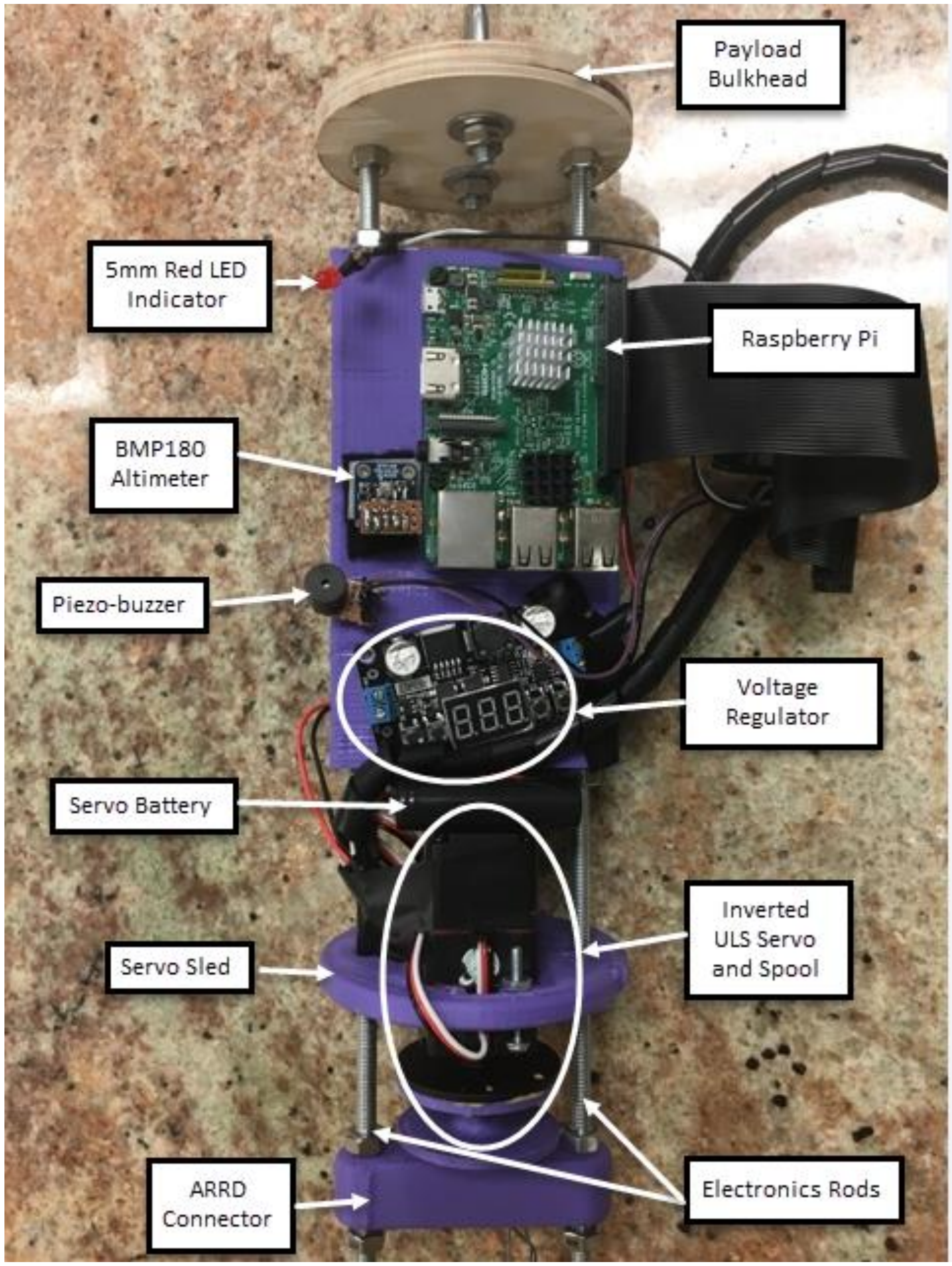


Figure 63: Payload Electronics, Assembled

4.4.4. Block Diagrams

Figure 64 illustrates the block diagram of the payload electronics.

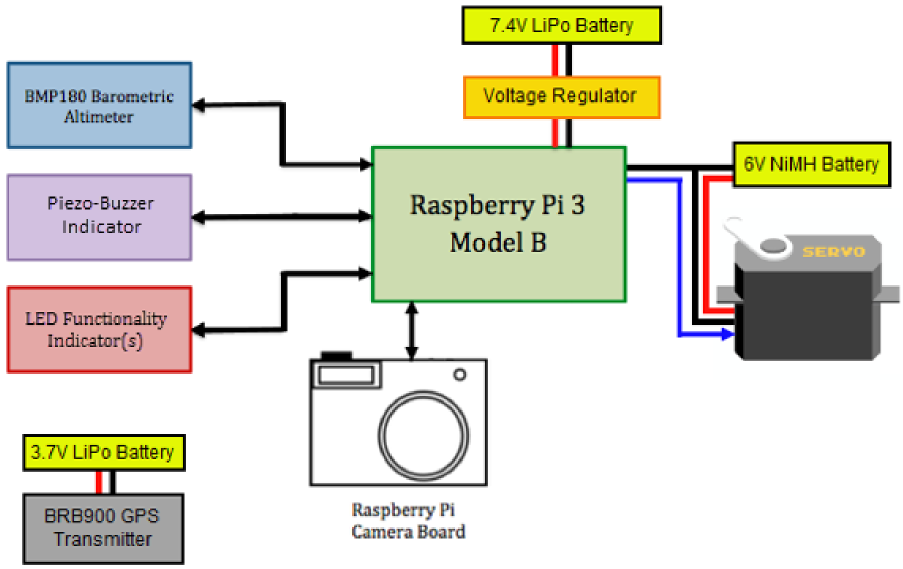


Figure 64: Payload Electronics Block Diagram

4.4.5. Batteries/Power

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.

4.4.6. Switch and Indicator Wattage and Location

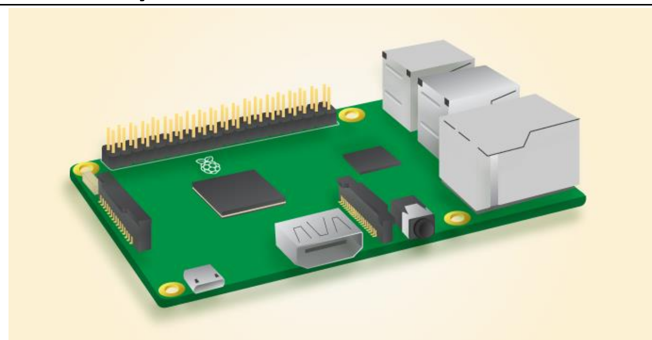
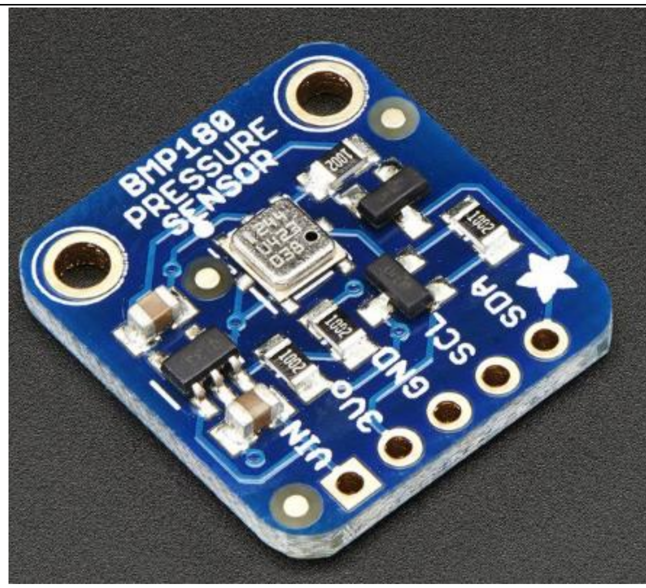
The implementation of a switch to control power to the system in order to allow for restart of the system without needing to disassemble the payload is being investigated. The switch will be placed on the forward face of the payload bulkhead to ensure ease of access even after the payload is fully assembled. The switch will be sturdy and recessed in order to greatly decrease the possibility of contact by another component, causing inadvertent movement of the switch, during launch vehicle assembly and flight.

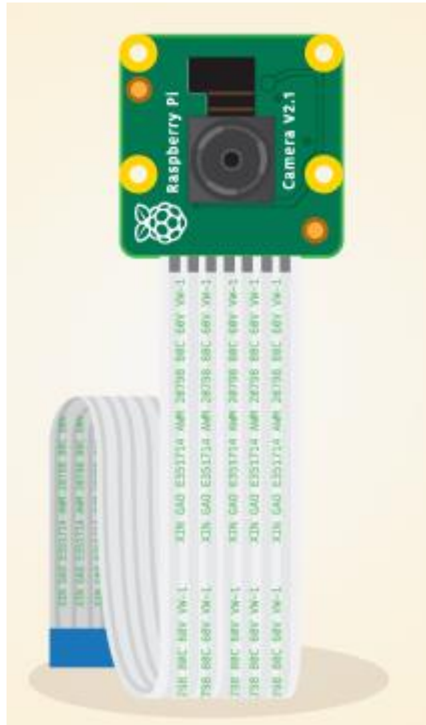
The only sources of potential hazard come from bad connections between electronics. LEDs and Piezo-buzzer indicators will ensure functionality of payload electronics prior to launch. In the case of malfunction, the electronics can easily be taken out for troubleshooting and rectification. Extreme caution will be taken to guarantee the electrical connections are properly made during payload assembly.

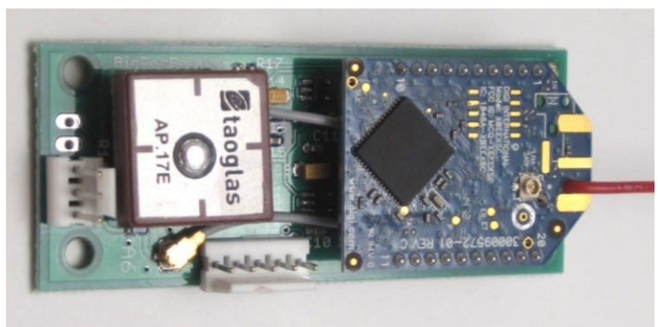
4.4.7. TDS Hardware

The TDS system hardware will include Adafruit BMP180 Sensor, which will function as an altimeter to log telemetry data, 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 BigRedBee BRB900 GPS unit for locating the payload upon landing. The TDS can be seen below at the component level in Table 6.

Table 6: Payload Electronics Hardware

Raspberry Pi 3 Model B	 [1]
Adafruit BMP 180 Sensor	 [2]

Raspberry Pi Camera Module 2	 [3]
DROK LM2596 Voltage Regulator	 [4]
Venom 20C 2S 5000mAh LiPo Battery	 [5]

5mm LED	
Piezo-buzzer	
BigRedBee BRB900	 [6]

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 inner diameter 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 upon descent.

4.4.8. 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 reveals the number and color of the target identified, e.g. “Target 2 – Yellow.” An example can be seen in *Figure 65*___***: Image After Processing***___ below.

Figure 65: Image After Processing

4.5. ULS

4.5.1. ULS Hardware

The ULS is an active system that automatically uprights the payload upon ground impact. This design was chosen because of its robustness in achieving the upright landing objective as defined by NASA.

A high-torque continuous-rotation servo acts 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 body tube wall, through a metal guide and attach to the outside of each leg. The metal guide was discovered to be necessary in order to provide an additional moment arm that will allow the linear motion of the cables being retracted to translate to the legs rotating to their final deployed position. The ULS Legs are held in their upright (flight) position using appropriately sized Velcro. When the servo begins rotating, the Velcro is sheared 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 rectangular 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. Table 7***: ULS Hardware*** below shows the ULS Hardware components.

Table 7: ULS Hardware

SpringRC SM-S8166R Continuous Rotation Servo with Spool Attachment	
Tenergy6V 2000mAh NiMH Battery Pack	

ULS Legs	
Medium Weight Braided Steel Wire	

Metal Guide	

4.5.2. ULS Software

Once the entire payload electronics are turned on, the ULS hardware will be configured so the cables are completely taught at the bottom, deployed position. Then, the spool will rotate enough to allow slack for the ULS Legs to be rotated to their stowed position. Upon landing, the servo will rotate back to its previous position, orienting the payload upright. The program for servo operation is written in Python and uses telemetry data to initiate servo rotation.

4.6. Full-Scale Flight Review

The payload recovery system, managed by the Jolly Logic Parachute Release device, deployed at 1000 ft. AGL and the payload landed safely. The payload structure incurred minimal damage as landing under parachute leaves the system with low kinetic energy.

The system failed to accomplish any of the criteria necessary for a successful TDS & ULS performance.

Analysis of the system and its performance allowed the team to identify a number of potential causes for the failure and rule out many other potential causes; however, the team is unable to identify with certainty a single specific cause for the failure.

4.6.1. Relevant Events and Observations

The day prior to the full-scale test launch, a finalized version of the code was produced and readied for the test flight.

Some amount of testing of the finalized program was accomplished, including testing of the full flight procedure by "tricking" the altimeter into registering values indicative of flight. During this testing, the system's performance was normal and no abnormalities or problems were observed.

During payload assembly on launch day, team members verified all wire connections of the TDS & ULS were connected properly, then connections were additionally secured with 3M-brand electrical tape where allowed by the design of the payload.

Upon conclusion of the payload sled preparation, the TDS & ULS control system battery was connected to the voltage regulator. Subsequently, the control system gave indication of a successful boot and program start with a series of three beeps from the system buzzer.

At the time which the assembled payload was inserted into the vehicle for final vehicle assembly, members of the team observed that the indicator LED was not blinking, which it should have if system function was normal. The team then inspected the system for additional signs of a problem. Because the system had previously indicated a successful program start, and because all connections appeared to still be secure, it was concluded that the lack of LED indication was either due to a failure of the LED itself or an inability to discern the light from the LED in the bright sunlight, so vehicle assembly was continued.

Upon recovery of the payload after landing, it was observed that the ULS legs were not deployed. Additionally, no signs of problems with or failures of the ULS subsystem hardware were observed.

The voltage regulator and Raspberry Pi both indicated system power was normal.

Upon return to NCSU and analysis of data on the Raspberry Pi, it was found that no data log for the flight had been created. No telemetry data was recorded, and no images were captured.

Upon return to NCSU the night of flight test day, the copy of the code used in the test flight was committed and pushed to the Github repository to ensure it would be preserved in its state to allow for accurate analysis of the test.

4.6.2. Analysis of TDS & ULS System Failure

The TDS & ULS control system booted correctly and successfully started the main script prior to final payload assembly. The main script broke and/or ended prematurely at some point after the calling of the flightWithLandingDetection(): function -- which begins with the sounding of the start indicator beeps from the buzzer.

The lack of a telemetry data log saved from the test suggests that the program broke/ended prior to the creation of the telemetry data log file and the beginning of telemetry logging.

- The creation of the log file occurs almost immediately following the conclusion of the start beep sequence.
- This conclusion allows the point at which the failure occurred to be pinpointed to a very narrow window within time and within the program.
- The only actions in the code between the end of the start sequence beeps and the creation of an instance of the :class: telemetryDataLog (which creates and saves a log

file with headers upon its initialization) was the initialization of three variables for later use in the program.

- None of these actions have the reasonable potential to cause a program-ending exception, so they can be ruled out as potential causes.
- All of this suggests that a previously unseen problem occurred during the creation of the telemetryDataLog instance.

The program had previously consistently executed correctly at all stages in the very limited testing able to be performed in the days leading up to the launch. Based on this it is concluded that the failure was most likely the result of an unhandled exception causing the program to break. However, the ultimate cause of that exception cannot be determined with absolutely certainty.

Loss of power can be ruled out as a cause because the Raspberry Pi and voltage regulator indicated power was normal throughout payload and final vehicle assembly and upon recovery after the flight. Furthermore, any momentary or intermittent loss of power would be followed by an automatic restart of the script at system reboot. Data logs would have been created for each of these program instances. No such logs were found following the flight test.

No total failure of any sensor component can be ruled out as a cause.

- After the flight, testing was done on the system that revealed all sensors and components to be functioning normally and as designed. Testing has yet to replicate the issue.
- A complete inability to interface with the BMP180 altimeter would have thrown an exception and caused a failure of the program prior to the sounding of the start sequence beeps on the buzzer.
- Likewise, an inability to establish a connection with the camera module would have thrown an exception and caused the program to break prior to the sounding of the series of beeps which indicate successful program start.
- No other components of the system send input to the Raspberry Pi, so none of them would produce an error in the program if their connection to the Raspberry Pi was interrupted.

At this juncture in the review and analysis of the system and the events of the test launch, the team is unable to pinpoint with certainty an ultimate cause for the failure of the TDS & ULS system.

4.6.3. Recommended Changes to System

Based on the full-scale flight test review above, the team has identified several recommended changes to the payload system software, hardware, and procedures.

Software Changes

- Implement comprehensive exception and error handling in the code to allow system to continue operation in face of abnormalities.
- Implement debug logging to allow for analysis of system performance and improved ability to diagnose conditions leading to off-normal system performance.

Hardware Changes

- Redesign the TDS & ULS system electronics hardware to improve security of connections during assembly and flight.
- Move system components to a board mounted atop the Raspberry Pi to reduce the number of wire-to-wire plug connections and reduce the amount of wire-clutter present in the payload.
- Improve indication of system status with additional LEDs.
- Add a switch accessible at the forward payload bulkhead that would control power to the system in order to allow for restart of the system without the need to disassemble the payload. The switch should be sturdy and recessed in order to prevent inadvertent movement during flight.

Procedural Changes

- Implement a QA/QC (Quality Assurance/Quality Controls) process for production code and hardware, including involving more team members in the QA/QC process.
- Improve assembly checklists:
    - Add specific checklist items for verifying each and every connection one at a time as/once the payload sled is assembled.
    - Include provision for confirming payload function in case of suspected abnormality.
- Fabricate duplicate identical component boards to enable swapping of parts in situation of component malfunction discovered during launch preparations.
- Accomplish payload construction in a manner which allows for much greater time frame to perform testing of the system prior to the test flight.

5. Safety

5.1. Safety Officer

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

5.2. Safety and Environment

5.2.1. 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 8 shows the Launch Hazard Analysis. Table 9 shows the Construction Hazard Analysis.

Table 8: Launch Hazard Analysis

Procedure	Concern	Risk	Mitigation	Confidence
Launch	Assembly of Rocket Motor	Possible damage to 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. Nitrile gloves are worn by individuals handling the motor to avoid contaminants from entering rocket	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	Possible damage to rocket or rocket components	Two hands are used to transport each component when taking the rocket from the car to the assembling area.	Cautious handling protects the rocket from falls that could damage components and harm the launch.

Procedure	Concern	Risk	Mitigation	Confidence
	Vehicle Assembly Vicinity	Possible damage to rocket components, injury to launch personnel	Individuals present at launch but not presently participating in launch day procedures will maintain a distance of at least 5 feet from the area in which the rocket is being assembled.	Team members (safety officer and others) will monitor vehicle assembly location and keep people at a safe distance of over 5 feet from the assembly zone.
	Assembly of Vehicle	Possible damage to rocket components, injury to launch personnel	Individuals will strictly follow the launch day checklist, using the checklist to address any concerns and difficulties encountered during launch. Black powder will not be inserted into the vehicle until all other sections are assembled, and all nonessential team members will remain clear of the vehicle once the powder has been inserted. Rocket will be handled slowly and carefully post-insertion of black powder, per launch day checklist. LiPo battery will be handled carefully. If damaged, shorted, or misshaped, the battery will be disposed of in a purpose built LiPo	The launch day checklist will be carefully written and rehearsed in the days prior to launch of the rocket, allowing team members to accurately and safely assemble and launch the vehicle.

Procedure	Concern	Risk	Mitigation	Confidence
			disposal bag, and the battery will be replaced.	
	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 9: 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 (safety glasses and hearing protection) 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 (safety glasses and hearing protection) will be worn at all times during operation.

Procedure	Concern	Risk	Mitigation	Confidence
	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 (safety glasses and hearing protection) 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.

Procedure	Concern	Risk	Mitigation	Confidence
	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 charges will be carefully measured and put into airtight containers by the safety officer. On launch day, following the checklist accurately and slowly, the safety officer will insert the black powder charges into the rocket.	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.

Procedure	Concern	Risk	Mitigation	Confidence
	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.

5.2.1.1. 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.

5.2.1.2. 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.

5.2.1.3. 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.

5.2.1.4. 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.

5.2.1.5. 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.

5.2.1.6. 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.

5.2.1.7. Ignition System

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

5.2.1.8. Size

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

5.2.1.9. 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.

5.2.2. FMECA

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.

5.2.3. 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.

The primary goal of the Environmental Threat Analysis (ETA) process is the identification of environmental threats to the safe launch and recovery of the launch vehicle. An environmental threat is one that poses a threat to either the launch vehicle and/or team member/bystanders before, during, or after the launch and recovery of the launch vehicle.

Table 10 and Table 11 show the Environmental Hazard and Threat Analysis Scales, respectively. The ETA will be addressed in Table 14 below.

Table 10: 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.

Table 11: Environmental Threat Analysis Scale

1	Possible critical or catastrophic damage to launch vehicle
2	Possible minor damage to launch vehicle
3	Unlikely damage to launch vehicle

5.2.4. NAR High Power Rocket Environmental Safety Code

5.2.4.1. 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.

5.2.4.2. 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.

5.2.4.3. 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).

5.2.4.4. 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.

5.2.5. Vehicle 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 12 shows the Launch Vehicle Environmental Hazard Analysis and Table 13 shows the Payload Environmental Hazard Analysis.

Table 12: Launch Vehicle Environmental Hazard Analysis

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

System	Component	Hazard	Cause	Effect	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

System	Component	Hazard	Cause	Effect	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
	Rail Buttons	3	Normal and/or abnormal operation	No effect	No recommendation
	Shock Cord	3	Normal and/or abnormal operation	No effect	No recommendation

Table 13: Payload Environmental Hazard Analysis

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

System	Component	Hazard	Cause	Effect	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
	Venom 20C 2S 5000mAh LiPo Battery	2	Catastrophic failure of LiPo Battery	The LiPo battery will explode within payload, possibly causing it to litter the field	Ensure that battery has no damage prior to launch, is properly charged, and is secured in launch vehicle.
	Polycarbonate Viewing Surface	3	Normal and/or abnormal operation	No effect	No recommendation

System	Component	Hazard	Cause	Effect	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

System	Component	Hazard	Cause	Effect	Recommendation
	Servos	3	Normal and/or abnormal operation	No effect	No 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

5.2.6. Environmental Threat Analysis

Table 14, below, shows the Environmental Threat Analysis.

Table 14: Environmental Threat Analysis

Environmental Phenomena	System	Component	Hazard	Effect	Recommendation
Cloud Cover	Vehicle		1	Loss of sight of the launch vehicle may result in injury to property and or person and possibly death.	Do not launch vehicle beyond cloud cover.

Environmental Phenomena	System	Component	Hazard	Effect	Recommendation
	Payload		2	Loss of sight of the payload may result in injury.	
Rain/Snow/Hail	Vehicle	Black Powder Charges	1	When wet, black powder will not ignite - this will prevent the airframe sections from separating.	Store black powder in a cool dry place and only remove from container when it is to be used
		ARRD	3	When wet, the black powder within the ARRD will not ignite, preventing the PBR from separating from the airframe.	Store ARRD in a dry location and avoid using in damp or rainy conditions.
		Motor	3	Propellant will not ignite when wet	Do not fly if damp or rainy conditions.
		Avionics	1	Avionics may fail when exposed to water.	
	Payload	Electronic Subassembly	3	The PBR will not be able to achieve its task.	
High Winds	Vehicle		3	High Drift	Refer to the wind drift. calculations.
	Payload				
Bodies of Water	Vehicle	Kevlar Shock Cord	1	Kevlar matrix systems that lack a resin may begin to slip in wet conditions such as being submerged in bodies of water.	Before flight, keep shock cord away from bodies of water.
		Avionics	1	Avionics may fail from exposure to water potentially preventing the deployment of the creating a hazard of falling debris.	Before flight, keep avionics section away from bodies of water.

Environmental Phenomena	System	Component	Hazard	Effect	Recommendation
	Payload	Electronics Subassembly	3	The PBR will not be able to achieve its task.	Before flight, keep the PBR away from bodies of water
Extreme Temperatures	Vehicle		3	Portions of the vehicle may expand or contract due to temperature changes making assembly or disassembly difficult.	No Recommendation
	Payload		3	Portions of the payload may expand or contract due to temperature changes making assembly or disassembly difficult.	
High Humidity	Vehicle	Avionics	1	Avionics may fail from exposure to high humidity potentially preventing the deployment of the parachutes creating a hazard of falling debris.	Store in a cool dry place.
	Payload	BRB GPS	2	Humidity may cause a failure of the BRB GPS which may render the unrecoverable.	Store in a cool dry place.
UV Exposure	Vehicle	Airframe	3	Degradation of paint.	Ensure that a clear coat protective layer is applied to the vehicle to prevent paint degradation.
Hard Surfaces	Vehicle	Rail Buttons Bulkheads and fins Nosecone Airframe	2	Hard surface may damage element beyond repair. Vehicle will not be able to be relaunched as per requirements.	Follow checklist and launch procedure in order to prevent vehicle from experiencing hard landing. Launch only over soft. ground.

Environmental Phenomena	System	Component	Hazard	Effect	Recommendation
		Motor			
	Payload		2	Hard surface may damage element beyond repair. Vehicle will not be able to be relaunched as per requirements.	Follow checklist and launch procedure in order to prevent vehicle from experiencing hard landing. Launch only over soft. ground.
		Electronics Subassembly			
		Polycarbonate Body Tube			
Vegetation	Vehicle		3	The vehicle may become trapped in trees. The team may be unable to retrieve the vehicle.	Avoid launch sites with heavy vegetation. Avoid launching when winds are high as the drift. will likely place the vehicle in the path of vegetation.
		Parachutes	3	Parachutes may become tangled	
	Payload		3	The payload may become trapped in trees. The team may be unable to retrieve the payload.	

6. Launch Operations Procedures

6.1. Night Before Checklist

- ☐ Charge drill batteries
- ☐ Charge payload battery
- ☐ Charge GPS battery
- ☐ Measure black powder:
  - Main: 3.0g and 3.1g
  - Drogue: 4.0g and 4.1g
  - ARRD: 0.2g
- ☐ Recommendations:
  - Encourage full night of sleep
  - Encourage full breakfast & hydration
  - Encourage packing items night prior

6.1.1. Packing Checklist

- ☐ Toolbox
- ☐ Nosecone
- ☐ AV bay
- ☐ Payload bay
- ☐ Payload
- ☐ Fin can
- ☐ Parachutes box:
    - Main and shock cord
    - Drogue and shock cord
    - Payload parachute and jolly logic
    - Quicklinks (7x)
- ☐ Baby Wipes
- ☐ Trash bags
- ☐ Gloves
- ☐ Paper Towels
- ☐ Folding table
- ☐ Battery powered drill:
- ☐ Both batteries fully charged
- ☐ Drill bits
- ☐ Extra rotary switches
- ☐ Tarps
- ☐ Zipties
- ☐ Ethernet cable
- ☐ Lipo batteries
- ☐ Multimeter
- ☐ HDMI – HDMI cable
- ☐ Payload supply box
- ☐ ARRD housing components box (white)
- ☐ AV components (red)
- ☐ Extra jumper wires
- ☐ 3M electrical tape (2x)
- ☐ Blue painter's tape
- ☐ Mallet
- ☐ Screwdriver kit
    - Include small, black screwdriver with red tip
- ☐ Scissors
- ☐ Forceps (2x)
- ☐ Wire cutters
- ☐ Needle-nose pliers

- ☐ Table
- ☐ Cinderblock
- ☐ Funnel
- ☐ Velocity measuring rods
- ☐ E-matches (6+)
- ☐ Motor reload kit (Aerotech L2200G)
- ☐ Propellant sleeve
- ☐ Motor casing (75mm)
- ☐ Forward seal
- ☐ Motor igniter
- ☐ Measuring tape
- ☐ Rope (for measuring CP)
- ☐ Laptop
- ☐ GPS receiver
- ☐ Personal items:
  - Sunscreen
  - First-aid kit
  - Water

6.1.2. Recovery Checklist

6.1.2.1. List of Items

- ☐ Nosecone
- ☐ AV bay
- ☐ Parachutes:
  - 2 ft. drogue parachute
  - 14 ft. Iris Ultra main parachute
- ☐ Kevlar wraps:
  - 12x12 in wrap (2x)
  - 24x24 in wrap (1x)
- ☐ 25 ft, 1 in width Kevlar shock cord (2x)
- ☐ Quicklinks (7x)
- ☐ Jolly Logic Parachute Recovery Device (w/ band)
- ☐ 3/8" steel quick link (4x)
- ☐ Blackpowder bottle
- ☐ Funnel
- ☐ Electrical tape
- ☐ E-matches (4x)
- ☐ Baby powder

- ☐ Shear pins (4x)
- ☐ Small, black screwdriver with red tip

6.1.2.2. Black Powder Preparation

- ☐ Measure out black powder charges:
  - o Main ejection: 3.0g
  - o Redundant main ejection: 3.1g
  - o Drogue apogee ejection: 4.0g
  - o Redundant drogue apogee ejection: 4.1g

6.1.2.3. Main Parachute Recovery

- ☐ Properly fold and roll parachute within its shock cord
- ☐ **IMPORTANT: Check that all rubber bands are removed from parachute fabric and shroudlines**
- ☐ Use a quicklink to attach 24x24 in Kevlar wrap in main parachute shock cord mid-length loop
- ☐ Fold shock chord accordion-style and use a rubber band to secure (NOT THE PARACHUTE!)
- ☐ Connect "nose" end of shock cord to the nosecone U-bolt using another quicklink
- ☐ Have a second team member confirm the quicklink is secured to the nosecone U-bolt
- ☐ Carefully insert the shock chord and main parachute in the remaining volume of the nosecone
- ☐ Connect "body" end of shock cord to the FWD AV bay bulkhead U-bolt using another quicklink
- ☐ Have a second team member confirm the quicklink is secured to the nosecone U-bolt

6.1.3. Avionics Checklist

6.1.3.1. List of Items

- ☐ Avionics sled:
  - o Velcro straps (2x)
  - o StratoLogger CF altimeters (2x)
  - o StratoLogger CF instruction manual (hair must be pulled back!)
- ☐ Fresh 9V batteries (2x)
- ☐ AV Bay
- ☐ AftAV bay (removable) bulkhead
- ☐ Small, black screwdriver with red tip
- ☐ 5/16 in hex nuts (6x)

- ☐ Plumber’s putty
- ☐ Electrical tape
- ☐ Digital multimeter (to test wires)
- ☐ Scissors and/or knife

6.1.3.2. Avionics Launch Procedure

- ☐ Insert 2 fresh 9V batteries into the metal clips with the base of the battery set into the clip well
- ☐ Make sure the Velcro doesn't impede the attachment points
- ☐ Use Velcro straps to fasten the batteries in place
- ☐ Clip batteries into power adaptor and secure in place
- ☐ Place clip tabs around battery and secure with zip ties oriented longways
- ☐ Using the battery connecters, connect each battery to their respective altimeter
- ☐ Connect the short wires from the altimeter terminal block labelled "Switch" to the rotary switch wires in the AV bay using the clips at the end of each wire [red-to-red and green-to-green]
- ☐ Test each altimeter for continuity one after the other by using a flat head screwdriver to turn the external switches to the ON position
- ☐ If there is an error signal (loud siren) use the instruction manual to troubleshoot
- ☐ Turn off each altimeter after testing!
  - o Allow another member to check that altimeters are turned off
- ☐ Connect the drogue and main wires to the altimeter "Drogue" and "Main" wires using the clips at the end of the wires [red-to-red and green-to-green]
  - o Each altimeter should be connected to the main and drogue blast caps now
- ☐ Tape the connections using the 3M electrical tape
- ☐ Make sure the two 5/16 in threaded rods within the AV bay are tightened
- ☐ Insert the avionics sled by sliding it down the two 5/16 in rods in the AV bay
  - o Stop when the threaded rods touch the coupling rods
  - o Check to make sure that no wires are going to be pinched by the sled or bulkhead
- ☐ Using two 5/16 in hex nuts, secure the AV sled by threading the nuts flush against the end of the sled
- ☐ Using two 5/16 in hex nuts, thread the nuts onto the rods to the indicated line on the rods
- ☐ Take the removable (aft) bulkhead and slide it down the remaining length of threaded rod
- ☐ Confirm that the bulkhead is 6-6.125 in from the aft. side of the AV body tube
- ☐ Using two more 5/16 in hex nuts, secure the bulkhead in place by threading the nuts flush against the face of the bulkhead

- ☐ Check altimeters to confirm settings and connections are correct
- ☐ Use small amount of putty to create a 6" diameter ring and create a seal between the bulkhead and the inner airframe wall

6.1.4. ARRD Housing Checklist

6.1.4.1. List of Items

- ☐ Fin can
- ☐ ARRD housing (two purple pieces)
- ☐ ARRD & instruction manual
- ☐ 0.1g black powder for ARRD
- ☐ Plumber's putty
- ☐ E-matches (2x)
- ☐ ARRD switches (no connection clips)
- ☐ Two altimeters [“PA” (black Velcro) is primary, “RA” (white Velcro) is redundant]
- ☐ 5/16-18 hex nuts (3x)
- ☐ Small, black screwdriver with red tip
- ☐ Fresh 9V batteries (2x)
- ☐ Wire cutters/strippers
- ☐ Duct tape

6.1.4.2. ARRD Launch Procedure

- ☐ Prime ARRD with two e-matches following the instruction manual
- ☐ Unscrew base and then push piston up with your fingers to remove toggle
- ☐ With screwdriver, remove the 5, ¼" ball bearings
  - o DO NOT DISLODGE THE SPRING OR LOSE THE BALL BEARINGS
- ☐ Place ball bearings in red anodized body, as shown in instruction manual
- ☐ Place shackle and toggle assembly into red body, next push the piston into the body up to the end of the threads
- ☐ Place 2 e-matches down through the base of the ARRD (wire leads first)
- ☐ Pull wires gently until heads of the matches are contained within the base, and bend the heads down flat with the base
- ☐ Place a small amount of plumber's putty inside the base in the hole from which the e-matches come from to fill in the hole
- ☐ Place pre-measured (0.2g) black powder into the base
- ☐ Place a small dot sticker over the black powder on the ARRD base
- ☐ Ensure that black powder isn't leaking from the base (even when the base is upside down)

- ☐ Holding the red body, and making sure that the shackle and toggle assembly remain fully inside the red body, screw the base and the body together by turning the red body
- ☐ Attach free end of 9V battery clip wires & rotary switch wires to altimeters [green to RA and red to PA]
  - Ensure the negative lead of the battery clip is inserted into the “Neg” terminal in the altimeter
- ☐ Attach free end of e-matches to each altimeter in the terminal labeled “Drogue”
  - There should only be 2”-3” of exposed e-match wire
- ☐ Velcro altimeters onto the ARRD Housing such that the e-matches protruding from the "Drogue" terminal blocks face radially inward
- ☐ Place ARRD in top half (bigger piece) of ARRD housing
- ☐ Place top half of the ARRD housing on top of the lower half
- ☐ Insert Switch holder into grove in the housing
  - Ensure battery clips are run behind switch holder
  - Secure with duct tape so the holder is fully within the housing but without covering the front of the switches
- ☐ Clip 9V batteries to the battery clips
- ☐ Test altimeters outside of fin can to ensure all connections are sound (Confirm with manual)
- ☐ **TURN SWITCHES TO OFF** position following successful test of each altimeter
- ☐ Screw ARRD housing into center hole in fin can bulkhead
  - The entire unit will have to spin as one
  - The fit against the wall and U-Bolt will be very snug
  - Take care to keep all wiring connections in-tact
- ☐ Screw the 5/16th rods into their holes so that the exposed length from the bulkhead to the top of the rod is 5.5” to 6”
- ☐ Secure ARRD Housing with a 5/16”-18 nuts on each of the rods

6.1.5. Avionics Bay Black Powder Charge Assembly

6.1.5.1. Main Parachute Black Powder Charge Assembly (Primary and Secondary)

- ☐ Ensure ALL altimeters/rotary switches are set to the off position
- ☐ Unscrew all terminal blocks on the forward AV bulkhead
- ☐ Primary charge:
  - Remove plastic protective e-match cover from e-match
  - Remove pre-cut wire insulation from end of e-match
  - Separate the two leads
  - Make a 180° bend (U-turn) in each lead approximately 1 cm in length
  - Place exposed e-match leads into terminal block labelled “P”

        - NOTE: altimeter wires should already be connected to other end of terminal blocks. If they have been dislodged, reconnect them now.
    - Tighten down the screws in the "P" terminal block
    - Place e-match head within the blast cap labelled "P"
        - Ensure that the wire is bent over the edge and that the head is flat on the cap bottom
    - Tape the e-match wire to the outside of the of the blast cap keeping the head flat at the bottom
    - Carefully pour **3.0g** of black powder into the "P" blast cap
    - Fill the remaining space in the blast cap with paper towel
        - NOTE: the paper towel should fill the space, but not be packed in tightly!
    - Place small (2-3 in) strips of 3M-brand electrical tape on top of the "P" blast cap to cover the blast cap completely
    - Wrap electrical tape all the way around the outside of the blast cap to keep the top layers tight
- ☐ Redundant main chute charge:
    - Repeat the above steps with the following changes
        - Use terminal block labelled "S"
        - Use **3.1g** of black powder

6.1.5.2. Drogue Parachute Black Powder Charge Assembly (Primary and Secondary)

- ☐ Ensure ALL altimeters are set to the off position
- ☐ Primary charge:
    - Remove plastic protective e-match cover from e-match
    - Remove pre-cut wire insulation from end of e-match
    - Separate the two leads
    - Make a 180° bend (U-turn) in each lead approximately 1 cm in length
    - Place exposed e-match leads into terminal block labelled "P"
        - NOTE: altimeter wires should already be connected to other end of terminal blocks. If they have been dislodged, reconnect them now.
    - Tighten down the screws in the "P" terminal block
    - Place e-match head within the blast cap labelled "P"
        - Ensure that the wire is bent over the edge and that the head is flat on the cap bottom
    - Tape the e-match wire to the outside of the of the blast cap keeping the head flat at the bottom
    - Carefully pour **4.0g** of black powder into the "P" blast cap
    - Fill the remaining space in the blast cap with paper towel

    - NOTE: the paper towel should fill the space, but not be packed in tightly!
  - Place small (2-3 in) strips of 3M-brand electrical tape on top of the "P" blast cap to cover the blast cap completely
  - Wrap electrical tape all the way around the outside of the blast cap to keep the top layers tight
- ☐ Redundant charge:
  - Repeat the above steps with the following changes using terminal block labelled "S" and **4.2g** of black powder

6.1.6. Forward (FWD) Rocket Assembly

- ☐ Slide the AV bay onto the nosecone section
- ☐ Line up using indicators on the outside of the rocket and insert 4 shear pins to secure

6.1.7. Aft. (AFT) Rocket Assembly Checklist

6.1.7.1. List of Items

- ☐ Fin can with ARRD housing installed
- ☐ Payload bay
- ☐ Payload with ARRD connecting rope attached
- ☐ Drogue with shock cord
- ☐ Nosecone/AV bay assembly with AFT. bulkhead puttied on
- ☐ Shear pins (4x)
- ☐ Screws to connect payload bay to AV bay (4x)

6.1.7.2. Aft. Rocket Assembly Procedure

- ☐ Feed FWD drogue quicklink through payload bay and connect to AFT. avionics bulkhead
  - Have a second team member confirm the quick link is secured to the nosecone U-bolt
- ☐ Insert drogue chute and recovery harness into payload bay and push as far FWD as possible
- ☐ Slide payload bay onto FWD rocket assembly and connect using the 4, #8 metal screws in the red plastic component organizer box
- ☐ Connect AFT. drogue quicklink to U-bolt on fin can
  - Have a second team member confirm the quicklink is secured to the nosecone U-bolt
- ☐ Connect payload to ARRD using the connection rope on the payload
- ☐ Check lengths of threaded rods so that payload rests flat on each of them
- ☐ Connect Jolly Logic to payload parachute
  - Ensure the Jolly Logic is armed to release at 1000 ft

- Ensure the Jolly Logic is on prior to insertion to the payload bay
- ☐ Slide payload (with fin can attached) onto payload bay rails
  - Ensure shock cord does not tangle/loop around the rails
- ☐ Feed all shock cord into payload bay
- ☐ Slide payload bay and fin can together such that shear pin holes align
- ☐ Insert 4 shear pins into the connection between the fin can and the payload bay
- ☐ Ensure rail buttons and AV switches are NOT in line with each other

6.1.8. Motor Checklist

6.1.8.1. List of Items

- ☐ Motor (Aerotec L2200G)
- ☐ 75mm liner
- ☐ 75mm casing
- ☐ Lube
- ☐ Pliers

6.1.8.2. Motor Launch Procedure

- ☐ Following the instructions provided in the propellant casing, assemble the motor under L3 mentor supervision
- ☐ Insert motor into tail section
- ☐ Tighten motor retainer

6.1.9. Launch Pad Checklist

6.1.9.1. List of Items

- ☐ Fully assembled rocket with payload and motor installed
- ☐ Igniter
- ☐ 12 ft. x 1515 launch rail
- ☐ Small, black screwdriver with red tip
- ☐ Blue tape
- ☐ Cameras
- ☐ Lube/Vaseline
- ☐ Safety glasses
- ☐ Ladder

6.1.9.2. Launch Pad Procedure

- ☐ Grease up launch rail if needed
- ☐ Carefully slide rocket onto rail
- ☐ Make sure launch rail is at the right angle, and is locked into position

  - Use another team member and L3 mentor to confirm launch rail is locked
- ☐ Take team picture
- ☐ All non-essential personnel leave the area
- ☐ All individuals remaining at the launch pad must wear safety glasses
- ☐ Arm all 4 altimeters and ensure they are still programmed appropriately
  - Two sets of 3 short beeps from AV bay
  - Two sets of 1 short beep emanating from the fin section
- ☐ Insert igniter fully into motor
- ☐ Tape ignitor into place
- ☐ Connect igniter to launch pad power
- ☐ Ensure pad continuity
- ☐ Ensure spectators are at least 300 ft. back from rocket
- ☐ LAUNCH!

6.1.10. Payload Checklist and Launch Procedure

6.1.10.1. Payload Packing Checklist

- ☐ PBR structure (if not assembled)
  - Payload body (flange should be connected)
  - Retainer cap
  - Retainer body (should be connected by twelve (12) screws)
  - Viewing surface
  - Mounting surface
  - 4 x Rail buttons and hardware
    - Four (4) 8-32 x ¾" socket flat screws
    - Eight (8) 8-32 x ¾" hex nuts
  - U-bolt
  - Four (4) U-bolt washers
  - Four (4) U-bolt hex nuts
- ☐ PBR Internals (if not assembled)
  - Two (2) electronics rods
  - Electronics Sled (battery platform should be connected)
  - Bulkhead
  - Raspberry Pi Microcontroller
  - Voltage Regulator
  - BMP180
  - Venom 20C 2S Battery
  - Raspberry Pi Camera Module v2 ribbon cable
  - ARRD Connector

- ARRD Shock Cord
- Twelve (12) ¼” x 20 hex nuts
- Raspberry Pi Camera Module v2
- Camera Mount and mounting hardware
- Wires for electronics subassembly
- Hardware for electronics subassembly

- ☐ Four (4) Bulkhead Tabs (if not assembled)
  - Four (4) ¼” x 20 0.75” long screws
  - Four (4) ¼” x 20 hex nuts
- ☐ Parachute Recovery System (if not assembled)
  - Parachute
  - Jolly Logic
  - Rubber bands
  - Quick link
  - Kevlar sheet
  - Big Red Bee BRB900
- ☐ ULS (if not assembled)
  - Four (4) ULS leg hinges
  - Four (4) ULS legs
  - Four (4) cables - metal braided wire
  - Extra roll of metal braided wire
  - Spring RC Servo
  - Tenergy Battery

6.1.10.2. Payload Assembly

- ☐ 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.
- ☐ Ensure the rail buttons are connected to the PBR body.
- ☐ Connect the retainer body to the PBR body with the fastening hardware that came with the retainer.
- ☐ Connect the electronics rods into the bulkhead and secure it on both sides of each rod with hex nuts.
- ☐ Connect the U-bolt onto the bulkhead and secure it by placing a washer and hex nut on both sides of each post.
- ☐ Assembly the electronics subassembly and wire it, but do not connect the battery to the Raspberry Pi.
- ☐ Connect the ribbon cable to the Raspberry Pi (it is not connected to the camera now).

- ☐ Secure any free wires to the electronics sled with electrical tape (the battery and Raspberry Pi are still unconnected).
- ☐ Screw two hex nuts onto the electronics rods.
- ☐ Connect ground wire of servo to its 6V NiMH battery as well as a ground pin on the Raspberry Pi.
- ☐ Connect servo power (red) wire to battery and servo signal wire to Raspberry Pi GPIO pin.
- ☐ Attach four (4) ULS cables to the servo spool.
- ☐ Slide servo and battery into designated 3D printed sled and secure to the electronics rods using two hex nuts.
- ☐ Slide the electronics subassembly onto the electronics rods and secure it with a hex nut on each rod.
- ☐ Screw two hex nuts onto the electronics rods.
- ☐ Attach the ARRD shock cord to the ARRD connector.
- ☐ Secure the BRB900 to the electronics subassembly.
- ☐ Connect the Raspberry Pi to the battery.
- ☐ 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.
- ☐ Put the viewing surface into the retainer cap.
- ☐ Connect the mounting surface and the camera subassembly.
- ☐ Secure the camera subassembly with electrical tape.
- ☐ Slide the payload internals into the payload body.
- ☐ Push the ARRD shock cord through its cutout in the mounting surface and viewing surface.
- ☐ Connect the camera subassembly to the ribbon cable.
- ☐ Secure the mounting surface onto the electronics rods.
- ☐ Screw the retainer cap (with viewing surface) onto the retainer body (which has the mounting surface on it).
- ☐ Wrap the parachute.
- ☐ Connect the parachute and Kevlar sheet to the quick link.
- ☐ Wrap the Kevlar sheet around the parachute.
- ☐ Connect the quick link to the U-bolt.
- ☐ Attach the ULS Legs to the payload body at the designated location using hinges.
- ☐ Feed the four ULS cables through the walls of the payload (one for each 90 degrees around circumference of payload) and subsequently through the metal guides.
- ☐ With the ULS Legs at their deployed position, attach the cables to the ULS Legs so there is no slack, i.e. they are completely taught.
- ☐ Allow the servo to rotate in order to allow slack in the cables.

- Secure the ULS Legs to the outside of the payload body using one square inch of Velcro.
  - NOTE: The Payload is now assembled.

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 1,100 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 §3.1.2.1. 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 in §7.1.4. 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, Figure 66, 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 66: Test Stand

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

The Compliance Matrix can be found in Appendix D.

7.3. Budget Plan

The total projected budget for the NSL 2017 is $10,992.45. The budget is broken down in further detail in the Sections below.

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	In House	
	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	In House	
	Shear Pins	In House	
	Kevlar Shock Cord	In House	
	Fruity Chute 84" Iris Ultra Compact	1	$ 345.00
	Fruity Chute 18" Iris Ultra Compact	1	$ 60.00
	Speaker Wire	In House	
	Black Powder	In House	
	Electronics Rotary Switches	In House	
	1/8" Threaded Rods	In House	
	Aero Pack 54 mm Retainer (Flanged	1	$ 40.66
	Duracel 9V Battery	4	$ 11.31
	Entacore 1000 Altimeter	In House	
	GPS	In House	
	Stratologger CF Altimeter	In House	
	RATTworks ARRD	In House	
	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	In House	
	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	In House	
	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 - 78	2	$ 1.50
	TO-220 Clip-On Heatsink	2	$ 1.50
	10uF 50V Electrolytic Capacitors - Pa	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	In House	
	3D Printed Acrylic Grazing Sheet	In House	
	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	3	$ 749.97
	Fiberglass Body Tube 6"	96"	$ 414.86
	Fiberglass Coupler 6"	36"	$ 207.39
	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
	5/16" U-Bolt	4	$ 15.08
	75mm Retention Tube	1	$ 20.00
	1515 Rail Buttons	2	$ 9.30
	Shear Pins	In House	
	Kevlar Shock Cord	In House	
	Drogue 2' Parachute	In House	
	Main 14' Iris Parachute	1	$ 828.00
	Wiring	In House	
	Black Powder	In House	
	Electronics Rotary Switch	4	$ 49.65
	5/16" Threaded Rods	In House	
	Aero Pack 75 mm Retainer (Flanged)	2	$ 53.50
	Duracel 9V Battery	4	$ 11.31
	Big Red Bee GPS	1	$ 309.00
	Stratologger CF Altimeter	4	$ 235.20
	RATTworks ARRD	In House	
	Coupling Nut	2	$ 2.48
			$ 3,594.66

7.3.4. Full-Scale Payload Budget

	Fullscale			
	Item	**Quantity**	**Price**	
Payload	3D Printed Mounting Sheet 75 mm	In House		
	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	In House		
	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 - 7805 TO-220	2	$	1.50
	TO-220 Clip-On Heatsink	2	$	1.50
	10uF 50V Electrolytic Capacitors - Pack of 10	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	In House		
	3D Printed Acrylic Grazing Sheet	In House		
	1"x1/2"T-Slot Rails -14"	2	$	8.38
			$	**939.86**

7.3.5. Travel Budget

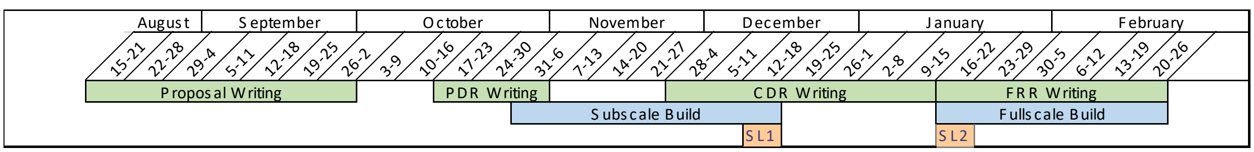
Travel		
Event	Item	Price
Huntsville	Hotel	$ 3,820.80
	Gas	$ 1,300.00
	Van Rental	$ 511.20
Bayboro	Van Rental	$ 119.70
		$ 5,751.70

7.4. Funding Plan

	Fall	Spring	
Engineering Council	$ 2,829.86	$ 1,000.00	
Space Grant	$ 3,000.00		
	$ 5,000.00		
Student Government Association (SGA)	$ 1,400.00	$ 950.00	
Engineering Technology Fund	$ 2,000.00	Emergency	
	$14,229.86	$ 1,950.00	$16,179.86

7.5. Timeline

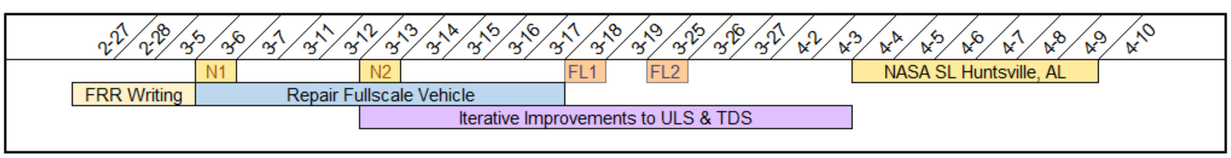
7.5.1. Past Timeline



SL1: Subscale Launch 1

SL2: Subscale Launch 2

7.5.2. March-April Timeline



N1: NASA Deadline 1, FRR due at 8am CST

N2: FRR Presentation 9:30am CST

FL1: Full-Scale Re-Launch 1

FL2: Full-Scale Re-Launch 2 (in case of inclement weather for FL1)

Iterative Improvements to the ULS & TDS:

- Complete Image Analysis Functionality (3-1 through 3-13)
- Lab & Ground Test Full TDS System (3-13 through 3-17)
- Launch Test TDS System (3-18)
- Payload Electronics Reconstruction & Rewrite Payload Checklist (3-12 through 3-15)

7.6. Educational Engagement Plan and Status

Salem Elementary School Outreach

Where: Salem Elementary School, Apex, NC 27523

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

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.

Lacy Elementary School's STEM Night

Location: Lacy Elementary School, Raleigh, NC 27607

When: Thursday January 19, 2017 5:00pm – 8:00pm

Members of the High-Powered Rocketry Club attended the Lacy Elementary School STEM night to give a presentation on high-powered rocketry, NASA SLI, and engineering at NC State. The team also brought a collection of previous years' rockets to have on static display and answer questions on the various components of the rockets. In addition, the club launched water bottle rockets with assistance from the students.

Weatherstone Elementary STEM Expo

Location: Weatherstone Elementary School, Cary, NC 27513

When: Saturday January 21, 2017 10:00am-2:00pm

The High-Powered Rocketry Club had a classroom 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, the team had a water bottle rocket workshop where students designed and built their own water bottle rocket to launch with some coaching from the team members.

The Franciscan School Science Olympiad

Location: The Franciscan School, Raleigh, NC 27613

When: Friday January 27, 2017 3:30pm-5:00pm

Amy S., Zach V., and John I. represented the High-Powered Rocketry Club at The Franciscan School where they gave a brief presentation on STEM, aerospace engineering, and what the club does. Following the presentation, they taught some of the participants that were part of a water bottle rocket Science Olympiad team on some tips and tricks to consider when designing their rockets. Following this, there was a quick demonstration of a water bottle rocket launch.

Astronomy Days

Location: North Carolina Museum of Natural Sciences, Raleigh NC 27601

When: Saturday January 28, 2017 9:00am-5:00pm and Sunday January 29, 2017 12:00pm-5:00pm

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 talked to thousands of individuals about rockets and the club itself. The booth featured static displays of rockets both from the club and from the Tripoli Rocket Association plus posters describing high-powered rocketry designs and flights.

NC MSEN Pre-College Program Presentation and Demonstration

Location: North Carolina State University, Raleigh NC 27695

When: Thursday March 2, 2017 3:30pm-5:00pm

A group from the NC MSEN Pre-College Program came to North Carolina State University's Centennial Campus where members of the High-Powered Rocketry Club set up a presentation in one of classrooms. The presentation covered the engineering design cycle, what the club does, and water bottle rocket design. Following the presentation, the students were split up into teams and were able to design and build their own water bottle rockets with coaching from the team members. After the building of the rockets, the team brought the students outside and launched all the rockets that the students built.

8. References

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

[4] “DROK Great Handy LM2596 DC Volt Buck Converter with Voltmeter Creates Easy Convenient Voltage Regulation,” DROK, http://www.droking.com/drok-great-handy-volt-buck-converter-with-voltmeter-creates-easy-convenient-voltage-regulation/ [retrieved 9 January 2017].

[5] “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].

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

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 parachute deploys at wrong altitude	Altimeter detects incorrect altitude	Altitude between apogee and 1200 ft. detected	Excessive drift	4	Verify each altimeter chirps the appropriate program at the launch site.
				Altitude between 800ft. and 200ft. detected	Kinetic energy will exceed 75 ft-lb	2	

System	Function / Component	Failure Mode	Causal Factors	Failure Effects		Hazard	Recommendations
				Subsystem	System		
				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 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	

System	Function / Component	Failure Mode	Causal Factors	Failure Effects		Hazard	Recommendations
				Subsystem	System		
		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 parachutes	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

System	Function / Component	Failure Mode	Causal Factors	Failure Effects		Hazard	Recommendations
				Subsystem	System		
		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

System	Function / Component	Failure Mode	Causal Factors	Failure Effects		Hazard	Recommendations
				Subsystem	System		
			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	1	Visual inspection after completing construction before any implementation
			Loads beyond design specifications			1	Based on subscale flight data, factor of safety is sufficient
			Damaged during handling			1	Replace damaged bulkhead

System	Function / Component	Failure Mode	Causal Factors	Failure Effects		Hazard	Recommendations
				Subsystem	System		
		U-Bolt separates from bulkhead	Loads beyond design specifications			1	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. Ensure excessive material is not removed during sanding
			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 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

System	Function / Component	Failure Mode	Causal Factors	Failure Effects		Hazard	Recommendations
				Subsystem	System		
			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	Based on flight data, the factor of safety is sufficient.
			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

System	Function / Component	Failure Mode	Causal Factors	Failure Effects		Hazard	Recommendations
				Subsystem	System		
	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

System	Function / Component	Failure Mode	Causal Factors	Failure Effects		Hazard	Recommendations
				Subsystem	System		
			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

System	Function / Component	Failure Mode	Causal Factors	Failure Effects		Hazard	Recommendations
				Subsystem	System		
	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

NC STATE UNIVERSITY

System	Function / Component	Failure Mode	Causal Factors	Failure Effects		Hazard	Recommendations
				Subsystem	System		
			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 5 degrees from vertical	Possible mission failure and hazard to ground crew and spectators	1	Rail buttons will be epoxied into body to ensure they don't separate
			Rail Buttons Break			1	2 standard rail buttons for a 1.5-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.

System	Function / Component	Failure Mode	Causal Factors	Failure Effects		Hazard	Recommendations
				Subsystem	System		
			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 lbs
			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		2	Review altimeter checklist and ensure altimeters are

System	Function / Component	Failure Mode	Causal Factors	Failure Effects		Hazard	Recommendations
				Subsystem	System		
			Altimeter programmed incorrectly	or will get tangled in shock cord	Drogue will be prevented from deploying	2	properly programed and that all wiring is secured
			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 meaningful data	Payload fails to identify and differentiate targets	4	Thoroughly check camera systems prior to launch
			Broken lens during flight			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

System	Function / Component	Failure Mode	Causal Factors	Failure Effects		Hazard	Recommendations
				Subsystem	System		
		Loose wiring	Electrical system Hardware integrity compromised during flight			4	Verify payload electronics are functional by inspecting LED indicators prior to launch
			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	Verify payload electronics are functional by inspecting LED indicators prior to launch

System	Function / Component	Failure Mode	Causal Factors	Failure Effects		Hazard	Recommendations
				Subsystem	System		
		Compatibility issues with hardware	TDS system not tested for functionality			4	
		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

System	Function / Component	Failure Mode	Causal Factors	Failure Effects		Hazard	Recommendations
				Subsystem	System		
			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	

System	Function / Component	Failure Mode	Causal Factors	Failure Effects		Hazard	Recommendations
				Subsystem	System		
		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-lbs	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	Verify payload electronics are functional by inspecting LED indicators prior to launch
			Improper wiring			4	

System	Function / Component	Failure Mode	Causal Factors	Failure Effects		Hazard	Recommendations
				Subsystem	System		
	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

System	Function / Component	Failure Mode	Causal Factors	Failure Effects		Hazard	Recommendations
				Subsystem	System		
		Fracture during flight	Loads beyond design specifications			4	Structural testing
		Improper assembly	Loose/Improper connections			4	Verify payload electronics are functional by inspecting LED indicators prior to launch
		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

System	Function / Component	Failure Mode	Causal Factors	Failure Effects		Hazard	Recommendations
				Subsystem	System		
			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

System	Function / Component	Failure Mode	Causal Factors	Failure Effects		Hazard	Recommendations
				Subsystem	System		
		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 to desired orientation	Payload fails upright landing requirement	4	Ensure servo has necessary torque
			Electrical pull on battery too large, drains battery too quickly			4	Test servo prior to complete system integration

System	Function / Component	Failure Mode	Causal Factors	Failure Effects		Hazard	Recommendations
				Subsystem	System		
			Weak/dead battery			4	Verify batteries fully charged on launch day using multimeter
	Rectangular Lexan ULS 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

System	Function / Component	Failure Mode	Causal Factors	Failure Effects		Hazard	Recommendations
				Subsystem	System		
		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
	Metal Guide	Guide does not remain intact to payload body	Cables provide too much stress on guide	Payload cannot upright itself	Payload fails upright landing requirement	4	Verify strength of leg connection
			Improper assembly			4	Post-assembly inspection

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
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	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: StratoLogger CFs.
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.
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.
1.3	All recovery electronics shall be powered by commercially available batteries.	Identification	All electronics will be powered by commercially available 9V batteries.
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.

Section	Description of Requirement	Method of Compliance (MOC)	Description of MOC
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.
1.6	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.
1.7	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.
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.
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.
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.

Section	Description of Requirement	Method of Compliance (MOC)	Description of MOC
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 L2200G motor is being used for the full-scale launch vehicle.
1.12	Pressure vessels on the vehicle shall be approved by the RSO	Design Review	The vehicle contains no pressure vessels
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 2.25, while Barrowman's equations give a stability margin of 2.10, both of which are well above 2.0.
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 70.9 fps not accounting for drag, rail friction, non-constant thrust, and propellant burn-off, which leaves a margin of error.
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.
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 TDS and ULS and have smaller dimensions than the full-scale model.
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.

Section	Description of Requirement	Method of Compliance (MOC)	Description of MOC
1.17	All teams shall successfully launch and recover their full-scale rocket prior to FRR in its final flight configuration.	Test	Full-scale re-launch will take place before March 27. FRR will be submitted by March 6.
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.
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.
1.17.7	Full-scale flights must be completed by March 6th.	Test	Full-scale launch will take place in February with a re-test taking place in March (with permission from NASA).
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.
1.19.1	The launch vehicle shall not utilize forward canards	Design Review	The vehicle will not utilize forward canards
1.19.2	The launch vehicle shall not utilize forward firing motors.	Design Review	The full-scale vehicle will use an Aerotech L2200G motor.
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 L2200G motor.
1.19.4	The launch vehicle shall not utilize hybrid motors.	Design Review	The full-scale vehicle will use an Aerotech L2200G motor.

Section	Description of Requirement	Method of Compliance (MOC)	Description of MOC
1.19.5	The launch vehicle shall not utilize a cluster of motors.	Design Review	The full-scale vehicle will use an Aerotech L2200G motor.
1.19.6	The launch vehicle shall not utilize friction fitting for motors	Design Review	No friction fitting will be utilized in motor installation.
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.
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.
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 AGL, the main parachute will be released from between the upper airframe and the nosecone. The launch vehicle is expected to land with 67.8 ft-lb at 9.87 ft/s.
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.

Section	Description of Requirement	Method of Compliance (MOC)	Description of MOC
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 14 feet were chosen and fit the requirements according to calculations.
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.
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	Two StratoLogger CFs will be used to fire the black powder charges that decouple the rocket sections and release the payload and parachutes.
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.
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.
2.8	Each altimeter shall have a dedicated power supply	Design Review	Each altimeter will be powered individually by nine volt batteries.

Section	Description of Requirement	Method of Compliance (MOC)	Description of MOC
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.
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.
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 BigRedBee 900 MHz radio to communicate the location of the vehicle to the ground before and after the payload separation.
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
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.
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.

Section	Description of Requirement	Method of Compliance (MOC)	Description of MOC
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 in a prefabricated mount or custom fitted 3D printed avionics sleds in which the only components are two batteries and altimeters.
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.
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.
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.
3.1.1	Each team shall choose one design experiment option from the list.	Inspection	Landing detection and controlled landing was chosen as the experiment.
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.

Section	Description of Requirement	Method of Compliance (MOC)	Description of MOC
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.
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.
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.
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.
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.
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.

Section	Description of Requirement	Method of Compliance (MOC)	Description of MOC
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.
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.
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.
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.
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.
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.
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.

Section	Description of Requirement	Method of Compliance (MOC)	Description of MOC
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.
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.
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.
4.4	Each team shall identify a "mentor."	Identification	The team's student mentor has been identified.
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.
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.

Section	Description of Requirement	Method of Compliance (MOC)	Description of MOC
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.
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.
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.
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.
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.
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.

Section	Description of Requirement	Method of Compliance (MOC)	Description of MOC
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.
5.8	All deliverables must be in PDF format	Demonstration	All deliverables will be saved in PDF format.
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.
5.10	In every report, the team shall include the page number at the bottom of the page.	Demonstration	Page number will be included.
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.
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.
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.

Appendix E: Milestone Review Flysheet

Milestone Review Flysheet

Institution	NC State University	Milestone	Flight Readiness Review

Vehicle Properties	
Total Length (in)	125
Diameter (in)	6.2
Gross Lift. Off Weigh (lb)	52.6
Airframe Material	G12 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, 2 x centering ring

Stability Analysis	
Center of Pressure (in from nose)	91.8
Center of Gravity (in from nose)	77.9
Static Stability Margin	2.25
Static Stability Margin (off launch rail)	2.25
Max Thrust-to-Weight Ratio	13.3
Rail Size and Length (in)	1.5 x 1.5 x 144
Rail Exit Velocity	65.3 ft/s

Ascent Analysis	
Maximum Velocity (ft/s)	639
Maximum Mach Number	0.57
Maximum Acceleration (ft/s/s)	409
Target Apogee (From Simulations)	5302
Stable Velocity (ft/s)	52
Distance to Stable Velocity (ft)	4.4

Recovery System Properties	
Drogue 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)	83.9
Recovery Harness Material	Kevlar
Harness Size/Thickness (in)	3/4in
Recovery Harness Length (ft)	25 ft

Recovery System Properties	
Main Parachute	
Manufacturer/Model	Fruity Chutes / Iris Ultra Toroidal
Size	168 in
Altitude at Deployment (ft)	1100
Velocity at Deployment (ft/s)	81
Terminal Velocity (ft/s)	9.87
Recovery Harness Material	Kevlar
Harness Size/Thickness (in)	1
Recovery Harness Length (ft)	25 ft

Harness/Airframe Interfaces		Tubular Kevlar Shock Cord / U-bolt with quick link		
Kinetic Energy of Each Section (Ft-lbs)	Section 1	Section 2	Section 3	Section 4
	4607			

Harness/Airframe Interfaces		Tubular Kevlar Shock Cord / U-bolt with quick link		
Kinetic Energy of Each Section (Ft-lbs)	Section 1	Section 2	Section 3	Section 4
	67.8	10.9		

Recovery Electronics	
Altimeter(s)/Timer(s) (Make/Model)	2 x StratologgerCF
Redundancy Plan	Redundant charge fired 1 second after apogee
Pad Stay Time (Launch Configuration)	1 hour

Recovery Electronics	
Rocket Locators (Make/Model)	Big Red Bee 900 MHz GPS
Transmitting Frequencies	900 MHz
Black Powder Mass Drogue Chute (grams)	4.00
Black Powder Mass Main Chute (grams)	3.00

Milestone Review Flysheet

Institution	NC State University	Milestone	Flight Readiness Review

Autonomous Ground Support Equipment (MAV Teams Only)	
Capture Mechanism	Overview
	N/A
Container Mechanism	Overview
	N/A
Launch Rail Mechanism	Overview
	N/A

Igniter Installation Mechanism	Overview N/A

Payload	
Payload 1	Overview 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 N/A

Test Plans, Status, and Results	
Ejection Charge Tests	Black powder ejection charge testing took 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. Since calculations assumed empty tubes smaller charges were tested first. Testing for the main recovery system was conducted using the completed nosecone and avionics bay sections. Testing for the drogue chute was conducted using a constructed deployment test rig.
Sub-scale Test Flights	Second Sub-scale launch was conducted on January 21st, 2017 due to minor issues with the first subscale launch that was conducted on December 17th, 2016. Second subscale confirmed design was capable of ejecting payload and safely delivering the launch vehicle and payload to the ground. Full-scale was built on confidence in design provided by the second subscale launch.
Full-scale Test Flights	The full-scale test flight took place on February 25th , 2017. The test validated all launch vehicle and payload systems and provide confidence in mission success of target altitude. However, fin can detached from parachute and fell ballistic and the payload failed to engage target differentiation system and upright landing system, but recovery system safely delivered

	payload to the ground. Fin Section was mostly recovered and repairs and redesigns are being made leading up to the next test launch currently scheduled for March 18th. A back up launch is also available for March 25th in case of weather issues.

Milestone Review Flysheet

Institution	NC State University

Milestone	Flight-Readiness Review