NC STATE UNIVERSITY

Tacho Lycos
2019 NASA Student Launch
Critical Design Review

High-Powered Rocketry Club at NC State University
911 Oval Drive
Raleigh, NC 27695

January 11, 2019

Common Abbreviations & Nomenclature

AGL	=	above ground level
APCP	=	ammonium perchlorate composite propellant
ARRD	=	advanced retention and release device
AV	=	avionics
BP	=	black powder
CDR	=	Critical Design Review
CG	=	center of gravity
CP	=	center of pressure
EIT	=	electronics and information technology
FAA	=	Federal Aviation Administration
FMECA	=	failure mode, effects, and criticality analysis
FN	=	foreign national
FRR	=	Flight Readiness Review
HEO	=	Human Exploration and Operations
HPR	=	High Power Rocketry
HPRC	=	High-Powered Rocketry Club
L3CC	=	Level 3 Certification Committee (NAR)
LCO	=	Launch Control Officer
LRR	=	Launch Readiness Review
MAE	=	Mechanical & Aerospace Engineering Department
MSDS	=	Material Safety Data Sheet
MSFC	=	Marshall Space Flight Center
NAR	=	National Association of Rocketry
NCSU	=	North Carolina State University
NFPA	=	National Fire Protection Association
PDR	=	Preliminary Design Review
PLAR	=	Post-Launch Assessment Review
PPE	=	personal protective equipment
RFP	=	Request for Proposal
RSO	=	Range Safety Officer
SL	=	Student Launch
SLS	=	Space Launch System
SME	=	subject matter expert
SOW	=	statement of work
STEM	=	Science, Technology, Engineering, and Mathematics
TAP	=	Technical Advisory Panel (TRA)
TRA	=	Tripoli Rocketry Association

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1.1 Team Summary

1.1.1 Team Name and Mailing Address

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1.2 Launch Vehicle Summary

1.2.1 Size and Mass

The current leading launch vehicle design is 99 inches long with a diameter of 5.5 inches. The takeoff weight of the launch vehicle is 41.9 pounds.

1.2.2 Final motor choice

The launch vehicle will utilize an Aerotech L1150R motor.

1.2.3 Official Target Altitude

The team is declaring a target altitude of 4090 feet.

1.2.4 Recovery System

1.2.5 Rail Size

The launch vehicle shall launch from a 1515 rail.

1.2.6 Milestone Review Flysheet

This document has been submitted separately.

1.3 Payload Experiment Summary - "The Eagle and the Egg"

The team aims for the payload to successfully eject from the launch vehicle, arm the motors, and safely fly to and deliver the simulated navigational beacon. To accomplish the mission, the team will utilize a payload pod, designated the "Egg," which will house the UAV, the "Eagle," while the launch vehicle is in flight. The purpose of the Egg is to protect the UAV, provide the UAV a means to self-right, and to act as a place to take off from once the launch vehicle has landed. A receiver will be placed forward of the payload bay on a removable bulkhead that will receive a signal from the hand-held radio transmitter. This receiver will activate a preprogrammed controller that will control all the electronics involved in deploying the payload.

2. Changes Made Since PDR

Table 2-1 Changes Made Since PDR

Change	Reason for Change
Location of nosecone bulkhead will be recessed further into the nosecone.	The bulkhead will be too large to fit through the nosecone shoulder if it is designed to fit farther aft in the nosecone.
Payload bay removable bulkhead will be 0.5 inch thick rather than 0.375 inch.	Analysis showed that stresses were too high and would potentially damage the bulkhead with a thickness of 0.375 inch. See Section 3.1.3.4(a).
Payload bay removable bulkhead will be secured using single screw L brackets rather than with two screws on each flange.	After the analysis done in Section 3.1.3.4(b), the extra screws were not necessary to have sufficient strength and the additional space for the payload deployment system is favorable.
AV bay bulkhead will be a total of 0.75 inch thick rather than 0.5 inch.	Analysis showed that stresses were too high and would potentially damage the bulkhead with a thickness of 0.5 inch. See Section 3.1.3.6(a).
Motor block will be 1 inch thick rather than 0.75 inch.	With the change in motor, maximum thrust increased; with this increase, stresses increased requiring a thicker motor block. In addition, more surface area was desired for better adherence to the body tube. See Section 3.1.3.7(c).
Motor block will be recessed 0.375 inch into the aft end of the fin can.	Recessing the motor block allows for room to fillet the motor block with epoxy for better strength.
Fin can bulkhead will be 0.75 inch rather than 0.625 inch.	The fin can bulkhead was strengthened to withstand expected loading. See Section 3.1.3.7(a).
The Full-Scale Launch Vehicle motor shall be an Aerotech L1150R rather than an Aerotech L850W.	Decreased Launch Vehicle mass warranted the use of a less powerful motor to achieve target apogee.

The Stepper motor used in the payload bay shall be moved to the forward side of the removable bulkhead.	Limited space on the aft side of the bulkhead. Reduces minimum distance from the pusher to the bulkhead, allowing the latch to be flush with the bulkhead.
The main parachute shall be a FruityChutes Iris Ultra 84 inch parachute rather than an Iris Ultra 120 inch parachute.	The launch vehicle's mass has decreased since PDR. This requires a smaller parachute to meet descent time and drift requirements. The 84 inch diameter parachute meets the wind drift, descent time, and landing kinetic energy requirements.
Solenoid Mounting changed from bottom of body to top.	This adjustment allows for the beacon to be held closer to the UAV body, keeping the beacon more secure during launch vehicle flight and UAV flight.
Power Cell protection changed from a cradle to a sled design.	This sled design takes up less space and allows for a more easily constructed and implemented 3D printed piece.

3. Vehicle Criteria

3.1 Design and Verification of Launch Vehicle

3.1.1 Team Mission Statement

The purpose of Tacho Lycos (High-Powered Rocketry Club at NC State University) shall be to stimulate interest in rocketry at North Carolina State University by designing and building high-powered rockets with the help of Tripoli Rocketry Association certified mentors and competing in NASA Student Launch. Furthermore, the club aims to inspire K-12 students across North Carolina to pursue STEM careers through hands-on educational events.

3.1.2 Mission Success Criteria

Mission success is defined firstly as compliance with the requirements of the NASA Student Launch Competition as defined in Table 6-1 as well as the team derived requirements described in Table 6-2. The team has also defined a successful mission as one that achieves the target apogee stated in Section 1.2.3, safe landing with both parachutes deploying, deployment of UAV after landing, and placement of the beacon in the designated target area.

3.1.3 Final DesignFinal Design

3.1.3.1 Body Material

The final selection for body material for the full-scale launch vehicle is fiberglass. The body of the launch vehicle is responsible for housing all the necessary launch vehicle components such as the motor, parachutes, avionics, and payload. Each of these components are attached to the launch vehicle body, whether it be directly or through being attached to a bulkhead that is then attached to the body. Because of this, it is imperative to ensure that the airframe material will be able to withstand the loads it will experience during flight. To determine the strength necessary for the fiberglass body material, the compressive force on the launch vehicle was calculated as follows:

$$F_C = F_D + F_I \tag{1}$$

Where F_D is the drag force on the airframe and F_I is the inertial force. The drag force on the launch vehicle is calculated below:

$$F_D = C_D * \frac{\rho V^2}{2} A \tag{2}$$

Where C_D is the coefficient of drag, ρ is the density of air, V is the velocity of the launch vehicle, and A is the reference area. Air density is assumed constant at a value of 0.0749 lbm/ft^3 and the area is 15.9 in^2. The coefficient of drag for the current airframe configuration is 0.371 based on simulations performed in RockSim and the maximum velocity is 495 ft/s. This gives a drag force of F_D = 11.93 lbf. The inertial force is calculated as follows:

$$F_I = ma \tag{3}$$

Where m is the mass of the launch vehicle and a is the peak acceleration. The final design with fiberglass body tubes has a mass of m = 41 lbm and the peak acceleration using the current leading motor selection is 230 ft/s^2. Using these values, the inertial force on the launch vehicle is calculated to be 292.86 lbf; this means that the total force on the airframe is 304.79 lbf.

Fiberglass is the strongest commercially available material used in hobby rocketry and, though crush test data is not available, with an expected load of only 304.79 lbf, the team is confident that fiberglass will be able to withstand any normal flight loads and still be reusable. In addition, fiberglass is impervious to moisture, unlike the next leading alternative, Blue Tube 2.0. Use of Blue Tube would save weight and cost, however, would require filling the grooves with wood filler as well as sealing to prevent potential water damage. Weather conditions in North Carolina can often lead to wet ground conditions on launch days, and in the past, this has led to lack of reusability with Blue Tube body tubes. Due to the significant improvement in ease of manufacture and the unpredictable launch field conditions, the additional cost and weight is worth the use of fiberglass in order to produce the most durable vehicle possible.

3.1.3.2 Overall Vehicle Layout

The final launch vehicle design will utilize the payload forward configuration described in the PDR. In this configuration, shown in Figure 3-1**Error! Reference source not found.**, the payload bay will be permanently attached to the nosecone during flight using fasteners which will be discussed below. Attached to the payload bay by a coupler is a section of body tube to house the main parachute which will be permanently attached to the AV bay during flight using the same fasteners. The drogue parachute will be housed in the fin can forward of the forward bulkhead. Each of the three sections will be tethered by shock cord.

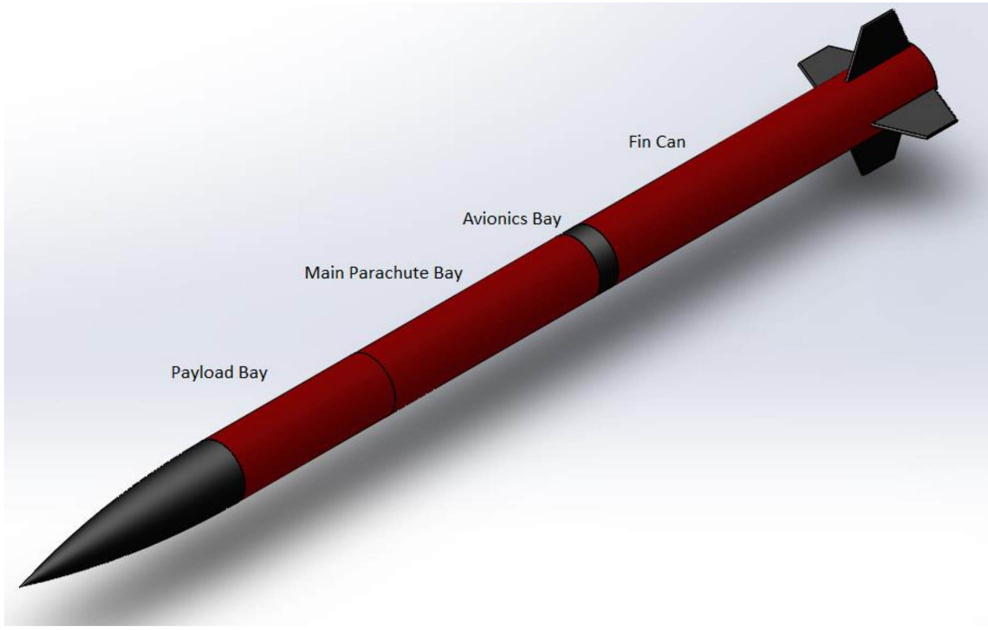

Figure 3-1 Overall Vehicle Layout

This configuration breaks the two heaviest sections, the fin can and the payload bay, up so that they are not attached during descent. This reduces kinetic energy at landing as the total mass of any individual section is reduced or allows for the vehicle to have a higher velocity at landing and still meet the kinetic energy requirements. This faster velocity means that better parachute options can be considered that will help to meet the 90 second descent time requirement. This division of mass also means that the load on any particular bulkhead at drogue or main parachute deployment will also be significantly less. Finally, this configuration utilizes four fins rather than three, which allows for greater flight stability; for more details, see Section 3.1.3.7(d).

This configuration consists of a 22 inch long nosecone with a 2.75 inch coupler, a 16.5 inch long payload bay, 22.5 inch long main parachute bay, 2 inch AV bay band, a 35 inch long fin can, and a 22 inch long motor tube. All body tubes are 5.5 inches in diameter. The payload bay and main parachute bay are joined by a 11 inch long coupler centered between the two sections. The fin can, AV bay band, and main parachute bay are joined by the AV bay coupler, which is 10.25 inches long. The AV bay coupler lies 5.5 inches into the fin can and 2.75 inches into the main parachute bay since it will remain attached to the AV bay during flight. A dimensioned drawing is provided in Figure 3-2.

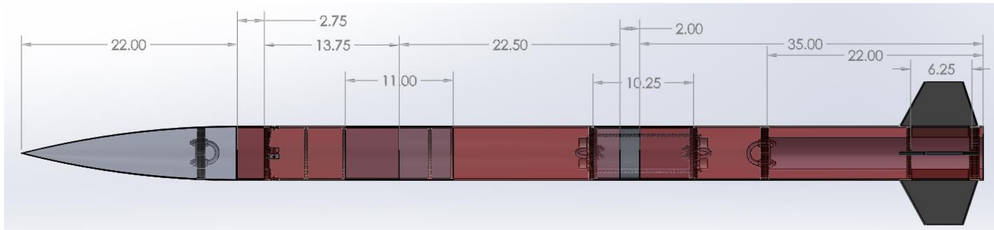

Figure 3-2 Launch Vehicle Dimensions

This configuration does not allow for the orientation of the payload upon landing to be predicted; however, due to developments in the payload deployment system, this orientation control is no longer necessary. Because of this, the benefits to kinetic energy and loads at parachute deployment have resulted in this being the chosen configuration.

3.1.3.3 Nosecone

The nosecone shape is a 4:1 ogive design. Its shape provides a larger interior space in which payload deployment electronics can be stored aft of the bulkhead. This space is necessary to house the payload deployment electronics discussed in Section 5.3.

The nosecone will be 22 inches with a 2.75 inch long shoulder. A permanent bulkhead will be fabricated to have a diameter to fit the inner diameter of the nosecone shoulder. This bulkhead will be recessed into the nosecone to where its curvature reaches this diameter. The nosecone bulkhead cannot possibly be further aft than this location as it would then be too large to fit through the inner diameter of the shoulder; however, it will not be recessed further than this in order to save as much adherence area as possible to ensure that the nosecone is as secure as possible. As shown in Figure 3-3, this location is approximately 3.30 inches into the nosecone past the shoulder. This bulkhead being recessed into the nosecone allows extra space for the payload deployment system within the nosecone. The nosecone bulkhead will have a U-bolt attached which will be secured to the main parachute shock cord. The nosecone assembly will have a mass of 2.62 lb.

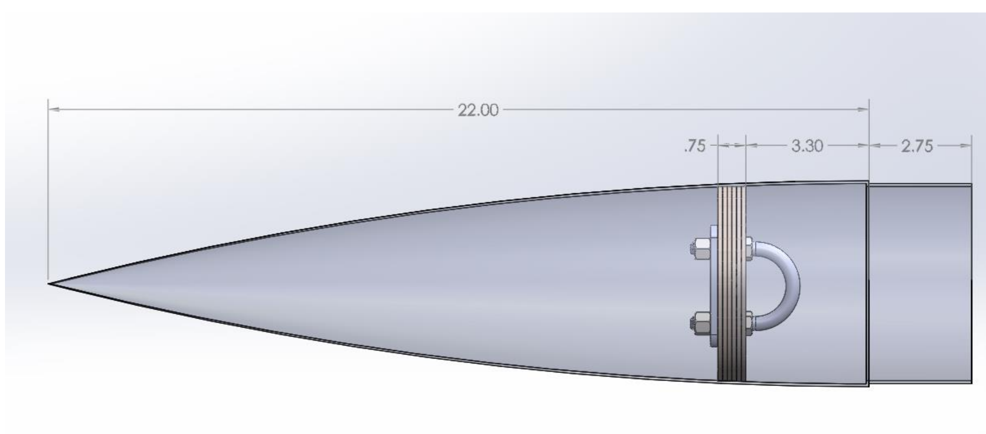

Figure 3-3 Nosecone Assembly Dimensions

3.1.3.3(a) Nosecone Material

The nosecone will be made of fiberglass just as the rest of the launch vehicle body is. This material choice allows for added weight at the forward end of the launch vehicle to help with stability. In addition, epoxy does not bond well with plastic but does bond with fiberglass; therefore, the bulkhead will be able to be securely installed into the nosecone using epoxy. Because of this, exterior screws through the nosecone will not be necessary, reducing the amount of disruptions in the flow over the nosecone as much as possible. The nosecone will not need nosecone ballast and therefore a machined metal tip will not be necessary. This material selection will allow the nosecone to be as durable as possible so that it can be launched multiple times.

3.1.3.3(b) Nosecone Bulkhead

The nosecone bulkhead will be made of six layers of 1/8 inch thick aircraft birch plywood for a total thickness of 0.75 inch. Its diameter will match the inner diameter of the nosecone shoulder, nominally 5.375 inches, and will be sanded to match the contour of the nosecone. A U-bolt will be attached through two holes such that the U-bolt is centered in the bulkhead. This bulkhead will be secured to the nosecone with epoxy that will be allowed to cure for 24 hours. If the testing described in Section 6.1.1 indicates that this epoxy will not be sufficient to secure the bulkhead, wood screws will be added through the exterior of the nosecone.

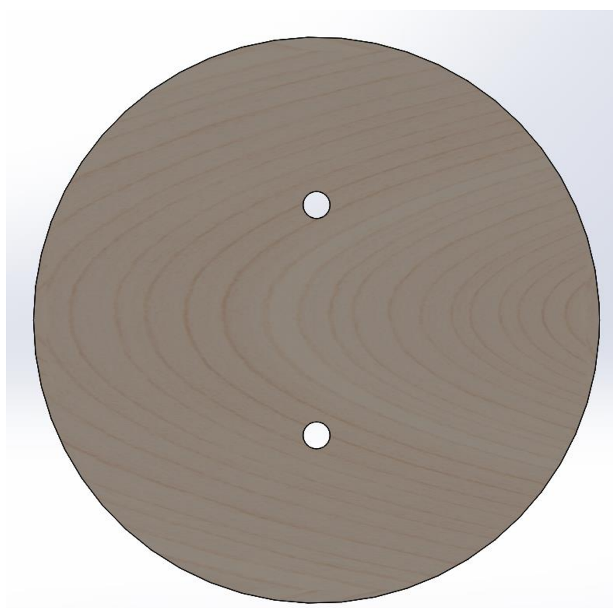

Figure 3-4 Nosecone Bulkhead

Based on the acceleration changes seen in RockSim simulations, the nosecone bulkhead is expected to experience a load of 234.44 lbf at main parachute deployment. Using this load value, hand calculations were done to determine an approximate maximum stress value in the bulkhead. Then, finite element analysis was done in ANSYS to obtain a more accurate view of the stresses in the bulkhead under this loading. The results of this analysis are shown in Figure 3-5; in this view, the load at deployment is being applied out of the page.

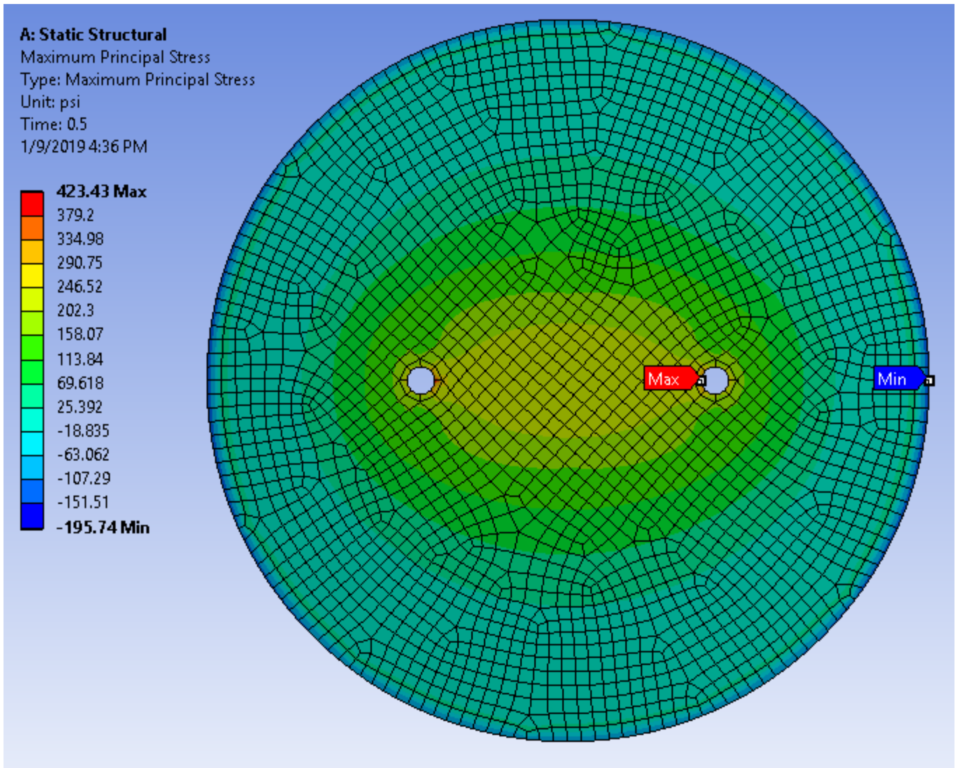

Figure 3-5 Nosecone Finite Element Analysis

The finite element analysis shows a maximum tensile stress of 423.43 psi at the edge of the U-bolt hole and a maximum compressive stress of 195.74 psi at the edge joined to the nosecone. The tensile strength of birch wood is minimum perpendicular to the grain at 1000 psi and the compressive strength is also minimum perpendicular to the grain at 1570 psi[1]. These values were used because the orientation of each of the layers are not known and, by using the minimum values, this is the most conservative value to compare to, ensuring that the analysis will not lead to false acceptance of designs. Based on these values, this bulkhead design has a factor of safety of 2.36 and therefore, the team is confident that it will be able to withstand the loads it will experience.

3.1.3.4 Payload Bay

The payload deployment system requires that the payload exit the vehicle through the open coupler section at the end of the payload bay upon landing. This system requires centering rings throughout the payload bay which support the payload deployment pod as well as a bulkhead at the forward end of the payload bay to which the deployment electronics and the pod will be secured during flight. The

[1] (European Birch Wood n.d.)

centering rings and depth of the payload bay make access to the bulkhead difficult; for this reason, this bulkhead will be attached by four L-brackets and will be removable. This is depicted in Figure 3-6.

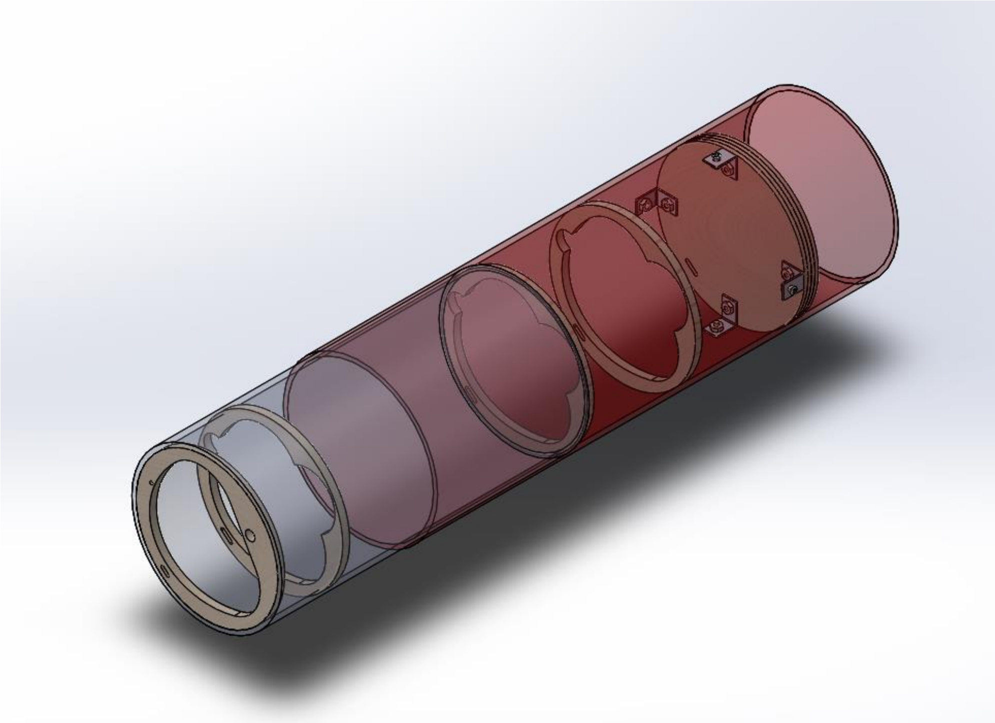

Figure 3-6 Payload Bay with Removable Bulkhead

The payload deployment electronics, stepper motor and other hardware, and the latch which will secure the payload during flight will all be attached to this bulkhead. The shock cord from the main parachute will be routed through all the centering rings and this removable bulkhead and will be secured to a permanent bulkhead within the nosecone.

The removable bulkhead will be located 2.75 inches from the forward edge of the payload bay; this means that the nosecone shoulder will be in contact with the bulkhead during flight, adding an additional layer of security to this bulkhead. The centering rings will be spaced as shown in **Error! Reference source not found.**. To support the payload pod during flight and deployment. There will be a centering ring at the edge of the payload bay coupler which will function to prevent the payload pod from retracting into the body along with the stepper motor after deployment; the centering ring just forward of this last ring ensures that the weight of the pod will not cause it to pitch downward during deployment until it has exited the vehicle by providing a second point of support. The payload bay assembly will have a mass of 9.6 lb, including the weight of the payload.

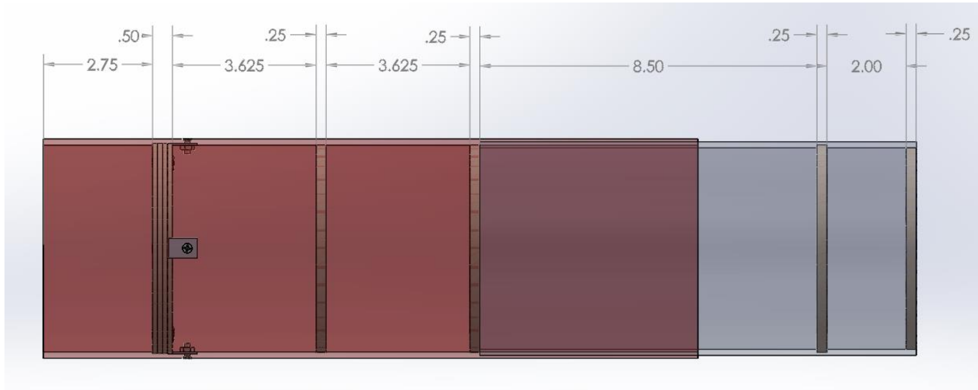

Figure 3-7 Payload Bay Dimensions

This design allows for the payload to be secured prior to installing the bulkhead into the body tube which increases accessibility significantly. The team will be able to visually ensure that the payload is secured properly and that all electronics are functioning properly before flight. In addition, there will be no disruptions to the outer surface of the launch vehicle from a hatch. Finally, there will be more space on the bulkhead itself to attach payload deployment hardware as there will be no U-bolt taking up some of the space.

This configuration presents some challenges: potential damage to the bulkhead, centering rings, or shock cord from being routed through off center as well as the face that the nosecone is not the most secure place to have a bulkhead which will endure loading from parachute deployment. This design was used during subscale launch in order to validate the use of this routing method. The shock cord, bulkhead, and centering ring were all inspected after flight and it was determined that there was no damage done due to parachute deployment. In order to ensure that none will be experienced during full-scale flight, care will be taken during manufacturing to ensure that all shock cord slots in the bulkhead and centering rings are filed down such that no sharp edges that could potentially damage the shock cord will be present. In addition, the shock cord will be pulled taught through this section prior to flight so that there will not be any loose length of shock cord to potentially get caught or damage the bulkhead or a centering ring.

In addition to this, testing will be done to ensure that the nosecone bulkhead will be able to withstand the expected loading during parachute deployment. This testing is discussed in Section 6.1.1.

3.1.3.4(a) Payload Bay Bulkhead

The payload bay bulkhead will be constructed of four layers of 1/8 inch aircraft grade birch plywood for a total thickness of 0.5 inch. Its diameter will match the inner diameter of the body tube, nominally 5.225 inches. It will be attached to the body of the launch vehicle during flight using four evenly spaced L-brackets that will also allow for it to be removeable during flight preparation. These L-brackets may not be located in the exact location given; however, they will remain evenly spaced so that analysis done on this configuration is still valid. The bulkhead will feature a slot, as shown in Figure 3-8, which will allow the shock cord to pass through and attach to the bulkhead within the nosecone. This bulkhead will support all of the payload deployment hardware including the stepper motor and the latch which will secure the payload during flight.

Figure 3-8 Payload Bay Bulkhead

Because this bulkhead supports all of the payload system, it is imperative that it is able to withstand in flight loading. Based on a maximum weight estimate of the payload of 5.5 pounds, the payload bay bulkhead will experience a load of 106.65 lbf at main parachute deployment. Finite element analysis was done by supporting the bulkhead where the L-brackets will be located and applying the 5.5 lb load over the aft surface of the bulkhead as the components will all be spread out over the surface. The results from this analysis are shown in Figure 3-9.

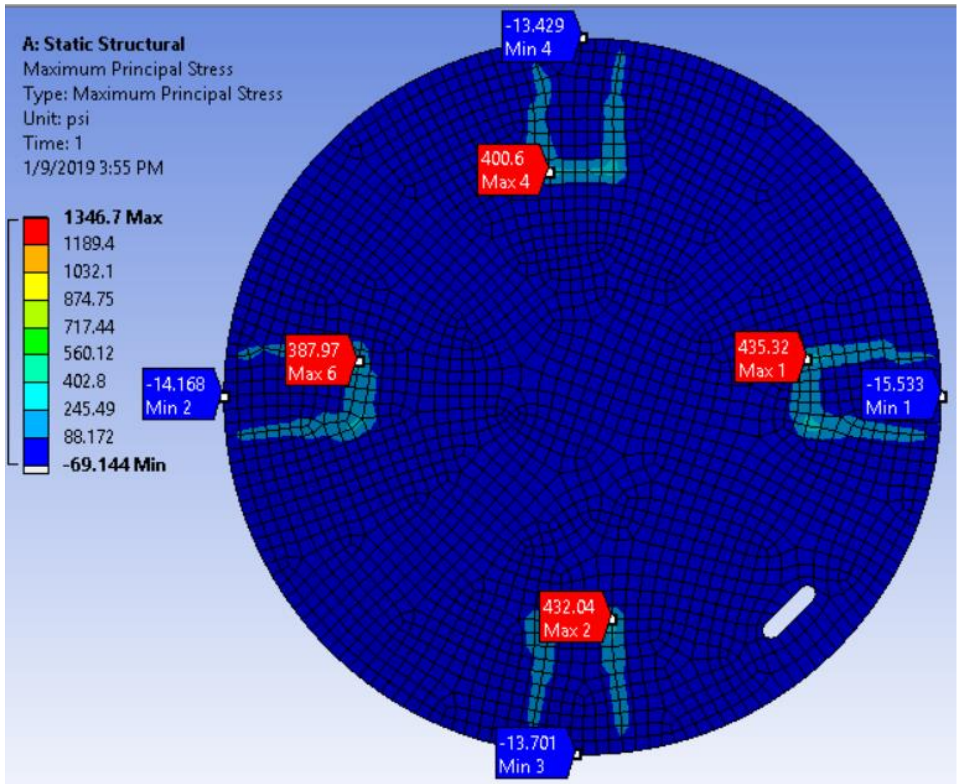

Figure 3-9 Payload Bay Bulkhead Finite Element Analysis

Though the scale shown indicates the maximum tensile stress as being 1346.7 psi and the maximum compressive stress being 69.144 psi, these are stresses on the L-brackets rather than on the bulkhead; the maximum stresses are indicated on the bulkhead by flags at each location. As can be seen from these results, the main concern in this bulkhead is the tensile stresses located where the edge of the L-bracket is. The maximum tensile stress is 435.32 psi, which, using a strength value of 1000 psi in tension, gives this bulkhead a factor of safety of 2.30. Based on this factor of safety, the team is confident that this bulkhead will be able to withstand the loading it will experience during normal flight.

3.1.3.4(b) Payload Bay Bulkhead Screws

The payload bay bulkhead will be secured to the body tube with four #6-32 stainless steel machine screws. Due to the 106.65 lbf load the payload bulkhead will experience, the screws will also experience significant stresses. This joint is a simple single shear joint, so the shear stress in the screws can be calculated as follows.

$$\tau = \frac{F}{A} \tag{4}$$

Where F is the load applied and A is the cross-sectional area of the screw. The diameter of #6 machine screws is 0.138 inches. The load value is divided by four because the four screws will each support this load evenly; using these values, the shear stress in each of the screws is 1782.60 psi. Though the exact grade of the stainless steel is unknown, the lowest listed shear strength in the material property data website MatWeb[2] is 33000 psi. Using this value, the screws have a factor of safety of 18.51, meaning that they will be sufficiently strong enough to withstand normal flight loads.

3.1.3.4(c) Payload Bay Centering Rings

Each of the three centering rings which are spread throughout the length of the payload bay will be constructed of two layers of 1/8 inch aircraft grade birch plywood for a total thickness of 0.25 inch. The cross section of the centering rings is shown in Figure 3-10.

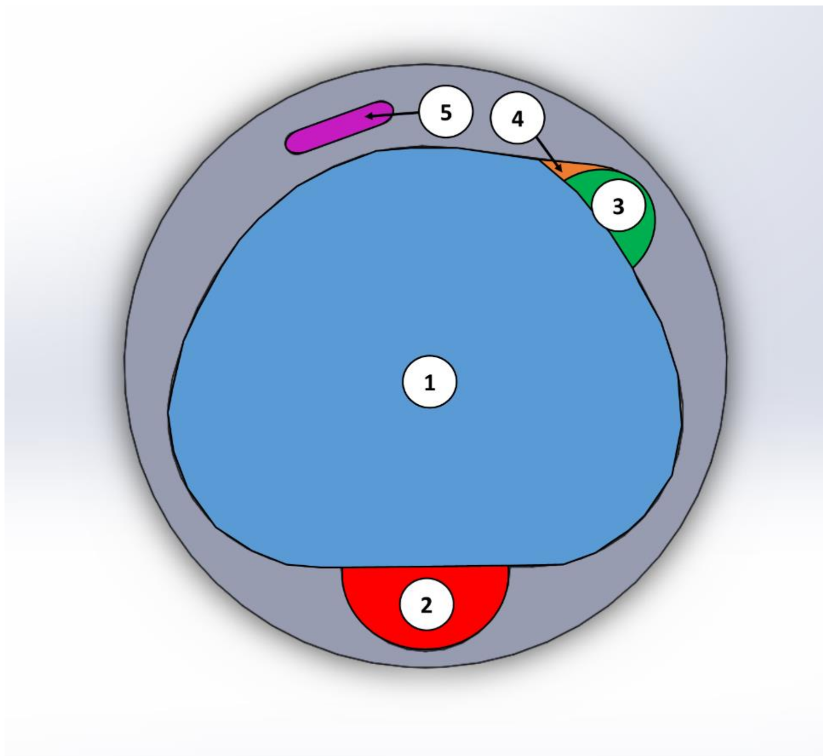

Figure 3-10Payload Bay Centering Ring

The centering rings were designed to accomplish a number of purposes. The different regions indicated in Figure 3-10 are the sections cut out from the plywood, each removed for a specific reason. The payload pod, pusher, lead screw and auxiliary rod are all explained in greater detail in Section 5.2.1. The region labeled 1 is the same shape as the payload pod and supports the pod in both lateral directions. The matching irregular shape of the pod and region 1 ensures the pod is unable to rotate. Region 2 leaves space for the lead screw to traverse the length of the payload bay. The reason it is a semicircle and not

[2] (Overview of Materials for Stainless Steel n.d.)

a drilled hole is because the pusher also must surround the lead screw and pass through the centering ring. Region 2 was designed to be as large as possible to allow for a proper fitting for the pusher around the lead screw. Region 3 was removed for the same reason as region 2, but for the auxiliary rod and the pusher. Region 4 was removed so the pusher has more clearance to pass through the ring. Finally, region 5 allows the shock cord to pass through the payload bay until it reaches the nosecone bulkhead.

The final centering ring, located at the aft side of the payload bay, is similar, but not identical to, the design shown in Figure 3-10. The primary difference in design is replacing regions 2, 3, and 4 with two holes to align with the lead screw and auxiliary rod. These holes will support the rods without allowing for compression. The lack of semicircular cutouts will also prevent the pusher from leaving the body tube.

3.1.3.4(d) Payload Bay Plug

Because the payload bay is connected to the main parachute bay during flight, it is necessary to seal it off from the black powder in order to protect it from the deployment charges as well as to maintain pressure within the main parachute bay at deployment. To do so, a plug will be used. This plug will be fabricated from layers of 1/8 inch birch plywood; two layers will match the shape of the centering ring at the end of the payload bay and two will match the inner diameter of the body tube. This plug is shown in Figure 3-11.

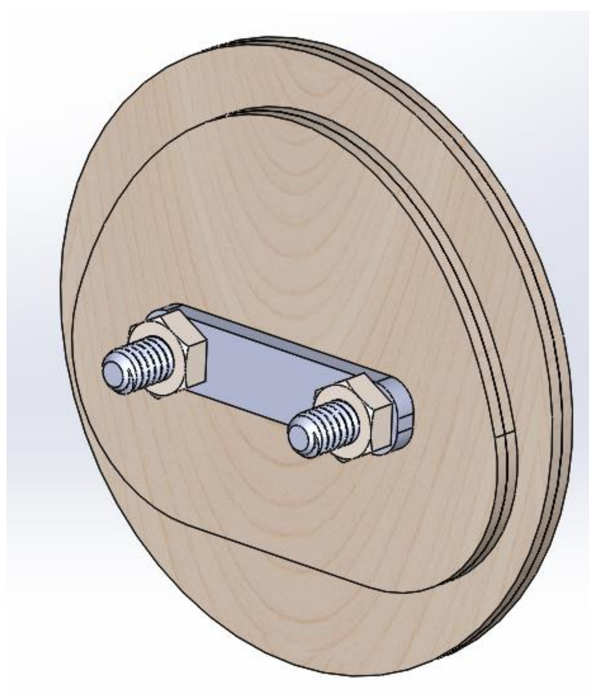

Figure 3-11 Payload Bay Plug

The two layers which match the shape of the centering ring will be slightly smaller than the inner shape of the centering ring so that there is room to secure elastic onto the plug. This elastic will ensure a secure attachment within the centering ring during flight and will also help to seal the payload bay off. In addition, a U-bolt will be attached to the plug which will be attached to the shock cord such that the plug remains attached to the vehicle after the main parachute is deployed.

3.1.3.5 Main Parachute Bay

A 22.5-inch-long section of body tube will be included between the payload bay and the AV bay to house the main parachute and shock cord lengths. This section of body tube will be attached to the AV bay during flight with fasteners but will be removable for flight preparation. This section will have a mass of 4.75 lb, including the mass of the main parachute.

3.1.3.6 AV Bay Design

The AV bay will consist of a length of coupler with a short section of body tube and is capped on either end by bulkheads. The thin section of body tube exists to provide space for key switches to altimeters and pressure ports, but the AV bay is otherwise housed within the coupler section. The bulkheads will be secured by two threaded rods running the length of the AV bay which will also function to support the avionics sled. Blast caps for black powder as well as U-bolts which will be secured to each parachute will be located on each bulkhead. This configuration is shown in Figure 3-12.

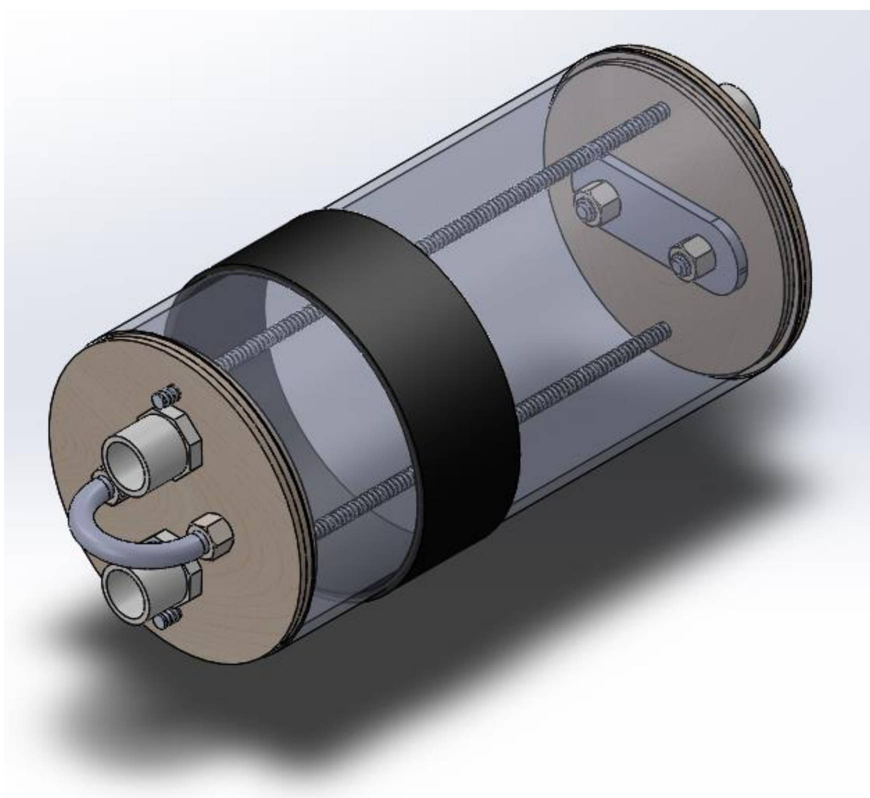

Figure 3-12AV Bay

A dimensioned drawing of this section is provided in Figure 3-13. The coupler section will be a total of 10.25 inches long and the body tube section will be 2 inches long. The body tube section will be located such that 2.75 inches of coupler will connect to the main parachute bay as these two sections will not separate during flight and 5.5 inches will connect to the fin can, as these two sections will separate at drogue deployment. The AV bay assembly will have a mass of 5.42 lb including a ballast amount of 0.85 lb. This ballast is included here to affect the center of gravity, and therefore the stability, of the launch vehicle as little as possible but to add weight due to the expected weight of the payload getting lighter since PDR.

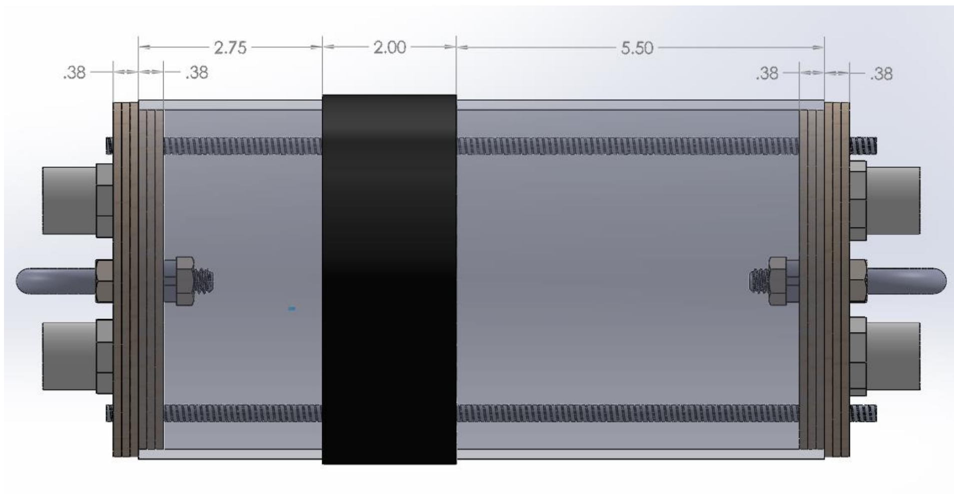

Figure 3-13AV Bay Dimensions

This configuration allows for the AV bay to fully prepared before being inserted into the launch vehicle; this means that avionics preparation will not delay payload preparation or vice versa, as well as that preparing the AV bay will not require reaching into long, narrow sections of body tube to load blast caps, attach shock cords, etc. Though access to the inside of the AV bay will not be possible once installed in the launch vehicle, the ease of access for preparation and the time saved by being able to do tasks in tandem, as well as the fact that no interruptions in the outer surface will be introduced by an external hatch, greatly outweighs this potential drawback.

3.1.3.6(a) AV Bay Bulkheads Design

The AV bay bulkheads will cap each end of the AV bay coupler section and will consist of three 1/8-inch layers of aircraft grade birch plywood which match the inner diameter of the body tube, nominally 5.225 inches, and three layers which match the inner diameter of the coupler section, nominally 5.075 inches. This configuration allows the bulkheads to seal the AV bay from black powder charges and is shown in Figure 3-14.

Figure 3-14 AV Bay Bulkhead

The two bulkheads will be secured by two ¼ inch thick threaded rods which will run the full length of the AV bay and will have bolts on them to hold the bulkheads tight. In addition, each of these bulkheads will have U-bolts which will secure the shock cords connected to each of the main and drogue parachutes. The U-bolt will be centered in the bulkhead and perpendicular to the plane made by the two threaded rods, as shown in Figure 3-15.

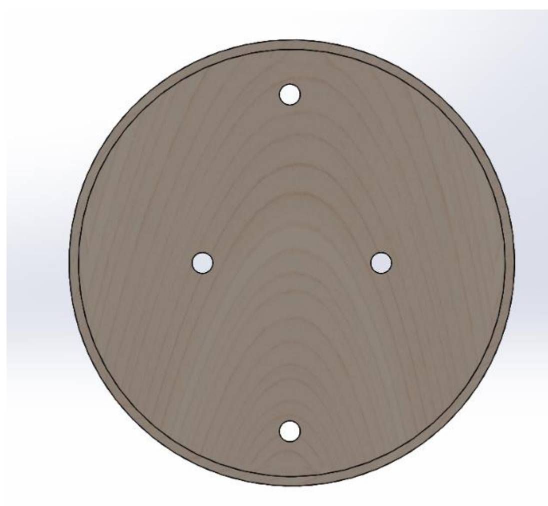

Figure 3-15 AV Bay Bulkhead Top View

In addition to the U-bolts and threaded rods, these bulkheads will house the blast caps for black powder charges and terminal blocks to ignite the black powder.

Because these bulkheads are only secured by the two threaded rods and will experience high loads at parachute deployment (particularly at main deployment), the bulkheads were examined using finite element analysis to ensure that they will be capable of withstanding this loading. Based on acceleration simulation data from RockSim, the forward AV bay bulkhead will experience a load of 173.75 lbf at main parachute deployment. Constraining the bulkhead by two washer-sized areas around the threaded rods and applying this load, the finite element analysis results shown in Figure 3-16 were obtained.

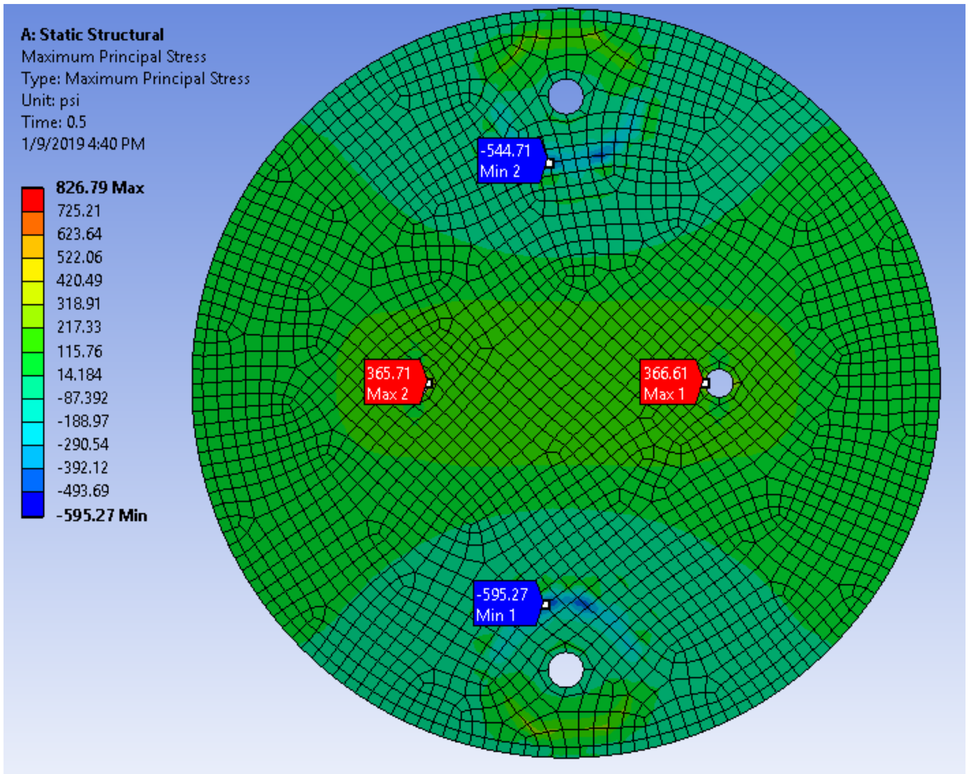

Figure 3-16 AV Bay Bulkhead Finite Element Analysis Results

Though the scale on the left shows a maximum tensile stress of 826.79 psi, this stress is located on the washers which will be made of a stronger material and will be able to withstand this stress. The maximum tensile stress experienced by the bulkhead is located at each of the U-bolt holes at values of 365.71 psi and 366.61 psi. The maximum compressive stress is experienced where the bulkhead interacts with the edge of the washers with values of 544.71 psi and 595.27 psi. Using tensile strength of 1000 psi and compressive strength of 1570 psi[1] as discussed in Section 3.1.3.3(b), this bulkhead has a factor of safety of 2.64 and will therefore be able to withstand loading seen in flight.

3.1.3.7 Fin Can Design

The fin can will consist of a bulkhead at the forward end of the motor tube, a centering ring, and an engine block at the aft end of the motor tube. The forward centering ring will be attached to the forward end of the fin tabs and the engine block will attach to the aft end of the fin tabs. The fin can will also house the drogue parachute which will be secured to a U-bolt on the forward fin can bulkhead. This configuration ensures that there is no single point of failure in the drogue attachment point to the fin can as well as allowing for the shock cord to be interchangeable if necessary. The fin can assembly is shown in Figure 3-17.

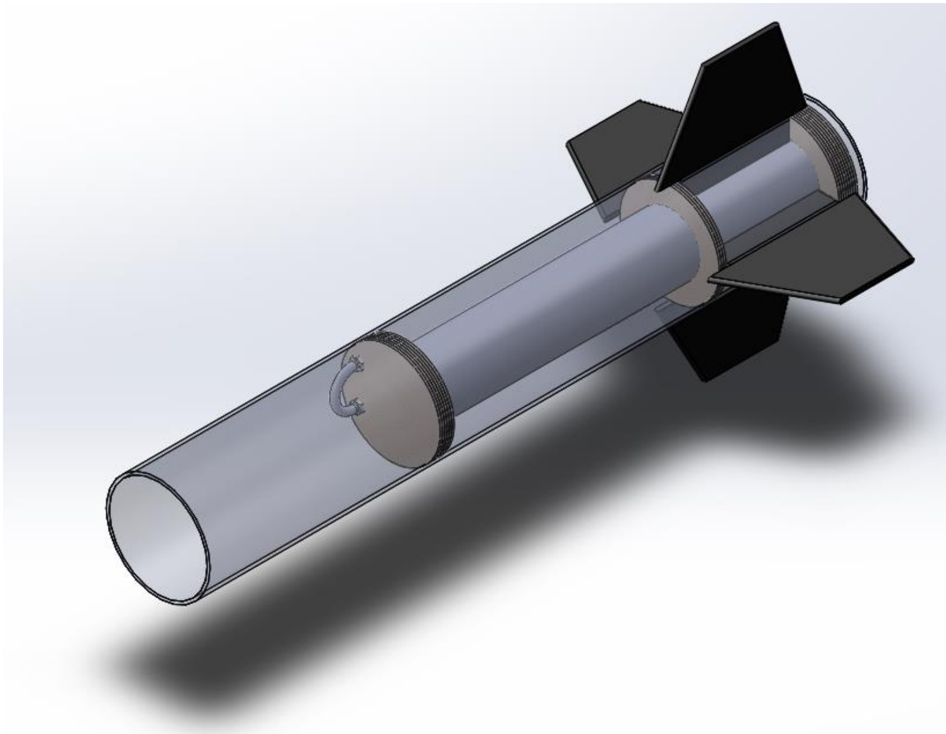

Figure 3-17Fin Can Assembly

The fin can will have a 12.375 inch long section forward of the bulkhead to house the drogue parachute. The fin can bulkhead will sit at the forward end of the motor tube. The motor tube will be a total length of 22 inches to house the motor casing. The motor block will be recessed 0.375 inches from the aft end of the fin can to allow room for epoxy filleting in order to strengthen the attachment point as much as possible. A flanged motor retainer will be utilized for additional security and to mitigate any issues that could arise from the relatively low melting point of epoxy; if only epoxy were to be used to secure the motor retainer, the heat from the motor could potentially cause the motor retainer to become unattached during flight.

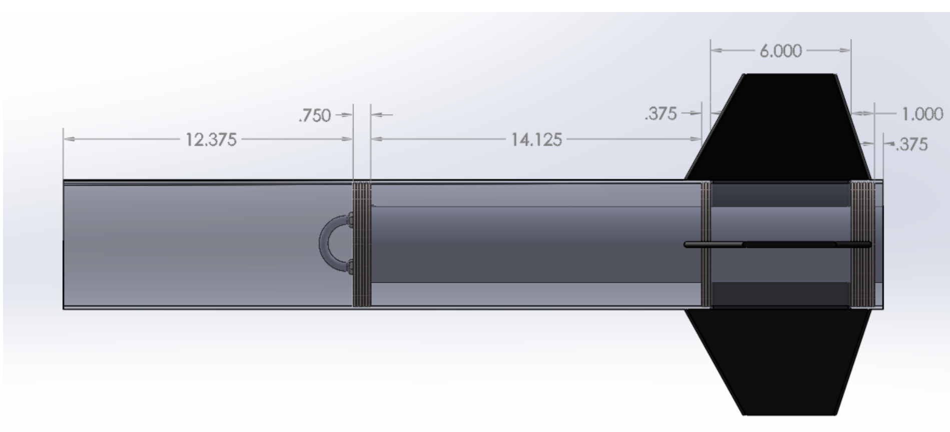

Figure 3-18Fin Can Assembly Dimensions

The mass of the fin can assembly at burnout will be 10.5 lb, including the weight of the drogue parachute and shock cord.

3.1.3.7(a) Fin Can Bulkhead Design

The fin can bulkhead will be constructed of six layers of 1/8 inch aircraft grade birch plywood for a total thickness of 0.75 inch. The fin can bulkhead will have a U-bolt attached which will be secured to the drogue parachute shock cord. The bulkhead is shown in Figure 3-19.

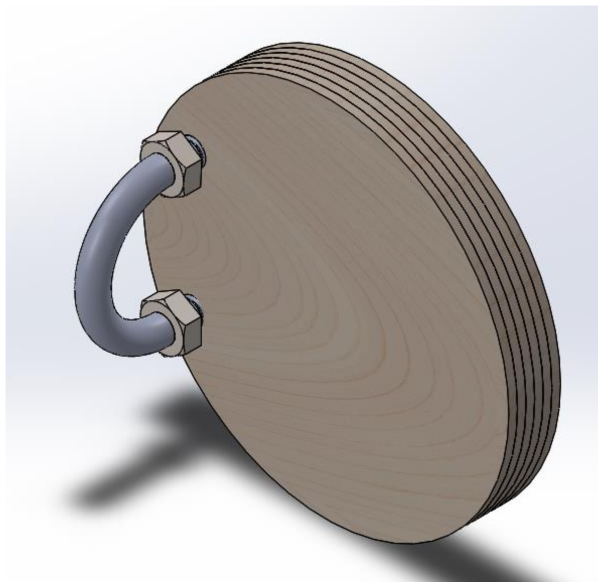

Figure 3-19 Fin Can Bulkhead Forward

The aft most layer of this bulkhead will have a circle cut out to match the outer diameter of the motor tube, nominally 3.25 inches. This cut out will provide support for the motor tube both in flight and during production. The aft side of this bulkhead is shown in Figure 3-20.

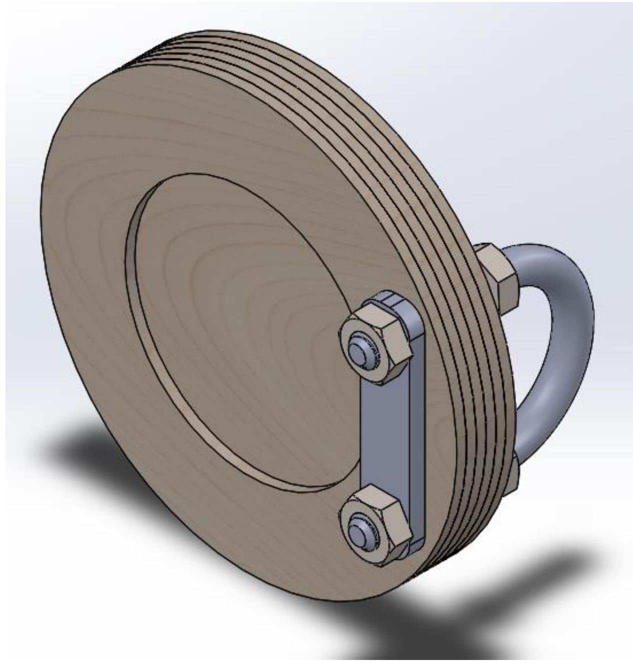

Figure 3-20 Fin Can Bulkhead Aft

The fin can bulkhead will be attached to the drogue parachute which will be deployed at apogee. Due to this, it is difficult to calculate the load that the bulkhead will experience at drogue deployment; however, it is expected that this load will be significantly smaller than the loading at main deployment due to the smaller size of the drogue parachute and the smaller change in acceleration. In addition, the fin can will be lighter at drogue deployment than the nosecone and payload bay will be at main deployment. Because of this, the fin can bulkhead will be the same thickness as the nosecone bulkhead and will be assumed to have a higher factor of safety than the nosecone bulkhead and therefore safe for flight.

3.1.3.7(b) Motor Tube Centering Ring Design

The motor tube centering ring will be constructed of three layers of 1/8 inch aircraft grade birch plywood for a total thickness of 0.375 inch. The outer diameter will match the inner diameter of the fin can body tube, nominally 5.225 inches, and the inner diameter will match the outer diameter of the motor tube, nominally 3.25 inches. The centering ring is not intended to bear any load from the motor tube but is intended to support the motor tube, both in construction and in flight. The motor tube centering ring is shown in Figure 3-21.

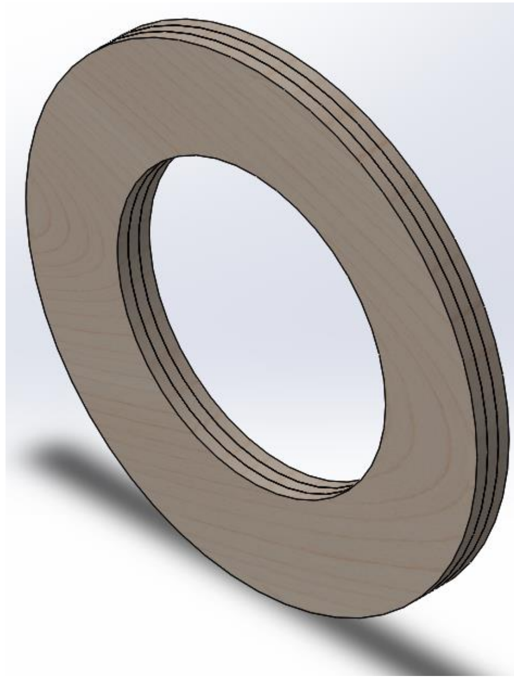

Figure 3-21 Motor Tube Centering Ring

3.1.3.7(c) Motor Block Design

The motor block will be made of eight layers of 1/8 inch aircraft grade birch plywood for a total thickness of 1 inch. The outer diameter of the motor block will match the inner diameter of the fin can body tube, nominally 5.225 inches and the inner diameter will match the outer diameter of the motor tube, nominally 3.25 inches. The motor block will be epoxied to both the body tube and the motor tube and allowed to cure for at least 24 hours. It is intended to bear the full load of the thrust during flight; the forward fin can bulkhead and the centering ring are not intended for this purpose. The motor block is shown in Figure 3-22.

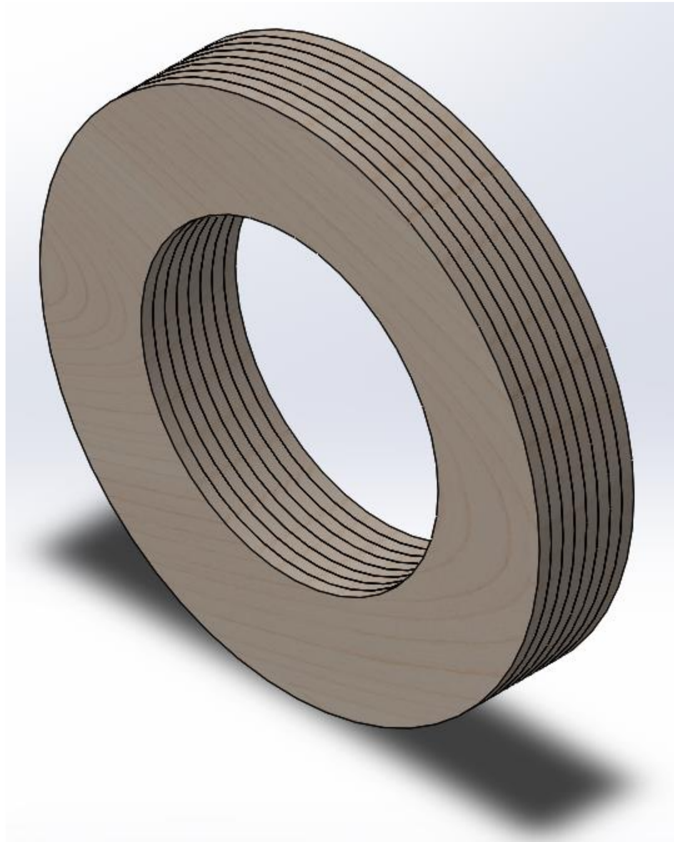

Figure 3-22 Motor Block

Because the motor block is the only component intended to bear the load from the thrust of the motor and is meant to transfer the load to the body tube, it is imperative that it will be able to withstand the full load it will experience. Using the Aerotech L1150, the maximum thrust force the motor block will experience is 294 lbf. Initial hand calculations were done using a load of 588 lbf to add a factor of safety and indicated that the motor block would need to be 1 inch thick to withstand this load with a reasonable stress in the material. Additional finite element analysis was done to further examine the stress which would be experienced by the motor block; these results are presented in Figure 3-23, Figure 3-24, and Figure 3-25.

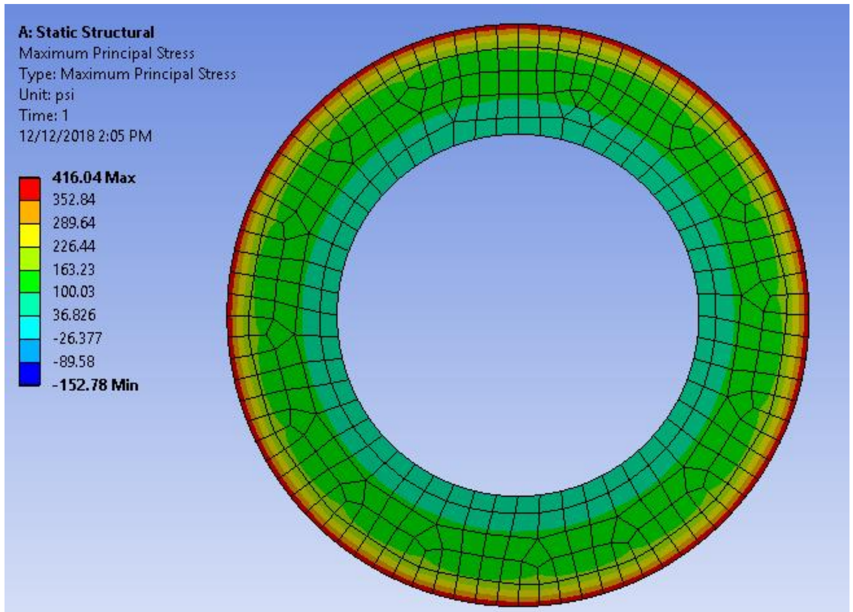

Figure 3-23 Motor Block Finite Element Analysis Bottom View

Figure 3-23 shows the motor block from the aft side where the force applied to it from the motor tube is applied into the page along the inner surface. The maximum tensile stress is experienced at the outer edge where it is secured to the body tube and has a value of 416.04 psi. Using a tensile stress allowable of 1000 psi, this gives the motor block a factor of safety of 2.4. However, this stress results from twice the load the motor block is likely to experience, which gives a factor of safety of 4.8, which indicates that the motor block will be able to withstand any loading it will experience in normal flight.

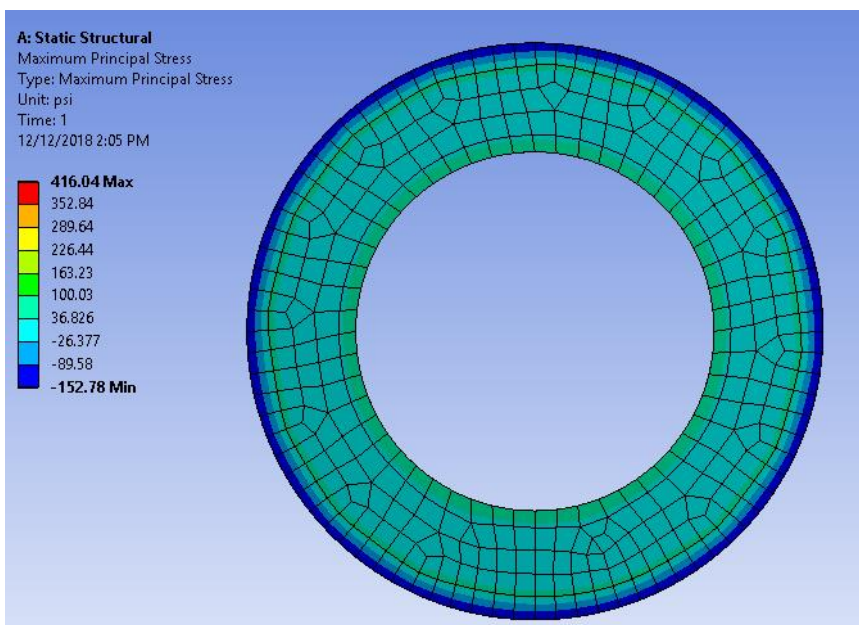

Figure 3-24 Motor Block Finite Element Analysis Top View

Figure 3-24 shows a top view of the motor block during loading. The maximum compressive stress is located at the outer edge of the motor block where it attaches to the motor tube. The maximum compressive stress value of 152.78 psi; because this is significantly lower than the tensile stress and the compressive stress allowable is higher than the tensile allowable, this compressive stress is not the most crucial loading that the motor block will experience.

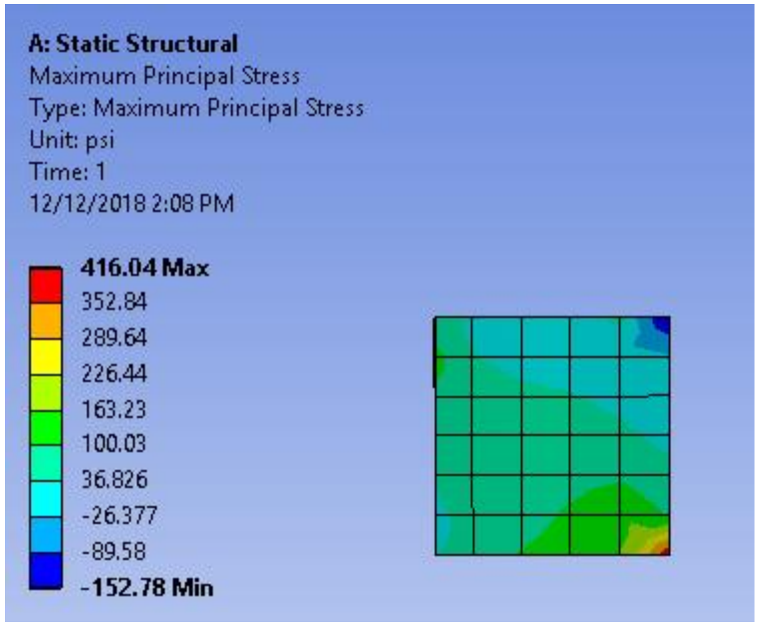

Figure 3-25 Motor Block Finite Element Analysis Cross Section

Figure 3-25 shows a cross section of the motor block where the left edge is the inner edge which attaches to the motor tube and the right edge is the outer edge which attaches to the body tube of the fin can. In this image, the force from the motor tube is being applied in the upwards direction. This shows that the maximum tensile and compressive stresses are both concentrated to the corners of the motor block where it attaches to the body tube. Other than these high stress areas, the majority of the cross section is under very low stress. This indicates that these attachment points are critical; because of this, the motor block is slightly thicker than it needs to be in order to handle in flight stresses so that there is more surface area for the motor block to adhere to the fin can.

3.1.3.7(d) Fin Design

The fins of the launch vehicle will be constructed of two layers of 1/8 inch aircraft grade birch plywood for a total thickness of 0.25 inch. The fins will have a 6-inch-long fin tab which will be inserted through slots in the fin can and will be epoxied to the centering ring, motor tube, and motor block. The root cord is 8 inches and the tip cord is 4 inches with a sweep length of 2.5 inches. Because the launch vehicle will not reach speeds of over Mach 0.7, fin flutter is not of concern and therefore fiberglass or other stronger materials are not needed. The forward and aft ends of the fins will be rounded. The fin dimensions are shown in Figure 3-26.

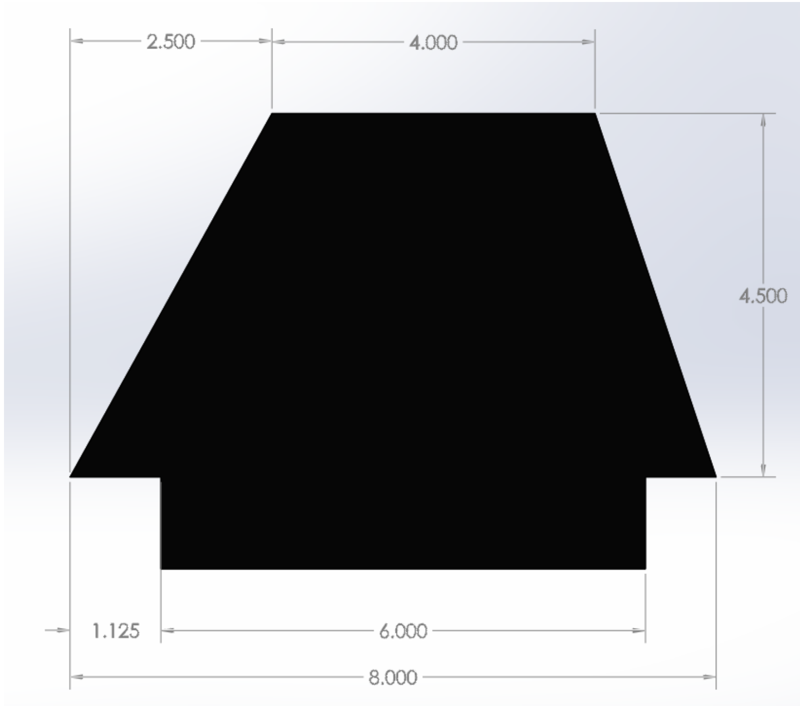

Figure 3-26Fin Dimensions

3.2 Subscale Flight Results

3.2.1 Recorded Flight Data

Two PerfectFlite StratoLoggerCF Altimeters were used to record flight data and manage recovery events onboard the subscale launch vehicle. This configuration is similar to that of the full-scale launch vehicle design, see Section 3.3.2. Figure 3-27 is a plot of the subscale launch vehicle's altitude and velocity during flight. This data was recorded by the primary altimeter as it gives the most accurate representation of the recovery events. The subscale achieved an apogee of 1129 ft. and a top speed of 400 fps. The launch vehicle descended under the drogue parachute at a rate of 53 fps and under the main parachute at a rate of 17 fps.

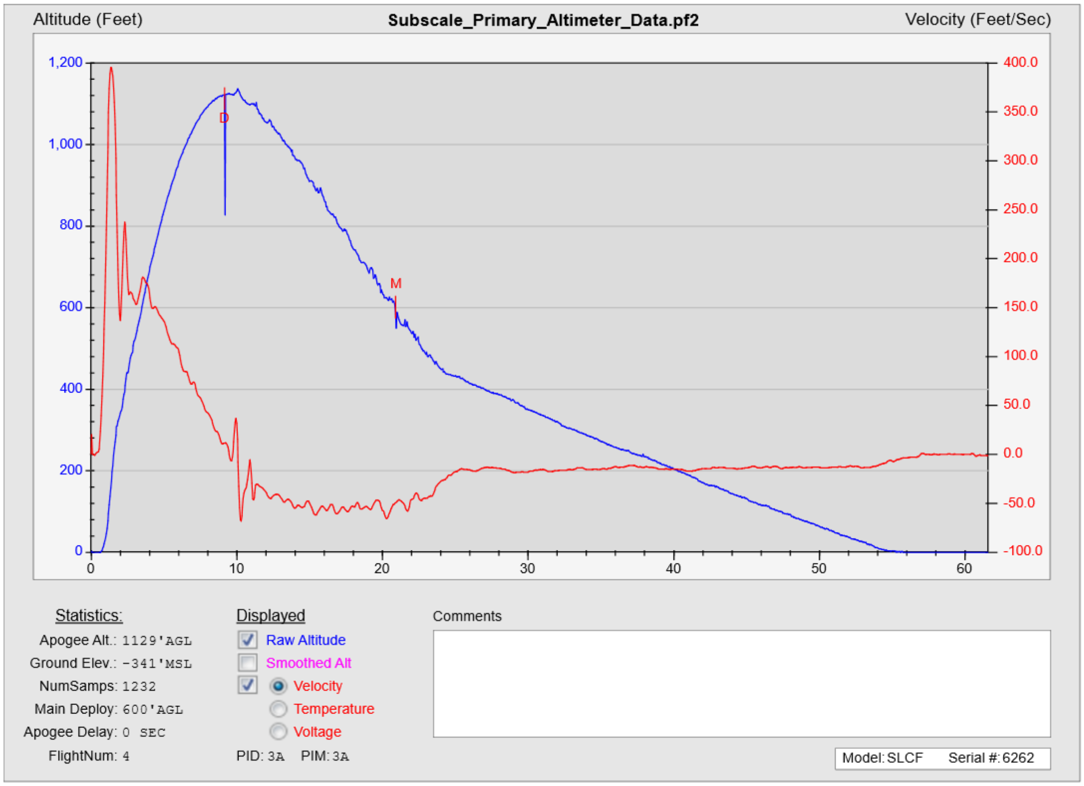

Figure 3-27 Primary Altimeter Flight Data for Subscale Launch

3.2.2 Scaling Factors

The subscale was sized based on the dimensions of the leading alternative design as described in the PDR. A body diameter of 4 inches was selected as this was the smallest size tube that still allowed access to attach the fin can shock chord U-bolt. A ratio of the subscale and full-scale body diameters was found to be 8:11 or 72.7%. This scaling factor was used to scale the length of the body tubes, as well as bulkhead locations.

Dimensions that could not be scaled appropriately include the body tube thickness, bulkhead thicknesses, fin thickness, and motor tube diameter. In the case of bulkhead and fin thicknesses, these components are constructed by laminating sheets of 1/8 inch birch plywood. As a result, their thicknesses can only be varied in 1/8 inch increments. Motor tubes are available in only a few sizes. The subscale launch vehicle utilized a motor tube that accepts a 38mm, or 1.5 inches motor casing. Similarly, body tubes come in standard diameter sizes with little to no variance in wall thickness between sizes.

Because the stability margin is measured in cal, the stability margin was held constant for the subscale. However, because of the thickness of the fins remaining ¼ inch the CP and by extension the CG were not located proportionally in the subscale.

3.2.3 Launch Day Conditions

The sub-scale was launched on November 17th in Bayboro North Carolina under the supervision of the club mentors and with the permission of TRA prefecture #65. Prior to launch, an anemometer reading indicated an average windspeed of 4.3 mph. The launch rail used was an 8ft, 1515 rail set at 5 deg downrange. At launch, the sub-scale weighed 12.3 lb with a stability margin of 2.13 cal.

RockSim was used to simulate the subscale launch using the data gathered at the launch field. The flight profile shown in Figure 3-28 predicts an apogee of 1366 ft, a maximum velocity of 73 fps and drogue and main parachute descent rates of 64 fps and 17 fps, respectively.

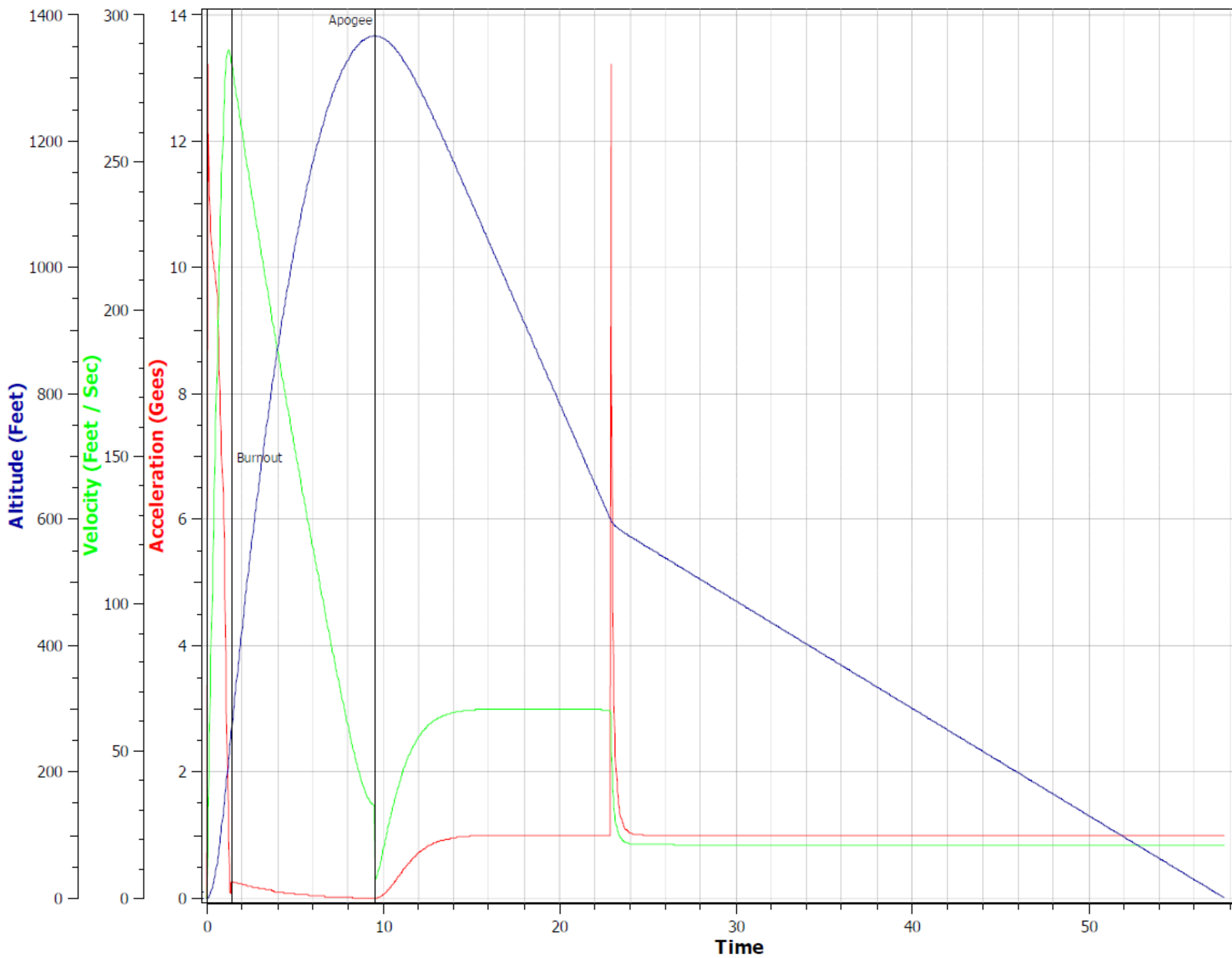

Figure 3-28 RockSim Simulation of Subscale Launch

3.2.4 Subscale Flight Analysis

The subscale performed as expected with one key exception. The apogee achieved by the subscale was lower than the simulated apogee by roughly 15%. Video recordings of the launch suggest that the vehicle encountered a gust of wind shortly after rail exit. This caused the vehicle to weathervane in a manner more extreme than the simulations. This initial perturbation set the launch vehicle on a drastically angled trajectory, on which it remained for the duration of the ascent.

3.2.4.1 Drag Coefficient Calculation

The Drag coefficient of the subscale launch vehicle was calculated using the RockSim drag simulation tool. This tool estimated the drag coefficient of the subscale to be 0.385. Figure 3-29 shows the drag contributions of various sections of the launch vehicle at the at the estimated full-scale launch velocity of 527 fps, see Section 3.4.1.

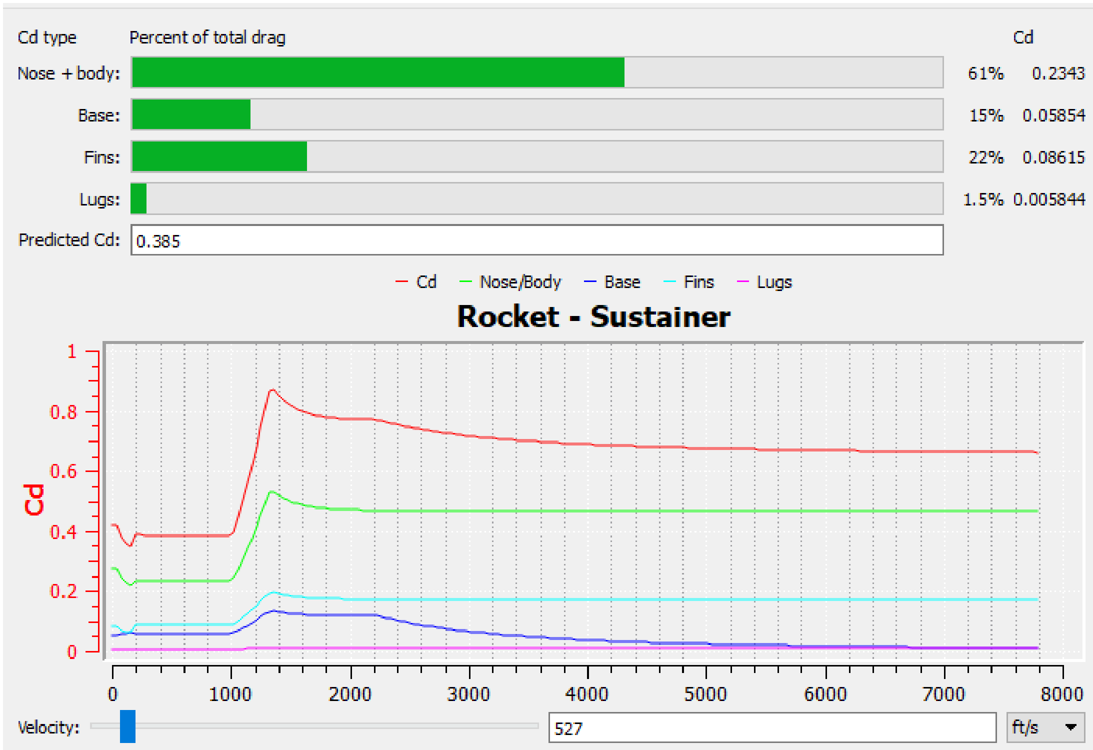

Figure 3-29 RockSim Drag Simulation of Subscale Vehicle

3.2.5 Impact to Full-Scale Design

The club's mentors as well as the RSO advised that the fin area of the subscale should be increased to prevent low altitude weathervane scenarios like the one experienced during this launch. As a result, the full-scale launch vehicle fin area has been increased by 18% on each fin. During the subscale build process, the team realized that the mass budget for the payload bay may have been over estimated. With the arrival of all the payload hardware, the team weighed this equipment and elected to reduce the mass budget for the payload section. This weight reduction warranted reexamination of motor options. Additionally, stability margin and ballasting strategies had to be explored as the changes in weight and fin sizing affected both of these values. Changes to fin sizing are discussed in section 3.1.3.7(d). Changes to stability margin are discussed in section 3.4.2. Lastly, parachute sizing, wind drift, and kinetic energy calculations had to be reevaluated, discussed further in Section 3.3.

3.3 Recovery Subsystem

3.3.1 Description of Recovery Events

Successful recovery system performance begins in the avionics bay. For the recovery system, the avionics bay houses two altimeters, the main altimeter and the redundant altimeter. Ideally the system would function with one altimeter, but redundancy lies in including a second. For the full-scale, at apogee, a signal is sent from the main altimeter to the terminal block in the drogue compartment, aft of the avionics bay and forward of the fin can/motor Section. The terminal block relays the signal through an E-match to a small PVC cap housing enough black powder to complete the first separation, covered by 3M electrical tape to secure the electronic match within the cap. The calculations for the exact black powder charge sizes are described in Section 3.3.10 and will be tested in ground ejection tests prior to launch. The transmitted signal will cause the first separation to occur, and the drogue parachute will release. One second after apogee, a second, redundant altimeter will send a signal through the terminal block in the drogue compartment to an E-match inserted into a second, same-sized black powder charge in an identical PVC setup, releasing the drogue parachute should there be an interruption or failure in the first, main system charge. At this point, the first separation of the recovery system is complete.

The second step of the recovery system is a successful, second separation and release of the main parachute. For the full-scale launch vehicle, the second separation will occur at 600 ft AGL. At 600 ft AGL, the main altimeter, housed in the avionics bay, will send an electrical signal to the terminal block in the compartment housing the main parachute. The signal will transmit from the terminal block through an E-match connected to a PVC cap filled with an appropriately sized black powder charge, secured with 3M electrical tape. This charge will pressurize the main cavity and forcefully separate the nosecone from the midsection of the launch vehicle, releasing the main parachute deployment bag. This will allow for more time during the unfurling of shroud lines and parachute opening, decreasing the force from the parachute opening on the separated body sections. At an altitude of 550 ft AGL, a terminal block to a second E-match connected to a second, separate PVC cap containing the same-sized black powder charge, also sealed by painters' tape to contain the charge. The calculations for charge sizes are included in Section 3.3.10 and will also be tested with ground ejection tests prior to launch. At this point, the second, main separation of the recovery system is complete.

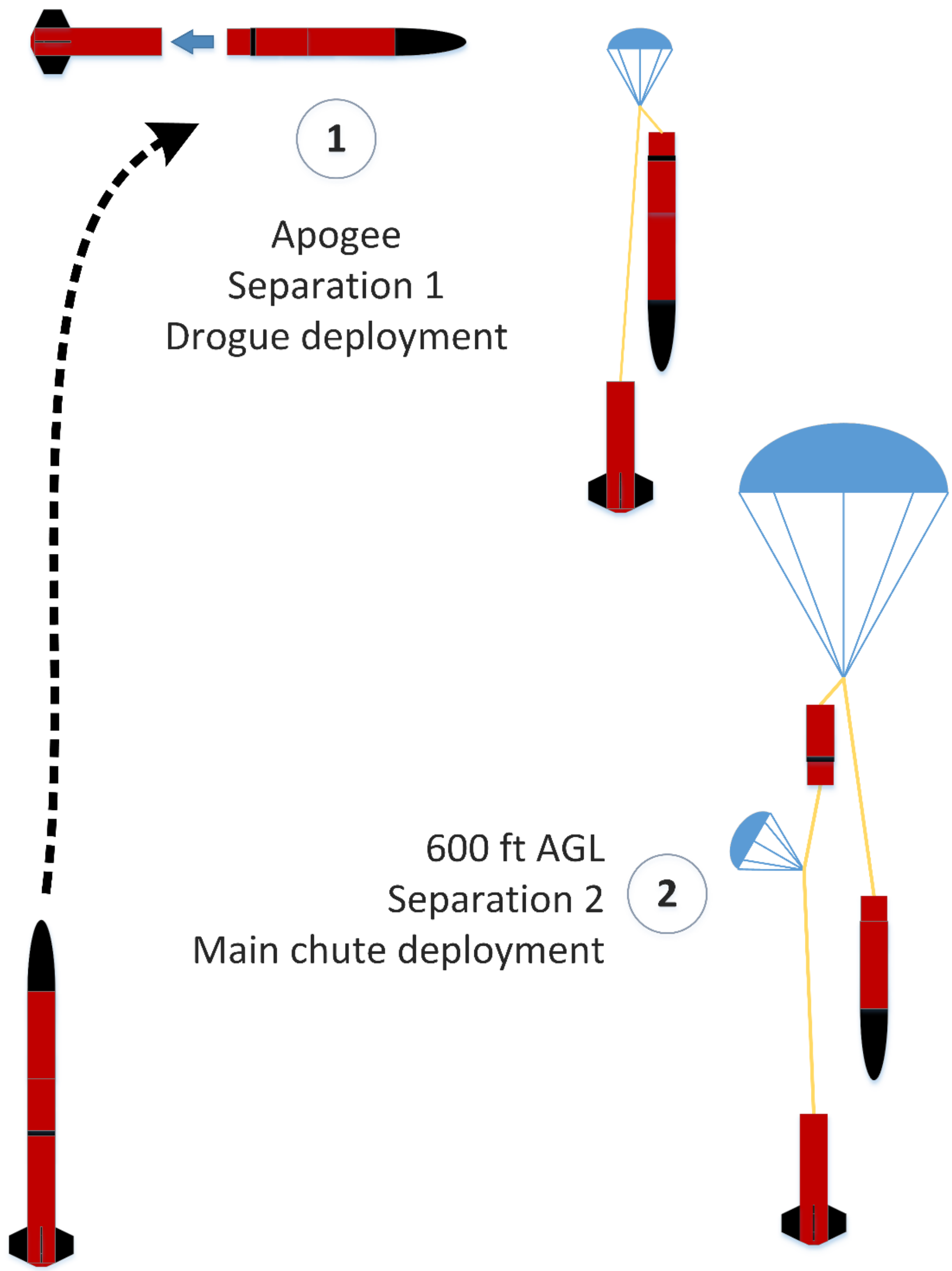

Figure 3-30 Recovery Events Overview

At each joint between separable sections, two nylon shear pins will be used to ensure no premature separations of sections occur during flight. Following the competition rules, the team will always conduct ground tests of black powder ejection events as described in the Requirements Verification and Testing Section to confirm to confidently separate launch vehicle sections without damaging any components before each flight. See Section 6.1.11 for more information.

3.3.2 Altimeters

Two PerfectFlite StratoLoggerCF altimeters will control the events of the recovery system. One altimeter will be designated the "Primary" altimeter, and the other will be designated the "Redundant" altimeter.

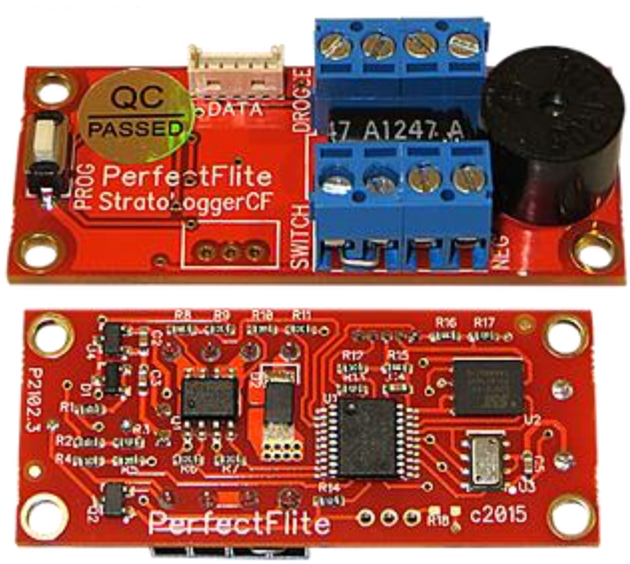

Figure 3-31 PerfectFlite StratoLoggerCF Altimeter

The StratoLoggerCF measures altitude with a resolution of one foot at altitudes less than 38,000 ft MSL. This was deemed accurate enough to achieve reliability of the recovery system and record accurate telemetry data of the flight. The StratoLoggerCF requires the launch vehicle to reach an apogee of at least 100 ft AGL to function correctly. This is well below the target apogee for the launch vehicle. In addition to altitude, the StratoLoggerCF records data detailing the ambient temperature and battery voltage. The StratoLoggerCF is capable of up to 18 minutes of recording per flight which is sufficient for the expected duration of the mission.[3]

Each altimeter onboard the launch vehicle will be independently powered by its own power source, controlled by its own power switch, and connected to its own black powder charge for each event. This ensures the complete independence of each altimeter for full dual-redundancy of the system. The batteries powering each altimeter will be commercially-available, Duracell brand 9 Volt alkaline batteries. These batteries have a service life in excess of 300 hours before decreasing to the minimum voltage required to operate the StratoLoggerCF altimeters.[4] The screw switch controlling each altimeter's power supply allows the altimeter to be turned off until the launch vehicle is on the pad undergoing its final launch preparations.

[3] (PerfectFlite n.d.)
[4] (Duracell Batteries 2008)

The launch vehicle will be equipped with a BigRedbee 900 GPS tracker which will transmit the launch vehicle's GPS location on the 900 MHz band. This will be received by a ground station connected by USB cable to a laptop operated by a team member. The laptop will display graphically in three dimensions in the mapping software Google Earth the latitude, longitude, and altitude received from the GPS tracker. This data can be viewed in real-time to track the launch vehicle. The location data is also logged for post-flight analysis and review. In addition, the receiver ground station displays the tracker status and received latitude and longitude coordinates on an LCD display on the receiver device without needing to be connected to the laptop computer. This provides a redundant method of tracking the launch vehicle in case the laptop malfunctions or is otherwise inoperable.

The GPS tracker within the launch vehicle will be powered by a 3.7 V, 1000 mAh, Lithium Polymer (LiPo) battery. This battery will solely be powering the GPS tracker. This meets the required 2-hour pad, flight, and post-flight time needed to locate and recover the launch vehicle. The device will be powered on during preflight preparations on the launch pad.

There is no second tracking device in the vehicle because failure of the tracking device would not result in any safety risks or failure to meet the mission success criteria. Thus, it is not considered a flight-critical or mission-critical component. The tracking device itself is considered a redundant solution to the primary means of locating the launch vehicle during and after flight: visually tracking the launch vehicle during its flight and descent. The tracking device serves as a backup to this method if any abnormal flight events render this method unsuccessful.

To ensure uninterrupted power for the recovery avionics systems, batteries for altimeters are only used for a single flight. Prior to flight, the batteries are tested to ensure their voltage is sufficient for flight.

The avionics system will be contained within the midsection of the launch vehicle. This will allow the avionics to be prepared separately from the rest of the vehicle assembly process. Because the avionics assembly process includes the loading of energetics, this will enhance safety while also allowing the team to prepare the launch vehicle for flight quickly to meet the requirement that the vehicle must be ready for flight within two hours of the opening of the FAA waiver at the launch site.

3.3.3 Electrical Schematic of Recovery System

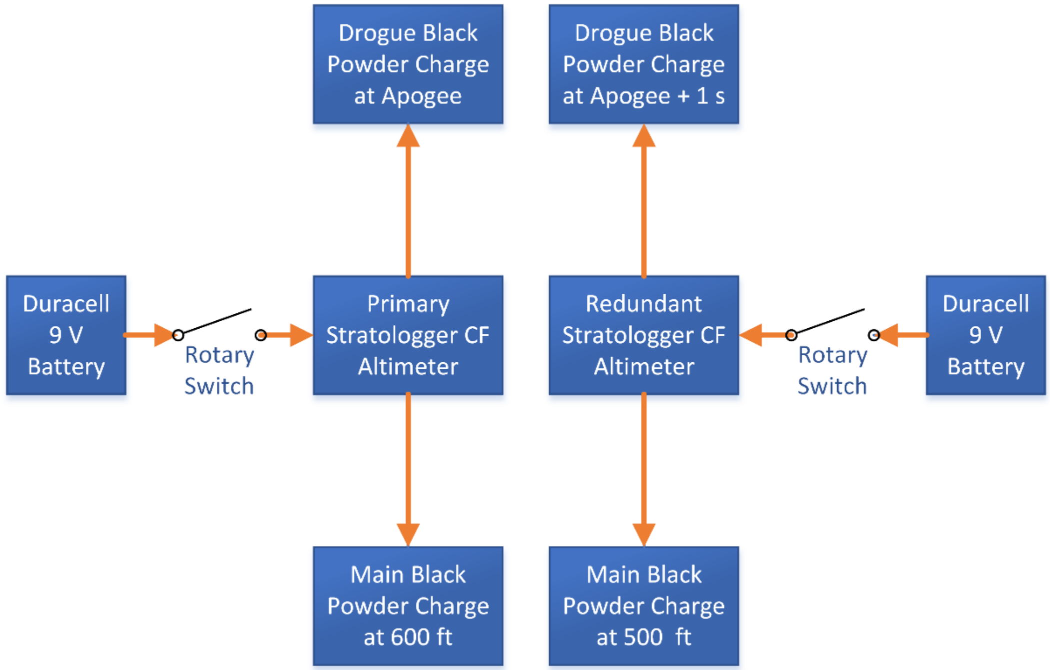

Figure 3-32 Electrical Schematic of Leading Alternative for Recovery System

This schematic demonstrates the full independence and dual redundancy inherent to the system design and compliance with competition handbook requirements 3.6. This schematic also demonstrates the design's compliance with competition handbook requirement 3.4, which states that the recovery system electrical circuits will be completely independent of any payload electrical circuits. The altimeters will each be independently powered by a commercially-available Duracell 9 V battery, in adherence to competition handbook requirement 3.5.

3.3.4 Avionics Sled

The AV sled will be constructed from aircraft-grade birch plywood. The sled will be assembled from sections of plywood sheeting laser-cut to shape. These joints will be sanded for surface preparation before being bonded using wood glue. Each StratoLoggerCF altimeter will be affixed to the AV sled by four aluminum M3 machine screws. Each of the two commercially-available 9 V batteries powering each altimeter rest snugly within a compartment in the AV sled. Plastic zip ties secure the batteries within the compartments and ensure the power connectors remain attached to the batteries' terminals.

Two screw switches will be mounted on the avionics sled within the avionics bay airframe to allow the altimeters to be powered on using a screwdriver. Other types of switches considered include rotary key switches, which require a specific key to operate, and sliding two-position switches. The two-position sliding switches were not selected because their design risks possible unintended movement of the switch if the switch were to be subjected to high g-forces or aerodynamic forces on the switch in the direction of the switch sliding motion. Screw switches and rotary key switches do not suffer that same vulnerability. The rotary key switches were not selected because the requirement for use of a key to operate the switch presents a safety hazard. The key would need to be kept with personnel closest to the vehicle at all times in order to allow the altimeters and their connected energetics to be disarmed safely without unnecessary delay. Furthermore, in the event of the launch vehicle landing with un-detonated black-powder charges still contained within the vehicle, it is hazardous to remain near the vehicle until all altimeters controlling the charges have been powered off. Any recovery personnel not possessing the required key would be unable to complete this urgent task. This ability to actuate the altimeter power switches using only a screwdriver, edge of a blade, or fingernail enhances the safety of the launch vehicle and mitigates risks associated with the recovery system. For these reasons, the team selected the non-key-activated screw switches to control power to the altimeters.

The altimeters, due to their design, are not sensitive to RF radiation, so there will be no interference from the GPS tracker location transmitter, and no risk from placing the GPS tracker transmitter device in the same bay as the altimeters. Nonetheless, a portion of metal foil will be installed between the GPS transmitter and the altimeters to further mitigate any risk of RF interference with the altimeters. Likewise, because the payload will contain radio transmitters, shielding will be installed between the altimeters within the AV bay and the payload compartment. As with the shielding between the GPS transmitter and the altimeters, this shielding is purely to further mitigate the already low risks of RF radiation from the payload systems affecting the altimeters.

To ensure that the altimeters are working correctly, both altimeters will be tested as described in the Requirements Verification and Testing section, see Section 6.1.10.

3.3.5 Avionics Bay Sampling Holes

To mitigate risk of pressure anomalies within the AV bay during flight, openings must be drilled in the walls of the AV bay. Four static ports will be spaced evenly around the circumference of the avionics bay. The use of four static ports will reduce the risk of pressure fluctuations from wind or flight at any angle of attack. The diameter of the static ports is determined using the following equation, from the manufacturer's manual for the StratoLoggerCF altimeter:[3]

$$H = D^2 * L * 0.0008 \text{ in}^{-2} \tag{5}$$

Where *H* is the diameter of the static ports, *D* is the internal diameter of the avionics bay, *L* is the internal length of the avionics bay.

3.3.6 Kinetic Energy at Landing

The team shall design a recovery system such that no independent section of the vehicle lands with greater than 75 ft-lb of kinetic energy. The kinetic energy of each section at landing can be calculated using the following equation:[5]

[5] (Jain 2009)

$$KE = \frac{1}{2}mv^2 \qquad (6)$$

Where m is the mass of the section and v is the descent rate of the vehicle under main parachute. Given the current leading alternative design for the recovery system uses a dual-deployment recovery system in which all independent sections remain tethered and make their final descent beneath a single main parachute, this means the vehicle's descent rate under the main parachute is constrained by the velocity required to meet this kinetic energy requirement. Thus, equation (6), can be re-arranged to calculate the maximum allowable descent rate for each independent section of the vehicle using the following equation:

$$v_{max} = \sqrt{\frac{2\,KE}{m}} \qquad (7)$$

Where v_{max} is the maximum allowable descent velocity of the section, KE is the maximum allowable kinetic energy of the section, 75 ft-lb, and m is the mass of the section. The results of Equation (7) were plotted in Figure 3-33, below, to demonstrate how the mass of the section affects the maximum allowable descent rate of that section.

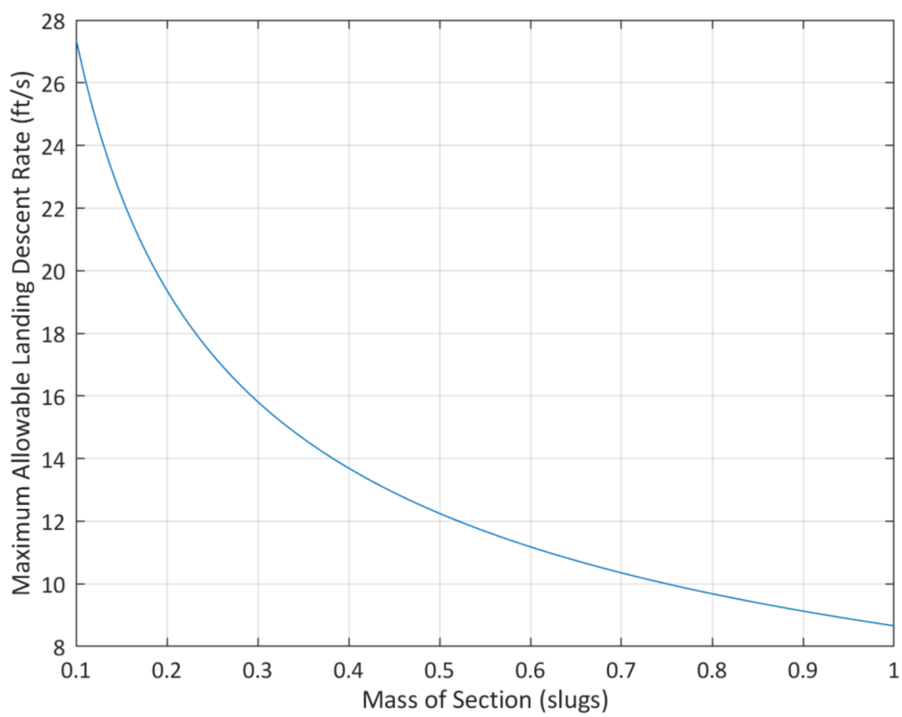

Figure 3-33 Plot of Maximum Landing Descent Rate vs. Section Mass

Equation (7) was used to calculate the maximum allowable descent velocity for each independent section of the leading vehicle design alternative for use in the development and selection of the design alternatives for the recovery system. The results of those calculations for the leading vehicle design alternative are shown below in Table 3-1.

Table 3-1 Maximum Descent Rate to Achieve Landing Kinetic Energy Requirement for Each Independent Section

Section	Mass	Maximum Descent Velocity
Nosecone	0.3744 slugs	20.0 ft/s
Midsection	0.2685 slugs	23.6 ft/s
Fin Can	0.4267 slugs	18.7 ft/s

Because all three independent sections of the leading design alternative will be tethered and descending together under the same main parachute in the leading recovery system design alternative, the descent rate of the vehicle under main parachute must not exceed any of the maximum descent velocities listed in Table 3-1, above, if the system is to meet the landing kinetic energy requirement. The implications of this are discussed further in Section 3.4.4.

Table 3-2, below, lists the masses and landing kinetic energy of each section, calculated using Equation (6) and the calculated descent rate of the leading alternative vehicle design under the leading main parachute alternative detailed in Section 3.3.7 Main Parachute. The results of these calculations demonstrate the leading design alternative meets the required performance to achieve the required landing kinetic energy.

Table 3-2 Kinetic Energy at Landing of Independent Sections

Section	Mass	Kinetic Energy at Landing
Nosecone	0.3744 slugs	66 ft-lb
Midsection	0.2685 slugs	47 ft-lb
Fin Can	0.4267 slugs	75 ft-lb

3.3.7 Main Parachute

To calculate the descent velocity of the vehicle under parachute, the following equation is used:

$$v = \sqrt{\frac{W}{2\,\rho\,C_D\,\pi\left(\frac{D}{2}\right)^2}} \tag{8}$$

Where v is the descent velocity, W is the weight of the vehicle (after motor burnout), ρ is the density of air, C_D is the drag coefficient of the parachute with reference to the nominal area of the parachute, and D is the nominal diameter of the parachute.

Due to budgetary constraints, a team-derived requirement was established stating the team shall use a main parachute already in the team's inventory. The Fruity Chutes 84 inch Iris UltraCompact is the only acceptable main parachute alternative to meet the competition recovery system requirements and this team derived requirement. Thus, it was determined that the Fruity Chutes 84 inch Iris UltraCompact parachute was selected for use as the launch vehicle's main parachute. The parachute has a drag coefficient for 2.10. This results in a main parachute descent rate of 18.7 ft/s.

The main parachute deployment altitude was selected to be 600 ft AGL to minimize wind drift and descent time while also allowing sufficient time for parachute deployment. The selected main parachute deployment altitude meets the competition handbook requirement 3.1.1, which states that the main parachute shall be deployed no lower than 500 ft.

3.3.8 Drogue

The Fruity Chutes 24 inch Compact Elliptical parachute is the launch vehicle's drogue parachute. It will be deployed at apogee by the separation of the midsection and fin can, as described previously. The Fruity Chutes 24 inch Compact Elliptical parachute has a drag coefficient of 1.47. This results in a drogue parachute descent rate of 79.1 ft/s. The drag produced by the parachute will reduce the descent velocity of the launch vehicle to allow for a safe and controlled deployment of the main parachute.

3.3.9 Shock Cord Sizing

All shock cord used in the recovery system will be 5/8 inch tubular Kevlar, which is rated to 2000 lbf, making it capable of withstanding the decoupling forces. The team has used this type of shock cord successfully in the past for launch vehicles of similar size and weight to the vehicle, thus the team expects it to perform safely.

The length of shock cord to be used between each tethered section is 360 inches. This length is sufficient to allow the safe separation of the sections during descent. Figure 3-34 shows the shock cord sizing with respect to the separated sections of the leading alternative design.

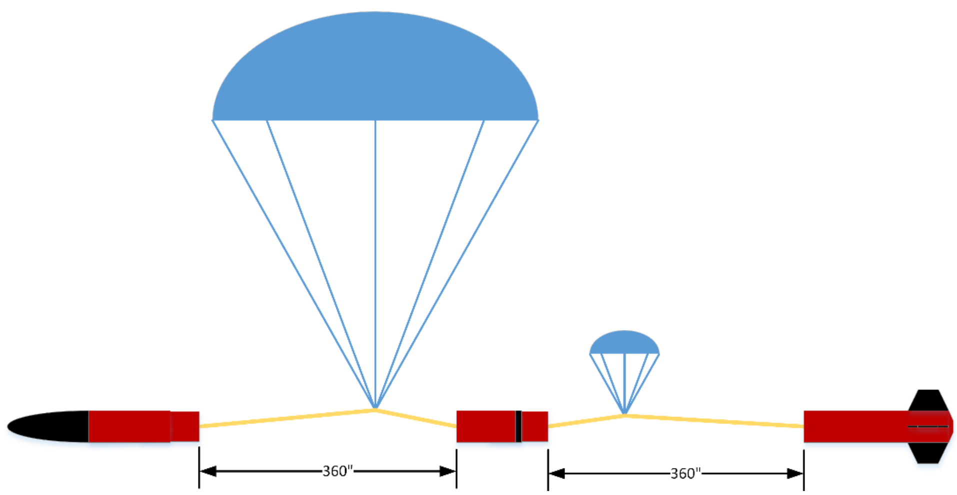

Figure 3-34 Shock Cord Sizing Diagram

3.3.10 Black Powder Sizing

The two separations of the recovery system will be conducted by the detonation of black powder charges. The team will use Goex 4F black powder in all stages of separation. The amount of black powder used in detonation is determined by the following equation in order to accurately predict the amount of pressure required for stage separation:

$$m = L * D^2 * 0.006 \quad (9)$$

In this equation, *m* is the mass of black powder in grams, *D* is the diameter of the separating section in inches, and *L* is the length of the separating section in inches. The constant 0.006 is key in converting the "volume" of the tube into the mass of black powder required. This constant is based on the strength of the black powder charges' detonation required to propel the sections apart. This calculation assumes a required 15 psi to overcome frictional forces between the two sections. This calculation must be precise in order to generate enough force to complete separation and not break the materials housing the compartments.

Equation (9) was used to determine the size for the primary black powder charges used for deployment of the main and drogue chute. The inner diameter for both the main and the drogue chute sections is 5.25 inches. The length of the drogue chute section is 11.75 and the length of main chute section is 17 inches. Using Equation (9), the primary black powder charge will be 2.8 grams for the main chute and 2.0 grams for the drogue chute deployment.

For redundancy, the team will use two different altimeters wired to two different black powder charges per stage. The redundant black powder charge will go off approximately one second after the primary is set to go off to account for failure in the primary system. In order to prevent one charge detonating the other, over-pressurizing the compartment, the team houses the charges in PVC tubing and cover the ends with paper towel for a controlled detonation. During preliminary design discussion, two considerations were made in determining the size of the redundant charge: a slightly larger black powder charge than calculated in case the primary is not strong enough to overcome frictional forces, and an identically sized black powder charge where a fault in the primary charge wiring. The team decided the first option with a larger black powder charge would reduce the most risk as having a larger black charge would address any potential wiring faults as well as the potentially larger frictional forces. The redundant charge is 2.5 grams for the drogue chute and 3.5 grams for the main chute. This redundant system will enable a safe deployment of both chutes in case of a fault in the primary recovery system thus facilitating a safe recovery of the launch vehicle.

3.4 Mission Performance Predictions

3.4.1 Flight Profile Simulations

RockSim was used to model the flight of the launch vehicle using the following parameters

Table 3-3 Launch Simulation Parameters

Parameter	Assumption	Justification
Launch Rail Angle	5 degrees	Handbook Requirement 1.12
Launch Rail Length	144 in	Handbook Requirement 1.12

Wind speed	8.2 mph	Avg at launch site[6]
Launch direction	Into wind	Prevailing wind at launch site[6]

These parameters produced Figure 3-35 and Figure 3-36, below.

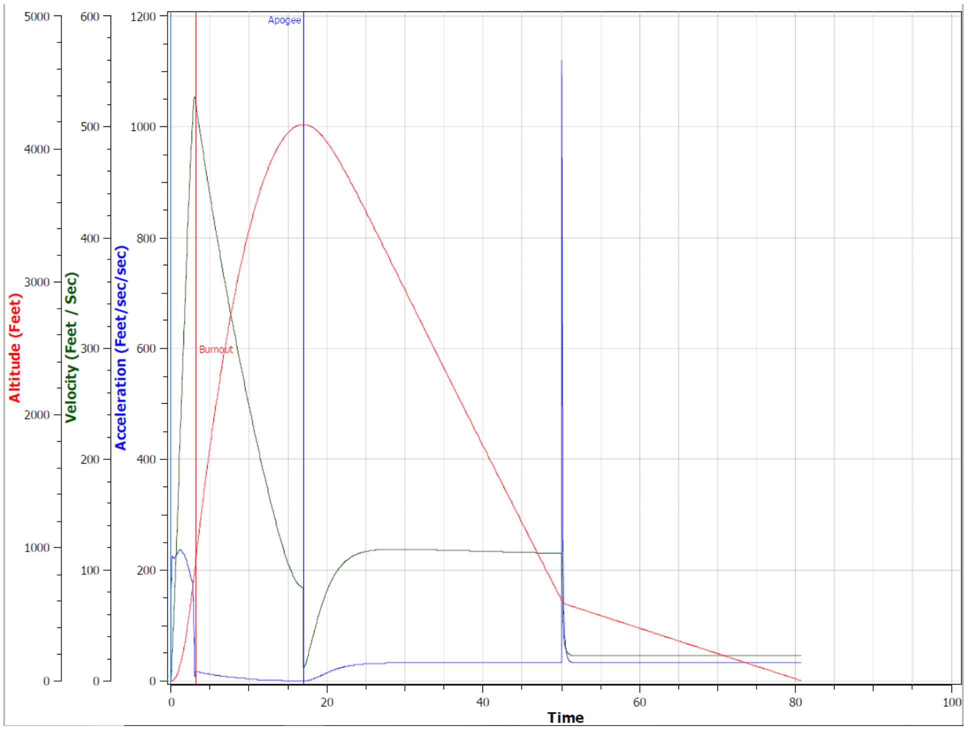

Figure 3-35 Altitude/Velocity/Acceleration vs. Time for launch in nominal conditions

[6] (Weather Spark n.d.)

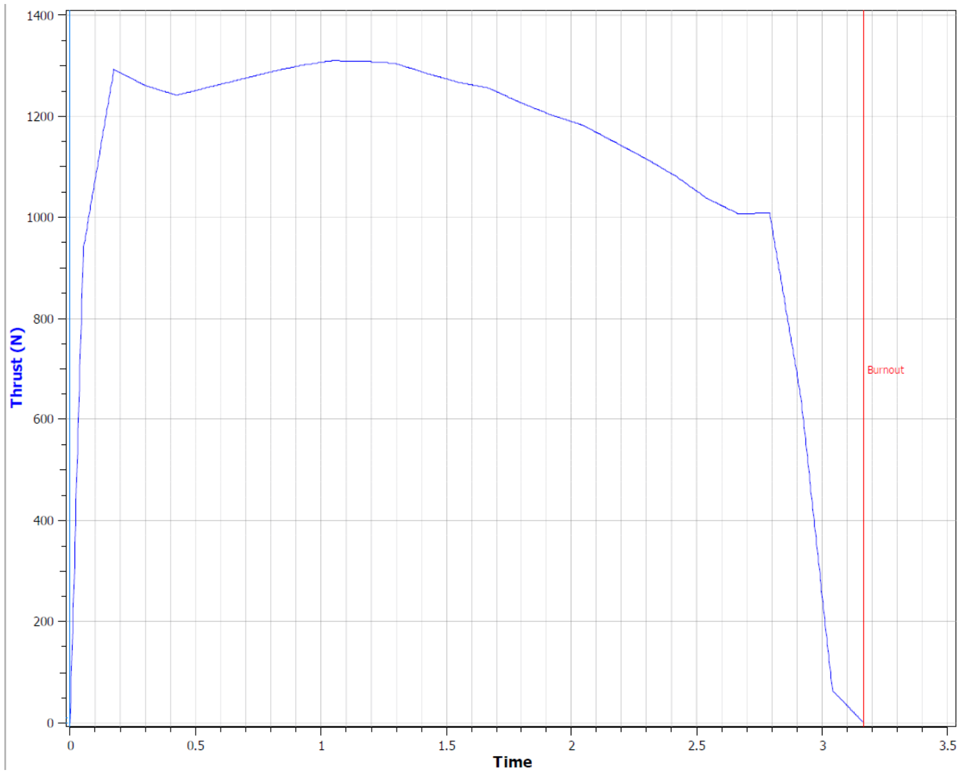

Figure 3-36 Thrust Curve for Aerotech L1150R

From the data in Figure 3-35 the launch vehicle apogee was found to be 4185 ft. This is less than 100 ft from the target apogee. Max velocity was found to be 527 fps or Mach 0.46. This is well below the team derived requirement of 0.7 Mach. Rail exit velocity was found to be 67.2 fps, which is above the required 52 fps. Furthermore, the launch vehicle reaches a velocity of 52 fps at 87 inches up the launch rail. This makes it safe to launch on the 8 ft launch rails used by the local TRA chapter. Based on the thrust curve in Figure 3-36, the thrust to weight ratio of the launch vehicle is now 7.1:1 thanks to the reduction in weight and increased thrust of the new motor.

3.4.2 Stability Margin

Barrowman's Method allows the launch vehicle to be split into three parts: nosecone, transition, and fins. Since the launch vehicle does not include a transition Section, only the nosecone and fin equations were considered. The coefficient for nosecones C_N can be defined as a constant equal to 2. The arm length for any ogive nosecone X_N can be defined as:

$$X_N = 0.446 * L_N \tag{10}$$

where L_N is the length of the nosecone. Using L_N = 22 inches, X_N was calculated to be 10.252 inches. The coefficient for fins C_F can be defined as:

$$C_F = \left(1 + \frac{R}{S+R}\right)\left[\frac{4N\left(\frac{S}{d}\right)^2}{1 + \sqrt{1 + \left(\frac{2L_F}{C_R + C_T}\right)^2}}\right] \tag{11}$$

where R is the radius of the launch vehicle body, S is the fin semi-span length, N is the number of included fins, d is the diameter of the launch vehicle body, L_F is the fin mid-chord line length, C_R is the fin root chord length, and C_T is the fin tip chord length. Using R = 2.75 inches, S = 4.5 inches, N = 4 inches, d = 5.5 inches, L_F = 4.52 inches, C_R = 8.0 inches, and C_T = 4.0 inches, C_F was calculated to be 6.56. The equation for the arm length of the fins X_F can be defined as:

$$X_F = X_B + \frac{X_R}{3}\frac{C_R + 2C_T}{(C_R + C_T)} + \frac{1}{6}\left[(C_R + C_T) - \frac{C_R C_T}{(C_R + C_T)}\right] \tag{12}$$

where X_B is the distance from nosecone tip to fin root chord leading edge and X_R is the fin sweep length measured parallel to the launch vehicle body. Using X_B = 89.5 inches, X_R = 2.5 inches, C_R = 8.0 inches, and C_T = 4.0 inches, X_F was calculated to be 92.17 inches. The equation for CP position of the entire body is a weighted average of the coefficient for each component, and can be defined as:

$$X_{CP} = \frac{(C_N X_N + C_F X_F)}{C_N + C_F} \tag{13}$$

The CP position was calculated to be 73.03 inches from the nosecone tip, which is 0.14 inches aft of the CP position from RockSim. This difference equates to an increase of .03 calibers to the stability margin. However, this disparity can be explained by comparing the complexity of the RockSim calculation to the simplicity of the Barrowman's Method. When calculating the CP position, RockSim considers effects due to flight speed, nosecone shape, nosecone length, body diameter, body length, fin shape, fin location, fin leading edge shape, and surface roughness due to body paint. Compared to Barrowman's Method, which only considers nosecone shape, nosecone length, fin shape, and fin location, the RockSim calculation is much more advanced and can be considered more accurate. Though Barrowman's Method was used to approximately confirm the CP position, the RockSim prediction for CP position was used when calculating the launch vehicle stability margin and determining the amount of ballast necessary for stable flight. The equation for the stability margin of a launch vehicle S_M can be defined as:

$$S_M = \frac{X_{CP} - X_{CG}}{d} \tag{14}$$

Where X_{CP} and X_{CG} are the distances from nosecone tip to the launch vehicle CP and CG, respectively, and d is the launch vehicle outside diameter. Stability margin is measured in calibers, where one caliber is equal to the launch vehicle outside diameter. Using the results from RockSim, X_{CP} = 72.89 inches and X_{CG} = 61.81 inches, the stability margin was calculated to be 2.01 caliber. Since this value is the stability margin of the launch vehicle after full assembly and before launch, it exceeds the handbook requirement that the launch vehicle must have a stability margin of at least 2.0 when exiting the launch rail since the stability margin will only increase during flight. Figure 3-37 illustrates the movement of the Stability margin, CG, and CP locations throughout the flight profile discussed in Section 3.4.1

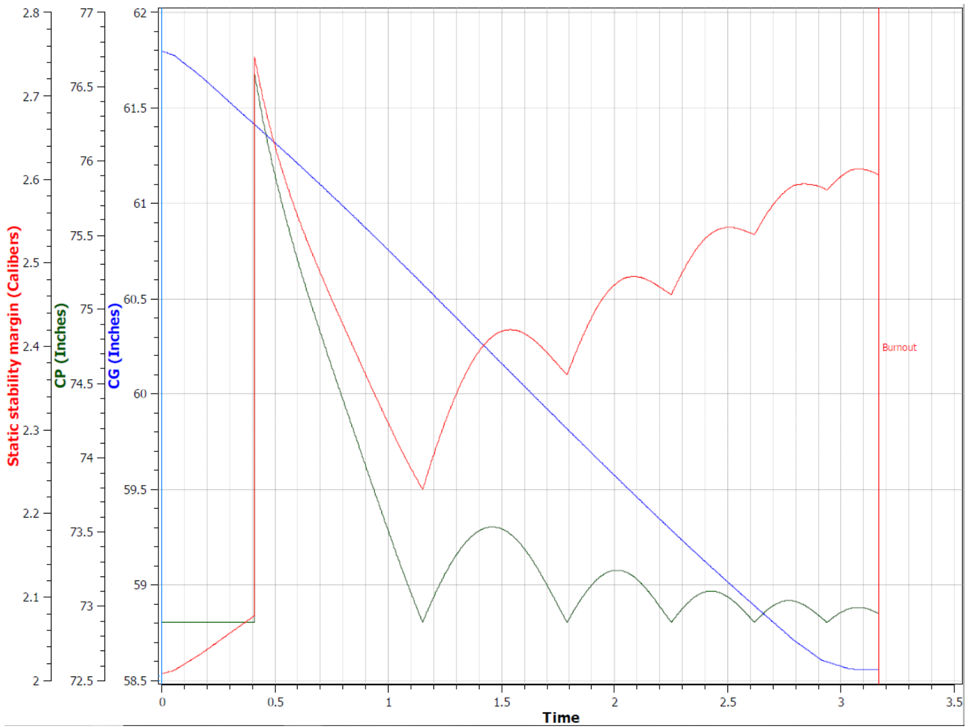

Figure 3-37 Launch Vehicle Stability Margin

The launch vehicle CG continues to move FWD as the propellant is consumed. Also, the Launch vehicle CP can be seen varying due to changes in angle of attack as weather veining occurs. At no point during the flight does the static stability margin drop below 2.0 caliber.

3.4.3 Kinetic Energy Calculations

Methods for calculating section kinetic energies at landing is detailed in Section 3.3.6.

3.4.4 Descent Time Calculations

Descent times were calculated to determine wind drift and are shown in Table 3-4.

3.4.5 Wind Drift Calculations

Table 3-4 details the results of hand-calculations for the wind drift of the vehicle between apogee and landing using the performance of the leading alternative design. These calculations represent a worst-case scenario for wind drift due to a number of simplifying assumptions they make. These calculations assume that apogee occurs directly above the pad, a constant wind speed and direction, and a constant, standard-sea-level air density throughout the descent. The apogee listed for each wind speed is the result of RockSim simulations to determine the most likely apogee altitude at that wind speed. These simulations used a zero-degree (i.e. fully vertical) launch rail, as opposed to the five degrees off-vertical that the launch rail will be angled in the actual competition flight. The results listed demonstrate the leading alternative design's performance meets the required wind drift distance and descent time requirements for the entire range of operational conditions for which the vehicle is designed.

Table 3-4 Wind Effect on Apogee and Drift

Wind Speed	Apogee	Descent Time	Drift Distance
0 mph	4311 ft AGL	79 s	0 ft
5 mph	4300 ft AGL	79 s	577 ft
10 mph	4262 ft AGL	78 s	1148 ft
15 mph	4195 ft AGL	77 s	1703 ft
20 mph	4100 ft AGL	76 s	2236 ft

3.4.5.1 Alternative Wind Drift Calculations

To confirm the validity of the hand calculations of drift and descent performance, RockSim flight simulations were performed. The distance between the location at which the vehicle launched and landed for each wind speed is presented below in Table 3-5. The results of these simulations are significantly lower than the results of the hand calculations.

Table 3-5 RockSim Simulation Results for Wind Drift

Wind Speed	Apogee	Landing Distance from Launch Pad
0 mph	4311 ft AGL	0 ft
5 mph	4300 ft AGL	159 ft
10 mph	4262 ft AGL	316 ft
15 mph	4195 ft AGL	465 ft
20 mph	4100 ft AGL	607 ft

3.4.5.2 Discrepancies in Wind Drift Calculations

The distance between the location at which the vehicle launched and landed for each wind speed is presented. The drift results of the RockSim simulations presented above in Table 3-5 are significantly lower than the results of the hand calculations presented in Table 3-4 for the entire range of operational wind conditions. From analysis of both methods, it was concluded that the hand-calculation methods represent a worst-case scenario for wind drift due to their assumptions that: apogee occurs directly above the launch pad, the wind is a constant direction and velocity, and the air density is a constant standard-sea-level value.

The most significant factor in the difference between the results of the two methods is the hand-calculation method's assumption that apogee will occur directly above the launch pad. This is an inaccurate assumption for a number of reasons. First, in the competition launch, the launch rail will be angled five degrees from vertical away from the crowd. This initial pitch angle on the launch vehicle will prevent it from flying straight vertical in the manner assumed by the hand calculations.

Furthermore, the nature of the vehicle's stability in flight will cause it to weather-vane in the direction of the wind, further increasing the difference between its flight path angle and the vertical direction. This tendency to weathervane results in the vehicles apogee occurring at a lower altitude and further from the pad in the direction the wind is blowing from. These two factors will cause both the descent time and the landing distance from the pad to decrease. Because the vehicle's apogee will occur upwind of the pad, much of the vehicle's wind drift will be bringing it back in the direction of the launch pad before it actually passes over the launch pad location. The hand calculations do not model any of these flight dynamics effects, whereas the RockSim simulations used in the alternative calculation method do.

4. Safety

4.1 Launch Concerns and Operation Procedures

To better understand the hazards and risks associated with launch vehicle assembly and launch, the team created checklists. These checklists encompass the launch vehicle assembly to include the preparation of recovery devices and the motor. The checklists include warnings, required PPE and required personnel. These checklists can be found in Section 9.

4.2 Personnel Hazard Analysis

A description of potential personnel hazards, their causes, and the resulting effects are presented in Table 4-1.

Table 4-1 Personnel Hazard Analysis

Environment	Hazard	Causal Factors	Effects	Likelihood	Severity	Mitigation
Launch day	Lack of visibility	Cloud cover	Ground crew and spectators at risk of descending launch vehicle components	2	3	NAR Safety Code does not allow for launches into cloudy conditions, and club members are instructed prior to and throughout launch day to be aware of ongoing launches. If the RSO's signals of a launch occurring cannot be heard from the team's work site, the RSO will be informed by the club safety officer to accommodate this situation.
	Slippery ground surfaces	Heavy precipitation	Injury of recovery sub-team members in the process of retrieving the separated launch vehicle components	1	3	Weather forecasts will be used to determine a range of launch dates with favorable conditions. Severe precipitation conditions will result in cancellation of launch, as human safety is at major risk. In the case of inconsistent to light precipitation conditions, launch will be carried forward with the RSO's approval. Waterproof materials will be brought to shelter the launch vehicle and its components for assembly prior to launch, and recovery after launch. Launch day procedures

					concerning recovery efforts detail actions and behaviors prioritizing human safety over project safety in unfavorable recovery conditions. Additionally, the club safety officer will accompany the recovery sub-team throughout the launch vehicle retrieval process to ensure safety of the crew.
Unpredictable launch vehicle flight and descent paths	High velocity cross-winds	Ground crew and spectators at risk of descending launch vehicle components Injury of recovery sub-team members in the process of retrieving separated launch vehicle components	2	3	Weather forecasts will be used to determine a range of launch dates with favorable conditions. NAR Safety Code prohibits launching in wind conditions exceeding 20 miles per hour, and windspeed will be requested from the RSO prior to launch if launch conditions are questionable. If under excessively windy conditions, launch vehicle assembly will be carried out in whatever shelter provided by the RSO or a team member's vehicle. Launch day procedures concerning recovery

	Severe humidity	Ground crew and spectators at risk of descending launch vehicle components	2	3	efforts detail actions and behaviors prioritizing human safety over project safety in unfavorable recovery conditions. The club safety officer will accompany the recovery sub-team throughout the launch vehicle retrieval process to ensure safety of the crew. Additionally, all team members will be instructed prior to and throughout launch day on ongoing launches and measures on steering clear of any potentially dangerous flight paths.
Drastically uneven ground surface conditions	Water features and non-level ground surfaces	Injury of recovery sub-team members in the process of retrieving the separated launch vehicle components.	2	3	Launch day procedures concerning recovery efforts detail actions and behaviors prioritizing human safety over project safety in unfavorable recovery conditions. The club safety officer will accompany the recovery sub-team throughout the launch vehicle retrieval process to ensure safety of the crew. Additionally, all team members will be instructed prior to and throughout launch day on steering clear of possible walking hazards on the launch field.
Live black powder charges within launch vehicle after descent	Severe humidity affecting altimeter calibration	Injury of recovery sub-team members in the process of retrieving the separated launch	1	3	Recovery sub-team members will be equipped with nitrile gloves, leather gloves, safety glasses, and other equipment to handle black powder charges and disarm avionics system

			vehicle components.			prior to handling. Launch day procedures concerning recovery efforts detail actions and behaviors prioritizing human safety over project safety in unfavorable recovery conditions. The club safety officer will accompany the recovery sub-team throughout the launch vehicle retrieval process to ensure safety of the crew.
Lab site	Unprotected chemical exposure to Class 6 materials	Improper or no personal protective equipment used	Injury of team members engaging in the fabrication process	1	3	Prior to engaging activities in the lab site, all team members are briefed on Class 6 materials used in fabrication, the respective personal protective equipment, and the location of each within the lab. Procedures will be posted around the lab site as a reminder of safety procedures respective to each material used. The Lab Safety Binder contains MSDS sheets on each material used within the lab, and procedures on reactionary measures for chemical exposure. Additionally, the club safety officer will accompany team members throughout the fabrication process.
	Flying shrapnel	Improper or no personal protective equipment used	Injury of team members engaging in fabrication process	1	3	Prior to engaging activities in the lab site, all team members are briefed on the location of personal protective equipment within the lab. Procedures will be posted around the lab site as a reminder of safety procedures respective to each piece of equipment used. The Lab

					Safety Binder contains preventative and reactionary measures respective to equipment in operation around the lab site. Additionally, the club safety officer will accompany team members throughout the fabrication process.
Unprotected exposure to Class 1, 4, and 5 materials (black powder, Lithium Polymer Batteries)	Improper or no personal protective equipment used Improper storage of energetics	Injury of team members engaging in fabrication process	1	4	Prior to engaging activities in the lab site, all team members are briefed on the location of personal protective equipment within the lab. Procedures will be posted around the lab site as a reminder of safety procedures respective to each energetic material used. The Lab Safety Binder contains preventative and reactionary measures respective to materials in storage and/or operation around the lab site. The club safety officer will accompany team members throughout the assembly and fabrication process. Concerning the motor and black powder, a minimum number of individuals will be allowed contact. The primary handlers of the motor are the safety officer and club advisors. In unforeseen circumstances another club officer may be necessary but unlikely. The team's adherence to manufacturer supplied instructions in the storage, handling, and assembly of the motor shall mitigate any motor failures due to

					misuse. The motor is stored in the flame and hazard cabinet secured in its original packaging, and is not permitted to be assembled in any area not under NAR and/or TRA supervision. Additionally, all energetics material is stored securely in their original packaging within the flame and hazards cabinet.

4.3 Failure Modes and Effects Analysis (FMEA)

See Appendix A: FMEA Table for FMEA Tables relevant to this project. Clarifications for the mission success spectrum, severity levels, and likelihood levels are given in Table 4-2, Table 4-3, and Table 4-4, respectively.

Table 4-2 Clarifications on the Spectrum of Mission Failure to Mission Success

Level	Aspects	
	Project	Human
Complete Failure	Unrecoverable launch vehicle Unrecoverable UAV	Severe crew and/or spectator injuries due to operational and non-operational activities
Partial Failure	Launch vehicle repairable Successful takeoff and unsuccessful descent of launch vehicle UAV repairable Successful primary takeoff, unsuccessful beacon release, and unsuccessful secondary takeoff of UAV	Minor crew and/or spectator injuries due to operational and non-operational activities
Partial Success	Launch vehicle repairable Successful takeoff and descent of launch vehicle UAV repairable Successful primary takeoff, beacon release, and secondary takeoff of UAV	Near miss incidents involving crew and/or spectators related to operational and non-operational activities
Complete Success	Recoverable launch vehicle Nominal launch vehicle takeoff and descent Recoverable UAV Nominal UAV primary takeoff, beacon release, and secondary takeoff Launch operations can be repeated same day	No crew and/or spectator injuries related to operational and non-operational activities

Table 4-3 Clarifications of Severity

Level	Description
1	Human safety and project safety at minimum risk due to active safety measures.
2	Human safety and project safety at lesser risk due to active safety measures.
3	Human safety and project safety at greater risk despite active safety measures.
4	Human safety and project safety at maximum risk despite active safety measures.

Table 4-4 Clarifications of Likelihood

Level	Description
1	Minimum frequency of failure possible due to active safety measures.
2	Lesser frequency of failure possible due to active safety measures.
3	Greater frequency of failure possible despite active safety measures.
4	Maximum frequency of failure possible despite active safety measures.

4.4 Environmental Hazards to the Project

Potential environmental hazards to the project, their causes and effects, and mitigation methods are identified in Table 4-5.

Table 4-5 Environmental Hazards to the Project

Hazard	Casual Factors	Effects	Likelihood	Severity	Mitigation
Water exposure to electronic components onboard launch vehicle	Heavy precipitation	Water exposure to electronics components could result in failure to launch the launch vehicle, failure to separate the launch vehicle, failure to deploy and launch UAV, and/or failure to receive altimeter data pertaining to the challenge.	1	3	Weather forecasts will be used to determine a range of launch dates with favorable conditions. Severe precipitation conditions will result in cancellation of launch, as project and human safety is at major risk. In the case of inconsistent to light precipitation conditions, launch will be carried forward with the RSO's approval. Waterproof materials will be brought to shelter the launch vehicle and its components for assembly prior to launch, and recovery after launch.

Significantly altered and unintended flight path and descent	Sustained high velocity cross-winds	High velocity wind conditions could result in violent launch vehicle flight and descent, and hinder/prevent UAV flight. High velocity winds perpendicular to the launch rail's line of action pose a threat to the direction of flight for the launch vehicle – possibly resulting in a significantly lower apogee, violent parachute deployment and descent which may cause large drifting in descent and structural damage along the body tube, and violent ground impact causing structural damage. Damage to payload body tube and components may prevent UAV Containment Pod deployment. High velocity cross-winds could also put UAV performance at risk.	2	3	Weather forecasts will be used to determine a range of launch dates with favorable conditions. NAR Safety Code prohibits launching in wind conditions exceeding 20 miles per hour, and windspeed will be requested from the RSO prior to launch if launch conditions are questionable. The UAV design specifications have taken into consideration possibly high velocity cross-winds by increasing propeller size, battery capacity, and motor strength, and will undergo testing in similar conditions post-fabrication and prior to launch. If under excessively windy conditions, launch vehicle assembly will be carried out in whatever shelter provided by the RSO or a team member's vehicle.
Post-descent dynamic separated launch vehicle components	Non-uniform ground surface conditions including water features	Non-uniform ground surfaces such as trenches could compromise launch vehicle structural integrity and UAV performance. Water exposure to electronics components could result in failure to deploy and launch UAV, and failure to receive altimeter data pertaining to the challenge.	2	3	Choose a launch site that has no or minimal water features and ground uniformity in the feasible landing area.
Live black powder charges post-descent	Severe humidity	Severe levels of humidity could result in particularly assembly, launch vehicle flight and descent, UAV flight, and recovery efforts. Moisture in the air can compromise the integrity of the black powder charges, and the calibration of altimeters. These two issues also introduce the possibility of premature or latent	2	3	Weather forecasts will be used to determine a range of launch dates with favorable conditions. If the humidity on the day of launch is higher than expected, components will be stored to limit exposure to atmospheric conditions, and RSO will be asked for guidance on issue.

		separation that results in either an unstable flight or a ballistic descent. Any live black powder charges pose a risk to the recovery sub-team. Additionally, failures causing premature or latent separation may result in failure to deploy and launch the UAV.			
Torn parachutes and tangled shroud lines during descent	Proximity to wooded area	Trees within the launch vehicle descent path can damage parachutes and shroud lines, and impede recovery efforts. Failure to reach the ground will result in failure to deploy the UAV, and retrieve altimeter data pertaining to the challenge. Any live black powder charges can also lead to an uncontrolled fire if the launch vehicle components are out of reach for the recovery sub-team.	1	2	Choose a launch site that has a large proximity away from wooded areas. If the launch vehicle is suspended in foliage out of the recovery team's reach, the local fire department will be called to assist in retrieval – no trees will be cut down.

4.5 Project Risks to the Environment

Severity levels and likelihood levels for environmental hazards are summarized in Table 4-6 and Table 4-7, respectively.

Table 4-6 Clarifications of Severity

Level	Description
1	Human safety and project safety at minimum risk due to active safety measures.
2	Human safety and project safety at lesser risk due to active safety measures.
3	Human safety and project safety at greater risk despite active safety measures.
4	Human safety and project safety at maximum risk despite active safety measures.

Table 4-7 Clarifications of Likelihood

Level	Description
1	Minimum frequency of failure possible due to active safety measures.

2	Lesser frequency of failure possible due to active safety measures.
3	Greater frequency of failure possible despite active safety measures.
4	Maximum frequency of failure possible despite active safety measures.

Potential project risks to the environment, the causes and effects of them, and mitigation efforts are presented in Table 4-8.

Table 4-8 Project Risks to the Environment

Hazard	Causal Factors	Effects	Likelihood	Severity	Mitigation	Verification
Fire at the launch site related to motor exhaust.	Motor exhaust creates a fire or damages the area surrounding the launch rail	The ground around the launch site becomes charred, killing any flora or micro fauna directly beneath or around the launch site	2	3	A blast deflector will be used beneath the launch vehicle, protecting the ground from exhaust in compliance with NAR Safety Code.	The launch safety officer will verify that a blast deflector is in place prior to each launch and inspect the ground afterwards around the launch pad with a fire extinguisher on hand
Fire around the launch vehicle due to a punctured battery.	Loose components during flight or improper handling during assembly punctures a battery.	The ground around the site of the fire becomes scorched, killing or seriously injuring any flora or fauna in the area. In more serious cases, the fire may grow and become out of control causing serious and lasting damage to the ecosystem.	2	3	All components used in the launch vehicle are designed to be strongly fastened to the vehicle during flight. Only designated, experienced members will be allowed to assemble the launch vehicle and its components.	The electronics lead and safety officer will verify that only batteries and electronics that have been handled and stored properly are used in the launch vehicle. The safety officer will also ensure that all electronics and batteries are inspected for leakages prior to their integration into the launch vehicle.
Fire around the launch vehicle due to a short or general failure in the electronics.	Exposed or faulty wiring creates an electrical short, or electronics overheat and start a fire.	The ground around the site of the fire becomes scorched, killing or seriously injuring any flora or fauna	2	3	The electronics lead, or safety officer, will verify that no wires are exposed in the launch vehicle	The team will verify the quality of the wiring and ensure that there are no exposed wires prior to each launch. Only electronics that are

		in the area. In more serious cases, the fire may grow and become out of control causing serious and lasting damage to the ecosystem.			prior to full vehicle integration. Electronics will be stored in a secure environment devoid of extreme temperature fluctuations or contact with other components that may inflict damage.	determined by the safety officer to be in good physical condition will be used in the vehicle.
Non-biodegradable waste is left at the launch site or surrounding environment.	Harmful components may be unintentionally expelled from the launch vehicle due to the forces of launch. Hazardous components in the launch vehicle may also be rendered unrecoverable through a failure of the recovery system. Additionally, the team may unintentionally leave debris at the launch field.	Non-biodegradable components or waste may be ingested by local organisms and cause injury, sickness, or premature death. Waste may also be detrimental to plant life or soil/water quality in the surrounding environment.	2	2	All components used in the launch vehicle are designed to be strongly restrained to the vehicle and no non-recoverable components will be used. Additionally, team members will thoroughly clean and inspect the launch field before departing.	Potentially harmful components will be inspected prior to launch to ensure they are securely attached to the launch vehicle. The launch site and the landing zone will be inspected for components or debris that had fallen off the launch vehicle. Prior to leaving the launch field, the team will ensure to remove any waste left by their activities. Each of these inspections will be verified by the safety officer to ensure all waste has been collected.
High kinetic energy impact of the launch vehicle with the ground.	A failure of the recovery system in which the parachutes do not deploy, deploy too late, deploy incorrectly, or are	Components of the launch vehicle may be strewn across the ground, leaving material in the environment which may be	2	4	Redundant ejection charges as well as a redundant altimeter, secondary to the primary altimeter	All black power charges will be carefully measured and verified by the faculty advisor, Dr. Chuck Hall, and the safety officer, for accuracy. All altimeters will be

	not properly secured to components leading to freefall.	ingested by local fauna and cause injury, sickness, or premature death. Waste may also be detrimental to plant life or soil/water quality in the surrounding environment.			and ejection charges, will be implemented in the launch vehicle. The redundant system will activate following a delay after the primary system, so, in the event the primary charges/altimeter fails, the redundant system will ensure recovery deployment. Parachutes will be folded using consistent techniques and stored in safe conditions when not in use.	programmed by the electronics lead, and verified by the electronics lead and the faculty advisor to ensure the black powder chargers are triggered at the proper time. A larger redundant charge will be used for each ejection event to ensure that proper and complete ejection occurs. The redundant altimeter will be purchased from a separate manufacturer than the primary altimeter.
Battery acid or other electronic chemicals are leaked into the environment.	Improper handling or manufacturer error results in a puncture of the batteries installed in the launch vehicle.	Battery acid and other chemicals may be ingested by or cause injury to local flora and fauna. These hazardous components could also pollute the surrounding soil and water.	2	2	Batteries will be stored in a secure environment devoid of extreme temperature fluctuations or contact with other components that may inflict damage to the batteries. Prior to launch and after launch, batteries will be inspected and tested to verify that	The electronics lead and safety officer will verify that only batteries and electronics that have been handled and stored properly are used in the launch vehicle. The safety officer will also ensure that all electronics and batteries are inspected for leakages prior to their integration into the launch vehicle.

					they're in suitable condition. If a battery is not operable it will be disposed of according the MSDS standards.	
Damage to trees in the vicinity of the launch site.	The launch vehicle lands in one or several trees near the launch area.	Removing vehicle components from a tree could result in lasting damage to the tree or complete destruction to the tree and the habitat it provides to other organisms.	2	2	The launch safety officer will verify wind speeds do not exceed recommended levels. The launch will be postponed in the event that high wind speeds makes landing in a tree more likely. Also, launch sites with trees nearby will be avoided where possible.	In the event that components must be retrieved from a tree(s), the team and safety officer will ensure that retrieval is done in a way that minimizes damage to the tree(s) without compromising the safety of personnel.
Carbon Dioxide (CO_2) pollution due to club activities adds excess CO_2 to the environment.	CO_2 is released into the atmosphere from club related travel to the launch events and supply store.	Adding excess CO_2 to the atmosphere contributes to anthropogenic climate change, may be absorbed by water bodies to form carbonic acid which would have a negative impact on aquatic organisms especially those who use carbonate to form protective shells.	3	1	The team will attempt to cut travel/shipping related carbon emissions when possible.	The team will carpool to all launch events. The team will also use driving over flying when travelling long distances. When ordering parts, local options will be preferred if part quality is deemed to be equal or superior to that of other options.

5. Payload Criteria

5.1 Design of Payload Equipment

5.1.1 Summary of UAV Systems Designs

5.1.1.1 Mechanical Folding Arms

Initial performance calculations and research on hobby quadcopter forums for the proposed UAV indicated that a small, TinyWhoop sized UAV would have both insufficient flight time and thrust to accomplish the task of flying in possibly high winds while carrying the added weight of the beacon deployment system. In consideration of these limitations and upon further research, the team decided that a 220mm (8.66 inches) wheelbase UAV would be large enough to handle expected conditions and have enough customizable space to be easily modified to meet the team’s requirements. However, this presents obvious special issues, as an 8.66 inch frame would not easily fit inside the leading design launch vehicle diameter of 5.5 inches.

Such a large diameter wheelbase contradicts one of the main problems the team anticipated: payload compartment size. The smaller UAVs could easily mount in the launch vehicle flat against a bulkhead that supported it until launch, but as previously stated, they were not an option. The selection of a 220mm (8.66 inches) wheelbase would result in a launch vehicle diameter of over 8 inches, which the team was reluctant to pursue due to past teams’ challenges in dealing with large diameter launch vehicles and the difficulty in procuring body tubes of such a large diameter. To mitigate this issue, a simple hinge could be designed and added to the UAV to allow the arms to fold.

The hinges, which will operate via three bolts and a sliding rod, can be visualized using the models in Figure 5-1 and Figure 5-2. Figure 5-1 is the UAV in flight configuration, while Figure 5-2 is the UAV in a stored configuration. In order to create this modification to the UAV, the arms will each be cut 1 inch from the origin of the arm, as measured on the longest side. Holes of 1/8-inch diameter will be drilled in both the cut arm and remaining stub, and bolts will be placed in three static locations on the hinge. The fourth hole in the hinge, the slot, will have a steel rod that is epoxied into place on the arm, and allowed to slide freely through the slotted holes. This will allow for a 54-degree rotation about the static bolt on the arm. Each arm will also have a fillet radius of 0.3 inch on the rotating corner so that the arm does not stop itself from rotating.

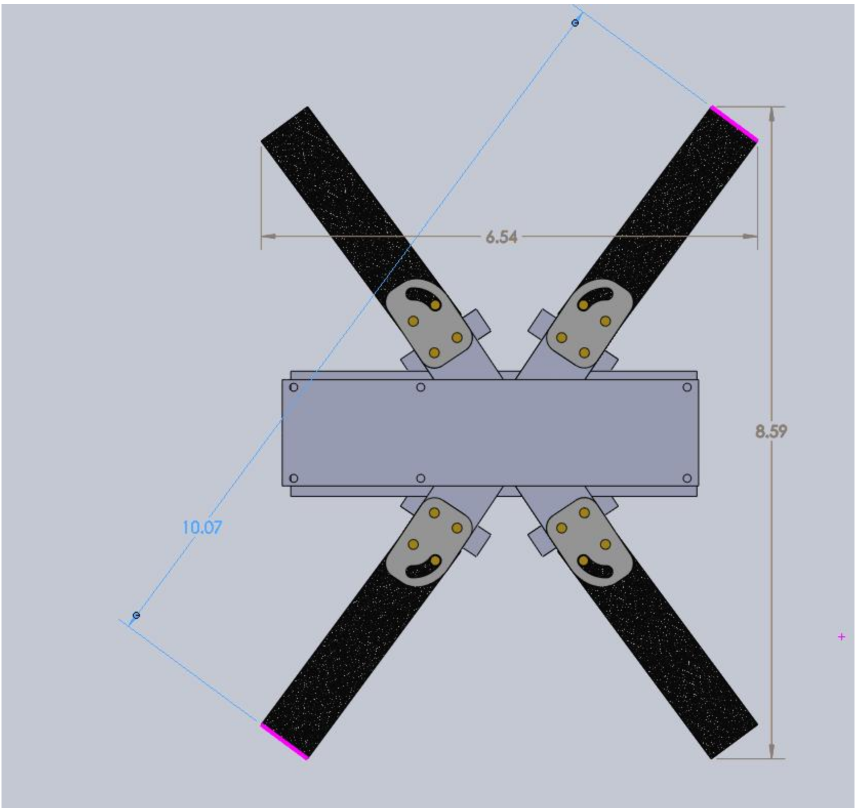

Figure 5-1 Open arm configuration for quadcopter

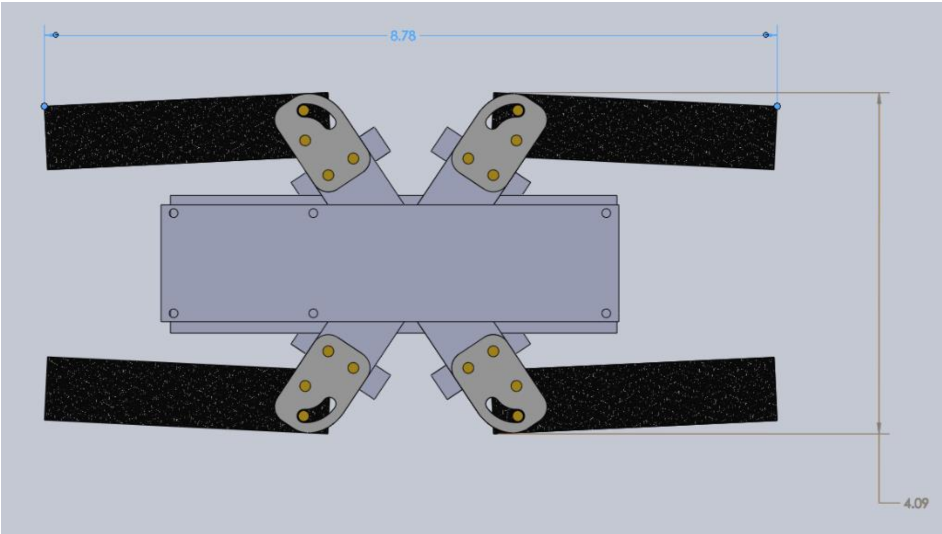

Figure 5-2 Closed arm configuration for quadcopter

Hinges will be placed on the top and bottom of the arm, which will allow for maximum load carriage through the hinge-bolt-arm system. Damping rubber washers can also be used in this system to dampen any vibration caused by the rotating motors and propellers. The hinges will be constructed out of ABS 3D-printed material, which allows for rapid changes and part creation.

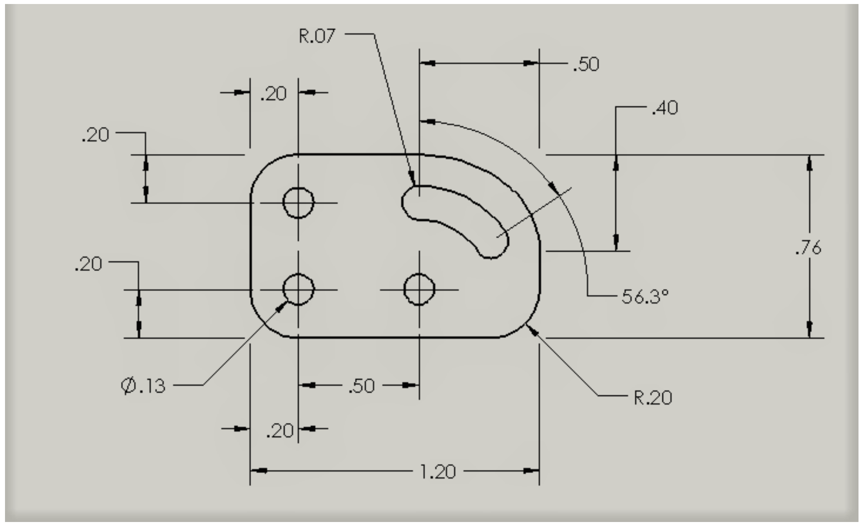

Figure 5-3 Dimensioned Hinge Drawing

The designed hinges will allow the UAV arms to unfold once the containment pod is ejected from the payload section. The primary force that will cause the arms to unfold is the reaction torque on the arms resulting from the spinning rotors. For example, if the front-left motor spins clockwise, to conserve angular momentum of the arm-motor system, the arm itself will rotate counterclockwise about the rotator pin. Typically, this phenomenon is used as a method to manipulate the yaw moment of quadcopters, but the hinge design does not allow for the reaction moment to be transferred to the rest of the body until the arm is fully extended. To supplement the force imparted on the arm from the motor spin, rubber bands or springs will be affixed to the diagonal arms (i.e., front-left to back-right) that will act to pull the arms open in flight moments where the motor spin is not enough to do so.

5.1.1.2 Simulated Navigational Beacon Deployment

While commercially available quadcopter payload deployment systems would offer an easy solution to the deployment of the simulated navigational beacon (SNB), most are designed for larger quadcopters akin to the DJI Phantom series. Due to the typically large size and lack of customizability, the team decided that none of these would best fit the proposed UAV. Following this conclusion, the team chose to pursue the design of a deployment system that is entirely original and custom for the team's quadcopter.

For easiest construction and installation, the team has opted to use a solenoid-based deployment. The solenoid directly works with a 5V source, of which a compatible connection is included on the flight controller. The proposed solenoid has 2 M2 mounting holes in the casing, allowing for easy mounting to the UAV. It has a throw of about 1/3 inch and can act as a push or pull solenoid. When voltage is applied, the solenoid will extend the arm until the voltage is broken. A 3D printed casing is placed around the solenoid pin to make sure the payload does not fall before the current is applied, activating the solenoid. The SNB will be hung from a bar that will be fit into the solenoid casing. The solenoid's activation and subsequent deactivation will push this bar through and out of the casing, and then drop the beacon. The team considered this method because it would be more stable with the large amounts of force experienced by the launch vehicle during launch.

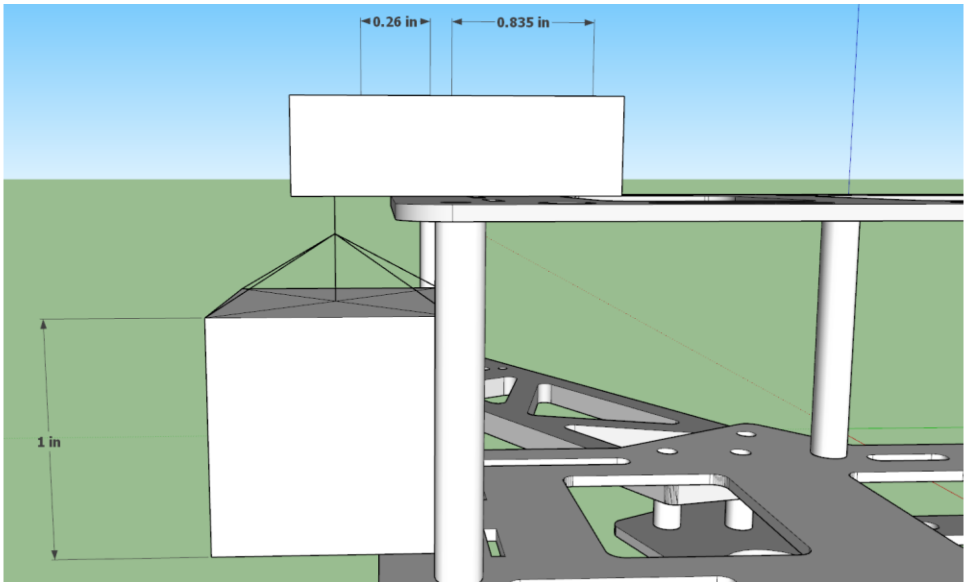

Figure 5-4 Trimble Sketch up Model Demonstrating Solenoid Design

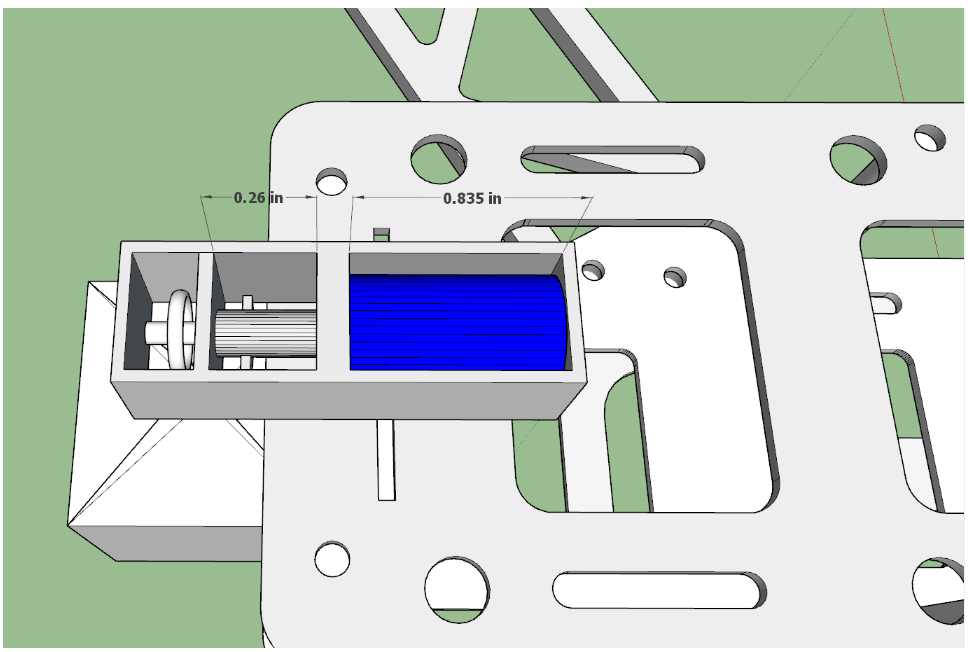

Figure 5-5 Trimble Sketch up Model demonstrating Solenoid Design op View

5.1.1.3 Power Cell Ground Protection

In compliance with requirement 4.4.10, the battery of the UAV must be protected from ground impact. While the obvious solution to this is a top-mounted battery, this presents problems with the payload deployment system. The deployment system, detailed in section 5.2.1.2, relies on the payload having a center of mass that tends to position the UAV level with the ground. To both comply with the aforementioned requirement and assist the leading deployment system, the battery shall be held underneath the UAV by two hook-and loop straps and then protected from ground impact by legs that are 3D printed and mounted to the bottom of the UAV. This so-called landing gear for the UAV will keep the propellers out of tall grass, should a landing take place in testing or competition outside of a tarp or other hard surface.

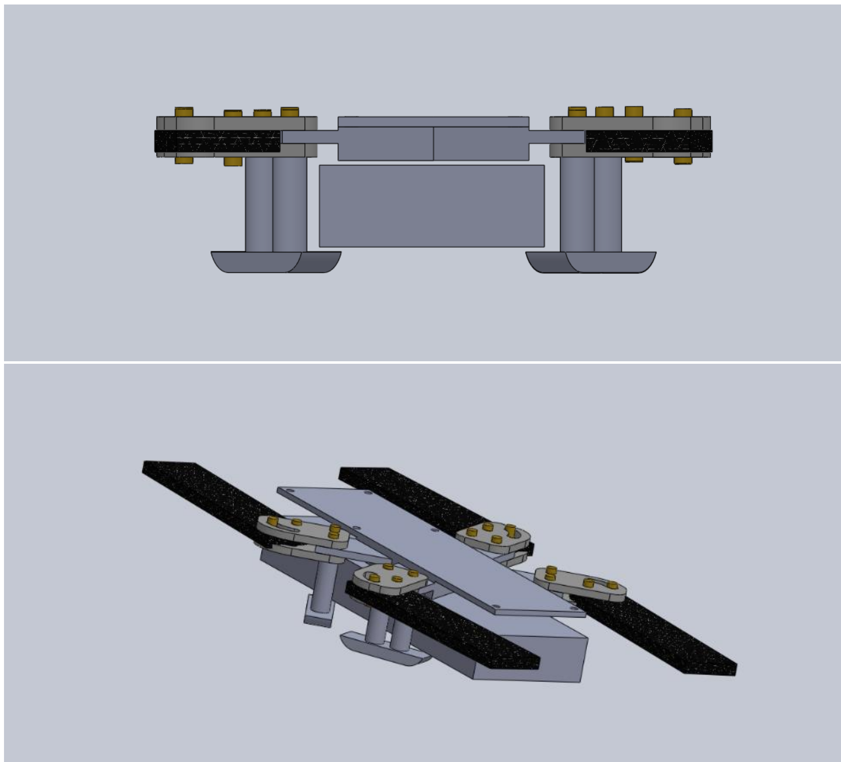

Figure 5-6 Trimble Sketch-up model demonstrating Solenoid design

The battery protection system design utilizes four 3D printed skids that keep the battery from coming in contact with the ground. The battery will be secured to the bottom of the drone body using Velcro, and the skids will take the impact of landing. Each skid is attached to the drone via the two screws that hold the hinge to the drone body. The skids will be produced by 3D printing, which will allow for rapid prototyping and construction.

5.1.1.4 Summary of UAV Performance and Systems Integration

These systems have been identified as having the least number of failure modes and most likely chances for success. The folding hinge design has some obstacles to be overcome, as it requires the hinges to be designed and printed, the quadcopter arms to be cut, and the hinges to finally be successfully installed. However, the team believes this arm design offers the best opportunity for a small folded width and best flight maneuverability. The solenoid design is the current choice as it is the most secure SNB deployment system considered thus far. While it does have certain downfalls thus far, being that the beacon is not rigidly held in place, the team has decided that the solenoid considerably lowers the risk of the beacon being prematurely deployed.

Picking electronic components that will power the quadcopter regardless of structural modifications was determined to be advantageous to both build schedule and budgeting timelines. This, however, presents the issue of estimating component impact on the performance of the quadcopter before buying or testing the components themselves.

The preliminary search for quadcopter flight characteristics based on component choice proved to be spotty at best. One method calculated the total flight time based solely on the battery capacity, discharge rate, and amount of battery discharged. As can be expected, this method is best-case-scenario flight time, failing to take into account propeller size, motor efficiency, or any other flight-related inconsistencies.

To obtain a better approximation of flight characteristics, hobby quadcopter forums and other university clubs recommended eCalc. eCalc is an online calculator that allows users to take measurements, readings, and statistics from quadcopter components and estimate the performance of the conglomerate vehicle. Figure 5-7 is a screen capture of xcopterCalc, one of the several calculators available on eCalc, which the team has purchased a full license to utilize. This screen capture includes the estimated weight of the quadcopter, as well as a few performance parameters the team expects of the quadcopter based on proposed electronics detailed in Section 3.5. Conveniently, xcopterCalc also outputs a graph that visually represents possible range calculations based on no drag and standard drag of quadcopters. This data is shown in Figure 5-8 and can be used to prove that the proposed components of the quadcopter will operate with desirable results even in unfavorable conditions like strong headwinds.

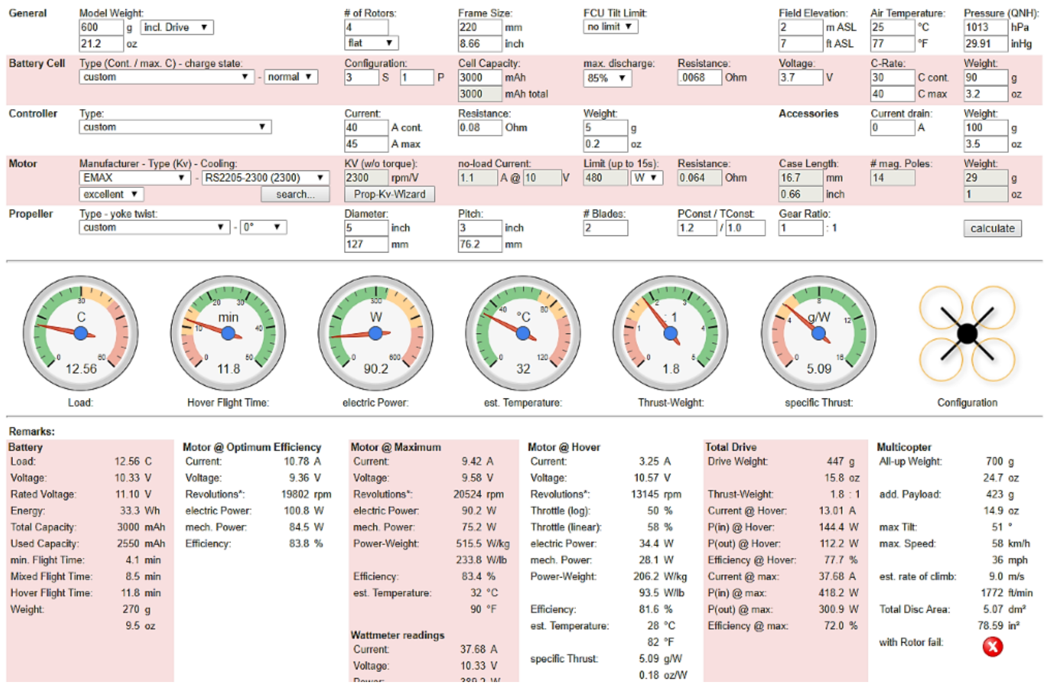

Figure 5-7 eCalc performance estimations

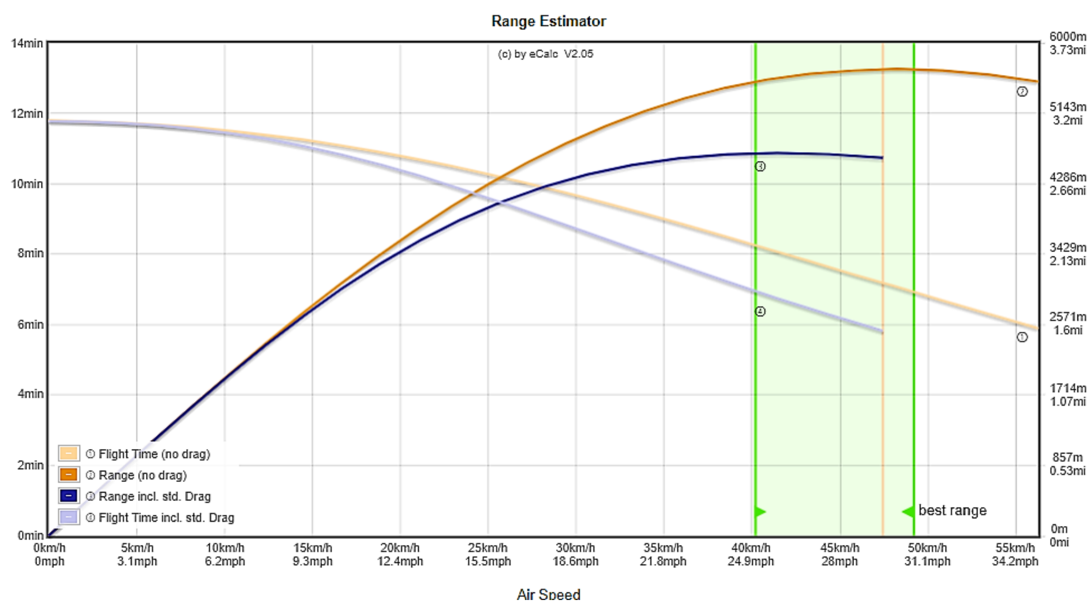

Figure 5-8 eCalc Range Estimator showing best range of operation for quadcopter

The eCalc charts shown above were generated using the parts list shown in Table 5-1. This combination of components gave the team optimal results for even adverse conditions.

Table 5-1 Quadcopter Electronic components list.

Component	Product	Notes
Motors	EMAX RS2205 2300KV	
Flight Controller	Airbot OmniNXT 7	

ESC	Airbot Typhoon32	35A 4-in-1
Power Cell	GOLDBAT 3S LiPo	11.1V, 3000mAh, 30C
Camera	Crazypony RunCam	
Propellers	Lumineer 5x3.5x2	
Frame	QAV-R 220	
Antennae	Pagoda 5.8GHz	(x2) circular polarized
Video Transmitter (VTX)	AKK K31	600mW out, 5V in
Radio Receiver	FrSky XM+ SBUS Mini	
Video Receiver	DX800 DVR 5.8GHz	
Radio Transmitter	FrSky Tarannis X-Lite	
Solenoid	Sparkfun Solenoid 5V	Run on 12V

5.1.2 Chosen Design Alternatives

5.1.2.1 Deployment Mechanism Chosen

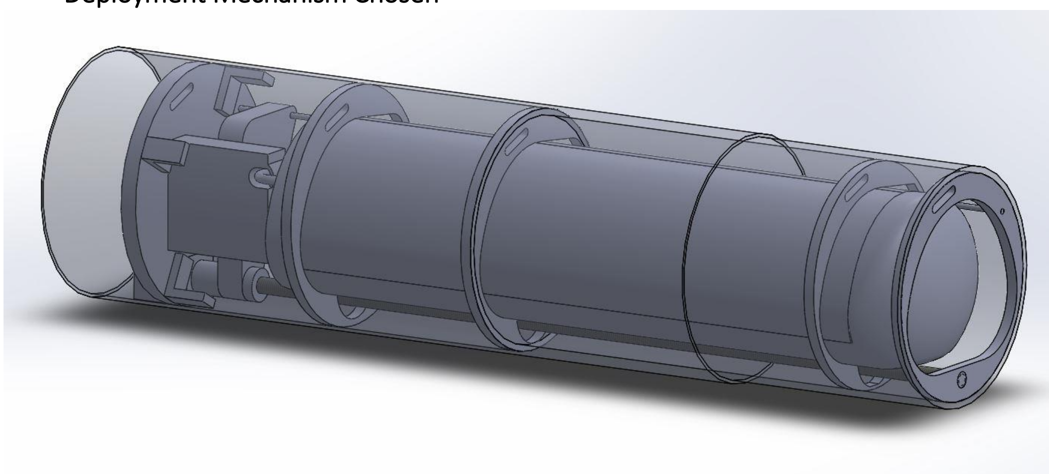

Figure 5-9 Payload Bay in Launch/Recovery Configuration

The design alternative chosen for the design of the payload bay is for the UAV to be contained in a pod suspended on a cantilevered beam. It was chosen for its simplicity, few moving parts, and ability to keep the pod safe. As opposed to a self-opening self-righting pod, this design adds some complexity to the payload bay and UAV, but vastly simplifies the design of the pod itself. This choice does come with notable drawbacks, including the need for a tube through the center of the UAV and the need for a rigid rod to act as a cantilever. To mitigate the possibility of the cantilever bending and damaging the UAV, a carbon fiber rod has been chosen for its high resistance to bending.

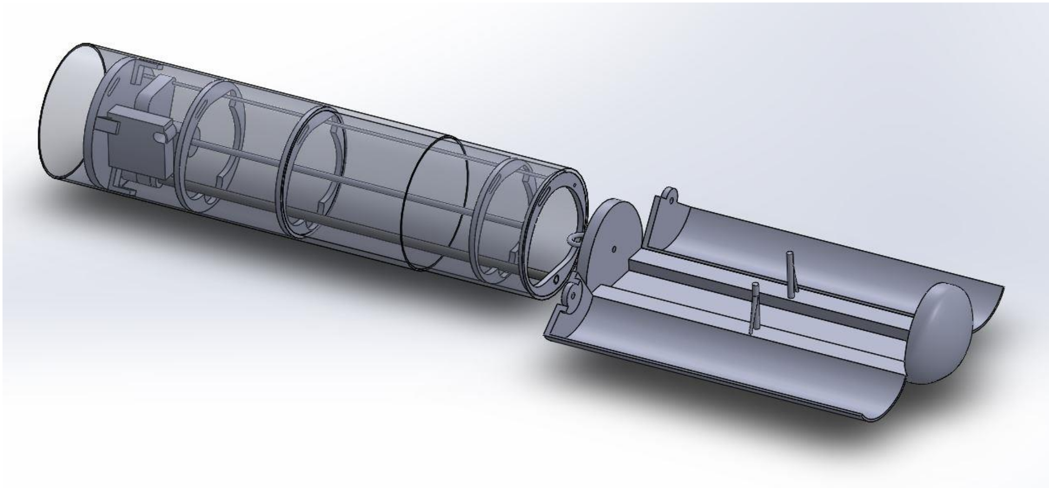

Figure 5-10 Payload Bay in Deployed Configuration

5.2 System Level Design Review

5.2.1 Payload Bay System Level Design Review

5.2.1.1 Centering Rings

The centering rings, while only a small area around the edge of the body tube and coupler, achieve several tasks. The centering rings support the payload pod, stop the pod from retreating into the payload bay, guide the shock cord through the payload bay, and support the end of the lead screw and auxiliary rod. There will also be a small piece of elastic stretched across the final centering ring that prevents the pod from retracting back into the launch vehicle should the pod not need to rotate after exiting. The centering rings will be made from a birch plywood/epoxy layup. The design of the centering rings is described in further detail in Section 3.1.3.4(c).

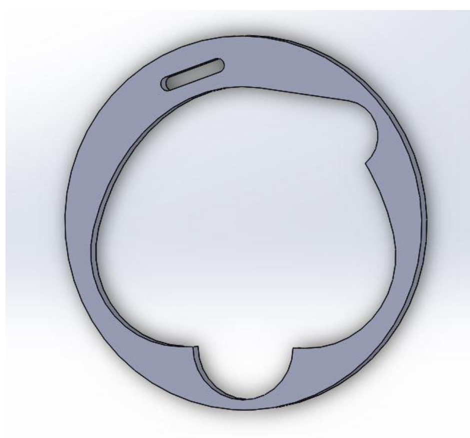

Figure 5-11 Centering Ring Example

5.2.1.2 Payload Pod

The payload pod will be made of PLA plastic 3-D Printed to exact specifications. The backplate will hold a U-Bolt to attach to the latch, as well as a hole to match the cantilevered rod. The nosecone houses the end of the cantilevered rod and is rounded to push debris away from the end of the launch vehicle during UAV deployment. The base has a channel cut into it in order to leave room for the UAV battery. The flaps are designed to hold in the folded arms of the UAV, have interlocking rings to prevent opening prematurely, and are hinged to allow full clearance after deployment. Finally, there are two vertical rods in the center, aligned to sit between the arms of the UAV, which push on the flaps, ensuring they open during deployment. These rods will be hinged to the floor of the pod, only able to push outwards. Small strips of surgical tubing pull these rods to the outside.

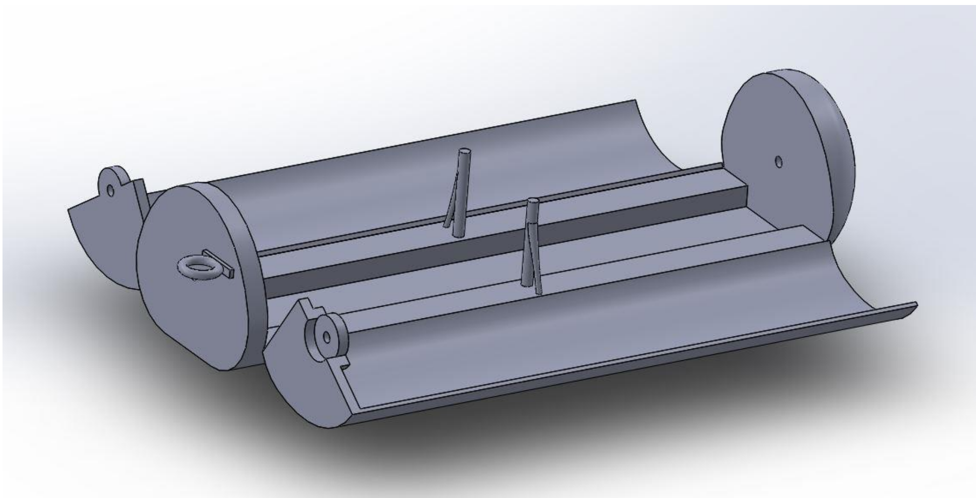

Figure 5-12 Payload Pod Opened with Vertical Pushing Rods

5.2.1.3 **Removable Bulkhead and Latch**

At the forward end of the payload bay is a half-inch thick, removable bulkhead, attached using L-brackets to the body tube. On the aft side of this bulkhead is a Southco R4-EM-63-161 latch. This can be triggered electronically by the Arduino located on the forward side of the bulkhead. The stepper motor, talked about in the next section, is also bolted on to this bulkhead. The structural aspects of the bulkhead are described in section 3.1.3.4(a).

5.2.1.4 **Stepper Motor, Lead Screw, and Auxiliary Rod**

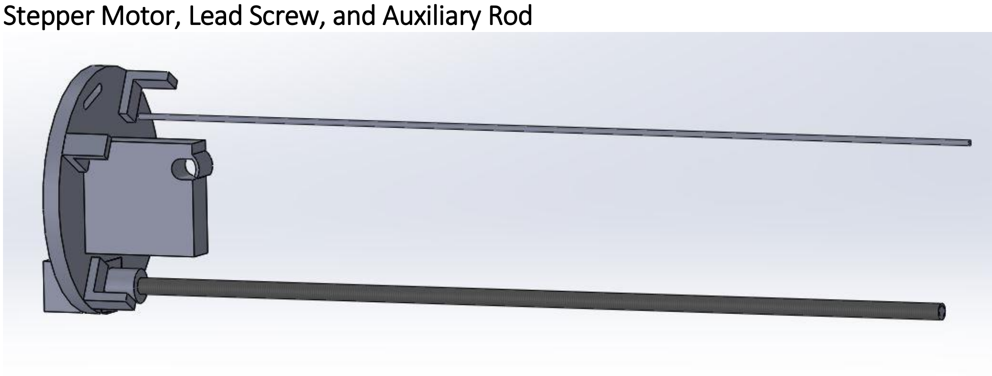

Figure 5-13 Aft Side of the Removable Bulkhead

The primary mechanism for deploying the payload pod is a stepper motor driving a lead screw. The pusher surrounds a threaded nut which is threaded perfectly with the lead screw. When the stepper motor turns the lead screw, the nut will either move towards the desired direction or spin in place. In order to ensure the former option is the only possibility, the pusher also slides along an auxiliary rod, preventing it from rotating in reference to the body tube. The system works identically in reverse in order to retract the rod. A stepper motor was chosen for its ability to stop at precise locations, reverse easily, and large torque at slow speeds.

5.2.1.5 Cantilever Rod and Pusher

The final two components of the payload bay are the pusher itself and the cantilevered rod. The pusher is designed to house the threaded nut, to slide along the auxiliary rod, and to push the payload pod far enough past the end of the final centering ring to clear any obstructions. The pusher will be made out of laser cut plywood layered with epoxy in order to create a strong part sized and shaped exactly as needed. The cantilevered rod, extending out from the pusher and holding the weight of the pod and UAV, needs to be extremely rigid in order to not bend at any point. To accomplish this, the rod will be a commercially available carbon fiber rod. Carbon fiber is both extremely light and very strong in tension, which is needed to resist the bending moment. In order to protect the UAV while the beam is retracting, the beam will be slid all the way through the UAV. This will ensure that the end of the beam will slide through the UAV while minimizing potentially damaging motion and maximizing support

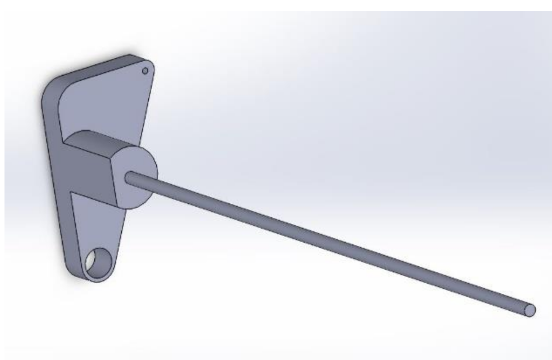

Figure 5-14 Pusher and Cantilevered Rod

5.2.2 How Payload Bay Components Interact

The payload bay contains many dependent and interacting parts. The steps of the deployment cover how the parts interact.

1. During launch, the UAV is surrounded by foam, cushioning the vibrations and forces of flight and recovery. The foam is held by the rigid walls of the payload pod. The pod is then restricted in 5 degrees of freedom by the centering rings. The final degree of freedom, axial translation, is restricted by a latch on the removable bulkhead attached to a U-bolt on the payload pod.

2. Upon sending the signal from within visual range of the launch vehicle, the receiver will signal the Arduino to start the deployment process. The first step of this process is the Arduino electronically unlatching the pod from the bulkhead. This allows the pod to move but applies no force to the pod yet.

3. The Arduino will next direct the stepper motor to spin the lead screw a predetermined number of rotations. This will force the pusher and threaded nut to either translate axially or rotate, and due to the pusher also sliding along the auxiliary rod, only to translate. Through a simple face contact, the pod will be forced out of the pod.

Figure 5-15 Payload Bay Configuration During Steps 1 to 3

4. As the pod exits the last centering ring, the weight of the pod (less than 3 pounds) is transferred to the centered, cantilevered rod extending from the pusher. The rod passes through the entirety of the pod, including through the UAV itself, stopping inside the nosecone of the pod. The flaps remain closed as long as the rod is through the pod. The pod, now free to rotate around the rod, will rotate heavy side down.

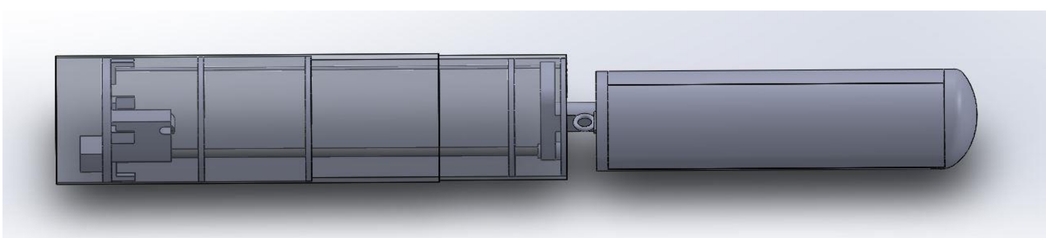

Figure 5-16 Payload Bay Configuration During Step 4

5. The Arduino, set on a time delay, will command the stepper motor to turn the lead screw in reverse. If the pod rotated more than a few degrees, the final centering ring will prevent the pod from retracting back into the body tube. In the unlikely situation the body tube was oriented near perfectly, a thin, flat piece of surgical tubing will be stretched across a corner of the final centering ring opening. This will stretch out of the way as the pod exits but will snap back across the opening when the pod clears it. This will act to prevent the pod from retracting into the body tube if it does not rotate

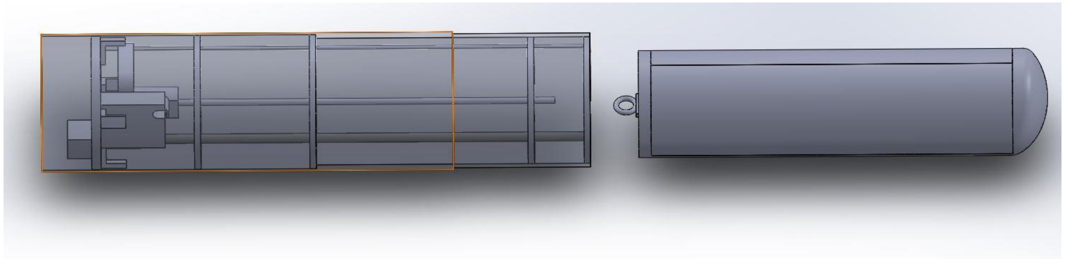

Figure 5-17 Payload Bay Configuration During Step 5

As the pusher retracts, the end of the rod will be separated from the UAV's electronics by either the pod, or by a tube running through the UAV. When the rod is fully retracted, two events will simultaneously occur: the pod will drop slightly under an inch to the ground, and the flaps will be forced open by the hinged rods on the interior of the pod. The hinged rods are pulled down and outwards by strips of surgical tubing.

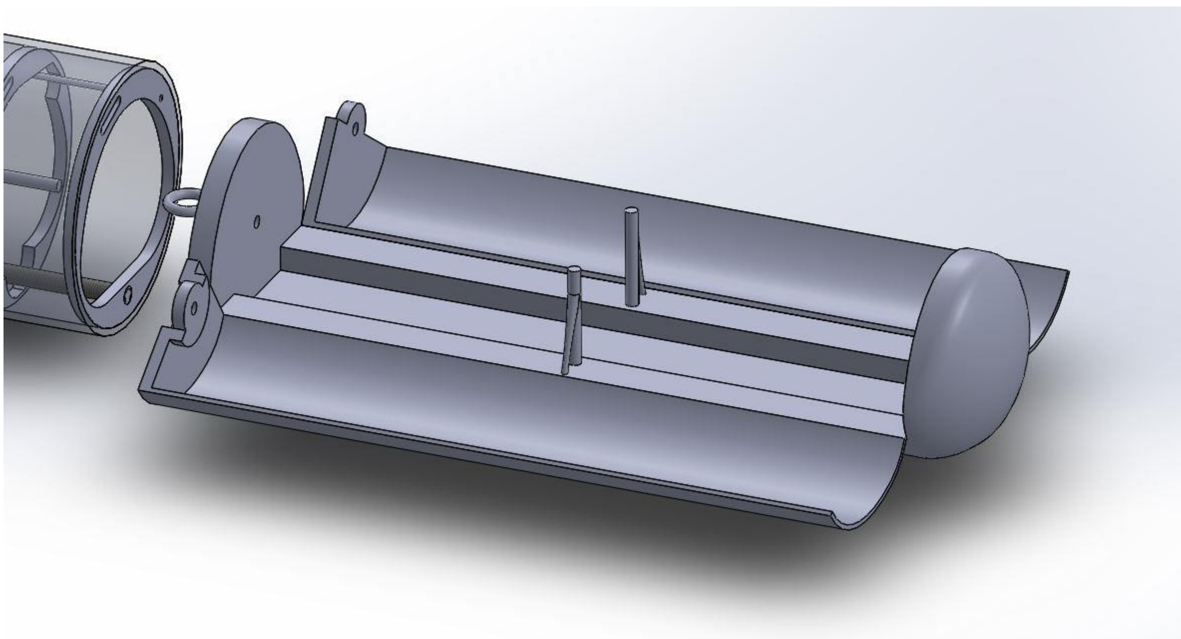

Figure 5-18 Payload Bay Configuration During Step 6 After Opening

6. This leaves the UAV, upright, on the ground, and unrestricted by the flaps of the pod. The arms of the drone are now free to unfold as described in section 5.1.1.1 and the arming signal can be transmitted as described in section 5.3.1.

5.3 Payload Electronics

5.3.1 Payload Deployment Electronics

In terms of physical layout, the payload deployment system shall utilize a container that encloses the power supply with a lid onto which an Arduino microcontroller is fastened; a working diagram of the container is presented in Figure 5-19. Usage of the container was selected because it provides a sure way to secure the power supply and sensitive electronics in place during flight, as the Arduino can be attached to the container lid with screws, which can be attached in turn to the rest of the container with other screws. The container is then attached to the removable bulkhead of the payload bay via small brackets, and this choice allows for simultaneous preparation of the payload deployment electronics subsystem at the launch field relative to other launch vehicle subsystems.

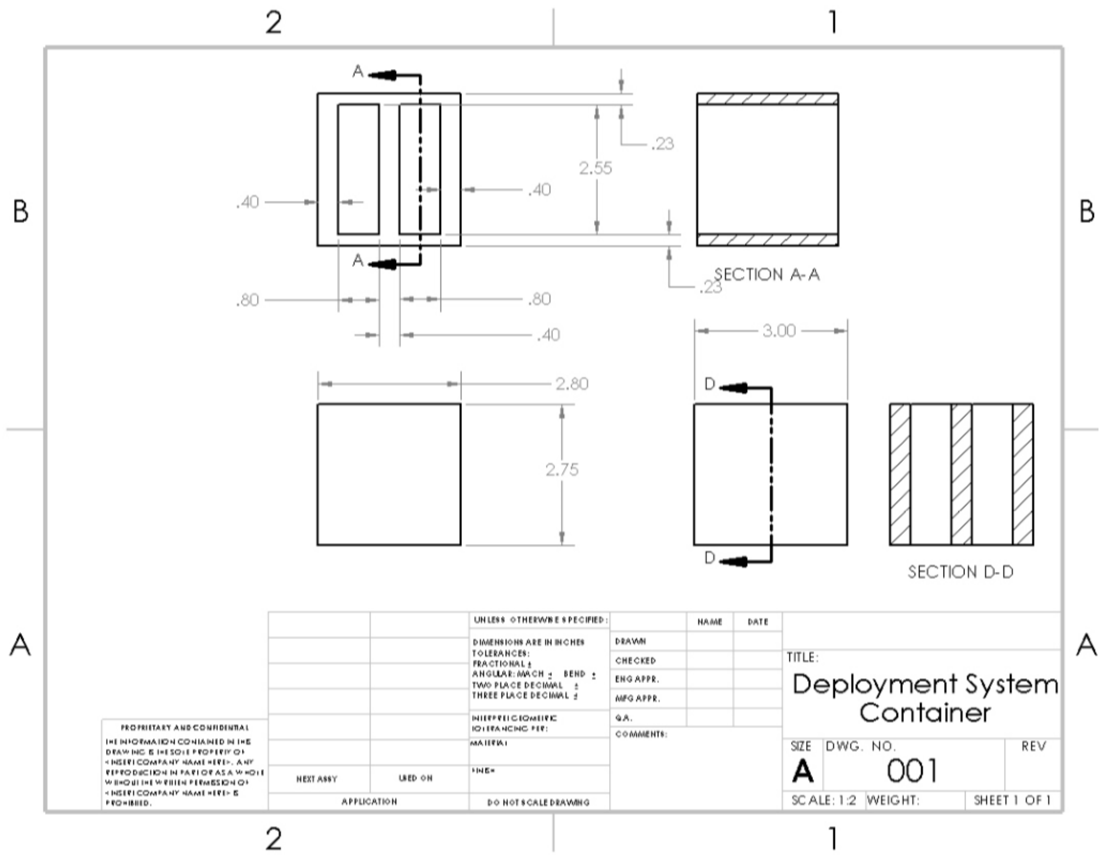

Figure 5-19 Payload Deployment Power Supply Container

This container design was chosen as it provides a secure enclosure for the deployment system electronics, with the battery packs contained inside and the Arduino microcontroller with radio receiver mounted on the container lid, all fastened with screws. For the electrical design, a schematic of both the deployment transmitter and onboard components is presented in Figure 5-20, with a generic block diagram of the deployment process included in Figure 5-21.

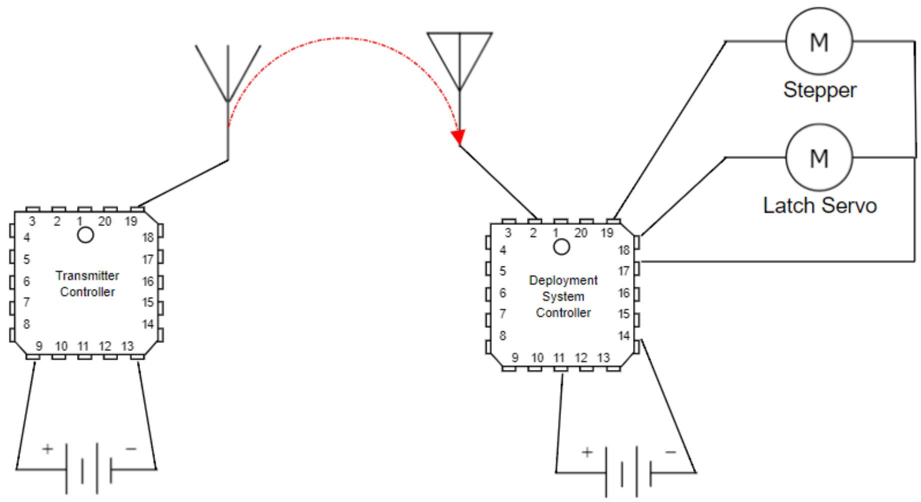

Figure 5-20 Schematic of Deployment Transmitter and Onboard Components

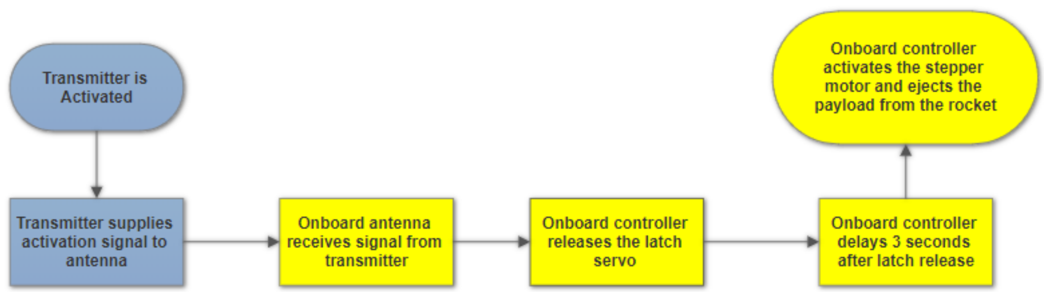

Figure 5-21 Block Diagram of Deployment Process

The radio transmitter previously mentioned, which utilizes a radio frequency of 433 MHz, is not onboard the launch vehicle but is taken to the RDO and triggered once the RSO approves its activation. Utilization of two AA-battery packs as the power source was chosen in order to provide sufficient electrical energy to meet the two-hour pad stay time and still be able to perform its task of deploying the payload pod from the launch vehicle upon a successful landing. To confirm this, an endurance test shall be performed on the completed payload deployment electronic subsystem, the details of which can be found in Section 6.1.5. Successful completion of the test is determined once two hours have passed and the deploy signal is sent from the radio transmitter; if the deployment subsystem successfully completes its task of ejecting the payload pod from the launch vehicle, the test is considered complete. An additional test for subsystem performance is a range test, which will encompass repeated deployment cycles at known distances up to a distance of two kilometers, which is the maximum range of the radio transmitter and receiver pair as given by the manufacturer. For this test, success is determined by whether or not the payload deployment cycle is completed by the onboard components when the radio transmitter is engaged at a distance of 1000 meters, in order to simulate a worst-case scenario in which the launch vehicle lands at the absolute edge of the acceptable landing radius of 0.5 miles from the launch rail with extra distance for redundancy.

5.3.2 How Payload Bay Components Interact

A schematic of the UAV electronic layout is provided Figure 5-22, with a list of component justification for each part provided in Table 5-2. The full list of UAV components is listed in Table 5-1.

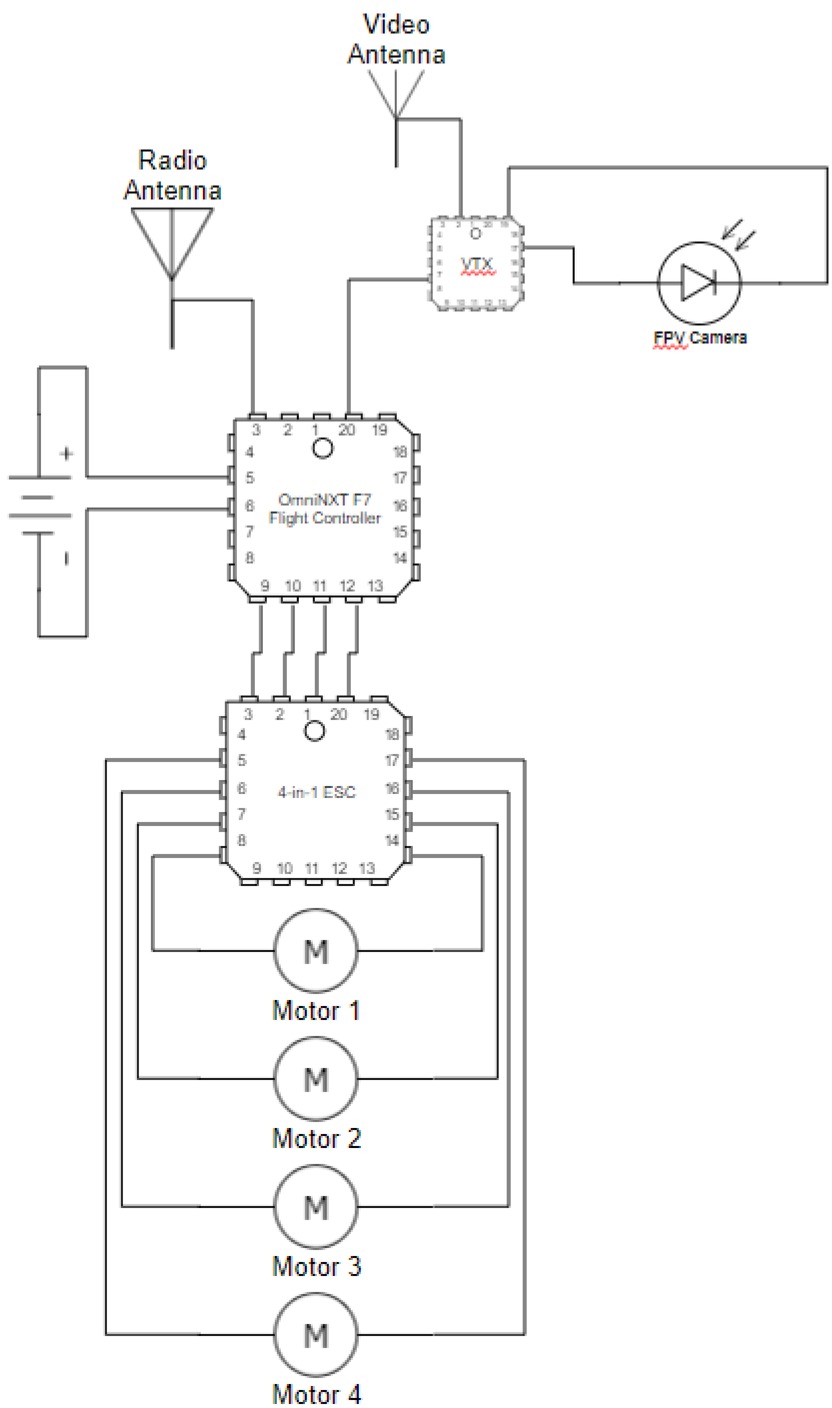

Figure 5-22 Block Diagram of Deployment Process

Table 5-2 Quadcopter Electronic Justifications.

Component	Product
Motors	Provide sufficient power at a minimal electrical power cost to maximize endurance
Flight Controller	See below
ESC	Designed to perfectly integrate with the flight controller
Power Cell	Provides sufficient power for the UAV to complete its mission
Camera	Allows the pilot to locate the nearest FEA with a minimal increase in onboard weight and battery strain
Antennae	Reduces the size and weight of the video subsystem onboard the UAV while still ensuring sufficient performance
Video Transmitter (VTX)	Is able to interface between the selected camera and the video receiver
Radio Receiver	Has the capability of interfacing between the transmitter and flight controller
Video Receiver	Operates on the same radio bands as the VTX
Radio Transmitter	The lightest possible choice for ease of transport to the RDO that also offers enough integrated switches to toggle all onboard features
Solenoid	Sparkfun Solenoid 5V

The flowcharts for the UAV flight and video feedback processes once deployed from the launch vehicle are presented below in Figure 5-23:

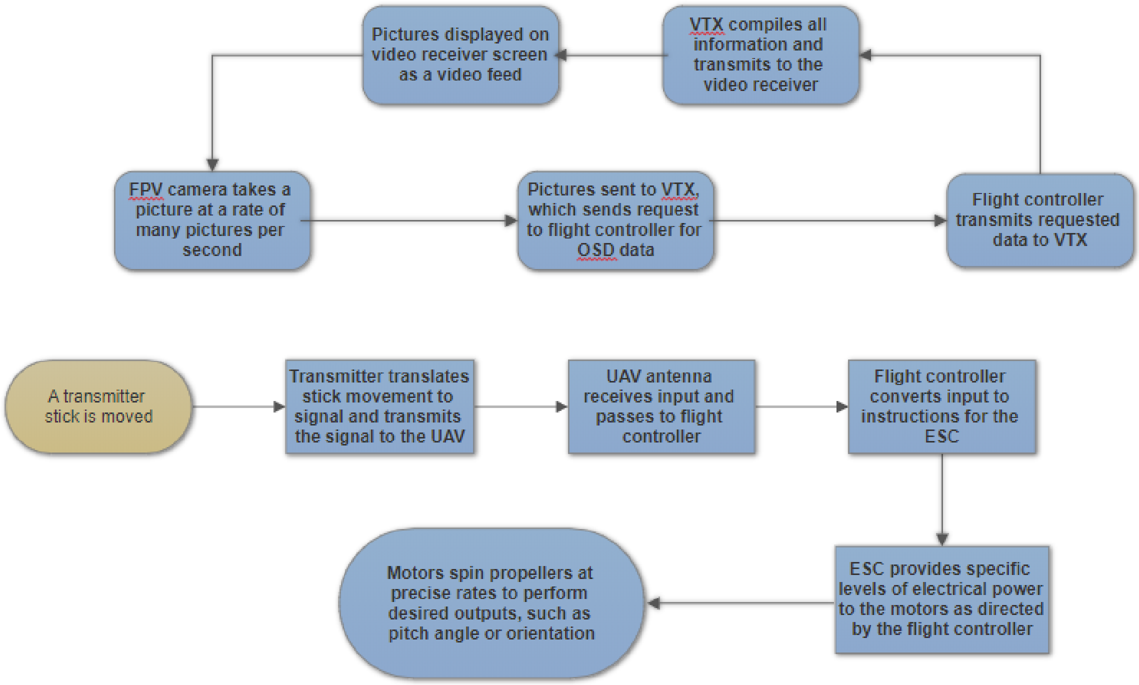

Figure 5-23 **Flowcharts of UAV Flight and Video Feedback Processes**

Figure 5-24 FrSky Tarannis X-Lite Radio Transmitter

Of vital significance is that the UAV radio signals utilize a radio band in the range of 2-2.4 GHz, which can be varied as needed based upon conditions at the launch field; the VTX and video receiver operate on any of the frequencies presented in Table 5-3.

Table 5-3 Suitable Video Transmission Frequencies, in MHz

Band	CH1	CH2	CH3	CH4	CH5	CH6	CH7	CH8
A	5865	5845	5825	5805	5785	5765	5745	5725
B	5733	5752	5771	5790	5809	5828	5847	5866
C	5705	5685	5665	5645	5885	5905	5925	5945
D	5740	5760	5780	5800	5820	5840	5860	5880

To satisfy the requirement that the UAV be disengaged while inside the launch vehicle, there shall be a switch on the transmitter set up so that while it is in the off position, the UAV flight controller disengages the motors and renders then unable to operate; this switch is flipped once the UAV is deployed and allows it to take off. As an additional precaution, the UAV will emit a set pattern of tones for loss of signal, arming and disarming of motors, low battery, and camera activation.

6. Project Plan

6.1 Testing

6.1.1 Bulkhead Failure Test

6.1.1.1 Test Description

The purpose of this test is to validate the strength of the adherence between the bulkheads in the launch vehicle and the body tube. The bulkheads are attached to the body tube using West Systems 2-part epoxy and will cure for at least 24 hours. However, the performance of epoxy is difficult to accurately calculate or predict and therefore must be tested to ensure that it will perform as needed. The nose cone bulkhead is of particular interest as it will experience the highest load of the epoxied bulkheads and also is the most difficult to properly install due to the contours of the nose cone. Because of this, this is designed specifically to validate this bulkhead.

6.1.1.2 Test Setup

For this test, a 5.5-inch length of 5-inch diameter fiberglass body tube will be used. A 5-inch diameter bulkhead will be constructed out of 6 layers of 1/8 inch aircraft grade birch plywood for a total thickness of 0.75 inch. A U-bolt will be attached to this bulkhead via two drilled holes and fastened using hex nuts and a metal plate. The U-bolt is mounted on the side opposite the load application point. This bulkhead will be installed into the section of body tube using West Systems 2-part epoxy and allowed to cure for at least 24 hours as would be done with actual construction of the launch vehicle. While this configuration very closely simulates the nose cone bulkhead design, it will be installed into a body tube section rather than a nose cone due to constraints based on the available testing machinery. A 5-inch diameter, 0.5-inch-thick aluminum bulkhead will be machined and secured to opposite end of the body tube section from the plywood bulkhead. This bulkhead is simply meant as an attachment point to the tensile rig and to reduce any additional points of failure that could be added to the system by using another plywood bulkhead for this purpose.

Once installed, the arm of the universal testing machine will attach to the U-bolt on the plywood bulkhead and a pulling load will be applied until failure of the bulkhead. During testing, the load applied as well as the distance of the arm from the original position will be measured to determine what load failure occurs at.

6.1.1.3 Safety Notes

During fabrication of the test specimen, safety glasses, masks, gloves, or other PPE will be worn by all personnel nearby when appropriate. Appropriate PPE will also be utilized when operating the test machine and all personnel will remain a safe distance away while testing is in progress.

6.1.1.4 Pass/Fail Criteria

The nose cone bulkhead is expected to experience a maximum load of 234.44 lbf during flight. A successful test will indicate a factor of safety of 2; this means the bulkhead will withstand a load of 468.88 lbf with no signs of damage.

6.1.1.5 Results

As of the time of submission of this document, this test has not yet been completed. The test will be run multiple times to ensure reliable data, and results will be documented in the Flight Readiness Review. If results indicate that the epoxy alone will not withstand the expected flight loading, screws will be utilized to secure the bulkhead in addition to epoxy.

6.1.2 Payload Deployment Demonstration

6.1.2.1 Test Description

The goal of this test is to demonstrate that the payload will successfully deploy from the rocket from any orientation. This test will be performed both on a prototype of the payload bay and the full-scale payload bay that will be used for qualification.

6.1.2.2 Procedure

The payload bay, including the pod, UAV, and Arduino, will be constructed on the removable bulkhead while it is outside of the body tube. Communication between the controller and the receiver, as well as continuity of all electronics will be ensured. The bulkhead will then be inserted and secured into the body tube. To simulate the rocket landing in an unknown orientation, the body tube will be rolled along the ground, and finally, the signal to deploy the payload will be sent.

6.1.2.3 Success Criteria

Success is defined as the pod leaving the body tube, orienting heavy side down, dropping to the ground and opening fully, revealing the UAV. The UAV should also be left with enough clearance to activate the motors and fly if the correct commands were sent.

6.1.2.4 Safety Notes

There are no specific concerns about the performance of the test besides normal considerations taken when using electronics and working in a testing environment.

6.1.2.5 Results

This test has not been completed as of the time of this document; the results will instead be presented in the Flight Readiness Review.

6.1.3 Payload Maximum Operating Range Test

6.1.3.1 Test Description

The purpose of this test is to determine the maximum operating range of the combination of UAV and deployment system, as it is difficult to foresee all possible interference factors that may inhibit successful operation at the launch site. This test shall provide a numerical operation window within which the launch vehicle needs to land in order to successfully deploy and fly the UAV.

6.1.3.2 Test Setup

The deployment system power supply will first be connected to the deployment system electronics; the UAV battery shall also be connected to the UAV flight controller and all onboard electronics will be engaged, in order to simulate the status of the payload upon landing. The transmitter power supply shall then be connected to the deployment system transmitter and prepared to send the activation signal while the UAV radio transmitter is turned on and connects to the UAV via a preset radio frequency. The video receiver shall then be turned on and establish a solid connection as well to the UAV on the appropriate radio frequency. For a baseline result, the deployment transmitter and UAV radio transmitter shall move a short distance away from the deployment system and UAV, and the activation signal shall be sent to the deployment system. The distance between the transmitter and receiver shall be recorded along with the success or failure of the deployment system activation when the signal is given. Next, the UAV transmitter shall attempt to make the UAV take off and respond to roll, pitch, and yaw inputs, with the UAV response recorded for all inputs. Afterwards, the deployment system shall be reset to its initial configuration. Both the deployment system and UAV shall move a linear distance of 50 m away from the initial site. This process shall repeat until the deployment system no longer activates or the UAV fails to respond to any input, at which point testing shall cease for that system and continue with the other.

6.1.3.3 Success Criteria

Success for the overall test is defined as a maximum operating range of 1000 meters or greater for both the payload deployment system and the UAV.

6.1.3.4 Safety Notes

There are no specific concerns about the performance of the test besides normal considerations taken when operating a UAV as found in public Law 112-95, Section 336.

6.1.3.5 Results

This test has not been completed as of the time of submission of this document; said results shall instead be presented in the Flight Readiness Review.

6.1.4 Payload Retention Test

6.1.4.1 Test Description

The purpose of this test is to test the latching retention mechanism. The test will be based on the maximum force of tension between the latch and the pod. Because of the payload bay configuration, all loading during parachute deployment can only put compressive forces on the latch. The largest tension force will nominally occur during ascent. Using RockSim, the maximum acceleration of the launch vehicle during ascent is 7.3 times gravitational acceleration. The duration of this max force should be 0.25 second. The payload pod, with the payload inside has not yet been completed; its weight will be referred to as w_{pod}. In order to ensure a factor of safety of 1.5, the tested weight will be at minimum 11 times w_{pod}. The test will also be performed again to test the connection between the eye ring and the payload pod itself.

6.1.4.2 Test Setup

With an expected combined pod and UAV weight between 2.5 and 3 pounds, the test weight will be between 25 and 35 pounds. For this reason, the test will be performed using commercially available standardized weights. To perform the test, a cord will connect the weights directly to the latch. To begin, the weights will be held by a team member, while another team member holds the latch. The weight will be slowly released, transferring the weight to the latch. After a period of 1 second, the weights will be picked up again, removing the load. This process will be repeated with the weight hanging from the eye ring while a team member holds the pod. The test will then be repeated for weights between 25 and 35 pounds in 5 pound increments. This should test the strength of the connection between the eye ring and the pod.

6.1.4.3 Success Criteria

Success is defined as the latch or eye ring showing no visual or auditory signs of failure, including unexpected movement or cracking noises.

6.1.4.4 Safety Notes

No body parts will be allowed below hanging weights. To prevent injury, the mechanisms will always be treated as though they will fail.

6.1.4.5 Results

This test has not been completed as of the time of submission of this document; said results shall instead be presented in the Flight Readiness Review.

6.1.5 Payload Pad Endurance Test

6.1.5.1 Test Description

The goal of this test is to determine the maximum pad stay time of the payload electronics. As described in NASA requirement 2.11, the onboard electronics must maintain functionality for at least 2 hours after being turned on, and if this condition is not met then the power supply subsystem will require adjustment.

6.1.5.2 Test Setup

The deployment system power supply will first be connected to the deployment system electronics; the UAV battery shall also be connected to the UAV flight controller and all onboard electronics will be engaged, to simulate the status of the payload upon landing. The transmitter power supply shall then be connected to the deployment system transmitter and prepared to send the activation signal while the UAV radio transmitter is turned on and connects to the UAV on a preset radio frequency. The video receiver shall then be turned on and establish a solid connection to the UAV as well on the appropriate radio frequency. As soon as this is done, a stopwatch shall be started while the deployment system and UAV remain under continuous observation. The stopwatch shall stop once either the deployment system or UAV loses power, with the time on the stopwatch recorded. All power sources will be recharged or replaced if possible, with the above steps repeated up to a total of three trials.

6.1.5.3 Success Criteria

Success is defined as both the payload deployment system and the UAV exhibiting a pad stay time of 120 minutes or greater.

6.1.5.4 Safety Notes:

There are no specific concerns about the performance of the test besides generic considerations taken when working with electronics.

6.1.5.5 Results

This test has not been completed as of the time of this document; said results shall instead be presented in the Flight Readiness Review.

6.1.6 Hover Test

6.1.6.1 Test Description

The below test is intended to determine the maximum no-wind hover time for the fully-loaded quadcopter. This allows the team to get an estimate of ideal competition day conditions and UAV performance under ideal conditions.

6.1.6.2 Test Setup

This test should be performed on a day with persistent winds of less than 3 mph. With the fully assembled quadcopter, connect the battery and ensure all systems are functional. Ensure that video is transmitting and received. Ensure that the quadcopter is receiving all directional inputs from the radio transmitter. Input controls to the quadcopter so that it hovers at approximately 10 feet from the ground. Record the time that the quadcopter hovers until the battery reaches 85% discharge (as indicated by the flight controller). Repeat the experiment for three, separate, fully charged, similar batteries.

6.1.6.3 Success Criteria

Failure is considered a flight time less than 5 minutes, as this is estimated to be sufficient time for the quadcopter to take-off, fly to, and land at the FEA.

6.1.6.4 Safety Notes

To ensure safety of all personnel involved in testing, all FAA guidelines for UAVs of this size shall be adhered to. The quadcopter shall not be operated near trees or other obstructions, including cars, people, and buildings. The quadcopter shall not be operated in unsafe environmental conditions including rain, sleet, snow, high winds, or any other adverse weather.

6.1.6.5 Results

This test has not been completed as of the time of this document; they will instead be presented in the Flight Readiness Review. If the UAV were to fail this test, the electronic components including the battery, motors, propellers, and flight controllers must be reevaluated.

6.1.7 Adverse Conditions UAV Flight Test

6.1.7.1 Test Description

Determine the flight time and range of quadcopter under normal conditions. “Adverse” conditions are intended to simulate windy day conditions as the team anticipates in Huntsville, Alabama on competition day. This allows the team to get a more accurate estimate of performance under competition conditions, ideally giving a lower bound.

6.1.7.2 Procedure

This test should be performed on a day with sustained winds of greater than 10 mph. A quarter mile is measured and marked in an open field with no obstructions. With the fully assembled quadcopter, connect the battery and ensure all systems are functional. Ensure that video is transmitting and received. Ensure that the quadcopter is receiving all directional inputs from the radio transmitter. Fly the quadcopter from one end of the measured distance to the other with no breaks in laps. Record the number of times the span is covered, and the time of flight, until the battery reaches 85% discharge (as indicated by the flight controller). Repeat the experiment for three, separate, fully charged, similar batteries.

6.1.7.3 Success Criteria

Failure is considered a flight time less than 5 minutes, as this is estimated to be sufficient time for the quadcopter to take-off, fly to, and land at the FEA.

6.1.7.4 Safety Notes

To ensure safety of all personnel involved in testing, all FAA guidelines for UAVs of this size shall be adhered to. The quadcopter shall not be operated near trees or other obstructions, including cars, people, and buildings. The quadcopter shall not be operated in unsafe environmental conditions including rain, sleet, snow, high winds, or any other adverse weather. This test, as stated earlier, requires specific atmospheric conditions, therefore care must be taken to ensure the conditions for the test are met without endangering the testing personnel.

6.1.7.5 Results

This test has not been completed as of the time of this document; they will instead be presented in the Flight Readiness Review. If the UAV were to fail this test, the electronic components including the battery, motors, propellers, and flight controllers must be reevaluated.

6.1.8 GPS Functionality Demonstration

6.1.8.1 Test Description

As described in NASA requirement 3.11, the launch vehicle shall contain an onboard tracking device to transmit the location of the vehicle upon touchdown. The BigRedBee 900 GPS onboard the launch vehicle must function properly to fulfill this requirement.

6.1.8.2 Test Setup

The LiPo battery powering the BigRedBee 900 GPS will be charged to its maximum capacity, indicated by a voltage of 4.2 V. The GPS radio receiver will also be charged prior to the demonstration. The battery will then be connected to the GPS, and the assembly will be taken outdoors to an area with clear, unobstructed view of the sky.

6.1.8.3 Success Criteria

The GPS must acquire at least four satellites within five minutes of beginning the demonstration. The data retrieved from the GPS following the conclusion of the demonstration must reflect an accurate depiction of the path tracked.

6.1.8.4 Results

This test has not been completed as of the time of this document; they will instead be presented in the Flight Readiness Review.

6.1.9 Recovery Electronics Pad Endurance Test

6.1.9.1 Test Description

The goal of this test is to determine the maximum pad stay time of the recovery electronics. As described in NASA requirement 2.11, the onboard electronics must maintain functionality for at least 2 hours after being turned on. This test will determine how long all recovery electronics will be able to remain on. The recovery electronics are two PerfectFlite StratoLoggerCF altimeters and one BigRedBee GPS.

6.1.9.2 Test Setup

On the drogue and primary parachute circuitry of a StratoLoggerCF altimeter, an LED linked with a 350-ohm resistor will be placed in series for the altimeter. This resistor is used to reduce the amperage of the electric circuit in order to prevent the LED from blowing out. A 9V battery is then connected to each altimeter to supply power. A timer is started upon applying power to the altimeter. The altimeter will sound its start-up beep sequence then sound continuity beeps every 0.8 seconds. The timer will run until either the continuity beeps stop, or the time passes 120 minutes. This process is repeated 3 times for both the primary and secondary altimeters.

GPS will be connected to its power supply and set up as described in the GPS Functionality Demonstration. A timer is started upon applying power to the GPS. The GPS receiver will be monitored until the timer hits 120 minutes or until the GPS's voltage reaches 3.0 V, the minimum safe voltage for the battery.

6.1.9.3 Success Criteria

Success is defined as both the PerfectFlite StratoLoggerCF altimeters and the BigRedBee GPS have a pad stay time of 120 minutes or greater.

6.1.9.4 Safety Notes

There are no specific concerns about the performance of the test besides normal considerations taken when working with electronics.

6.1.9.5 Results

This test has not been completed as of the time of this document; they will instead be presented in the Flight Readiness Review. The results of this experiment will determine what batteries are used to power the recovery electronics.

6.1.10 Altimeter Demonstration

6.1.10.1 Demonstration Description

The purpose of this demonstration is to verify the functionality of the flight altimeters and ensure an electrical signal is carried to both the drogue and primary chutes lines.

6.1.10.2 Demonstration Setup

For this demonstration, both flight altimeters will put through this process to validate their functionality. Each PerfectFlite StratoLoggerCF will be programmed according to the planned configuration for the actual full-scale test launch. On the drogue and primary parachute circuitry, an LED linked with a 350-ohm resistor will be placed in series for the altimeter. This resistor is used to reduce the amperage of the electric circuit in order to prevent the LED from blowing out. After this set up has been completed, a nine-volt battery is plugged in to verify continuity of the altimeter and then it is placed in a vacuum chamber.

With the altimeter hooked up to the LED circuits and nine-volt battery in the vacuum chamber, the vacuum chamber will then mimic conditions similar to what the altimeter will experience during flight.

6.1.10.3 Safety Notes

Appropriate PPE will also be utilized when operating the vacuum chamber and all personnel will remain a safe distance away while testing is in progress.

6.1.10.4 Pass/Fail Criteria

A successful demonstration of the altimeters will consist of the altimeters triggering the LED's at the appropriate phase of the simulated flight, I.e. drogue chute at simulated apogee and main chute at 500 feet. Failure would be considered if one or both LED's fail to trigger based upon conditions in the simulated flight.

6.1.10.5 Results

As of the time of submission of this document, this test has not yet been completed. The test will be run multiple times to ensure reliable results will be documented in the Flight Readiness Review. If an altimeter is not functioning correctly, it will be replaced prior to launch.

6.1.11 Black Powder Ejection Demonstration

6.1.11.1 Demonstration Description

The purpose of this demonstration is to verify the functionality of the black powder charges prior to launch. This will also allow the team to choose more precise black powder charge sizes.

6.1.11.2 Demonstration Setup

For this demonstration, the launch vehicle shall be assembled with all recovery devices, as it would be on launch day. The black powder charges shall be installed and a mass simulator in both the avionics bay and payload bay. The team shall then take the assembled launch vehicle and line it up against a wall lined with foam boards.

The e-match wires are then connected to the ejection testing switch via alligator clips. A 9V battery is then attached to the ejection testing switch. With the permission of the team's advisor, the switch is then turned to the on position after a countdown of 5 seconds. A single black powder charge will fire. This is repeated for both the primary and secondary black powder charges.

6.1.11.3 Safety Notes

Appropriate PPE will also be utilized when handling all black powder and when setting off the black powder charges

6.1.11.4 Pass/Fail Criteria

A successful demonstration of the black powder ejection system is defined by full separation between the avionics bay and fin can for drogue and main parachute bay and payload bay for main.

6.1.11.5 Results

As of the time of submission of this document, this test has not yet been completed. The test will be run multiple times to ensure reliable results will be documented in the Flight Readiness Review. This demonstration is used to verify the black powder charge sizing.

6.2 Requirements Compliance

6.2.1 NASA Requirements

Table 6-1 Requirement Verification Plan

Handbook Item	Compliance	Method of Verification	Verification Plan
1.1	Team members shall complete 100% of the project, including design, construction, written reports, presentations, and flight preparation.	Inspection	Team members shall operate independently of advisors and mentors. Team members shall be trained by the safety officer on proper use of lab tools and equipment to verify ability to function independently.
1.1	Team members shall work alongside L3 mentors in handling motors and black powder charges.	Demonstration	Team safety officer shall train members on proper safety techniques regarding all energetics.
1.2	Executive board members shall provide and maintain a project plan including the following items: project milestones, budget and community support,	Inspection	Executive Board Members shall collaborate to produce an updated project plan with each milestone report.

	checklists, personnel assignments, STEM engagement events, and risk and mitigation.		
1.3	The Team shall not bring any Foreign Nationals to launch week activities.	Inspection	The Team shall not be bringing any FN to launch week activities.
1.4	The team shall identify all team members attending launch week activities by the Critical Design Review (CDR).	Inspection	The team shall include a list of all members attending launch week activities in the CDR milestone report.
1.5	The team shall engage a minimum of 200 participants in educational, hands-on STEM activities, as defined in the STEM Engagement Activity Report, by FRR.	Demonstration	The Team Outreach Coordinator shall organize STEM engagement events such that the team reaches 750 participants by FRR.
1.6	The team's Webmaster and Media Officer shall maintain all its forms of social media, including but not limited to: Facebook, Instagram, Twitter, and the team website.	Inspection	The team shall provide links to social media accounts to the NASA project management team to verify the team is maintaining an active social media presence.
1.7	The Team Lead shall email all deliverables to the NASA project management team.	Inspection	The Team Lead shall include language in the email asking if the content is viewable and shall expect a response.
1.8	The Team Lead shall save all deliverables in PDF format	Inspection	The Webmaster shall verify the report is in PDF format prior to uploading to the website.
1.9	The team shall use a template that includes a table of contents based on the headings and subheadings of the report.	Inspection	The team shall use a cross referencing table of contents.
1.10	The team shall use a template that includes a footer with page number.	Inspection	The Team Lead shall verify the pages display the correct page numbers at the bottom of the page.

1.11	The Team Lead shall reserve a teleconference room at the University with access to a reliable landline and internet connection.	Inspection	The Team Lead shall reserve the room two weeks in advance by confirmation with the department secretary.
1.12	The Senior Design team shall design a launch vehicle to launch on a 1515 rail.	Demonstration	The Structures lead shall use the team's 1515 rail to slide the assemble launch vehicle into place to verify alignment and fit.
1.13	The team shall identify two mentors, Alan Whitmore and Jim Livingston.	Inspection	Alan Whitmore and Jim Livingston shall maintain their L3 certifications with both TRA and NAR for the duration of the project.
2.1	The team shall design a launch vehicle to fly between 4,000 and 5,500 feet AGL.	Analysis	The team shall use Rocksim software to simulate flight and verify the simulation has an apogee between 4,000 and 5,500 feet AGL.
2.2	The team shall declare a target altitude goal in the PDR milestone document.	Inspection	The target altitude is 4,090 feet AGL.
2.3	The team shall design a vehicle to carry two commercially available barometric altimeters. One altimeter shall be chosen as the primary altimeter.	Demonstration	The recovery and avionics lead shall use two PerfectFlite StratoLogger CF altimeters in the fabrication of the team's launch vehicle. One shall be marked as the primary altimeter.
2.4	The team shall design a vehicle with two altimeters armed by an external arming switch.	Demonstration	The recovery and avionics lead shall select a mechanical arming switch based on the wiring and placement of said switches.
2.5	The team shall design an altimeter bay in which each altimeter has its own power supply.	Demonstration	The recovery and avionics lead shall supply two commercially available 9V batteries. These two 9V batteries shall be tested

			before being wired into the altimeter circuit.
2.6	The team shall use rotary switches that shall be locked in the ON position for the entirety of the launch.	Analysis	The recovery and avionics lead shall investigate different rotatory switch styles and select a style that will remain locked in the on position while in flight.
2.7	The launch vehicle shall have a recovery system that will allow the team to relaunch the launch vehicle within the same day.	Analysis	The recovery and avionics lead shall choose two parachutes to serve as the drogue and main parachute for the launch vehicle. The full-scale airframe shall be made of fiberglass to resist inflight damage.
2.8	The launch vehicle shall have a maximum of four (4) independent sections.	Inspection	The launch vehicle shall have three (3) as described in Section 3.3.1.
2.8.1	The coupler/airframe shoulders shall be at least 1 body diameter in length	Inspection	The coupler/airframe shoulders shall be 5.5 inches which is one body diameter in length as described in Section 3.1.3.
2.8.2	The nosecone shoulder shall be at least ½ body diameter in length.	Inspection	The nosecone shoulder shall be 2.75 inches which is ½ body diameter in length as described in Section 3.1.4.
2.9	The launch vehicle shall be limited to a single stage.	Inspection	The launch vehicle shall use one L1150R in a single stage.
2.10	The launch vehicle shall be capable of being prepared for flight at the launch site within 2 hours of the time the Federal Aviation Administration flight waiver opens.	Demonstration	The team shall practice launch vehicle assembly prior to launch day to verify assembly fits within the time constraints.
2.11	The launch vehicle shall be capable of remaining in launch-ready configuration on the pad	Test	The team shall test each of the electronic systems to verify functionality for

	for a minimum of 2 hours without losing the functionality of any critical on-board components.		a minimum of two hours, see Section 6.1.5.
2.12	The launch vehicle shall be capable of being launched by a standard 12-volt direct current firing system.	Demonstration	The team shall use a commercially available motor to be ignited by a 12-volt commercially available igniter connected to the firing system.
2.13	The launch vehicle shall require no external circuitry or ground support equipment to initiate launch.	Inspection	The launch vehicle shall encompass all equipment required to initiate launch.
2.14	The launch vehicle shall use a commercially available solid motor propulsion system using APCP which is approved and certified by NAR and TRA.	Inspection	The launch vehicle shall use a L1150R motor produced by Aerotech.
2.14.1	The team shall make final decisions on motor choice by the Critical Design Review Milestone.	Demonstration	The launch vehicle shall use a L1150R motor produced by Aerotech.
2.15	The team shall not include any pressure vessels on the launch vehicle.	Inspection	The design documents shall not detail any pressure vessel as one shall not be included in the design.
2.16	The total impulse of the launch vehicle shall not exceed 5,120 Newton-seconds (L-class).	Inspection	The launch vehicle shall use a L1150R motor with a total impulse of 3,517.0 Newton-seconds.
2.17	The team shall design a motor with a minimum static stability margin of 2.0 at the point of rail exit.	Analysis	The launch vehicle's static stability margin shall be 2.01 calibers based on the current design.
2.18	The launch vehicle shall accelerate to a minimum velocity of 52 fps at rail exit.	Analysis	The Aerodynamic Simulation Subteam shall conduct simulations using the leading design configuration to verify a

			rail exit velocity of 52 fps or higher is achieved.
2.19	The team shall design and launch a subscale model of the launch vehicle.	Demonstration	The subscale model shall be launched on November 17th, 2018. Subscale results are described in Section 3.2
2.19.1	The subscale model shall resemble and perform aerodynamically similar to the full-scale launch vehicle.	Demonstration	The subscale model shall be 73% of the size of the full-scale launch vehicle.
2.19.2	The subscale model shall carry an altimeter capable of recording the model's apogee altitude.	Inspection	The subscale shall carry two StratoLogger altimeters to record altitude. Altitude results are recorded in Section 3.2.1.
2.19.3	The subscale model shall be a newly constructed launch vehicle, designed for this year's project.	Demonstration	The subscale shall be constructed in the weeks prior to launch.
2.19.4	Altimeter data from the subscale launch shall be included in the CDR report.	Inspection	The avionics and recovery team shall retrieve altimeter data from the subscale launch for inclusion in Section 3.2.1 of this document.
2.20.1	The team shall launch its full-scale launch vehicle in final flight configuration prior to FRR.	Demonstration	The team shall launch the full-scale launch vehicle in final flight configuration on February 9, 2019.
2.20.1.1	The vehicle and recovery system shall have functioned as designed.	Demonstration	The team shall perform a qualification launch of the full-scale launch vehicle to verify that the vehicle and recovery systems perform as designed.
2.20.1.2	The full-scale launch vehicle shall be a newly constructed launch vehicle, designed and built specifically for this year's project.	Demonstration	The team shall construct a new launch vehicle in preparation for the full-scale qualification launch.
2.20.1.3.1	If the payload is not flown, mass simulators	Demonstration	The team shall design the payload bay to accept a

	shall be used to simulate the payload mass.		mass simulator if necessary.
2.20.1.3.2	The mass simulators shall be located in the same approximate location on the launch vehicle as the missing payload mass.	Demonstration	The team shall measure the CG of the launch vehicle prior to launch to ensure the payload mass simulator is located appropriately.
2.20.1.4	The team shall not include any external probes in the design of the full-scale launch vehicle.	Demonstration	The full-scale launch vehicle shall be inspected prior to launch for the presence of any protruding features apart from rail buttons, key switches and fins.
2.20.1.5	The team shall use the competition motor for the qualification flight of the full-scale launch vehicle.	Demonstration	The Team shall use an Aerotech L1150R during both the full-scale demonstration flight and the competition flight.
2.20.1.6	The team launch the full-scale launch vehicle in the same ballasted configuration for the qualification flight and competition flight.	Demonstration	The launch vehicle shall be weighed prior to both the qualifying launch and competition launch. The weights shall be compared to verify that the launch vehicle is launched in the same configuration.
2.20.1.7	The Launch Vehicle shall not be altered after the qualification flight	Inspection	The team shall not make any alterations to the launch vehicle after a successful qualification launch has been completed.
2.20.1.8	The team shall record altimeter data from the qualification launch and provide this data in the FRR	Inspection	The Avionics and Recovery Subteam lead shall extract data from the qualification launch of the full-scale launch vehicle to be provided in the FRR.
2.20.1.9	The vehicle demonstration flight shall be completed before the FRR milestone report deadline.	Demonstration	The team shall perform a demonstration flight of the full-scale launch vehicle by mid-February.

2.20.2	The launch vehicle shall launch in its competition configuration, including a completed payload, prior to the payload demonstration flight deadline.	Demonstration	The team shall complete the competition payload and perform a payload demonstration flight by before the FRR Addendum deadline.
2.20.2.1	The payload shall be fully retained throughout the entirety of the flight, all retention mechanisms must function as designed, and the retention mechanism must not sustain damage requiring repair.	Test	The Payload Integration Subteam shall perform a payload retention test, subjecting the payload to flight forces using a mass simulator. The subteam shall verify the payload is retained throughout all regimes of flight. See Section 6.1.4.
2.20.2.2	The Payload flown during the payload demonstration flight shall be the final, active version of the payload.	Demonstration	The team shall fly the final version of the payload.
2.20.2.4	The team shall perform a payload demonstration flight prior to the FRR Addendum deadline.	Demonstration	The team shall perform a payload demonstration flight before the FRR Addendum deadline. This shall only happen if the payload is not flown on February 9, 2019.
2.22	Structural protuberances shall not be located forward of the burnout CG.	Demonstration	The Team shall not design a launch vehicle with structural protuberances forward of the burnout CG.
2.23	The team shall include necessary contact information on the outer airframe of the launch vehicle.	Demonstration	The team's name and launch day contact information shall be written on the fin can of the launch vehicle.
2.24.1	The launch vehicle shall not utilize forward canards.	Demonstration	The team shall not design a launch vehicle that utilizes forward canards or camera housings.
2.24.2	The launch vehicle shall not utilize forward firing motors.	Demonstration	The team shall not design a launch vehicle which utilizes forward firing motors.

2.24.3	The launch vehicle shall not utilize motors that expel titanium sponges	Demonstration	The team shall select a motor that does not expel titanium sponges
2.24.4	The launch vehicle shall not utilize hybrid motors.	Demonstration	The team shall design a launch vehicle that utilizes a solid launch vehicle motor.
2.24.5	The launch vehicle shall not utilize a cluster of motors.	Demonstration	The team shall design a launch vehicle that does not utilize a cluster of motors
2.24.6	The launch vehicle shall not utilize friction fitting for motors.	Demonstration	The team shall design a launch vehicle that utilizes a screw-cap motor retainer.
2.24.7	The launch vehicle shall not exceed Mach 1 at any point during flight.	Analysis	Multiple flight simulations of the launch vehicle shall be conducted to prove that Mach 1 shall not be exceeded during flight.
2.24.8	The launch vehicle ballast shall not exceed 10% of the vehicle's takeoff weight.	Analysis	By design, no more than 10% of the launch vehicle's takeoff weight shall be ballast material. This is determined through multiple RockSim simulations.
2.24.9	Transmissions from onboard transmitters shall not exceed 250 mW of power.	Test	The team shall test all onboard transmitters to verify none exceed 250 mW of power.
2.24.10	Excessive and/or dense metal shall not be utilized in the construction of the vehicle.	Demonstration	The team shall design the launch vehicle using lightweight composite materials.
3.1	The launch vehicle shall utilize a dual deployment recovery system.	Analysis	The Avionics and Recovery Subteam shall design a dual deployment recovery system utilizing a drogue parachute at apogee and a main parachute at a lower altitude.
3.1.1	The main parachute shall be deployed no lower than 500 feet.	Analysis	The Avionics and Recovery Subteam shall design the recovery

			system such that the main parachute is deployed no lower than 500 feet.
3.1.2	The apogee event shall contain a delay of no more than 2 seconds.	Demonstration	The Avionics and Recovery Subteam shall design the recovery system such that redundant ejection charges contain a delay of no more than 2 seconds.
3.2	Successful ejection tests of both parachutes shall be done prior to any launch.	Demonstration	Prior to each launch, the safety officer shall perform a successful ground ejection test for both the drogue and main parachutes. The team's advisor will be present to confirm success. See Section 6.1.11.
3.3	At landing, each independent section of the launch vehicle shall have a maximum kinetic energy of 75 ft-lbf.	Analysis	The Avionics and Recovery Subteam shall perform kinetic energy calculations of each independent section of the launch vehicle to verify that none exceed 75 ft-lbf. Upon completing the fabrication of the launch vehicle, the team shall measure the mass of each section and re-evaluate the suitability of the selected recovery system parachutes.
3.4	The recovery system electrical circuits shall be completely independent of all payload electrical circuits.	Analysis	The Avionics and Recovery Subteam shall generate schematic diagrams for all onboard electronics. The team shall verify the recovery circuits are independent of the payload circuits.
3.5	All recovery electronics shall be powered by	Analysis	The Avionics and Recovery Subteam shall choose recovery

	commercially available batteries.		electronics batteries from the commercially available options.
3.6	The recovery system shall contain redundant, commercially available altimeters.	Analysis	The Avionics and Recovery Subteam shall select the optimal altimeters after analyzing several brands. The PerfectFlite StratoLogger CF shall be the chosen altimeter.
3.7	The launch vehicle shall not utilize motor ejection as a deployment method.	Demonstration	The Avionics and Recovery Subteam shall design a recovery system that utilizes black powder charges for both primary and secondary deployment.
3.8	The launch vehicle shall utilize removable shear pins for both the main parachute compartment and the drogue parachute compartment.	Analysis	The team shall design a launch vehicle using 4-40 nylon shear pins at all separation points.
3.9	Recovery area shall be limited to a 2,500 ft. radius from the launch pads	Analysis	The Avionics and Recovery Subteam shall perform wind drift calculations using computer modeling software. These calculations will be verified with hand calculations.
3.10	The launch vehicle shall touch down within 90 seconds after apogee.	Analysis	The Avionics and Recovery Subteam shall design a recovery system that allows the launch vehicle to touch down within 90 seconds after apogee.
3.11	The launch vehicle shall use an electronic tracking device to transmit the position of the vehicle upon touch down.	Demonstration	The launch vehicle shall include a BigRedBee BRB900 transmitter to track the location of the launch vehicle upon touch down.

3.11.1	Any launch vehicle section or payload component, which lands untethered to the launch vehicle, will contain an active electronic tracking device.	Demonstration	The team shall design a launch vehicle that lands with all independent sections tethered together.
3.11.2	The electronic tracking device shall be fully functional during the official flight on launch day.	Test	The electronic tracking device shall be tested on the launch pad to confirm full functionality. See section 6.1.8.
3.12	The recovery system electronics shall not be adversely affected by any other on-board electronic devices during flight.	Test	The Avionics and Recovery Subteam shall test the recovery electronics near to the payload electronics to confirm that recovery electronics are adequately shielded. See section 6.1.10.
4.4.1	The team shall design a custom UAV that will deploy from the internal structure of the launch vehicle.	Analysis	The Payload Subteams shall design a UAV that deploys from the internal structure of the launch vehicle.
4.4.2	The UAV shall remain in an unarmed state until the launch vehicle has safely landed on the ground and is capable of being powered on remotely after landing.	Test	The UAV Subteam shall test the UAV flight control to verify it is incapable of transmitting commands while in an unarmed state 6.1.2.
4.4.3	The UAV shall be retained within the vehicle utilizing a fail-safe active retention system. The retention system will be robust enough to retain the UAV if atypical flight forces are experienced	Test	The Payload integration Subteam shall test reliability of the UAV retention system using a mass simulator. The payload retention system will be tested to limits that exceed the nominal flight regime by 10%. See Section 6.1.4.
4.4.4	The UAV shall be deployed from the launch vehicle under the supervision of the RDO.	Inspection	The Payload Deployment Lead shall activate the payload deployment system only after the

			launch vehicle has safely landed and only while supervised by the RDO.
4.4.5	The team shall fly the UAV to the FEA upon deployment.	Inspection	The team shall designate a drone pilot who is responsible for piloting the drone from the launch vehicle to the FEA.
4.4.8	The UAV shall drop a simulated navigational beacon upon reaching the FEA	Analysis	The UAV Subteam shall design a release mechanism on the UAV to release the navigational beacon.
4.4.9	The navigational beacon shall be a 1 inch cube with the university name on the surface of the beacon.	Inspection	The team shall make a 1 inch cube navigational beacon displaying the university name on the surface.
4.4.10	The UAV's batteries shall be sufficiently protected from impact with the ground.	Analysis	The UAV Subteam shall situate the batteries on the UAV such that they do not impact the ground.
4.4.11	The UAV's batteries shall be brightly colored and marked as a fire hazard.	Inspection	The UAV Subteam shall mark all batteries on the UAV as a fire hazard. The Safety Officer shall verify the batteries are easily distinguishable from other UAV parts.
4.4.12	The team shall abide by all applicable FAA regulations, including the FAA's Special Rule for Model Aircraft.	Inspection	The UAV Subteam Lead shall confirm that the UAV is operated in accordance with public Law 112-95 Section 336.
4.4.13	The UAV shall be registered with the FAA.	Inspection	The UAV Subteam shall register the UAV with the FAA. The registration certificate shall be with the team at competition.
5.1	The team shall use a launch and safety checklist included in the FRR milestone report.	Demonstration	The Senior Design Team in association with the Safety Officer shall write launch and safety checklists to be used on launch day.
5.2	The team shall identify a student safety officer.	Inspection	Shiv Oza shall serve as the team's safety officer.

5.4	During test flights, teams shall abide by the rules and guidance of the local rocketry club's RSO.	Demonstration	The Team Safety Officer shall inform all members of proper launch day safety and procedures in accordance with TRA and RSO guidelines. The safety officer, in addition to the club's mentors, will establish contact with the local rocketry club's administration and RSO to acquire approval to launch at NAR or TRA launches. The safety officer will remain a primary point of contact alongside the team lead to fully cooperate with the directions of the NAR Staff and RSO's at all junctures of the competition
5.5	Teams shall abide by all rules set forth by the FAA.	Demonstration	All team members shall abide by all FAA regulations regarding the operation of high-powered launch vehicles and UAS. During the design-to-manufacturing process, the safety officer will brief the team in the day prior to any launches to ensure the team is in accordance with regulations put forth by the FAA.

6.2.2 Team Derived Requirements

The below requirements were determined prior to the start of the project. The team developed these to limit the design process to more feasible options.

Table 6-2 Team Derived Requirements

Subteam	Description of Requirement	Reason for Requirement	Method of Verification	Verification Plan
General	The project shall be divided into six different subsystems: Aerodynamic Simulations, Structures, Avionics and Recovery, Payload Integration, Payload Communications, and Payload Structures.	Subdivision and delegation of tasks ensures stronger accountability. Sub-teams allow for senior design members to be subject matter experts as team leads. This will ensure that all requirements are met.	Demonstration	Senior Design members are delegated to lead sub-teams as noted in the Proposal.
General	The team shall meet weekly to discuss project goals and progress.	This will share up to date information with the entire team and creates additional method of task accountability.	Demonstration	Weekly meetings are scheduled for Thursdays at 7:30pm.
Budget	The payload shall cost no more than $1000.	By creating a hard limit on the cost of this section of the launch vehicle a better distributed budget can be achieved.	Demonstration	The treasurer shall manage the team's funds and ensure that no more than $1000 is spent.
Budget	The full-scale launch vehicle shall cost no more than $2500.	By creating a hard limit on the cost of this section of the launch vehicle a better distributed budget can be achieved.	Demonstration	The treasurer shall manage the team's funds and ensure that no more than $2500 is spent.
Outreach	The team shall engage over 750 K-12 students before the FRR milestone report.	NASA SL requires an outreach goal of 200 K-12 students. HPRC strives to exceed expectations regarding sharing interest in rocketry.	Demonstration	The Outreach Coordinator shall contact schools in the area for outreach opportunities.
Vehicle	The launch vehicle shall utilize a motor compatible with a motor casing already in the team's possession.	Not purchasing a motor casing allows the team the budgetary freedom to pursue more innovative payload designs.	Demonstration	The team shall select a motor that is compatible with the Aerotech 75/3840 motor casing that is already in inventory.

Vehicle	The launch vehicle shall not exceed a velocity of Mach 0.7.	At speeds over Mach 0.7, fin flutter occurs. Flutter increases the risk of cracking a fin, thereby making the launch vehicle non-compliant with handbook requirement 2.7.	Analysis	The team shall use Rocksim to model the flight profile of the launch vehicle to verify launch vehicle velocity does not exceed Mach 0.7.
Vehicle	The launch vehicle shall reach an apogee between 3850ft and 4180ft.	This range represents the range relative to a target apogee of 4090ft. This target was chosen in the interest of cost and weight-savings and is therefore a conservative apogee.	Analysis	The team shall use Rocksim to model the launch vehicle's performance under various wind conditions.
Vehicle	The launch vehicle shall have a static stability margin between 2.0 and 2.3 upon rail exit.	To meet the NASA SL requirement, a stability margin of 2.0 is necessary. The maximum value of 2.3 was selected because excessive stability margin causes undesirable weathervaning in high winds.	Analysis	The team shall use Rocksim to model the launch vehicle and calculate the static stability margin.
Vehicle	The launch vehicle's blast caps shall be located at the ends of body tubes.	This mitigates a safety concern from previous years in which the blast caps were located down a tube and were difficult to access.	Demonstration	The team shall design an avionics bay that exposes the blast caps.
Vehicle	The full-scale launch vehicle shall be constructed of fiberglass body tube.	Previous experience with other types of tubing has led the team to restrict construction material to fiberglass.	Demonstration	The structures lead shall construct the full-scale airframe consisting of fiberglass tubing.
Vehicle	All critical components of the launch vehicle shall be designed with a minimum factor of safety of 2.	This will ensure that assumptions made in analysis or reasonably higher than expected loading will not cause unpredicted failure during flight.	Analysis	The structures lead shall perform finite element analysis to ensure component designs meet a factor of safety of 2. See Section 3.1.3.
Vehicle	The nose cone bulkhead shall be designed to withstand a load of at least 468.88 lbf.	This reduces the likelihood of damage to the bulkhead during normal flight that could cause failure.	Testing	The structures lead shall perform testing on this bulkhead configuration to represent the final design and ensure no failure occurs. This

				test is described in Section 6.1.1.
Recovery	The launch vehicle shall use two StratoLogger altimeters to record flight data and trigger ejection charges.	To maximize safety during the launch the ejection charges must correctly fire therefore an accurate altimeter is a necessity. The team has found StratoLogger altimeters to be the most reliable.	Demonstration	The team shall purchase two StratoLogger altimeters to be used at competition.
Recovery	The altimeters shall use one 9V battery each.	StratoLogger altimeters use one 9V battery each.	Demonstration	The team shall purchase at least eight 9V batteries compatible with the StratoLogger altimeters.
Recovery	Drogue descent velocity shall be less than 100 fps.	This speed will minimize the deployment shock at main deployment.	Analysis	The recovery lead determined a target descent velocity is 79 fps with the given flight hardware.
Recovery	The launch vehicle shall use recovery devices that the team owns.	This restriction on the recovery section of the launch vehicle enables a better distributed budget for diversified development of flight systems.	Demonstration	The recovery lead shall design a recovery system that uses existing recovery devices.
Recovery	The black powder ejection charges shall produce at least a 15 psi pressure or produce a net force of 234 lbs on the bulkheads at the point of separation.	The 15 psi is a standard for most ejection charges in hobby rocketry. The 234 lbs is the nominal breaking force of the shear pins multiplied by a factor of safety of 1.5.	Demonstration	The recovery lead shall execute the black powder demonstration described in section 6.1.11 prior to launch.
Recovery	The launch vehicle shall use U-Bolts for all shock cord attachments.	This reduces the chance of recovery failure because a single point of failure would not result in a total failure of the system.	Demonstration	The structures lead shall design bulkheads to accommodate U-Bolts.

Payload	Video feed shall not be transmitted until the payload has fully exited the rocket.	This will keep the launch vehicle in compliance with the 250 mW maximum transmission power.	Demonstration	The team shall demonstrate this functionality in the payload qualifying launch.
Payload	The UAV and retention system shall fit inside a 5.5" diameter body tube.	The launch vehicle shall be 5.5" in diameter and the UAV must fit inside.	Analysis	The payload leads shall design a UAV system to fit inside the 5.5" tube.
Payload	The UAV and retention system shall weigh less than 5 lbs.	This restriction allows the stability of the rocket to be within the team's chose range.	Analysis	The payload leads shall design a UAV system to be less than 5 lbs.
Payload	The UAV deployment mechanism shall use a Southco R4-EM-63-161 latch.	The team already owns this latch and has tested its reliability in previous projects.	Demonstration	The payload integration lead shall design a payload retention system using the previously stated Southco latch.
Payload	The UAV shall be capable of flying at least 1.5 miles in unfavorable wind conditions.	The team wants to prepare for worst case scenarios on launch day and produce a UAV capable in flying in poor conditions.	Testing	The payload design lead shall test the UAV as described in Section 6.1.7.
Payload	The UAV shall have a hover flight time of at least 5 minutes.	The team believes this to be the maximum necessary flight time to reach the FEA.	Testing	The payload design lead shall test the UAV as described in Section 6.1.6.
Payload	The payload shall have an operating range of at least 0.6 miles.	The team believes this to be the maximum distance that the UAV could be from the pilot during the mission.	Testing	The payload communications lead shall test the operating range of the payload as described in Section 6.1.3.
Payload	The payload shall utilize a Taranis X-Lite radio transmitter.	This transmitter is much more portable and will be much easier to relocate to and from the RDO.	Demonstration	The payload communications lead shall design the UAV electronics to be compatible with the transmitter.

Payload	The payload deployment system shall utilize an Arduino microcontroller.	Previous experience with other microcontrollers has led the team to restrict the selection of microcontroller to an Arduino.	Demonstration	The payload communications lead shall design the payload deployment system around an Arduino.

6.3 Budgeting and Timeline

6.3.1 Budget

Table 6-3 details the year-long budget for the 2018-2019 competition year.

Table 6-3 Project Budget 2018-2019

	Item	Quantity	Price per Unit	Item Total
Subscale Structure	Aerotech I435T-14A	2	$56.00	$112.00
	Aero Pack 38mm Retainer	1	$27.00	$27.00
	Motor Casing	1	$340.00	$340.00
	38mm G12 Airframe, Motor Tube	1	$64.00	$64.00
	4" Phenolic Airframe, 3 Slots	1	$33.50	$33.50
	4" Phenolic Airframe	2	$26.00	$52.00
	4" Phenolic Coupler	4	$21.00	$84.00
	Plastic 4" 4:1 Ogive Nosecone	1	$23.00	$23.00
	Domestic Birch Plywood 1/8"x2x2	6	$12.68	$76.08
	3/4" L Brackets	4	$1.97	$7.88
	Rail Buttons	4	$2.50	$10.00
	U-Bolts	4	$1.00	$4.00
	Blast Caps	4	$2.50	$10.00
	Terminal Blocks	3	$7.00	$21.00
	Paint	1	$100.00	$100.00
	Key Switches	2	$12.00	$24.00
	Subtotal:			**$988.46**
Full-Scale Structure	Aerotech L1150R-PS	3	$200.00	$600.00
	5.5" G12 Airframe, Half Length (30"), 3 Slots	1	$130.00	$130.00
	5.5" G12 Airframe, Full Length (60")	1	$188.00	$188.00
	3" G12 Airframe, Half Length (30"), Motor Tube	1	$100.00	$100.00
	5.5" G12 Coupler 12" Length	3	$55.00	$165.00
	5.5" Fiberglass 4:1 Ogive Nosecone	1	$84.95	$84.95
	Domestic Birch Plywood 1/8"x2x2	8	$12.68	$101.44
	Aerotech 75/3840 Motor Case	1	$360.00	$360.00
	Motor Retainer	1	$44.00	$44.00
	3/4" L Brackets	4	$1.97	$7.88
	Rail Buttons	4	$2.50	$10.00
	U-Bolts	4	$1.00	$4.00
	Aerotech 75mm Forward Seal Disk	1	$37.50	$37.50

	Blast Caps	4	$2.50	$10.00
	Terminal Blocks	3	$7.00	$21.00
	Paint	1	$150.00	$150.00
	Key Switches	2	$12.00	$24.00
	Poster Printing (feet)	4	$10.00	$40.00
	Subtotal:			**$2,077.77**
Payload	Crazepony EMAX Brushless Motor	1	$56.99	$56.99
	OmniNXT F7 Flight Controller	1	$59.99	$59.99
	Electronic Speed Controller	1	$59.99	$59.99
	11.1V Lipo Battery	1	$21.99	$21.99
	FPV Camera	1	$19.99	$19.99
	Circular Antenna	1	$6.69	$6.69
	Lumenier 5x3.5 2 Blade Propeller	2	$1.79	$3.58
	Readytosky FPV Racing Drone Frame	2	$22.99	$45.98
	Lumenier circular polarized antenna	2	$10.19	$20.38
	AKK K31 Transmitter with Race Band	1	$11.99	$11.99
	FrSky XM+ SBUS Mini Receiver FPC Drone	1	$17.49	$17.49
	Lumenier DX800 DVR w/ 5.8GHz 32CH Receiver	1	$149.99	$149.99
	FRrSky X-Lite Radio Controller	1	$139.99	$139.99
	Arduino Uno	1	$24.95	$24.95
	Arduino USB Cable	1	$6.99	$6.99
	Arduino Servo Shield	1	$19.95	$19.95
	2KM Long Range RF Link Kit	1	$18.00	$18.00
	Breadboard	2	$9.95	$19.90
	LEDs	1	$6.99	$6.99
	Button	1	$5.85	$5.85
	Batteries	1	$15.20	$15.20
	Battery Clips	1	$5.66	$5.66
	Southco R4-EM Latch	1	$68.36	$68.36
	1.1”x1.1” stepper motor	1	$17.90	$17.90
	Hinges	4	$1.97	$7.88
	Aluminum rod	2	$2.21	$4.42
	Carbon Fiber Rod	2	$9.25	$18.50
	Surgical Tubing	2	$2.82	$5.64
	Nema 8 Bipolar Smallest Stepper Motor	1	$24.95	$24.95

	Subtotal:			**$886.18**
Recovery and Avionics	Iris Ultra 120" Compact Parachute	1	$504.00	$504.00
	24" Compact Elliptical Parachute	1	$53.00	$53.00
	Quick Links	8	$1.25	$10.00
	Kevlar Shock Cord (yard)	20	$4.34	$86.80
	Black Powder	1	$30.00	$30.00
	E-Matches	2	$29.00	$58.00
	Shear Pins	3	$3.00	$9.00
	StratoLogger CF Altimeter	4	$60.00	$240.00
	6" Deployment Bag	1	$43.00	$43.00
	18" Nomex Cloth	1	$24.00	$24.00
	BRB 900 Transmitter	1	$200.00	$200.00
	4" Deployment Bag	1	$39.00	$39.00
	13" Nomex Cloth	1	$13.00	$13.00
	Iris Ultra 60" Compact Parachute	1	$225.00	$225.00
	18" Compact Elliptical Parachute	1	$60.00	$60.00
	Kevlar Shock Cord (yard)	13.33	$2.55	$33.99
	Subtotal:			**$1,628.79**
Miscellaneous	Epoxy Resin	2	$86.71	$173.42
	Epoxy Hardener	2	$45.91	$91.82
	Nuts (box)	4	$5.50	$22.00
	Screws (box)	4	$5.00	$20.00
	Washers	4	$5.00	$20.00
	Wire	3	$13.00	$39.00
	Zip Ties	2	$11.00	$22.00
	3M Electrical Tape	4	$8.00	$32.00
	9V Batteries	2	$14.00	$28.00
	Wood Glue	2	$3.00	$6.00
	Rubber Bands	1	$5.00	$5.00
	Paper Towels	2	$25.00	$50.00
	Battery Connectors	3	$5.00	$15.00
	3-D Printer Filament	1	$19.99	$19.99
	Shipping			$1,200.00
	Incidentals (replacement tools, hardware, safety equipment)			$1,200.00
	Subtotal:			**$2,944.23**
Trav	Student Hotel Rooms (# rooms)	4	$791.70	$3,166.80

	Mentor Hotel Rooms (# rooms)	3	$1,178.10	$3,534.30
	Van Rentals (# cars)	2	$198.00	$396.00
	Gas (Miles)	1144	$0.60	$686.40
	Subtotal:			**$7,783.50**
Outreach	Bottle Rocket Launcher	1	$30.00	$30.00
	Paper	4	$10.00	$40.00
	Printing	500	$0.10	$50.00
	Subtotal:			**$120.00**
Promotional	T-Shirts	40	$14.00	$560.00
	Polos	30	$20.00	$600.00
	Stickers	1000	$0.30	$300.00
	Banner	1	$200.00	$200.00
	Subtotal:			**$1,660.00**
Total Expenses:				**$18,088.93**

6.3.2 Budget Plan

HPRC gets all its funding from multiple NC State University organizations, North Carolina Space Grant (NCSG), as well as a sponsorship from Rockwell Collins.

The Engineering Technology Fee at NC State is a funding source for senior design projects within the Mechanical and Aerospace Engineering department. Through the team's advisor and senior design professor, the team shall have access to $1,500 to put towards materials and construction costs.

The NC State University Student Government Association's Appropriations Committee is responsible for distributing university funds to campus organizations. The SGA allocates funds through an application process with a proposal, presentation, and an in-person interview. For the Fall session, the team has received $640 and a request for $1,500 will be placed in the spring semester, assuming the Appropriations Committee budget will remain the same.

Student and faculty advisor travel costs will be covered by NC State's College of Engineering Enhancement Funds. These funds come from a pool of money dedicated to supporting engineering extracurriculars at NC State. The total travel cost for University affiliated attendees comes to $6,000.

In addition to funding through NC State organizations, the North Carolina Space Grant will provide a large amount of monetary support to the club. NCSG accepts funding proposals during the fall semester and teams can request up to $5,000 for participation in NASA competitions. NCSG will review the proposal and inform the club on the amount awarded, which will likely be the full amount requested. These funds will be available for use starting November 2018.

Our sponsor, Rockwell Collins, has given $5,000 to be put toward the construction and launch of our competition rockets.

These totals are listed in Table 6-4, which compares the projected costs and incoming grants for the 2018-19 school year.

Table 6-4 Projected Costs for 2018-19 Competition Year

Organization	Fall Semester Amount	Spring Semester Amount	School Year Total
SGA Appropriations	$640.00	$660.00	$1,300.00
Engineering Technology Fee	-	-	$1,500.00
NC Space Grant	-	-	$5,000.00
Rockwell Collins	-	-	$5,000.00
College of Engineering	-	-	$5,500.00
Total Funding:			**$18,300.00**
Total Expenses:			**$18,088.93**
Difference:			**$211.07**

6.3.3 Timeline

The below table is a comprehensive timeline of team activities over the course of the competition schedule. Gannt charts illustrating this timeline can be found in Appendix C: Project Timeline Gantt Charts.

Table 6-5 Timeline for 2018-2019 Competition Year

Task Name	Duration	Start	Finish
Proposal	**21 days**	**Wed 8/22/18**	**Wed 9/19/18**
General	1 day	Mon 9/3/18	Mon 9/3/18
Vehicle Criteria	8 days	Tue 9/4/18	Thu 9/13/18
Payload Criteria	8 days	Tue 9/4/18	Thu 9/13/18
Safety	9 days	Thu 9/6/18	Tue 9/18/18
Project Plan	2 days	Mon 9/10/18	Tue 9/11/18
Proposal Complete	0 days	Wed 9/19/18	Wed 9/19/18
PDR Milestone Report	**22 days**	**Thu 10/4/18**	**Fri 11/2/18**
General	1 day	Tue 10/9/18	Tue 10/9/18
Vehicle Criteria	10 days	Thu 10/11/18	Wed 10/24/18
Payload Criteria	10 days	Thu 10/11/18	Wed 10/24/18
Safety	10 days	Thu 10/18/18	Wed 10/31/18
Project Plan	3 days	Mon 10/29/18	Wed 10/31/18
Changes Since Proposal	1 day	Wed 10/31/18	Wed 10/31/18
PDR Milestone Report Complete	0 days	Fri 11/2/18	Fri 11/2/18
Subscale Construction	**14 days**	**Wed 10/31/18**	**Sat 11/17/18**
Lasercut Bulkheads and Fins	2 days	Wed 10/31/18	Thu 11/1/18

Cut Airframe Tubes	3 days	Wed 10/31/18	Fri 11/2/18
Altimeter Testing	1 day	Thu 11/1/18	Thu 11/1/18
Bulkhead Fabrication	4 days	Fri 11/2/18	Wed 11/7/18
Payload Bay Bulkhead Installation	1 day	Mon 11/5/18	Mon 11/5/18
Nosecone Bulkhead Installation	1 day	Mon 11/5/18	Mon 11/5/18
AV Bay Bulkhead Installation	1 day	Tue 11/6/18	Tue 11/6/18
Fin Can Bulkhead/Centering Ring Installation	5 days	Tue 11/6/18	Mon 11/12/18
Drill Pressure Ports and Switch Holes in AV Bay	0.5 days	Tue 11/6/18	Tue 11/6/18
Lasercut AV Sled	1 day	Tue 11/6/18	Tue 11/6/18
Install Motor Tube	1 day	Tue 11/6/18	Tue 11/6/18
Checklist Writing	7 days	Tue 11/6/18	Wed 11/14/18
AV Sled Fabrication	3 days	Wed 11/7/18	Fri 11/9/18
Install Fwd Rail Button	1 day	Wed 11/7/18	Wed 11/7/18
Install Fins	3 days	Thu 11/8/18	Mon 11/12/18
AV Wiring	3 days	Mon 11/12/18	Wed 11/14/18
Install Aft Rail Button	1 day	Mon 11/12/18	Mon 11/12/18
Install Motor Retainer	1 day	Mon 11/12/18	Mon 11/12/18
Install AV Sled	2 days	Thu 11/15/18	Fri 11/16/18
Paint	1 day	Thu 11/15/18	Thu 11/15/18
Black Powder Demonstration	1 day	Fri 11/16/18	Fri 11/16/18

Subscale Launch	0 days	Sat 11/17/18	Sat 11/17/18
CDR Milestone Report	**40 days**	**Mon 11/19/18**	**Fri 1/11/19**
Changes Since PDR	7 days	Mon 11/19/18	Tue 11/27/18
Vehicle Criteria	31 days	Mon 11/26/18	Mon 1/7/19
Safety	32 days	Wed 11/28/18	Thu 1/10/19
Payload Criteria	27 days	Sat 12/1/18	Mon 1/7/19
Project Plan	7 days	Tue 1/1/19	Wed 1/9/19
Summary	2 days	Tue 1/8/19	Wed 1/9/19
CDR Milestone Report Complete	0 days	Fri 1/11/19	Fri 1/11/19
Testing	**36 days**	**Fri 1/11/19**	**Fri 3/1/19**
Bulkhead Failure Testing	3 days	Fri 1/11/19	Tue 1/15/19
Real Conditions Endurance Testing	2 days	Fri 1/18/19	Sun 1/20/19
Payload Pad Endurance Testing	3 days	Mon 1/21/19	Wed 1/23/19
Payload Deployment Demonstration	2 days	Mon 1/21/19	Tue 1/22/19
Payload Retention Testing	2 days	Thu 1/24/19	Fri 1/25/19
Recovery Electronics Endurance Testing	3 days	Tue 1/29/19	Thu 1/31/19
Hover Endurance Testing	2 days	Fri 2/1/19	Sun 2/3/19
Altimeter Demonstration	1 day	Fri 2/1/19	Fri 2/1/19
Black Powder Ejection Demonstration	1 day	Thu 2/7/19	Thu 2/7/19
GPS Testing	2 days	Thu 2/14/19	Fri 2/15/19

Payload Operation Range Testing	2 days	Fri 2/15/19	Mon 2/18/19
Full-scale Construction	**21 days**	**Mon 1/14/19**	**Sat 2/9/19**
Lasercut Bulkheads and Fins	2 days	Mon 1/14/19	Tue 1/15/19
Altimeter Testing	1 day	Mon 1/14/19	Mon 1/14/19
Bulkhead Fabrication	4 days	Tue 1/15/19	Fri 1/18/19
Cut Airframe Tubes	3 days	Wed 1/16/19	Fri 1/18/19
Fin Can Bulkhead/Centering Ring Installation	6 days	Thu 1/17/19	Thu 1/24/19
Lasercut AV Sled	1 day	Thu 1/17/19	Thu 1/17/19
Install Motor Tube	1 day	Thu 1/17/19	Thu 1/17/19
AV Sled Fabrication	3 days	Fri 1/18/19	Tue 1/22/19
Install Fwd Rail Button	1 day	Fri 1/18/19	Fri 1/18/19
AV Bay Bulkhead Installation	1 day	Mon 1/21/19	Mon 1/21/19
Nosecone Bulkhead Installation	1 day	Mon 1/21/19	Mon 1/21/19
Install Fins	3 days	Mon 1/21/19	Wed 1/23/19
Payload Bay Bulkhead/Centering Ring Installation	4 days	Tue 1/22/19	Fri 1/25/19
Drill Pressure Ports and Switch Holes in AV Bay	0.5 days	Wed 1/23/19	Wed 1/23/19
Install Aft Rail Button	1 day	Wed 1/23/19	Wed 1/23/19
Install Motor Retainer	1 day	Wed 1/23/19	Wed 1/23/19
AV Wiring	3 days	Mon 1/28/19	Wed 1/30/19

Integrate Payload	7 days	Mon 1/28/19	Tue 2/5/19
Install AV Sled	2 days	Wed 1/30/19	Thu 1/31/19
Checklist Writing	7 days	Wed 1/30/19	Thu 2/7/19
Paint	1 day	Tue 2/5/19	Tue 2/5/19
Black Powder Demonstration	1 day	Thu 2/7/19	Thu 2/7/19
Full-scale Launch	0 days	Sat 2/9/19	Sat 2/9/19
FRR Milestone Report	**16 days**	**Mon 2/11/19**	**Mon 3/4/19**
General	1 day	Wed 2/13/19	Wed 2/13/19
Safety	8 days	Fri 2/15/19	Tue 2/26/19
Vehicle Criteria	8 days	Mon 2/18/19	Wed 2/27/19
Payload Criteria	8 days	Mon 2/18/19	Wed 2/27/19
Project Plan	3 days	Tue 2/26/19	Thu 2/28/19
Changes Since CDR	1 day	Fri 3/1/19	Fri 3/1/19
FRR Milestone Report Complete	0 days	Mon 3/4/19	Mon 3/4/19
NASA SL Competition	**4 days**	**Wed 4/3/19**	**Sun 4/7/19**
Travel to Huntsville	1 day	Wed 4/3/19	Wed 4/3/19
LRR	1 day	Wed 4/3/19	Wed 4/3/19
Launch Week Kick-Off	1 day	Thu 4/4/19	Thu 4/4/19
Launch Week Activites	2 days	Thu 4/4/19	Fri 4/5/19
Rocket Fair	1 day	Fri 4/5/19	Fri 4/5/19
Competition Launch	1 day	Sat 4/6/19	Sat 4/6/19

Awards Ceremony	0 days	Sat 4/6/19	Sat 4/6/19
PLAR Milestone Report	**10 days**	**Mon 4/15/19**	**Fri 4/26/19**
General	1 day	Mon 4/15/19	Mon 4/15/19
Vehicle Results	3 days	Tue 4/16/19	Thu 4/18/19
Payload Results	3 days	Tue 4/16/19	Thu 4/18/19
STEM Engagement	2 days	Mon 4/22/19	Tue 4/23/19
Project Plan	2 days	Mon 4/22/19	Tue 4/23/19
Summary	1 day	Tue 4/23/19	Tue 4/23/19
PLAR Milestone Report Complete	0 days	Fri 4/26/19	Fri 4/26/19

7. References

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8. Appendix A: FMEA Table

Table 8-1 Failure Modes and Effects Analysis

System	Subsystem/ Component	Failure Mode	Causal Factors	Failure Effects: Subsystem	Failure Effects: System	Severity	Likelihood	Recommendations
Launch Vehicle	Nosecone	Structural fracture	Collision with object in flight path	Loss of nosecone recoverability	Loss of controlled and stabilized flight	2	1	Ensure that skies are clear of any foreign objects per NAR operations prior to launch. Any concerns will be reported to the RSO, and the launch will be halted until uncertainties regarding flight conditions are addressed.
			Manufacturing defect				2	Visual inspection after shipping and before assembly. Manufacturer and distributor will be contacted for a replacement prior to fabrication process.
			Damaged during handling within the lab, or handling and assembly prior to launch			2	2	Inspect for cracks, chips, or other damage periodically over the season, and during assembly prior to launch.
			Improper storage within lab and during transportation of component			2	2	Do not store items on top of Nosecone. Periodically inspect storage compartment.
			Nosecone collides with other launch vehicle component during descent and recovery		Damage to itself and other launch vehicle components	2	3	Ensure shock cord is long enough to separate nosecone from other components.
			Ground impact due to altimeter failure	Ballistic descent		2	2	Two different altimeters used for redundancy in mission safety, to prevent electronic errors. Conduct ground ejection tests of the

								calculated black powder charge masses to verify separation of sections and functionality of altimeter system. Periodically conduct ground altimeter redundancy system tests through simulating flight pressure conditions. Throughout handling, fabrication, and assembly prior to launch, confirm the wiring, functionality, and component integrity of the avionics system is in accordance to design specifications by testing continuity and simulated flight
		Premature separation from midsection	Coupler damaged during handling and fabrication within lab, or handling and assembly prior to launch	Potential for permanent structural damage	Loss of controlled and stabilized flight	2	2	Inspect for cracks, chips, or other damage periodically over the season and during assembly prior to launch. Replace any damaged components if possible. Identify fabrication missteps and establish preventative measures to reduce error frequency.
			Improper installation of screws into T-nut fasteners during assembly prior to launch			2	1	Follow design specifications for sizing, inspecting, and installing T-nut fasteners and screws during fabrication and assembly prior to launch.
			Epoxy for T-nut fastener blocks underneath coupler not cured or applied properly			2	1	Follow proper procedures for mixing, applying, and curing epoxy. Visually inspect connecting layer of epoxy between T-nut

								block and coupler for gaps with a flashlight.
			Altimeter malfunction		Failure to launch	2	2	Conduct grounded ejection tests of the calculated black powder charge masses to verify separation of sections, and functionality of altimeter system. Periodically conduct ground altimeter redundancy system tests through simulating flight pressure conditions. Throughout handling, fabrication, and assembly prior to launch, confirm the wiring, functionality, and component integrity of the avionics system is in accordance to design specifications by testing continuity and simulated flight
	G12 Fiberglass Airframe	Structural fracture	Manufacturing defect	Loss of structural integrity or usability of Fiberglass body sections or components	Premature separation of launch vehicle sections during flight	1	2	Visual inspection after shipping and before assembly. Manufacturer and distributor will be contacted for a replacement prior to fabrication process.
			Loads experienced beyond design specifications			1	2	Ensure body tube components can hold flight forces in accordance with design specifications. Ensure that all components can maintain a factor of safety of at least 2 during all regimes of flight.
			Damaged during handling and fabrication			1	2	Inspect each body tube component for cracks, bends, warping, or other damage

			within the lab, or handling and assembly prior to launch					periodically through the season, and during assembly prior to assembly. Replace any damaged components if possible. Identify fabrication missteps and establish preventative measures to reduce error frequency.
			Improper storage within lab and during transportation of component			2	2	Do not store items on top of Fiberglass. Periodically inspect storage compartment.
	Fins	Severe weather-cocking	Fin dimensions are not cut according to design	Loss of fin performance	Decreased flight stability, unpredictable flightpath, and possible damage to other components	2	2	Laser-cutting instrument used to cut fins to design specification with manufacturing precision. Fins are measured post-component fabrication to ensure dimensions match design specifications.
			Fins not installed at even increments around fin can (90 degrees to each other)			2	2	Fin slots are cut by manufacturer and will be measured prior to fabrication to ensure dimensions match design specifications. Manufacturer and distributor will be contacted for a replacement prior to fabrication process.
			Assembled launch vehicle CG is too far forward (Stability Margin >> 2.0)			2	2	Calculate Center of Pressure location through analytical means to verify the Center of Pressure location given by simulations. Assemble the launch vehicle prior to launch to measure the stability margin. Mass distribution within the launch vehicle will be analyzed

								for stability margins exceeding or under design specification.
		Fin separation	Loads experienced beyond design specifications	Loss of fin performance	Any one failure of a fin could lead to additional fin failures which will decrease flight stability and will likely cause a catastrophic failure	1	2	Analyze flight data and simulations to confirm that factor of safety is at a minimum of 1.5.
			Damaged during handling within the lab, or handling and assembly prior to launch			1	2	Inspect fins and connections for cracks, chips, or other damage periodically over the season, and during assembly prior to launch. Replace any damaged components if possible. Identify fabrication and assembly missteps. Establish preventative measures to reduce error frequency.
			Fin flutter			2	3	Launch vehicle will not exceed velocity necessary to induce significant flutter.
			Ground impact			2	2	Implement a recovery system design that ensures a low-speed surface impact.
	Motor	Motor fails to ignite	Igniter not installed correctly	Failure of vehicle to start launch	Team member and RSO must insert new igniter and restart launch sequence	4	1	Follow launch checklist and use mentor/RSO supervision to install igniter correctly.
			Faulty igniter used			4	1	Test batch of igniters prior to launch day to ensure quality.

			Motor assembled incorrectly			4	1	Safety Officer will follow launch checklist and use mentor/RSO supervision to install motor correctly.
		Catastrophic motor failure	Damaged during handling within the lab, or handling and assembly prior to launch	Possible destruction of launch vehicle	Complete mission failure and additional hazard to ground crew and spectators	1	2	Carefully inspect for cracks, chips, or other damage during assembly. Identify assembly missteps and establish preventative measures to reduce error frequency.
			Motor assembled incorrectly			1	1	Follow launch checklist and use mentor/RSO supervision to install motor correctly.
			Motor casing dislodged during motor burn			1	2	Ensure all connection points between motor tube, centering rings, and fins are joined properly using epoxy Perform careful inspection of joints prior to launch.
		Damage to motor casing	Superficial damage	Motor casing cannot be used	Launch vehicle is not safe to launch if damage is major	4	2	Carefully inspect for cracks, chips, or other damage during assembly. Damage deemed serious to the motor casing by the RSO will result in no launch. Identify handling and assembly missteps and establish preventative measures to reduce error frequency.
		Propellant contaminatio n	Launch vehicle fails to launch	Reduced performance of launch vehicle motor	Launch vehicle does not launch or perform as expected	2	2	Order from reputable source. Store and maintain motor fuel properly and in isolation from other materials in the
			Over-oxidized reaction			2	2	
			Reduced fuel efficiency			3	2	

								flame and hazards storage cabinet. Periodically inspect storage compartment.
	Bulkheads	Bulkhead separation from airframe during motor burn	Manufacturing defect	Reduced performance of launch vehicle motor and severe damage to other launch vehicle components	Ballistic descent	1	2	Visual inspection after shipping and before assembly. Manufacturer and distributor will be contacted for a replacement prior to fabrication process.
			Loads experienced beyond design specifications			1	2	Ensure bulkhead composite can hold flight forces in accordance with design specifications. Ensure that all components can maintain a factor of safety of at least 2 during all regimes of flight through analysis.
			Damaged during handling within the lab, or handling and assembly prior to launch			1	2	Inspect each bulkhead for cracks, warping, chips, or other damage during assembly. Replace any damaged bulkheads. Identify fabrication missteps and establish preventative measures to reduce error frequency.
			Epoxy not cured properly			1	2	Follow proper procedures for mixing, applying, and curing epoxy.

		U-bolt separation from bulkhead during recovery	Loads experienced beyond design specifications	Launch vehicle components not tethered to a parachute will continue accelerating during descent	Loss of safe and effective recovery system. Damage to body components Possible hazard to ground crew and spectators	1	2	Ensure U-bolt fasteners and bulkhead composites can handle near-instantaneous loading from parachute and shock cord deployment by simulating shearing force through application of sudden force equivalent to drogue and main deployment. Analyze testing to ensure that all components can maintain a factor of safety of at least 1.5 during all regimes of flight.
			Epoxy not cured properly			1	2	Follow proper procedures for mixing, applying, and curing epoxy.
	Rail Buttons/ Launch Rail	Vehicle does not leave launch rail as intended	Rail button(s) separate from launch vehicle	Vehicle leaves rail at unpredictable orientation and velocity	Probable mission failure and additional hazard to ground crew and spectators	1	2	Epoxy rail buttons into body tube to reduce risk of separation.
			Damaged during handling and fabrication within the lab, or handling and assembly prior to launch			1	2	Inspect each rail button and connection for cracks, warping, chips, or other damage during assembly. Replace any damaged rail buttons. Identify fabrication missteps and establish preventative measures to reduce error frequency.
			Launch rail breaks			3	2	Ensure that the rail is assembled correctly prior to launch. Ground crew and spectators will be located away from the launch pad as instructed by the RSO, NAR regulation, and the club safety officer.

		Vehicle does not leave launch rail at all	Rail button(s) becomes stuck in launch rail	N/A	Mission failure as flight does not take place	2	1	Prior to launch, contact the RSO to verify that rail buttons match size of launch rail slot. Lubricate the launch rail and rail buttons. Visually confirm that the vehicle moves smoothly on the launch rail during assembly and launch rail erection.
	Shear Pins	Pins break before charge detonation	Manufacturing defect	Loose assembly of compartment	Premature launch vehicle separation and recovery system deployment	2	2	Visual inspection after shipping and before assembly. Manufacturer and distributor will be contacted for a replacement prior to assembly process.
			Damaged during handling within the lab, or handling and assembly prior to launch			2	2	Inspect each shear pin and connection for cracks, warping, chips, or other damage during assembly. Replace any damaged shear pins prior to launch. Identify assembly missteps and establish preventative measures to reduce error frequency.
			Pins fall out of respective holes			2	2	Ensure size of holes drilled in body tube match diameter of shear pins.
			Loads beyond design specifications			2	2	Ensure pins can hold flight forces in accordance with design specifications.

		Pins don't break at charge detonation	Manufacturing defect	Failure to separate compartment	Loss of safe and effective recovery system	1	2	Visual inspection after shipping and before assembly. Manufacturer and distributor will be contacted for a replacement prior to assembly process.
			Pins too tight in body tube holes			1	2	Ensure size of holes drilled in body tube match diameter of shear pins.
			Poor design			1	2	Use calculations to ensure that pins will break from forces of detonation. Prior to launch, simulate shear pin in-flight separation through ground ejection testing with the calculated black powder masses. Identify design and fabrication missteps and establish preventative measures to reduce error frequency.
	Shock Cord	Incorrect or partial deployment of shock cord	Snags, tears, or rips during ejection	Parachute no longer tethered to entirety of launch vehicle airframe	Loss of safe and effective recovery system	1	2	Inspect shock cord for damage prior to launch. Ensure high-strength shock cord is used with a maximum loading greater than 1,500 lb. Ensure shock cord is folded and stowed properly in launch vehicle. Reduce/eliminate sharp edges in design to reduce risk of snagging shock cord and parachutes.

			Shock cord disconnects from airframe or parachutes			1	2	Ensure that connections between the shock cord, airframe, and parachutes are tight and secure.
			Shock cord stuck within launch vehicle airframe	Parachute not entirely deployed		1	2	Ensure that the shock cord and parachutes are folded and stowed properly in launch vehicle. Reduce/eliminate sharp edges in design to mitigate risk of blocking shock cord and parachutes.
	Parachute Deployment	Drogue parachute fails to deploy correctly	Drogue shock cord tangling	Parachute does not deploy correctly	Launch vehicle is recoverable	2	2	Prior to launch, assemble shock cord and parachute system to confirm that accordion-style folding of the shock cords do not tangle.
			Shock cord and U-bolt connections come loose			2	2	Prior to launch, assemble the shock cord and parachute system to confirm that the quick link connection points between the shock cord and U-bolts are fastened.
			Parachute bag does not fully open			2	2	Prior to launch, assemble the parachute bags correctly and make sure nothing can snag bags within the body tube.
		Parachute does not perform as expected	Tears/holes due to black powder burns	Parachute deploys but does not perform as expected	Launch vehicle is recoverable	2	2	Inspect for tears, holes, or other damage periodically over the season, and during assembly prior to launch Manufacturer and distributor will be contacted for a

								replacement prior to assembly process. Prior to assembly, parachutes will be wrapped according to launch day procedures in nonflammable sheets or deployment bag.
		Main parachute fails to deploy correctly	Failed black powder charge detonation	Parachute does not deploy correctly	Separation 2 is not successful, launch vehicle is not recovered safely	1	2	Conduct ground ejection tests of the calculated black powder charge masses to verify separation of sections, and functionality of altimeter system. Periodically conduct ground altimeter redundancy system tests through simulating flight pressure conditions. Throughout handling, fabrication, and assembly prior to launch, confirm the wiring, functionality, and component integrity of the avionics system is in accordance to design specifications by testing continuity and simulated flight.
			Main shock cords tangling		Launch vehicle is recoverable	2	2	Prior to launch, assemble shock cord and parachute system to confirm that accordion-style design for shock cords does not tangle.
			Shock cord and U-bolt connections come loose		Launch vehicle is not recovered safely	1	2	Prior to launch, assemble the shock cord and parachute system to confirm that the quick link connection points between the shock cord and U-bolts are fastened.

	Black Powder Charges	Single detonation failure	E-match doesn't light	Failure of one or more black powder charges	Will result in loss of safe and effective recovery system if redundant black powder charge(s) do not detonate	2	2	Conduct ground ejection tests of the calculated black powder charge masses to verify separation of sections, and functionality of altimeter system. Periodically conduct ground altimeter redundancy system tests through simulating flight pressure conditions. Throughout handling, fabrication, and assembly prior to launch, confirm the wiring, functionality, and component integrity of the avionics system is in accordance to design specifications by testing continuity, and simulated flight.
			Altimeter Malfunction			2	2	
		Redundant detonation failure	E-match doesn't light	Failure of both ejection charges	Failure of launch vehicle to separate and deploy parachutes	1	2	Conduct ground ejection tests of the calculated black powder charge masses to verify separation of sections, and functionality of altimeter system. Periodically conduct ground altimeter redundancy system tests through simulating flight pressure conditions. Throughout handling, fabrication, and assembly prior to launch, confirm the wiring, functionality, and component integrity of the avionics system is in accordance to design specifications by testing continuity, and simulated flight.
			Altimeter Malfunction			1	2	

		Charge causes damage to any component other than shear pins	Charge is too big	Causes violent separation and/or damage to nearby components	Potential to cause permanent damage to bulkheads or shock cord, resulting in a possible failure of parachute deployment	2	1	Verify that charges are sealed properly, and the correct amount of black powder is used with pre-flight checklist Conduct ground ejection tests of the calculated black powder charge masses to verify separation of sections, functionality of altimeter system, and minimal damage to separated launch vehicle components.
		Charge ignites but fails to cause separation	Charge is too small	No ejection	Failure of launch vehicle to separate and deploy parachutes	1	2	Conduct ground ejection tests of the calculated black powder charge masses to verify separation of sections, and functionality of altimeter system.
	Altimeters	No power to altimeters	Uncharged or insufficiently charged batteries	Loss of real-time altitude data, failure to ignite e-match	Failure of parachute deployment	1	1	Install new/unopened batteries at each launch. Confirm that all batteries have the correct voltage before flight using a multimeter.
			Battery becomes disconnected from altimeter			1	2	Ensure that altimeters are properly wired and that wires are secure prior to launch. Listen for appropriate beeps when powering on altimeters.

			Wiring short			1	2	Ensure that all wire is properly insulated and that all wires are securely contained in their respective terminals.
		No launch detected	Manufacturing defect	Lack of flight data	Failure of parachute deployment	1	2	Conduct ground ejection tests of the calculated black powder charge masses to verify separation of sections, and functionality of altimeter system. Periodically conduct ground altimeter redundancy system tests through simulating flight pressure conditions. Throughout handling, fabrication, and assembly prior to launch, confirm the wiring, functionality, and component integrity of the avionics system is in accordance to design specifications by testing continuity, and simulated flight. Listen for fault codes at launch site.
		False apogee detected	Manufacturing defect	Premature/late ejection of drogue parachutes	Increased load on drogue recovery hardware and bulkheads	2	2	Conduct ground ejection tests of the calculated black powder charge masses to verify separation of sections, and functionality of altimeter system. Periodically conduct ground altimeter redundancy system tests through simulating flight pressure conditions. Throughout handling, fabrication, and assembly prior to

								launch, confirm the wiring, functionality, and component integrity of the avionics system is in accordance to design specifications by testing continuity, and simulated flight. Listen for fault codes at launch site.
			Incorrect altimeter readings			2	2	Conduct ground ejection tests of the calculated black powder charge masses to verify separation of sections, and functionality of altimeter system. Periodically conduct ground altimeter redundancy system tests through simulating flight pressure conditions. Throughout handling, fabrication, and assembly prior to launch, confirm the wiring, functionality, and component integrity of the avionics system is in accordance to design specifications by testing continuity, and simulated flight. Ensure that pressure ports are sized correctly and listen for fault codes at launch site.
		Main parachute deploys at wrong altitude	Incorrect pressure readings or improper programming	Main deployment between apogee and 900 ft	Excessive drift, but surface impact will remain below required maximums	2	2	Conduct ground ejection tests of the calculated black powder charge masses to verify separation of sections, and functionality of altimeter system. Periodically conduct ground altimeter redundancy system tests through

				Main deployment lower than 500 ft	Kinetic energy at surface impact will likely exceed 75 ft-lb parachute	1	2	simulating flight pressure conditions. Throughout handling, fabrication, and assembly prior to launch, confirm the wiring, functionality, and component integrity of the avionics system is in accordance to design specifications by testing continuity, and simulated flight. Verify each altimeter chirps the appropriate program at the launch site. Ensure pressure ports are sized correctly.
	GPS	Ground system failure	Loss of power to ground receiver or the laptop	Inability to receive data from the GPS	Inability to track and recover the launch vehicle in less than an hour	3	2	Ensure that the receiver and laptop are fully charged at least 6 hours prior to flight.
		Loss of signal	Environment or launch vehicle materials blocking signal			3	2	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	2	Ensure that all transmitting devices are on separate channels and confirm with other teams and launch officials that no frequency conflict exists.
		Loss of power	Flight forces cause GPS to disconnect from power supply			3	2	Ensure that all GPS units are fully charged and use simulated load tests to determine the necessary procedures to secure the units.

	Avionics Sled	Detaches from secure position	Loads beyond design specifications	Damage to/loose wiring of avionics components	Loss of recovery system initiation, rocket unrecoverable	1	2	Use simulated load tests and add a sufficient factor of safety when designing sled.
		Malfunctions	RF radiation	Altimeter malfunction		3	2	Shielding for altimeters during assembly prior to launch
		Detaches from secure position	Damaged during handling within the lab, or handling and assembly prior to launch	Damage to/loose wiring of avionics components		1	2	Team members will be taught proper handling and installation procedures for the avionics sled.
			Improper maintenance			1	2	Pre- and post-launch thorough inspections of the avionics sled.
			Shock cords tangled		Rocket recoverable, Payload failure	3	2	Ensure shock cords and parachutes are folded correctly.
			Shock cord connections loose		Rocket recoverable, Payload failure	3	2	Test shock cord connections before flight, make sure secure
	Containment Pod Deployment System	Failure to enter motion in the payload tube	Stepper motor failure	Prevention of Containment Pod exit from the payload tube	Team Mission Failure (failure of UAV to deploy)	4	3	Motor will be tested before installation for current, voltage, and output parameters. The motor will undergo an integrated test with the screw-drive deployment system. Finally, the motor will be simulated for compressive stress undergone during initial takeoff and separation stages.

			Failure of electronically activated latch release			4	3	Electronically activated latches will be tested prior to installation for mechanical and electrical operational success. Electronically activated latches will then undergo integration testing to prove that they release the Containment Pod under vertical and horizontal orientations.
		Failure to exit payload tube	Stepper motor failure			4	3	Motor will be tested before installation for current, voltage, and output parameters. The motor will undergo an integrated test with the screw-drive deployment system. Finally, the motor will be simulated for compressive stress undergone during initial takeoff and separation stages.
			Buckling of threaded rod			4	2	Threaded rod will be tested for an ultimate stress, with a factor of safety of 1.5 from the reported maximum compressive stress provided in the material documentation of the part. Additionally, the threaded rod will be secured by a journal bearing on the open deployment direction to reduce compressive loading conditions.
			Centering Ring misalignment			4	2	Follow proper procedures for mixing, applying, and curing epoxy for the adhesion of the Centering Rings to inner payload body tube.

			Shock cord entanglement			4	2	Shock cord will be routed inline through channels positioned at the outer edges of the bulkheads to prevent an excess of shock cord disturbing the exit cavity. Additionally, the convex design of the Containment Pod's front end shifts any obstruction in the exit cavity out of its path.
		Failure to release Containment Pod	Shearing at pusher plate and threaded rod joint	Prevention of UAV Deployment	Team Mission Failure (failure of UAV to deploy)	4	3	Pusher plate material will be made of a balsa wood epoxy composite to increase plate's tolerance of shear stress, and decrease the likelihood of fracturing at joint locations. Additionally, a threaded collar will be inserted into the pusher plate to transfer loading from the thread rod joint to the area around the joint, effectively distributing the force over a larger area.
			Shearing at pusher plate and cantilevered rod joint			4	3	
			Shearing at pusher plate and support rod joint			4	3	
	Containment Pod	Failure to open Containment Pod in an upright position for UAV vertical takeoff	Elastic surgical tubing detachment	Prevention of UAV deployment	Team Mission Failure (failure of UAV to deploy safely)	4	3	The Containment Pod is designed and will be tested to exit the payload body tube in multiple orientations on the cantilevered beam. The egg-shaped cross section design and the off-center center of gravity location prevents the Containment Pod from deploying in an "unfavorable orientation" as the mass of the UAV will right the pod.
	UAV Arm Deployment System	Failure to extend UAV arms to a fully	Avionics package-to-motor wiring failure	Hindrance of UAV performance	Possible Team Mission Failure	4	2	Avionics package-to-motor wiring will be given some slack to account for tensile

		deployed position						stress experienced due to UAV Arm extension.
			Motor failure			4	2	Motor will be tested before installation for current, voltage, and output parameters. The motor will undergo an integrated test with the screw-drive deployment system. Finally, the motor will be simulated for compressive stress undergone during initial takeoff and separation stages.
			Improper installation of hinges			4	2	Hinges will be tested prior to launch under numerous angular acceleration conditions.
		Failure to secure UAV arms into a fully deployed position			Mission Failure	4	2	Hinges will be tested prior to launch under numerous angular acceleration conditions, and rigidity of UAV Arm position.
	Body Structure	Structural integrity failure	Damage during rocket flight	Hindrance of UAV performance	Team Mission Failure (failure to deploy UAV)	4	3	The Containment Pod shelters the UAV with an outer shell and an internal layer of padding foam to reduce loads experience on the UAV body structure.
			Manufacturing defect			4	2	Visual inspection after shipping and before assembly. Manufacturer and distributor will be contacted for a replacement prior to fabrication process.
	Electronics System	Wiring disconnectio n	Damage during flight	UAV cannot complete mission	Team Mission Failure (drone performance hindered)	4	3	Test the structural integrity of the parts and run structural analysis.

			Damaged during handling and fabrication within the lab, or handling and assembly prior to launch	UAV cannot complete mission		4	2	Follow proper manufacturing technique.
			Damage during UAV operation	UAV cannot complete mission		4	2	Run tests to determine UAV capabilities.
		Jammed	Foreign objects get stuck in the gears/motor	UAV performance hindered		4	2	Run tests in similar conditions to landing site.
		Does not operate not operate	Dead battery	UAV cannot complete mission		4	2	Ensure proper battery charging and handling techniques are followed.
			Signal is not sent properly	UAV cannot complete mission		4	2	Extensively test transceiver in all conditions.
			Programming bug	UAV cannot complete mission		4	2	Run tests on electronics system to ensure high performance.
	Battery	Low Charge	Improper charging techniques	UAV performance hindered	Team Mission Failure (drone performance hindered)	4	2	Adhere to proper charging technique.
			Improper storage	UAV performance hindered		4	2	Adhere to proper storage technique.
		Fire	Not following proper safety protocol	UAV cannot complete mission	Damage to payload	3	1	Maintain a high level of safety by monitoring battery quality prior to arrival to the launch field.

9. Appendix B: Checklists

Full-Scale Launch Checklist

Key:

PPE Required

Explosive - DANGER

AV BAY AFT BULKHEAD E-MATCH INSTALLATION:

Required Items:

- ❑ **AV Bay AFT Bulkhead**
- ❑ **Avionics Box**
  - ❑ **(2) e-matches**
  - ❑ **3M electrical tape**
  - ❑ **Scissors**
  - ❑ **Wire Cutters**
  - ❑ **Wire Strippers**
  - ❑ **Black Screwdriver w red tip**

PRIMARY:

- ❑ Unscrew all unoccupied terminal blocks on the AV Bay AFT bulkhead
- ❑ Trim the e-match to approximately 7 in length using wire cutters
- ❑ Remove red plastic protective e-match cover from e-match
- ❑ Separate the two leads
- ❑ Strip the wire insulation from end of e-match
- ❑ Make a loop with the exposed wire
- ❑ Feed the e-match through the **DP** wire hole
  - ❑ The e-match head should be on the side with blast caps
- ❑ Place exposed e-match leads into terminal block labelled **DP**
- ❑ Tighten down the screws in the **DP** terminal block
- ❑ Lightly tug on e-match wires coming out of the **DP** terminal block
  - ❑ Have a second team member confirm the e-match wires are secure
- ❑ Place e-match head within the blast cap labelled **DP**

- ❑ Bend the e-match wire such that it lies flat against the bulkhead
    - ❑ Secure the e-match wire to bulkhead with a small piece of electrical tape, ensure that no holes are covered
- ❑ Confirm the e-match wire is curved over the outside edge of the blast cap
- ❑ Confirm the e-match head is flat on the cap bottom
- ❑ Using 3M electrical tape, tape the e-match wire to the outside of the of the blast cap
- ❑ Confirm the e-match in the **DP** blast cap is connected to the terminal block labeled **DP**
    - ❑ Safety Officer Confirmation: ____________________
- ❑ Confirm all label are still visible

SECONDARY:

- ❑ Trim the e-match to approximately 7 in length using wire cutters
- ❑ Remove the red plastic protective e-match cover from e-match
- ❑ Separate the two leads
- ❑ Strip the wire insulation from end of e-match
- ❑ Make a loop with the exposed wire
- ❑ Feed the e-match through the **DS** wire hole
    - ❑ The e-match head should be on the side with blast caps
- ❑ Place exposed e-match leads into terminal block labelled **DS**
- ❑ Tighten down the screws in the **DS** terminal block
- ❑ Lightly tug on e-match wires coming out of the **DS** terminal block
    - ❑ Have a second team member confirm the e-match wires are secure
- ❑ Place e-match head within the blast cap labelled **DS**
- ❑ Bend the e-match wire such that it lies flat against the bulkhead
    - ❑ Secure the e-match wire to bulkhead with a small piece of electrical tape, ensure that no holes are covered
- ❑ Confirm the e-match wire is curved over the outside edge of the blast cap
- ❑ Confirm the e-match head is flat on the cap bottom
- ❑ Using 3M electrical tape, tape the e-match wire to the outside of the of the blast cap
- ❑ Confirm the e-match in the **DS** blast cap is connected to the terminal block labeled **DS**
    - ❑ Safety Officer Confirmation: _________________

- ❑ Confirm all labels are still visible

AV BAY FWD BULKHEAD E-MATCH INSTALLATION:

Required Items:

- ❑ **Avionics box**
  - ❑ **(2) e-matches**
  - ❑ **3M electrical tape**
  - ❑ **Scissors**
  - ❑ **Wire Cutters**
  - ❑ **Wire Strippers**
  - ❑ **Black Screwdriver w red tip**
- ❑ **FWD Avionics Bay bulkhead**

PRIMARY:

- ❑ Unscrew all terminal blocks on the AV Bay FWD bulkhead
- ❑ Trim the e-match to approximately 7 in length using wire cutters
- ❑ Remove the red plastic protective e-match cover from e-match
- ❑ Separate the two leads
- ❑ Strip the wire insulation from end of e-match
- ❑ Make a loop with the exposed wire
- ❑ Feed the e-match through the **MP** wire hole
  - ❑ The e-match head should be on the side with blast caps
- ❑ Place exposed e-match leads into terminal block labelled **MP**
- ❑ Tighten down the screws in the **MP** terminal block
- ❑ Lightly tug on e-match wires coming out of the **MP** terminal block
  - ❑ Have a second team member confirm the e-match wires are secure
- ❑ Place e-match head within the blast cap labelled **MP**
- ❑ Bend the e-match wire such that it lies flat against the bulkhead

    - ❑ Secure the e-match wire with a small piece of electrical tape
- ❑ Confirm the e-match wire is curved over the outside edge of the blast cap
- ❑ Confirm the e-match head is flat on the cap bottom
- ❑ Using 3M electrical tape, tape the e-match wire to the outside of the of the blast cap
- ❑ Confirm the e-match in the **MP** blast cap is connected to the terminal block labeled **MP**
    - ❑ Safety Officer Confirmation: _________________

SECONDARY:

- ❑ Trim the e-match to approximately 7 in length using wire cutters
- ❑ Remove the red plastic protective e-match cover from e-match
- ❑ Separate the two leads
- ❑ Strip the wire insulation from end of e-match
- ❑ Make a loop with the exposed wire
- ❑ Feed the e-match through the **MS** wire hole
    - ❑ The e-match head should be on the side with blast caps
- ❑ Place exposed e-match leads into terminal block labelled **MS**
- ❑ Tighten down the screws in the **MS** terminal block
- ❑ Lightly tug on e-match wires coming out of the **MS** terminal block
    - ❑ Have a second team member confirm the e-match wires are secure
- ❑ Place e-match head within the blast cap labelled **MS**
- ❑ Bend the e-match wire such that it lies flat against the bulkhead
    - ❑ Secure the e-match wire with a small piece of electrical tape
- ❑ Confirm the e-match wire is curved over the outside edge of the blast cap
- ❑ Confirm the e-match head is flat on the cap bottom
- ❑ Using 3M electrical tape, tape the e-match wire to the outside of the of the blast cap
- ❑ Confirm the e-match in the **MS** blast cap is connected to the terminal block labeled **MS**
    - ❑ Safety Officer Confirmation: _____________

AVIONICS BAY ASSEMBLY:

Required Items:

- ❑ FWD AV Bay Bulkhead
- ❑ AFT AV bay bulkheads
- ❑ GPS
- ❑ Assembled AV sled
- ❑ (2) pre-cut threaded rods
- ❑ AV Bay toolbox
- ❑ AV bay hardware bag
- ❑ AV bay section
- ❑ (2) 9V batteries
- ❑ Multimeter
- ❑ Plumbers Putty
- ❑ (3) Screw switches
- ❑ Rachet
- ❑ 7/16th Socket
- ❑ 200 mm adjustable wrench
- ❑ Wrench labeled "use for ¼ in nuts"
- ❑ Zipties
- ❑ Wire cutters

STEPS:

- ❑ Use multimeter to check primary battery voltages – 9V
    - ❑ If voltage is nominal, place 9V battery on AV sled and connect 9V plugs
- ❑ Secure Primary battery to AV Sled with zipties
    - ❑ Have a second team member verify
- ❑ Use multimeter to check secondary battery voltage – 9V
    - ❑ If voltage is nominal, place 9V battery on AV sled and connect 9V plugs
- ❑ Secure Primary battery to AV Sled with zipties
    - ❑ Have a second team member verify
- ❑ At this point altimeters should not be activated until launch vehicle is on launch pad
- ❑ Use multimeter to check voltage on LiPo battery (3.7V, attached to GPS)

- ❑ Attach GPS assembly to AV sled opposite the face with the altimeters with the transmitter facing FWD
  - ❑ Attach using zip ties UNDER the altimeter wiring
- ❑ Place screw switches in the on position
- ❑ Use multimeter to confirm continuity on each screw switch
- ❑ If continuity is present, place screw switches in the off position, else replace screw switch with one of the spares
- ❑ Confirm wires between primary altimeter and **MP** terminal block are still connected
- ❑ Confirm wires between secondary altimeter and **MS** terminal block are still connected
- ❑ Using the multimeter, confirm continuity on the wires attached to the forward AV bulkhead terminal blocks
  - ❑ Place one multimeter lead on the MAIN screw on the Primary altimeter labeled **P**
  - ❑ Place the other multimeter lead inside the terminal block labeled **MP**
  - ❑ Repeat for the second MAIN screw on the Primary altimeter
  - ❑ Place one multimeter lead on the MAIN screw on the Secondary altimeter labeled **S**
  - ❑ Place the other multimeter lead inside the terminal block labeled **MS**
  - ❑ Repeat for the second MAIN screw on the Secondary altimeter
- ❑ Confirm e-match wires are installed on the FWD AV Bulkhead
- ❑ Have Nathan verify the AV sled is ready to be inserted into the AV bay
- ❑ Halfway insert the AV sled into the AV bay
- ❑ Confirm Continuity of all avionics
- ❑ Connect the screw switch quick disconnects according to the below:
  - ❑ The switch wires labeled P connect to the GREEN wired quick disconnects
    - Have a second team member verify
  - ❑ The switch wires labeled S connect to the BROWN wired quick disconnects
    - Have a second team member verify
  - ❑ For the wires labeled GPS, the black wire connects to the other black wire and likewise for red
- ❑ Slide the AV bay body tube over the AV sled and bulkhead assembly as required during the previous step, once all switch wires are connected slide the tube fully down until it is flush along the forward bulkhead

- [ ] Probe pressure ports with small screwdriver
    - [ ] Confirm pressure ports are clear
- [ ] Ensure the forward end of the AV bay is aligned with the FWD AV bulkhead
- [ ] The altimeter screw switches should be opposite of the face of the AV sled that mounts the altimeters
- [ ] Confirm e-match wires are installed on the AFT AV Bulkhead
    - [ ] Have a second team member confirm
- [ ] Connect the GREEN **PD** altimeter wires to the **PD** terminal block on the AFT AV Bulkhead
    - [ ] Confirm tightness of connection
- [ ] Connect the BROWN **SD** altimeter wires to the **SD** terminal block on the AFT AV Bulkhead
    - [ ] Confirm tightness of connection
- [ ] Tighten and have the connection verified
- [ ] Slide the AFT AV bulkhead onto the threaded rods until flush with body tube
- [ ] Slide (2) washers onto each threaded rod
- [ ] Slide (1) ¼ in nut onto each threaded rod
- [ ] Slide (1) ¼ in cap nut onto each threaded rod
- [ ] Tighten until snug
- [ ] Have Nathan verify Assembly

Drogue Black Powder:

Required items:

- ❑ **AV Bay**
- ❑ **Paper Towels**
- ❑ **(2) 8.5x11, 20lb weight, 30% post-consumer recycled material copy paper**
- ❑ **Scotch tape**
- ❑ **Black Powder Charges**
  - o **Drogue Primary charge**
  - o **Drogue Secondary Charge**
- ❑ **Safety Glasses**
- ❑ **Nitrile Gloves**
- ❑ **Plumbers Putty**
- ❑ **3M electrical tape**
- ❑ **Scissors**

STEPS:

- ❑ Confirm that all members around the launch vehicle are wearing safety glasses
  - o Safety Officer Confirmation: ________________
- ❑ Confirm the members handling black powder are wearing nitrile gloves
  - o Safety Officer Confirmation: ________________
- ❑ Confirm All labels on AV Bay are still visible
- ❑ Turn Midsection so that the blast caps on the AFT avionics bulkhead are facing up
- ❑ Create a paper funnel using 1 sheet of copy paper and 1 piece of scotch tape
  - o Ensure inside of paper funnel is smooth
- ❑ Carefully pour the **Drogue Primary Charge** of black powder into the **DP** blast cap over the e-match head using the paper funnel for guidance
- ❑ Move the e-match so the black powder lies under the e-match head
- ❑ Fill the remaining space in the blast cap with fingertip sized pieces of paper towel
  - o The paper towel should fill the space, but not be packed in tightly!

- ❑ Place small (2-3 in.) strips of black electrical tape on top of the **DP** blast cap to cover the blast cap completely
  - o Do NOT have any major overlaps but leave no gaps with the electrical tape
  - o Ensure all edges are covered
  - o Have a second team member verify
- ❑ Wrap electrical tape all the way around the outside of the blast cap to keep the top layers tight
- ❑ Carefully pour the **Drogue Secondary Charge** of black powder into the **DS** blast cap over the e-match head using the paper funnel for guidance
- ❑ Move the e-match so the black powder lies under the e-match head
- ❑ Fill the remaining space in the blast cap with fingertip size pieces of paper towel
  - o The paper towel should fill the space, but not be packed in tightly!
- ❑ Place small (2-3 in.) strips of black electrical tape on top of the **DS** blast cap to cover the blast cap completely
  - o Do NOT have any major overlaps but leave no gaps with the electrical tape and
  - o Ensure all edges are covered
  - o Have a second team member verify
- ❑ Wrap electrical tape all the way around the outside of the blast cap to keep the top layers tight
- ❑ Use plumber's putter to seal any holes in the bulkhead (E-match holes, etc.)
- ❑ Confirm all holes are sealed
  - o Have a second member confirm
- ❑ Turn the AV Bay over onto a sheet of white copy paper
- ❑ Turn the AV Bay back over
  - o Confirm that no black powder has leaked onto the copy paper
  - o If yes, repeat the above steps

Main Black Powder:

Required items:

- ❑ **AV Bay**
- ❑ **Paper Towels**
- ❑ **(2) 8.5x11, 20lb weight, 30% post-consumer recycled material copy paper**
- ❑ **Scotch tape**
- ❑ **Black Powder Charges**
  - **Main Primary charge**
  - **Main Secondary Charge**
- ❑ **Safety Glasses**
- ❑ **Nitrile Gloves**
- ❑ **Plumbers Putty**
- ❑ **3M Electrical Tape**
- ❑ **Scissors**

STEPS:

- ❑ Confirm that all members around the launch vehicle are wearing safety glasses
  - Safety Officer Confirmation: ___________________
- ❑ Confirm the members handling black powder are wearing nitrile gloves
  - Safety Officer Confirmation: ___________________
- ❑ Make a paper funnel by rolling a sheet of copy paper and securing with a piece of scotch tape
- ❑ Carefully pour the **Main Primary Charge** of black powder into the **MP** blast cap over the e-match head using the funnel for guidance
- ❑ Move the e-match so the black powder lies under the e-match head
- ❑ Fill the remaining space in the blast cap with fingertip size pieces of paper towel
  - The paper towel should fill the space, but not be packed in tightly!
- ❑ Place small (2-3 in.) strips of black electrical tape on top of the **MP** blast cap to cover the blast cap completely

  - Do NOT have any major overlaps but leave no gaps with the electrical tape and
  - Ensure all edges are covered
  - Have a second team member verify
- ❑ Wrap electrical tape all the way around the outside of the blast cap to keep the top layers tight
- ❑ Carefully pour the **Main Secondary Charge** of black powder into the **MS** blast cap over the e-match head using the paper funnel for guidance
- ❑ Move the e-match so the black powder lies under the e-match head
- ❑ Fill the remaining space in the blast cap with pieces of paper towel
  - The paper towel should fill the space, but not be packed in tightly!
- ❑ Place small (2-3 in.) strips of black electrical tape on top of the **MS** blast cap to cover the blast cap completely
  - Do NOT have any major overlaps but leave no gaps with the electrical tape
  - Ensure all edges are covered
  - Have a second team member verify
- ❑ Wrap electrical tape all the way around the outside of the blast cap to keep the top layers tight
- ❑ Use plumber's putter to seal any holes in the bulkhead (E-match holes, etc.)
- ❑ Confirm all holes are sealed
  - Have a second member confirm
- ❑ Turn the AV Bay over onto a sheet of white copy paper
- ❑ Turn the AV Bay back over
  - Confirm that no black powder has leaked onto the copy paper
  - If yes, repeat the above steps
- ❑ Clear the workspace of all black powder in preparation for launch vehicle assembly

Main Parachute Recovery Assembly:

Required items:

- ❑ **Recovery box**
- ❑ **Nosecone**
- ❑ **Payload Bay**
- ❑ **Payload Plug**
- ❑ **Main Parachute Bay**
- ❑ **AV Bay**
- ❑ **(5) Safety Glasses**
- ❑ **Main parachute (84 inch Iris Ultra)**
- ❑ **5.5 in Deployment Bag**
- ❑ **(1) Large Nomex cloth**
- ❑ **Main parachute shock cord**
- ❑ **Philips head screwdriver (labeled POS)**
- ❑ **Recovery hardware box**

STEPS:

- ❑ Confirm that all members handling the launch vehicle are wearing safety glasses
- ❑ Route end of the Kevlar shock cord labeled one through slot in aft side of payload bay plug
- ❑ Route shock cord end labeled 1 through aft end of payload bay centering ring
- ❑ Route shock cord end labeled 1 through payload bay bulkhead
- ❑ Tie a bowline knot on the end of the shock chord labeled 1
  - ❑ Have a second team member confirm
- ❑ Attached **quicklink #1** to **end of shock chord labeled #1**
  - ❑ Do NOT tighten
- ❑ Attach **quicklink #1** to **nosecone bulkhead #1**
  - ❑ Tighten by hand

- ❑ Confirm the **quicklink #1** is secured to the nosecone bulkhead U-bolt by visual inspection and pulling on shock cord
  - ❑ Have second team member verify
- ❑ Insert nose cone shoulder into payload bay using marks to align holes
- ❑ Use (4) #6-32 ½ inch screws to secure nose cone to payload bay
- ❑ Pull shock cord taught through payload bay
- ❑ Attach **quicklink #2 to loop #2**
  - ❑ Do NOT tighten
- ❑ Attach **quicklink #2** to **payload bay plug #2**
- ❑ Confirm the payload bay plug rubber band is wrapped around the plug
  - ❑ If not, retrieve a rubber band from the recovery box and wrap around the plug
- ❑ Insert the payload bay plug into the payload bay centering ring
- ❑ Attach **quicklink #2** to **deployment bag loop #2**
  - ❑ Tighten by hand
- ❑ Fold length of shock cord **between loops #2 and #3** accordion-style
- ❑ Confirm the rubber band is NOT too tight and NOT covering any part of parachute
  - ❑ Two fingers should fit snugly under the rubber band
- ❑ Confirm the shock cord is still folded accordion style within the rubber band
  - ❑ If not repeat the previous steps
- ❑ Fold length of shock cord **between loops #3 and #4** accordion-style
- ❑ Secure with a single rubber band
- ❑ Confirm the rubber band is NOT too tight and NOT covering any part of parachute
  - ❑ Two fingers should fit snugly under the rubber band
- ❑ Confirm the shock cord is still folded accordion style within the rubber band
  - ❑ If not repeat the previous steps
- ❑ Final check that all rubber bands are removed from main parachute and shroudlines
  - ❑ The rubber bands on the shock cord will remain
- ❑ Attach **quicklink #3** to **loop #3**
  - ❑ Do NOT tighten
- ❑ Attach Large Nomex Sheet to **quicklink #3**
- ❑ Attach **quicklink #3** to **Main Parachute Loop #3**
  - ❑ Tighten by hand

- ❑ Slide FWD AV Bay coupler into main parachute bay using marks to align holes
- ❑ Use (4) #6-32 ½ inch screws to secure the two sections
  - ❑ Confirm Tightness
- ❑ Wrap Main Parachute deployment bag in large nomex sheet
- ❑ Route end of shock cord labeled 4 through the main parachute bay from the FWD end to the aft end
- ❑ Carefully insert the shock cord length **between loops #2 and #4** into main parachute bay from forward to aft
- ❑ Attach **quicklink #4** to **loop #4**
  - ❑ Do NOT tighten
- ❑ Attach **quicklink #4** to **AV Bay FWD bulkhead #4**
  - ❑ Tighten by hand
- ❑ Confirm the **quicklink #4** is secured to the AV Bay **FWD bulkhead #4** by visual inspection and pulling on shock cord
  - ❑ Have second team member verify
- ❑ Carefully insert the wrapped parachute into the space between stowed shock cords
  - ❑ The deployment bag loop labeled #2 should be pointed toward the nosecone
  - ❑ The deployment bag should sit completely inside the main parachute bay
  - ❑ Ensure that payload bay plug remains within the centering ring
- ❑ Carefully slide payload bay coupler into main parachute bay using marks to align shear pin holes
- ❑ Cut (4) 4-40 nylon shear pins so they are 1/2 in in length and insert into shear pin holes until tight
  - ❑ If shear pins are loose, place small piece of electrical tape over shear pin heads
- ❑ The launch vehicle should be able to hold its own weight from shear pins alone
  - ❑ Hold at nosecone and let the launch vehicle hang

Drogue Parachute Recovery Assembly:

Required items:

- ❑ **Recovery hardware box**
- ❑ **Fin can**
- ❑ **Completed Nosecone Midsection Assembly**
- ❑ **(5) Safety Glasses**
- ❑ **Drogue parachute (24 inch elliptical)**
- ❑ **4 in deployment bag**
- ❑ **Small Nomex cloth**
- ❑ **Drogue parachute shock cord**
- ❑ **Electrical Tape**
- ❑ **Scissors**

STEPS:

- ❑ Confirm that all members near the launch vehicle are wearing safety glasses
- ❑ Use quicklink **labeled #6 (called quicklink #6)** to attach nomex cloth to shock cord parachute loop **labeled #6 (called loop #6)**
    - ❑ Tighten by hand
- ❑ Use quicklink **labeled #8** to attach drogue parachute eye-bolt **labeled 8** to **loop #8**
    - ❑ Tighten quicklink by hand
- ❑ Fold length of shock cord **between loops #5 and #6** accordion-style
    - ❑ 8 in folds
- ❑ Secure the length of shock cord **between loops #5 and #6** with a single rubber band
- ❑ Confirm the rubber band is NOT too tight and NOT covering any part of parachute
    - ❑ Two fingers should fit snugly under the rubber band
- ❑ Confirm the shock cord is still folded accordion style within the rubber band
    - ❑ If not repeat the previous steps
- ❑ Fold length of shock cord **between loops #7 and #8** accordion-style
- ❑ Secure the length of shock cord **between loops #7 and #8** with a single rubber band

- ❑ Confirm the rubber band is NOT too tight and NOT covering any part of parachute
  - ❑ Two fingers should fit snugly under the rubber band
- ❑ Confirm the shock cord is still folded accordion style within the rubber band
  - ❑ If not repeat the previous steps
- ❑ Attach **quicklink #5** to **loop #5**
  - ❑ Do NOT tighten
- ❑ Attach **quicklink** #**7**to **loop #7**
  - ❑ Do NOT tighten
- ❑ Attach **quicklink #5** to AV Bay aft bulkhead **labeled #5**
  - ❑ tighten by hand
- ❑ Confirm the quicklink is secured to the AV Bay aft bulkhead U-bolt by visual inspection and pulling on shock cord
  - ❑ Have second team member verify
- ❑ Attach **quicklink #7** to fin can bulkhead **labeled #7**
  - ❑ tighten by hand
- ❑ Confirm the quicklink is secured to the fin can bulkhead U-bolt by visual inspection and pulling on shock cord
  - ❑ Have second team member verify
- ❑ Confirm the drogue parachute is properly inserted into the deployment bag
- ❑ Remove rubber band securing drogue parachute
  - ❑ Hold it tightly
- ❑ Confirm all rubber bands are removed from parachute and shroudlines
- ❑ Wrap nomex cloth around the deployment bag
  - ❑ Hold it tightly
- ❑ Carefully insert the shock cord length **between loops #6 and #7** into fin can cavity
- ❑ Carefully insert the drogue parachute deployment bag into the fin can cavity in the space between stowed shock cords
  - ❑ The yellow Fruity Chutes logo should be facing the fin can
- ❑ Carefully insert the shock cord length **between loops #5 and #6** into the fin can cavity

- ❑ Slide AV Bay coupler into fin can cavity using the marks to align the shear pin holes
- ❑ Cut (4) 4-40 nylon shear pins so they are ½ in length and insert into shear pin holes until tight
    - ❑ If shear pins are loose, place small piece of electrical tape over shear pin heads
- ❑ Confirm the assembled launch vehicle is able to hold its own weight from shear pins alone
    - ❑ Hold nosecone and let fin can hang

Motor Assembly:

Required items:

- ❑ **AeroTech L1150R reload kit**
- ❑ **AeroTech RMS 75/3840 motor casing with forward seal**
- ❑ **Vaseline Petroleum Jelly**
- ❑ **Nitrile Gloves**
- ❑ **Needle-nose pliers**
- ❑ **Baby wipes**
- ❑ **Alan/Jim**
- ❑ **Permanent Marker**
- ❑ **Painters tape**
- ❑ **Paper Towels**

Steps:

- ❑ Follow instructions for motor assembly from L3 mentor
- ❑ Prep Ignitor
  - Hold ignitor wire against the motor casing
  - Designate appropriate length by marking wire with sharpie
  - Separate ends of ignitor wire
  - Strip ends of ignitor wire
  - Recoil ignitor
  - Store in field recovery toolbox
- ❑ Return to launch vehicle assembly location
- ❑ Unscrew motor retainer
- ❑ Slide motor casing into motor tube
- ❑ Secure motor casing using retainer screw
- ❑ Have a second team member confirm the motor retainer screw is tight
- ❑ Measure the center of pressure of the launch vehicle
  - Center of pressure is at 72.89 inches from the nosecone
- ❑ Use a green circular sticker to mark the center of pressure of the launch vehicle
- ❑ Using the rope and fish scale, locate the center of gravity of the launch vehicle

  - ❑ Tie the rope around the middle of the launch vehicle
  - ❑ Move the rope until the launch vehicle balances
  - ❑ The balance point is the CG
  - ❑ Write the weight of the launch vehicle here: _______________
- ❑ Use a pink circular sticker to mark the CG
  - ❑ Measure the CG distance from the nosecone
  - ❑ Write the CG distance from the nosecone here: _______________
  - ❑ Should be approximately 61.81 inches
- ❑ Confirm the CG and CP are AT LEAST 11 inches apart
- ❑ Calculate the stability margin of the launch vehicle in calibers
  - (CP-CG)/D
  - Write stability margin here: ______

Launch Pad Procedure:

Required items:

- ❑ **Fully assembled launch vehicle with payload and motor installed**
- ❑ **Motor igniter**
- ❑ **6ft x 1515 launch rail**
- ❑ **Black screwdriver with red tip**
- ❑ **Blue painter's tape**
- ❑ **(4) Safety glasses**
- ❑ **Launch rail lubricant**
- ❑ **Stepladder (if necessary)**
- ❑ **Wire cutters**
- ❑ **Wire strippers**

Steps:

- ❑ Grease launch vehicle rail buttons and launch rail track
- ❑ Carefully slide launch vehicle onto launch rail
- ❑ Rotate launch rail into upright position and lock into place
    - Launch vehicle must be pointed downwind and 5° from vertical
- ❑ Confirm the launch rail is locked
    - Safety Officer Confirmation: ____________________
- ❑ Take team picture in front of launch vehicle
- ❑ Take Senior Design picture in front of launch vehicle
- ❑ All non-essential personnel must be directed to leave the launch pad
- ❑ Confirm all individuals remaining at launch pad wear safety glasses
    - Safety Officer Confirmation: _____________________

Arm both altimeters:

- ❑ Turn Primary screw switch to the ON position
- ❑ Confirm the PRIMARY altimeter (StratoLogger) is beeping correctly

    - Refer to beep sheet
- ❑ Turn Secondary screw switch to the ON position
- ❑ Confirm the SECONDARY altimeter (StratoLogger) is beeping correctly
    - Refer to beep sheet
- ❑ CONFIRM BOTH ALTIMETERS ARE ON BEFORE PROCEEDING
    - Safety Officer Confirmation: ___________________
- ❑ Attach igniter to wooden dowel
- ❑ Insert igniter fully into motor tube
- ❑ Tape igniter into place at the bottom of launch vehicle
- ❑ Confirm that launch pad power is cut off
- ❑ Connect igniter to launch pad power
- ❑ Ensure pad continuity
    - Readout should be between 1.5 and 3.5
- ❑ All personnel must navigate to safe locations behind launch table
- ❑ LAUNCH!

Main Altimeter (Top Key Switch) Beep Table - StratoLogger

Between each row there is a long beep

The Beeps: What do they mean	Write Beeps Here	Expected Output
A siren and error code if an error was encountered during the last flight.		Ignore, currently not important
A one-digit number (range of 1 to 9) corresponding to the currently-selected program preset.		Should be 1
A two second pause, and then a three- or four-digit number corresponding to the main deploy altitude setting.		IMPORTANT: Should be 550
(optional) only if you have added an apogee delay to the currently selected preset: A two second pause, and then a ***five second continuous tone*** *to warn you that your apogee firing is set to be delayed.*		IMPORTANT: SHOULD NOT SOUND
A two second pause, and then a three to six-digit number representing the apogee altitude of the last flight.		Ignore, currently not important
A two second pause, and then a two- or three-digit number representing the battery voltage in tenths of a volt (e.g. 9.2 volts would report as 92).		IMPORTANT: Should be between 8.8 and 11.0
A two second pause, and then continuity beeps repeated every 0.8 seconds – a single beep means drogue e-match continuity is OK, two beeps means main e-match continuity is OK, three beeps means both drogue and main have good continuity.		IMPORTANT: Should be 3

Secondary Altimeter (Bottom Key Switch) Beep Table - StratoLogger

Between each row there is a long beep

The Beeps: What do they mean	Write Beeps Here	Expected Output
A siren and error code if an error was encountered during the last flight.		Ignore, currently not important
A one-digit number (range of 1 to 9) corresponding to the currently-selected program preset.		Should be 1
A two second pause, and then a three- or four-digit number corresponding to the main deploy altitude setting.		IMPORTANT: Should be 550
*(optional) only if you have added an apogee delay to the currently selected preset: A two second pause, and then a **five second continuous tone** to warn you that your apogee firing is set to be delayed.*		IMPORTANT: SHOULD SOUND
A two second pause, and then a three to six-digit number representing the apogee altitude of the last flight.		Ignore, currently not important
A two second pause, and then a two- or three-digit number representing the battery voltage in tenths of a volt (e.g. 9.2 volts would report as 92).		IMPORTANT: Should be between 8.8 and 11.0
A two second pause, and then continuity beeps repeated every 0.8 seconds – a single beep means drogue ematch continuity is OK, two beeps means main ematch continuity is OK, three beeps means both drogue and main have good continuity.		IMPORTANT: Should be 3

Field Recovery Checklist

Required Materials:

- ❑ **Safety Glasses**
- ❑ **Nitrile Gloves**
- ❑ **Heavy Duty Gloves**
- ❑ **Rubber bands**
- ❑ **Pens**
- ❑ **Black Screwdriver with red tip**
- ❑ **Phone**

STEPS:

- ❑ Upon launch, watch the launch vehicle descend
- ❑ Observe where the launch vehicle lands
- ❑ Approach the launch vehicle on foot
- ❑ Once near the launch vehicle
    - ❑ Take note of whether all three sections of the launch vehicle are present
    - ❑ Take note of the state of all parachutes
- ❑ All recovery team members put on safety glasses
    - ❑ Confirm all present are wearing safety glasses
- ❑ If a parachute is open and pulling the launch vehicle
    - ❑ Do NOT grab hold of the shroudlines or shock cord
    - ❑ Approach the parachute from the billowed side without shroudlines
    - ❑ Use hands and body to pull down the parachute
    - ❑ Repeat for second parachute if necessary
- ❑ Use a rubber band to secure the Main Parachute
- ❑ Use a rubber band to secure the Drogue Parachute
- ❑ Listen to the altimeters to determine flight data
    - ❑ Use the beep sheets below to record flight data
- ❑ If beeps are NOT heard from one of the altimeters for more than 10 seconds assume a black powder charge did NOT go off
- ❑ If the launch vehicle did NOT separate, assume a black powder charge did NOT go off
- ❑ Team members manipulating the launch vehicle put on nitrile gloves
    - ❑ Confirm all team members manipulating the launch vehicle are wearing nitrile gloves
    - ❑ Perform this step even if you think all the black powder charges went off
- ❑ Carefully pick up the FWD end of the midsection
- ❑ Visually inspect the FWD Payload bulkhead for un-blown black powder charges
- ❑ If there is an un-blown black powder charge:
    - ❑ Equip heavy duty gloves before handling the body tube
    - ❑ Use the black screwdriver with the red tip to turn OFF the rotary switches

  - [ ] On the rotary switches the 220 position is OFF
- [ ] Carefully pick up the AFT end of the midsection
- [ ] Visually inspect the AFT Payload bulkhead for un-blown black powder charges
- [ ] If there is an un-blown black powder charge:
  - [ ] Equip heavy duty gloves before handling the body tube
  - [ ] Use the black screwdriver with the red tip to turn OFF the rotary switches
  - [ ] On the rotary switches the 220 position is OFF
- [ ] Take photographs
  - [ ] Nosecone showing bulkhead and U-bolt
  - [ ] Drogue parachute showing quick links
  - [ ] Landing layout
  - [ ] All quicklinks
  - [ ] Fin condition
  - [ ] Any body tube damage
- [ ] Pack up the launch vehicle and travel back to the launch site

Main Altimeter Beep Table – StratoLogger

Between each row there is a long beep

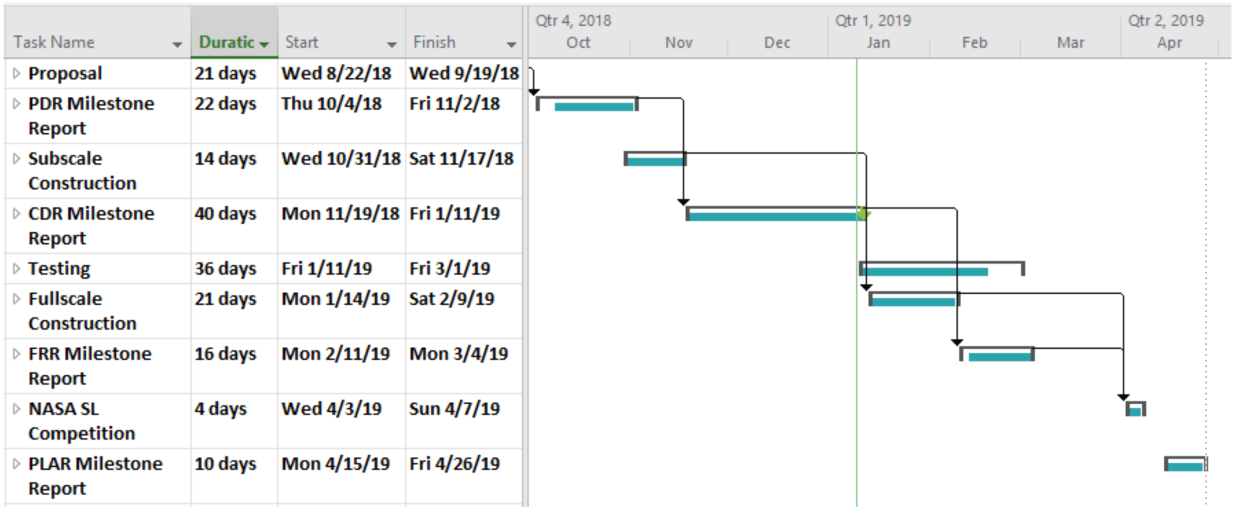
The Beeps: What do they mean	Write Beeps Here	Expected Output
An extra-long tone to indicate the start of the reporting sequence		Ignore, currently not important
A three to six digit number representing the peak altitude in feet		Should be approximately 4090 Record
A long separator tone followed by a two to five digit number representing the maximum velocity during the flight in miles per hour		Record
If the "siren delay" number is set to a number greater than zero, the altimeter will wait for the specified siren delay time, and then emit a 10 second warbling siren tone.		Ignore, currently not important
After a 10 second period of silence, the sequence repeats until power is disconnected.		Ignore, currently not important

Secondary Altimeter (Bottom Key Switch) Beep Table - StratoLogger

Between each row there is a long beep

The Beeps: What do they mean	Write Beeps Here	Expected Output
An extra-long tone to indicate the start of the reporting sequence		Ignore, currently not important
A three to six digit number representing the peak altitude in feet		Should be approximately 4090 Record
A long separator tone followed by a two to five digit number representing the maximum velocity during the flight in miles per hour		Record
If the "siren delay" number is set to a number greater than zero, the altimeter will wait for the specified siren delay time, and then emit a 10 second warbling siren tone.		Ignore, currently not important
After a 10 second period of silence, the sequence repeats until power is disconnected.		Ignore, currently not important

10. Appendix C: Project Timeline Gantt Charts



Task Name	Duratic	Start	Finish
Proposal	21 days	Wed 8/22/18	Wed 9/19/18
PDR Milestone Report	22 days	Thu 10/4/18	Fri 11/2/18
Subscale Construction	14 days	Wed 10/31/18	Sat 11/17/18
CDR Milestone Report	40 days	Mon 11/19/18	Fri 1/11/19
Testing	36 days	Fri 1/11/19	Fri 3/1/19
Fullscale Construction	21 days	Mon 1/14/19	Sat 2/9/19
FRR Milestone Report	16 days	Mon 2/11/19	Mon 3/4/19
NASA SL Competition	4 days	Wed 4/3/19	Sun 4/7/19
PLAR Milestone Report	10 days	Mon 4/15/19	Fri 4/26/19

Figure 10-1 Complete Project Timeline

Task Name	Duratio	Start	Finish
Subscale Construction	**14 days**	**Wed 10/31/18**	**Sat 11/17/18**
Lasercut Bulkheads and	2 days	Wed 10/31/18	Thu 11/1/18
Cut Airframe Tul	3 days	Wed 10/31/18	Fri 11/2/18
Altimeter Testin	1 day	Thu 11/1/18	Thu 11/1/18
Bulkhead Fabrication	4 days	Fri 11/2/18	Wed 11/7/18
Payload Bay Bulkhead Installation	1 day	Mon 11/5/18	Mon 11/5/18
Nosecone Bulkhead	1 day	Mon 11/5/18	Mon 11/5/18
AV Bay Bulkhead	1 day	Tue 11/6/18	Tue 11/6/18
Fin Can Bulkhead/Cente Ring Installation	5 days	Tue 11/6/18	Mon 11/12/18
Drill Pressure Ports and Switch Holes in	0.5 days	Tue 11/6/18	Tue 11/6/18
Lasercut AV Sled	1 day	Tue 11/6/18	Tue 11/6/18
Install Motor Tul	1 day	Tue 11/6/18	Tue 11/6/18
Checklist Writin	7 days	Tue 11/6/18	Wed 11/14/18
AV Sled Fabricat	3 days	Wed 11/7/18	Fri 11/9/18
Install Fwd Rail Button	1 day	Wed 11/7/18	Wed 11/7/18
Install Fins	3 days	Thu 11/8/18	Mon 11/12/18
AV Wiring	3 days	Mon 11/12/18	Wed 11/14/18
Install Aft Rail Button	1 day	Mon 11/12/18	Mon 11/12/18
Install Motor Retainer	1 day	Mon 11/12/18	Mon 11/12/18
Install AV Sled	2 days	Thu 11/15/18	Fri 11/16/18
Paint	1 day	Thu 11/15/18	Thu 11/15/18
Black Powder Demonstration	1 day	Fri 11/16/18	Fri 11/16/18
Subscale Launch	0 days	Sat 11/17/18	Sat 11/17/18

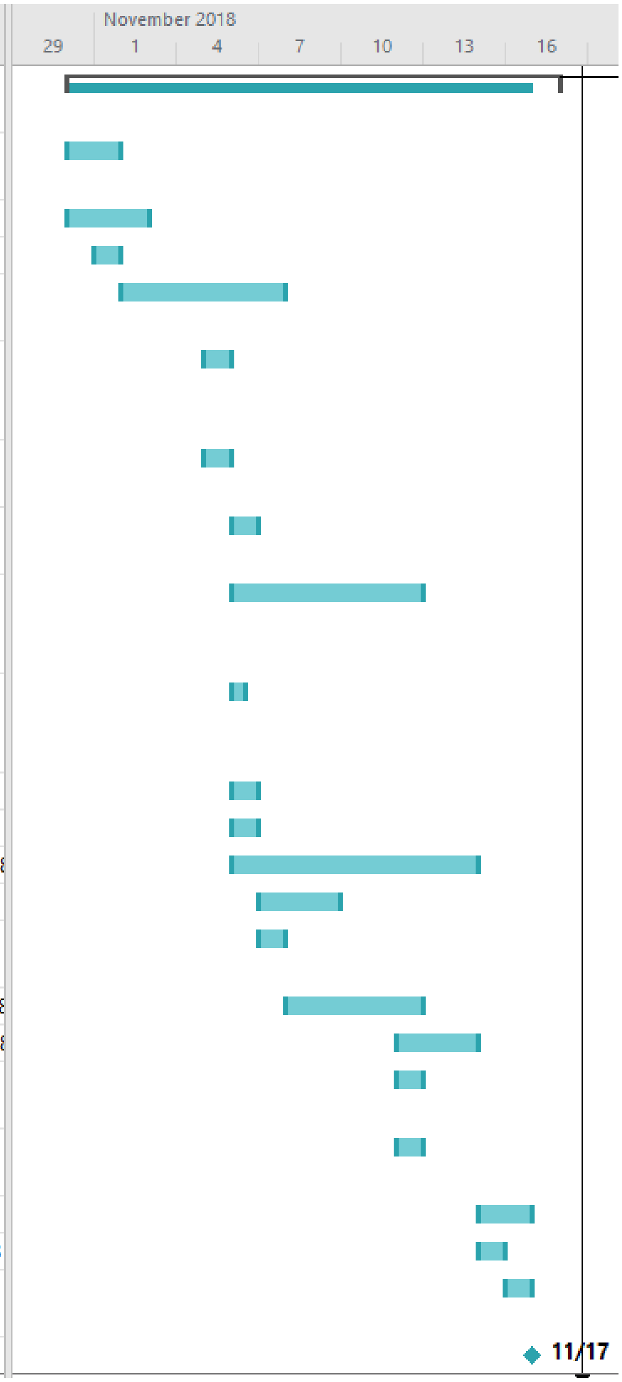


Figure 10-2 Subscale Construction Schedule

Task Name	Duratio	Start	Finish
Testing	**36 days**	**Fri 1/11/19**	**Fri 3/1/19**
Bulkhead Failure Testing	3 days	Fri 1/11/19	Tue 1/15/19
Real Conditions Endurance	2 days	Fri 1/18/19	Sun 1/20/19
Payload Pad Endurance Testing	3 days	Mon 1/21/19	Wed 1/23/19
Payload Deployment Demonstration	2 days	Mon 1/21/19	Tue 1/22/19
Payload Retention Testing	2 days	Thu 1/24/19	Fri 1/25/19
Recovery Electronics Endurance	3 days	Tue 1/29/19	Thu 1/31/19
Hover Endurance Testing	2 days	Fri 2/1/19	Sun 2/3/19
Altimeter Demonstration	1 day	Fri 2/1/19	Fri 2/1/19
Black Powder Ejection Demonstration	1 day	Thu 2/7/19	Thu 2/7/19
GPS Testing	2 days	Thu 2/14/19	Fri 2/15/19
Payload Operation Range Testing	2 days	Fri 2/15/19	Mon 2/18/19

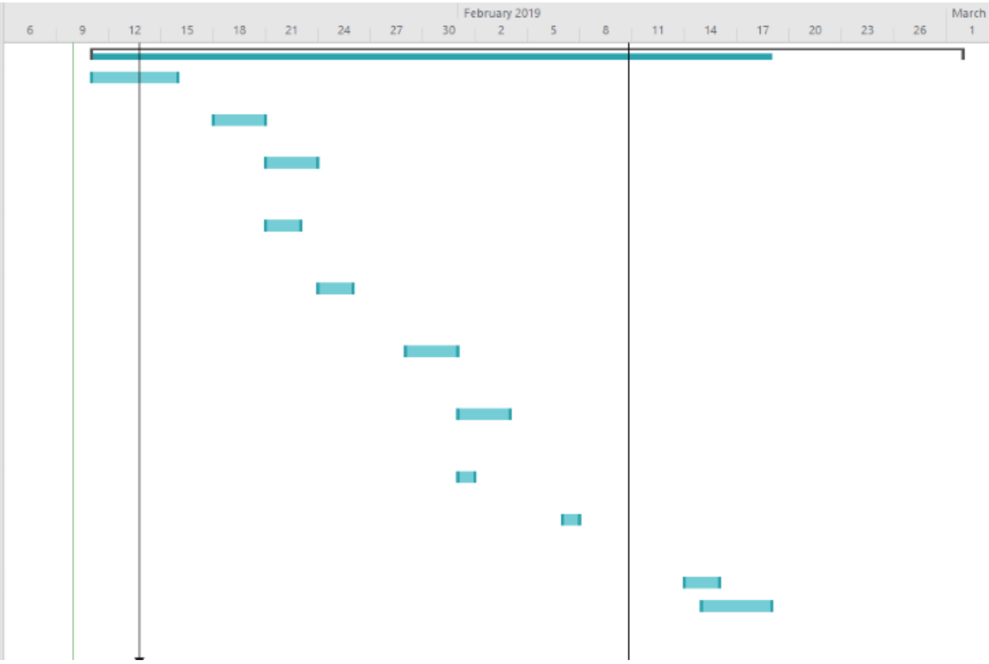


Figure 10-3 Testing Schedule

Task Mode	Task Name	Duratio	Start	Finish
	Fullscale Construction	**21 days**	**Mon 1/14/19**	**Sat 2/9/19**
	Lasercut Bulkheads and	2 days	Mon 1/14/19	Tue 1/15/19
	Altimeter Testin	1 day	Mon 1/14/19	Mon 1/14/19
	Bulkhead Fabrication	4 days	Tue 1/15/19	Fri 1/18/19
	Cut Airframe Tul	3 days	Wed 1/16/19	Fri 1/18/19
	Fin Can Bulkhead/Cente Ring Installation	6 days	Thu 1/17/19	Thu 1/24/19
	Lasercut AV Sled	1 day	Thu 1/17/19	Thu 1/17/19
	Install Motor Tul	1 day	Thu 1/17/19	Thu 1/17/19
	AV Sled Fabricat	3 days	Fri 1/18/19	Tue 1/22/19
	Install Fwd Rail Button	1 day	Fri 1/18/19	Fri 1/18/19
	AV Bay Bulkhead	1 day	Mon 1/21/19	Mon 1/21/19
	Nosecone Bulkhead	1 day	Mon 1/21/19	Mon 1/21/19
	Install Fins	3 days	Mon 1/21/19	Wed 1/23/19
	Payload Bay Bulkhead/Cente Ring Installation	4 days	Tue 1/22/19	Fri 1/25/19
	Drill Pressure Ports and Switch Holes in	0.5 days	Wed 1/23/19	Wed 1/23/19
	Install Aft Rail Button	1 day	Wed 1/23/19	Wed 1/23/19
	Install Motor Retainer	1 day	Wed 1/23/19	Wed 1/23/19
	AV Wiring	3 days	Mon 1/28/19	Wed 1/30/19
	Integrate Payloa	7 days	Mon 1/28/19	Tue 2/5/19
	Install AV Sled	2 days	Wed 1/30/19	Thu 1/31/19
	Checklist Writin	7 days	Wed 1/30/19	Thu 2/7/19
	Paint	1 day	Tue 2/5/19	Tue 2/5/19
	Black Powder Demonstration	1 day	Thu 2/7/19	Thu 2/7/19
	Fullscale Launch	0 days	Sat 2/9/19	Sat 2/9/19

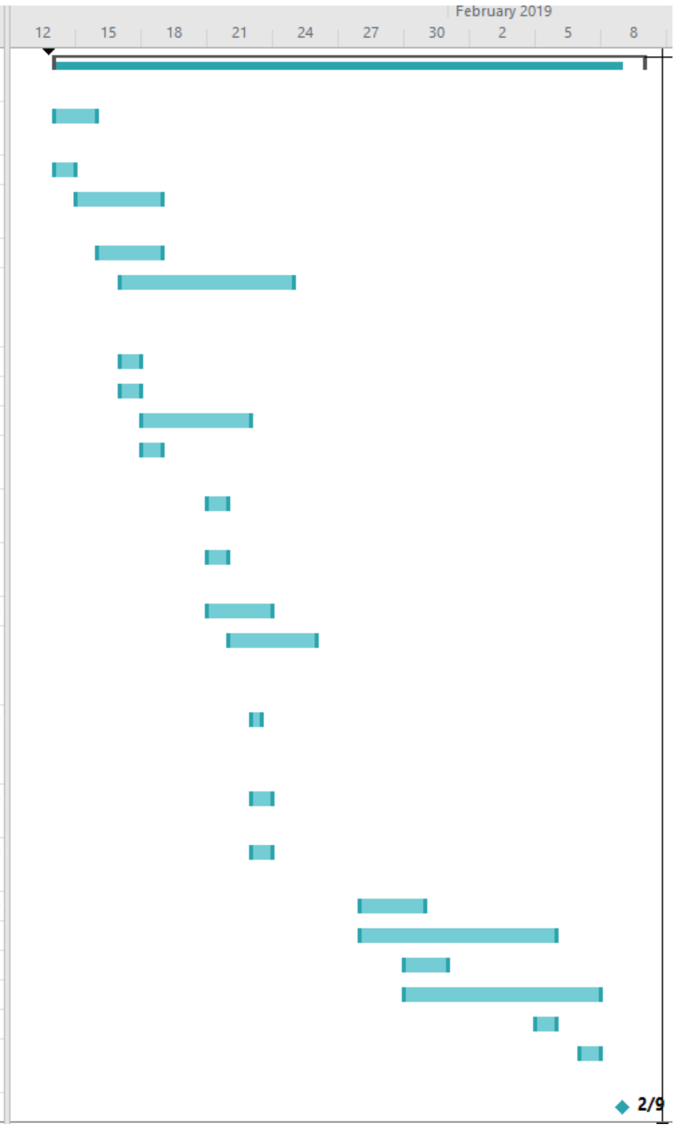


Figure 10-4 Full-scale Construction Schedule