NC STATE UNIVERSITY

Tacho Lycos
2019 NASA Student Launch
Preliminary Design Review

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

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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
SNB	=	Simulated Navigational Beacon
SOW	=	Statement of Work
STEM	=	Science, Technology, Engineering, and Mathematics
TAP	=	Technical Advisory Panel (TRA)
TRA	=	Tripoli Rocketry Association
UAV	=	Unmanned Aerial Vehicle

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1. Summary of PDR Report

1.1 Team Summary

1.1.1 Team Name and Mailing Address

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TRA Certification Number/Level: 02204, Level 3

1.2 Launch Vehicle Summary

1.2.1 Size and Mass

The current leading launch vehicle design is 99.0 inches long with a diameter of 5.5 inches. The rocket mass with the leading motor option is 43.4 pounds.

1.2.2 Preliminary motor choice

The current leading design favors the Aerotech L850W motor. See Section 3.1.5.

1.2.3 Official Target Altitude

The team is declaring a target altitude of 4090 feet. See Sections 3.3.1 and 3.3.2.

1.2.4 Recovery System

The current leading design favors a dual-deployment recovery system using two PerfectFlite StratologgerCF altimeters, a Fruity Chutes 24 inch Compact Elliptical Drogue deployed at apogee, and a Fruity Chutes 120 inch Iris Ultra main parachute deployed at 600 ft AGL.

1.2.5 Milestone Review Flysheet

This document has been submitted separately.

1.3 Payload Summary

1.3.1 Payload Title Payload Experiment Summary

The team aims for the payload to successfully eject from the rocket, 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 rocket is in flight. The purpose of the Egg is to protect the UAV, to provide the UAV a means to self-right, and to act as a place to take off from once the rocket 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 preprogramed controller that will control all the electronics involved in deploying the payload.

2. Changes Made Since Proposal

Table 2-1 lists all changes made to the full-scale launch vehicle since Proposal submission.

Table 2-1 Changes Made Since Proposal

Change	Reason for Change
Current leading design has moved the payload FWD of the AV bay.	Preliminary parachute calculations show that launch vehicle mass must be more evenly distributed among the independent sections in order to comply with all descent requirements. See Section 3.2.7.
The leading motor choice is now the L850W	The L850W delivers the leading design to an apogee of between 4175ft and 4375ft. This is superior to the L1150R which delivers the launch vehicle to an apogee between 3932ft and 3998ft. See Section 3.1.5.
The leading drogue parachute is now the 24-inch Compact Elliptical	The 24-inch Compact Elliptical allows the leading design to descend more slowly until main parachute deployment while still achieving required descent time and wind drift limits. This slower descent under drogue will reduce forces on the vehicle and recovery system during main parachute deployment. See Section 3.2.8.
The leading altimeter configuration is now two PerfectFlite StratoLoggerCF altimeters.	The use of two of the same model altimeter reduces the complexity created by having two different altimeters with two different methods for wiring and preparing for flight. This change reduces risk of human error during the pre-flight preparation of the launch vehicle.
The leading payload deployment process now has the UAV pod suspended on a rod while rotating heavy-side down.	Suspending the pod while it is self-righting decreases the process' reliance on favorable ground conditions. See Section 5.5.2.2.
The leading payload engagement process will now use a low-power mode instead of a magnetic switch.	Preliminary interpretation of the requirements suggested a need for the electronics to be completely powered off, but this is no longer needed.
Leading SNB deployment system now utilizes a solenoid and pin release system	This system is expected to be safer due to the decreased risk of premature beacon deployment.

3. Vehicle Criteria

3.1 Selection, Design, and Rationale of Launch Vehicle

3.1.1 Team Mission Statement

The purpose of the High-Powered Rocketry Club 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 the NASA Student Launch. Furthermore, the club aims to expand knowledge of STEM opportunities to K-12 students across North Carolina.

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 rocket launch as one that achieves the target apogee stated in Section 3.3.1, deploys the drogue parachute at apogee, and deploys the main chute at the target altitude stated in section 3.2.7.

3.1.3 Launch Vehicle Alternative Designs

3.1.3.1 Material

The body of the launch vehicle is responsible for housing all the necessary rocket components such as the motor, parachutes, avionics, and payload. Each of these components are in some way attached to the rocket 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 a body tube material, the compressive force on the rocket 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 the reference area, A. 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 leading 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 rocket and a is the peak acceleration. Based on the current leading configuration, the mass is m = 39.7 lbm for Blue Tube 2.0 body tubes and m = 43.4 lbm for fiberglass body tubes and the peak acceleration using the current leading motor selection is 192 ft/s^2. Using these values, the inertial force on the rocket is calculated to be 236.72 lbf for Blue Tube and 258.78 lbf for fiberglass. This means that the total force on the airframe using Blue Tube is 248.65 lbf and for fiberglass is 270.71 lbf. The material selected for the airframe will need to withstand this loading, so this will be an important factor in selecting a material. Due to strength as well as durability limitations, phenolic was not considered as a material option because it is believed that either Blue Tube 2.0 or Fiberglass would provide a much more durable and reusable airframe. The considerations for choosing between these materials are explained in Sections 3.1.3.1(a) and 3.1.3.1(b).

3.1.3.1(a) Blue Tube 2.0

Blue Tube 2.0 is a rocket body material made by Always Ready Rocketry. Blue tube is a spiral wound vulcanized paper airframe which is made to be stronger than phenolic. It also is thicker than phenolic and therefore has additional strength but is not brittle. The supplier information says that the material is capable of flying at Mach 1 speeds without having to modify the body tubes at all, including glassing or filling gaps. Figure 3-1 shows axial crush test data for Blue Tube 2.0, provided by Always Ready Rocketry[1].

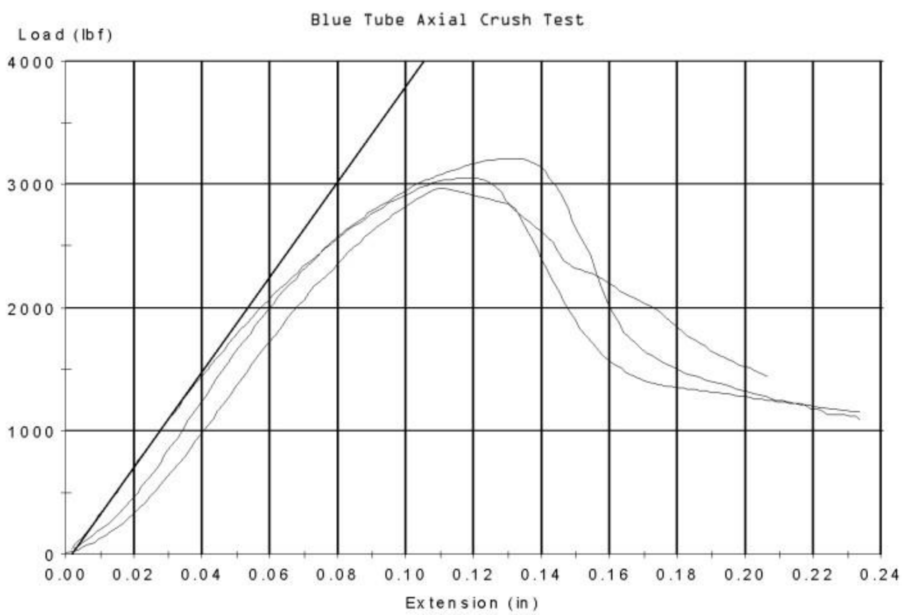


Figure 3-1: Blue Tube 2.0 Axial Crush Test Data

Based on the data given in Figure 3-1, the Blue Tube 2.0 body tubes are able to withstand up to 3000 lbf, meaning that at the worst-case load of 248.65 lbf, this design will have a factor of safety of 12.1. This confirms that Blue Tube will be

[1] (Always Ready Rocketry - What is Blue Tube 2.0 n.d.)

sufficiently strong to withstand the loads it will experience during flight. Blue Tube is also both lighter and cheaper than fiberglass body tubes and would therefore make a feasible option for the full-scale launch vehicle. However, because it is still a paper product, Blue Tube is still susceptible to moisture damage and therefore will require sealing. It also has grooves as a result of being spiral wound which means that wood filler will have to be applied in order to have completely smooth airflow over the surface. The purchase of these materials will be an additional cost which brings the total cost closer to fiberglass and also will require multiple hours of work to do properly.

3.1.3.1(b) Fiberglass

G12 Fiberglass body tubes are made of woven fiberglass filament and epoxy. Fiberglass tubes are the strongest material used in hobby rocketry, which means that at a maximum load of 270.71 lbf, it will be able to withstand any loading experienced during flight. However, the additional strength of the fiberglass causes these body tubes to be both heavier and more expensive than Blue Tube body tubes; 48 inches of Blue Tube 2.0 costs $56.95 while 60 inches of fiberglass body tube costs $188. This means that fiberglass costs over $2/inch more than Blue Tube 2.0. In addition, fiberglass body tubes are heavier: Blue Tube has a density of 0.751 oz/in^3 while fiberglass has a density of 1.07 oz/in^3. However, fiberglass is not susceptible to moisture damage as it is a composite material. These body tubes will not have to be sealed or have wood filler applied, which means that manufacturing and flight preparation will be easier to do and take less time.

3.1.3.2 Launch Vehicle Layout

The overall layout design of the launch vehicle is relatively modular which has led to two main configuration options. The first option includes the payload section aft of the AV Bay and attached to the fin can and the second includes the payload section forward of the AV Bay and attached to the nose cone. These are described further in Sections 3.1.3.2(a) and 3.1.3.2(b).

3.1.3.2(a) Payload Aft

The layout of the payload aft configuration is shown in Figure 3-2. This configuration has separate body tube sections for the fin can, payload bay, main parachute, AV bay, and drogue parachute that are all tethered together. The payload bay and fin can are permanently attached during flight using fasteners so that they can be detached during construction and flight preparation. This configuration also has only three fins to allow for the payload to exit the launch vehicle at a smaller angle to the ground to reduce any deployment issues that the ground may cause.

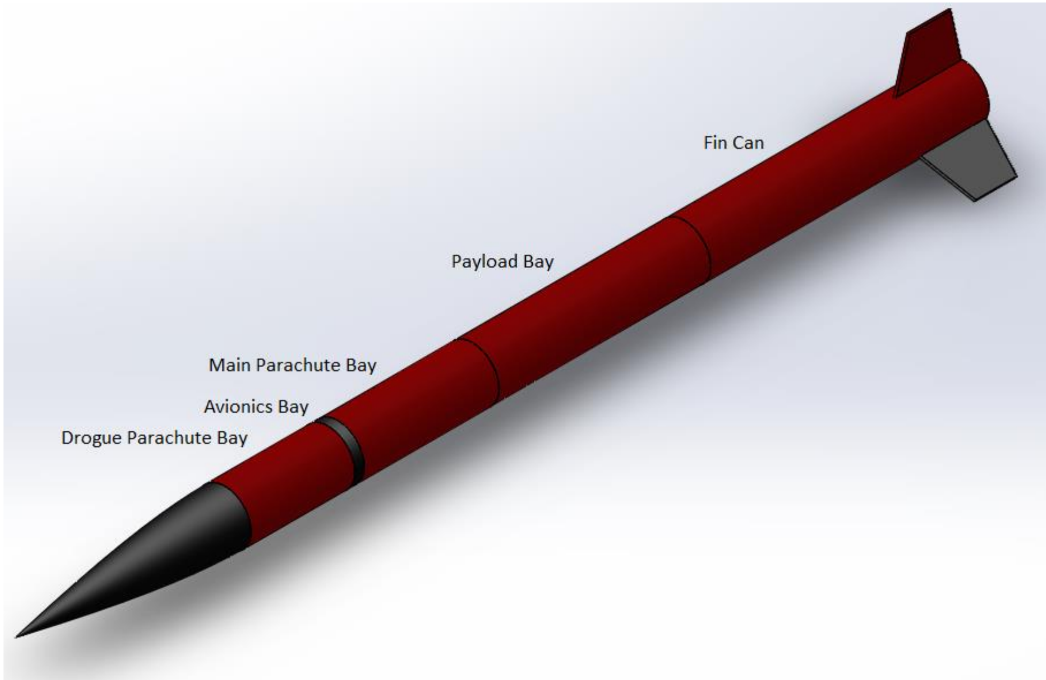


Figure 3-2: Payload Aft Configuration

This configuration allows for the use of the fins to plan the orientation in which the payload should be secured in the rocket. Because the fin can will naturally settle on two of the fins upon landing, there are three possible landing orientations for the payload/fin can section. Knowing this, the payload can be oriented in the payload bay such that it will be able to self-right from any of these possible orientations. In addition, this would allow the routing for the shock cord to align between two of the fins so that it will never be directly on top, meaning that it will not drape over the opening to the payload bay where the UAV is being deployed and block it from being deployed properly.

Though this configuration presents advantages in predicting the payload orientation upon landing, it also means that the two heaviest sections, the payload bay and the fin can, are attached during descent. This increases the kinetic energy at landing as well as significantly increasing the load that will be applied to the bulkheads during main parachute deployment. Based on OpenRocket simulations, the deployment of the main parachute would cause the payload and fin can to decelerate such that it will experience a g-force of 66 g's. In addition, the heavier sections would require a larger parachute which will take up more space and will cause the descent time to increase.

3.1.3.2(b) Payload Forward

The layout with the payload forward of the AV bay is shown in Figure 3-3. This configuration includes a separate body tube section for the payload bay, main parachute, AV bay, and fin can. The drogue parachute would be included between the AV bay and the forward fin can bulkhead. The payload bay is permanently attached to the nose cone during flight with fasteners so that they can be separated during construction and flight preparation. The AV bay is also permanently attached to the main parachute bay using the same fasteners. All three separate sections are tethered together with shock cord. Because the payload is not dependent on the fins in this configuration, this layout has four fins to allow for additional flight stability and easier construction.

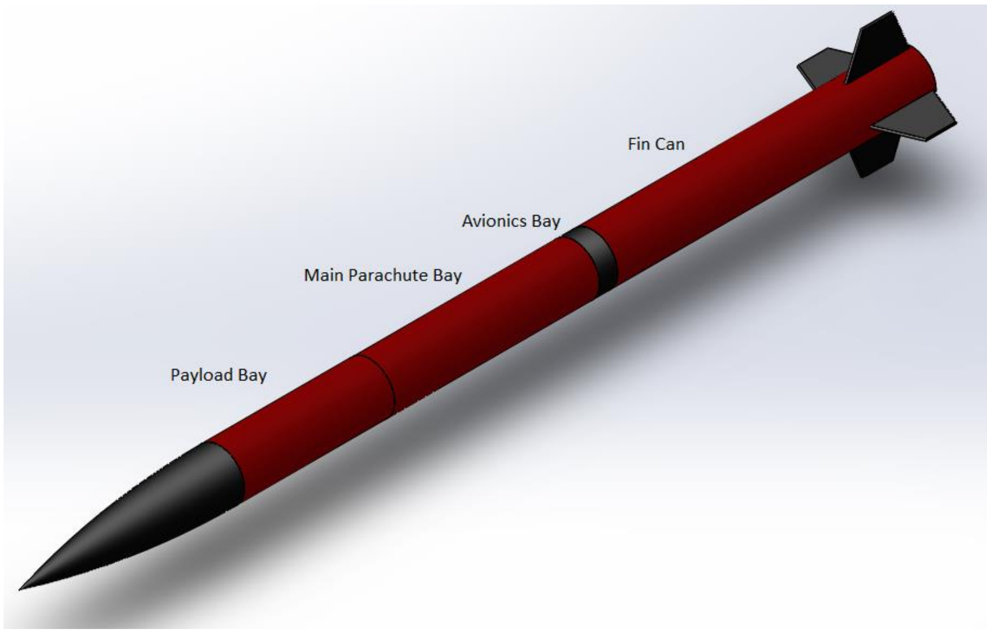


Figure 3-3: Payload Forward Configuration

This configuration breaks the two heaviest sections up so that they are not attached during descent. This helps to reduce kinetic energy at landing as it reduces the heaviest total weight of the sections, meaning that the launch vehicle can have a higher velocity at landing and still remain within the requirements. This opens up more parachute options that are beneficial to meeting the descent time limit of 90 seconds. In addition, the division of weight helps reduce the forces that will be applied to any of the bulkheads at parachute deployment.

This configuration has the same total length and center of pressure location and the weight of the payload being further forward moves the center of gravity forward, which increases the static margin. The two configurations also have a negligible weight difference.

3.1.3.3 Payload Bay

The current leading payload deployment design requires that the payload be ejected from the rocket after landing through the open coupler section at the end. There are centering rings throughout the payload which support the payload deployment pod; the payload will be secured to a bulkhead at one end of the payload bay. However, this makes accessibility difficult where the electronics and the latch to secure the payload will be mounted, so the payload bay was designed to give additional ease of access to that area. The two alternatives being considered are presented in Sections 3.1.3.3(a) and 3.1.3.3(b).

3.1.3.3(a) Access Hatch

The payload bay design including an access hatch from the outside of the body is shown in Figure 3-4. This design has a single bulkhead which will have all payload deployment electronics, the U-bolt connecting to the shock cord, and the latch which secures the payload pod attached to it. Both sides of the bulkhead will be utilized for space the payload deployment system, however, this makes ensuring that the payload is latched properly, adjusting any electronics on the inner edge of the bulkhead after installation, and attaching the shock cord very difficult. To provide better access to this area, a hatch will be cut and installed in the body of the launch vehicle. This hatch will be removable but secured during flight.

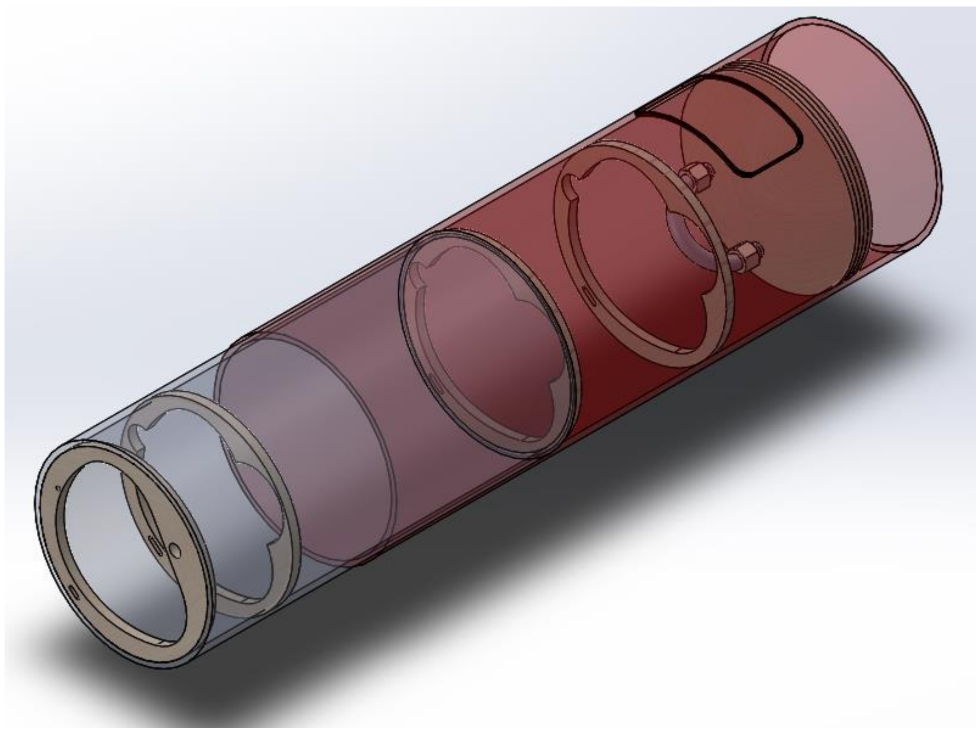


Figure 3-4: Payload Bay with Access Hatch

This design allows for the U-bolt attached to the main parachute to be in the payload bay where the bulkhead will be more securely installed. While the shock cord would still be routed through the centering rings, it would not have to be routed even further past the payload bay bulkhead.

However, this design will require cutting the hatch out of the launch vehicle body which would be difficult to accurately do with available materials. In addition, the hatch will have to have hardware to mount it to the launch vehicle for flight, and this hardware has potential to fail during flight causing the hatch to fall off. Air will also flow into the gap at the hatch edge, which will disrupt the flow over the launch vehicle body as well as potentially adding force that could remove the hatch. The hatch would also decrease load transfer in this area, reducing the strength of the vehicle in an unpredictable way. Finally, hardware to attach the hatch would add more weight and space limitations to an already heavy, space constricted area of the launch vehicle.

3.1.3.3(b) With Removable Bulkhead

The payload bay design with a removable bulkhead is shown in Figure 3-5. This design uses L-brackets to secure a removable bulkhead that will be located at the base of the coupler into this section. This bulkhead will have all payload deployment electronics, latches, and hardware attached to it and the shock cord will be routed through it to attach to a separate, permanently attached bulkhead.

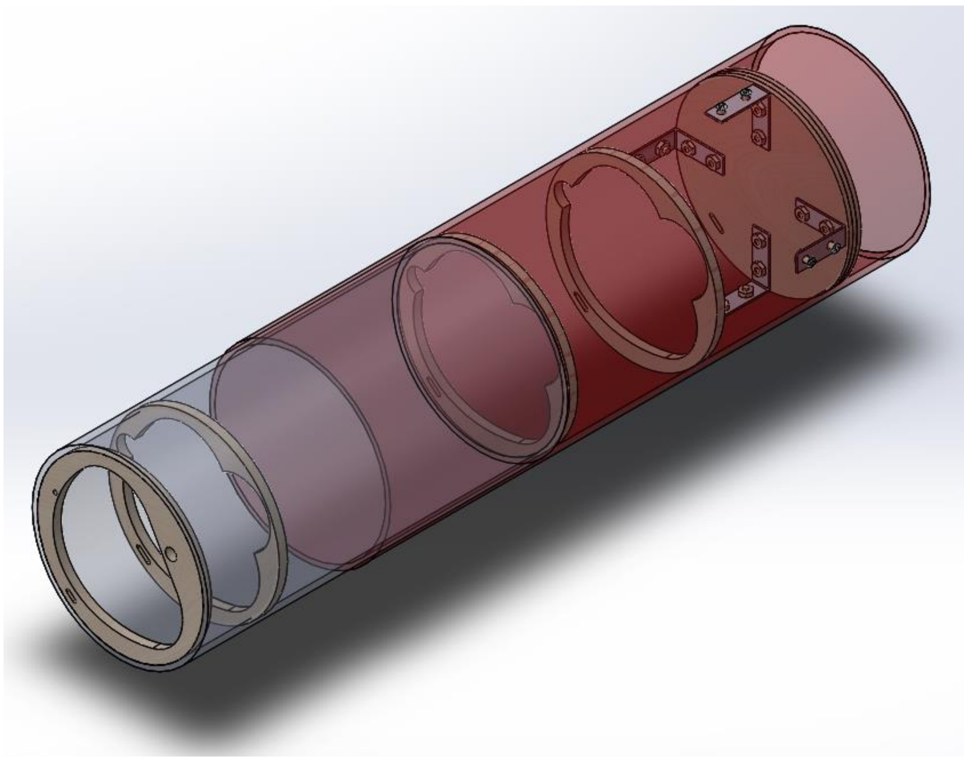


Figure 3-5: Payload Bay with Removable Bulkhead

This design allows all electronics and the payload to be secured prior to the bulkhead being inserted into the payload section. This ensures that the payload can be securely clamped and that all electronics can be easily accessed before the bulkhead is inserted into the payload bay. The outer rocket body will remain smooth allowing for the best flow over the body as possible. This also gives more space on the bulkhead for the payload deployment system because there is no longer a U-bolt in the way. However, in the leading launch vehicle configuration, the bulkhead that is attached to the shock cord will be contained within the nose cone. The shape of the nose cone means that this bulkhead will have a smaller diameter than the main body bulkheads, which could reduce its strength, and may have a less reliable attachment to the wall of the nose cone due to difficulty in matching the exact contours.

3.1.3.4 AV Bay

The AV bay contains the altimeters which measure the altitude of the launch vehicle and control parachute deployment. Because the altimeters control the ejection charges, the blast caps where the black powder is placed are attached to the bulkheads on either end of the AV Bay. The two AV bay configurations being considered are presented in Sections 3.1.3.4(a) and 3.1.3.4(b).

3.1.3.4(a) Integrated AV Bay

The integrated AV Bay design is shown in Figure 3-6. It consists of a length of body tube which will house the AV bay, the drogue parachute, and the main parachute. The AV bay is secured on two threaded rods which run between two bulkheads and a hatch is cut from the body tube for the full distance between the two bulkheads. This hatch will be secured to each of the bulkheads in two points, one at each corner. The blast caps are secured to the outside of each bulkhead along with a U-bolt which will secure the shock cord connecting to its respective parachute.

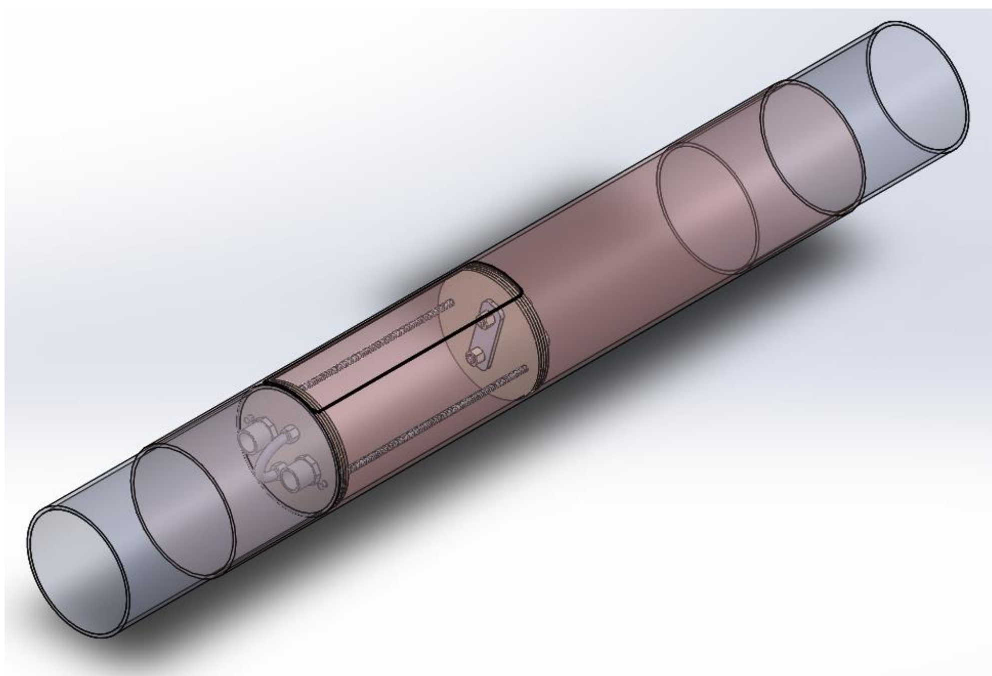


Figure 3-6: Integrated AV Bay

This design allows for the interior of the AV Bay to be accessible even when the launch vehicle is fully assembled. Because of this, any last-minute adjustments to altimeters can be performed easily. However, as can be seen in Figure 3-6, putting black powder into the blast caps as well as attaching the shock cords will require reaching into long pieces of body tube, which can make proper assembly difficult. In addition, the gap in the airframe where the hatch is cut out disrupts the air flow over the vehicle body and also disrupts the load transfer path through the fiberglass, meaning that the body will not be as strong as a solid fiberglass body.

3.1.3.4(b) Modular AV Bay

The Modular AV Bay design is shown in Figure 3-7 and consists of a length of coupler which is capped by a bulkhead on either side. It has a thin section of body tube to allow space for the key switches which will arm the altimeters but is otherwise contained within the coupler section. The blast caps are secured on the outside of each bulkhead and there is a U-bolt on each bulkhead which will attach to either the main or drogue parachute. The AV sled will be supported on the two threaded rods that run the length of the AV bay.

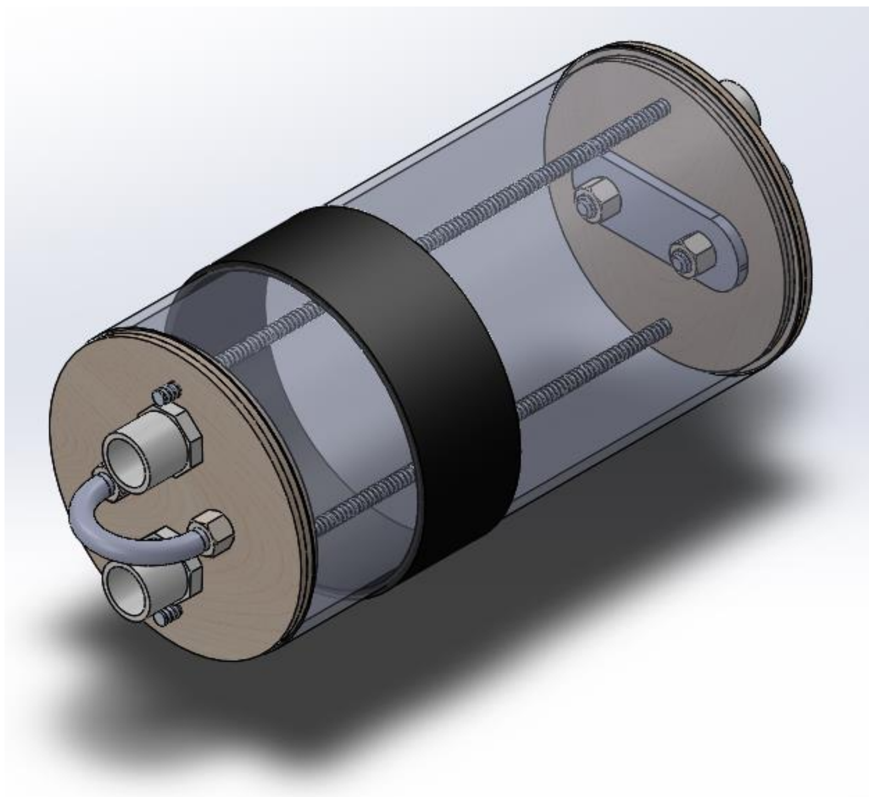


Figure 3-7: Modular AV Bay

This design allows the AV bay to be prepared on launch day separate from the rest of the launch vehicle so that all preparations can be done in parallel; it also makes the blast caps easily accessible to load the black powder charges as there are no long body tubes to reach into. However, this design makes it so that once the AV bay is installed into the launch vehicle, the altimeters are inaccessible and any fixes that may be necessary will be much more difficult to execute, involving completely disassembling the rocket.

3.1.3.5 Fin Can

The current leading design of the launch vehicle requires that the fin can be attached to a shock cord that is attached to the drogue parachute. In order to accomplish this, two alternatives are being considered: one which attaches the shock cord directly to the motor tube, and one which attaches the shock cord to a U-bolt within the fin can. These alternatives are discussed in Sections 3.1.3.5(a) and 3.1.3.5(b).

3.1.3.5(a) Shock Cord Attached to Motor Tube

The fin can design with the shock cord attached to the motor tube routes the shock cord through the forward fin can bulkhead. The shock cord is then wrapped around the motor tube as shown in Figure 3-8 and is epoxied to secure it.

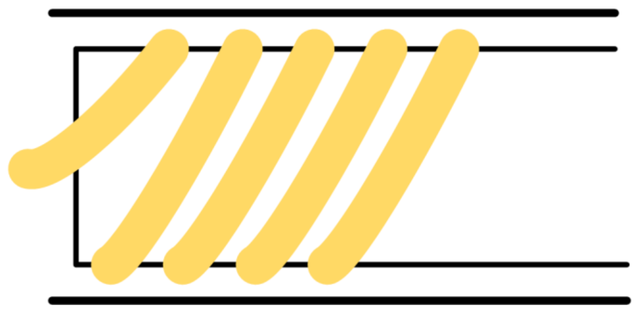


Figure 3-8: Fin Can with Epoxied Shock Cord

This design reduces the weight in the fin can, an already heavy section of the launch vehicle, by not requiring a U-bolt and by enabling the bulkhead to be thinner. This also removes points of failure at the U-bolt and the bulkhead, both in the bulkhead structure itself and at the joint between the bulkhead and the body tube. However, this creates a single point of failure for the shock cord attachment as if the epoxy fails, the shock cord will unravel, and the fin can will not be attached to a parachute during descent. In addition, if there is ever any damage to the shock cord which is attached to the motor tube, it would not be able to be replaced once the motor tube is installed in the launch vehicle.

3.1.3.5(b) Shock Cord Attached to U-Bolt

The fin can design with the shock cord attached to a U-bolt utilizes the bulkhead that is placed at the forward end of the motor tube. A U-bolt is installed through this bulkhead for the shock cord to be attached to. This configuration is shown in Figure 3-9.

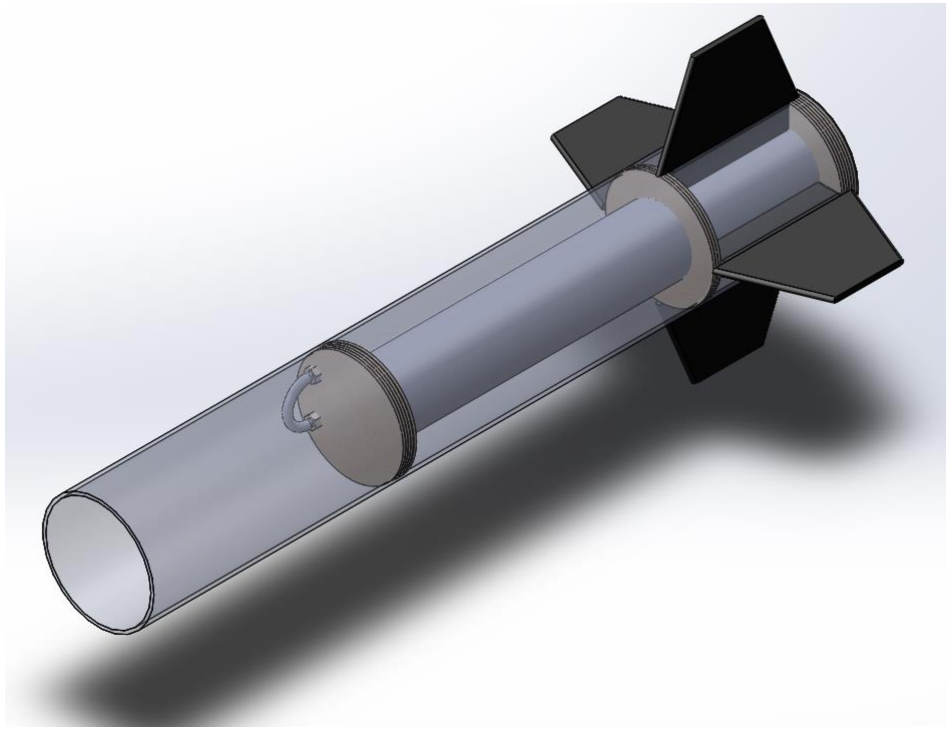


Figure 3-9: Fin Can with U-Bolt

This fin can configuration rids the system of single points of failure by using the U-bolt because it will remain secure even if one side fails. The U-bolt allows the shock cord to be attached to the launch vehicle on launch day, allowing the shock cord to be interchangeable should a different one be necessary at any point. However, the U-bolt adds weight to the system in a location of the launch vehicle which is already heavy.

3.1.3.6 Fin Configuration

3.1.3.6(a) Three-Fin Configuration

The 3-fin configuration is valued by hobby rocketeers for several reasons. Chief among them is the reduced complexity of the build process. To be affixed properly, fins should be secured to the body tube and motor tube of the rocket with epoxy fillets. Tight clearances in fin can make proper assembly a challenge. Therefore, it is advantageous to need fewer fillets. With fewer fillets comes the added benefit of less weight in the fin can. A light fin can will cause the center of gravity to be farther forward, contributing to the positive static stability of the launch vehicle.

The primary disadvantage of the 3-fin configuration is its lack of roll stability in cross wind conditions. Without 2 axis symmetry, 3 fin rockets tend to roll to an equilibrium location at high angles of attack, like those experienced at rail exit on windy days.

3.1.3.6(b) Four-Fin Configuration

The 4-fin configuration offers advantages in roll stability because of its 2axes of symmetry. Furthermore, the addition of an extra fin results in a smaller fin size to achieve the same center of pressure configuration. Traditionally, 4-fin rockets are easier to build because the fins are set at 90-degree angles to each other. The teams' manufacturing equipment is better suited to manufacturing fins cans in this manner.

Disadvantages of the 4-fin configuration are its longer construction time. The additional fin means another set of fillets must be applied and within a smaller area than the 3-fin configuration. While the overall fin size is smaller, the addition of an extra set of fillets adds weight to the fin can.

3.1.3.7 Nose Cone design

Commercial availability of large diameter fiberglass nosecones is limited. This constrained the launch vehicle to two alternative nosecones designs.

3.1.3.7(a) 5:1 Conical Nosecone

Conical nosecones are popular amongst hobbyist because they can be easily manufactured from low costs materials such as paper and plastic. Since the team will be using a commercial off the shelf nosecone, ease of manufacture is not a concern to the team. Conical nosecones are readily available, but only in a 5:1 ratio at body diameters between 5 and 6 inches.

Figure 3-10 is an illustration of the 5:1 conical nosecone. The long length of this nosecone makes it heavier than other styles of nosecone. This is a disadvantage as it takes weight away from payload and recovery components.

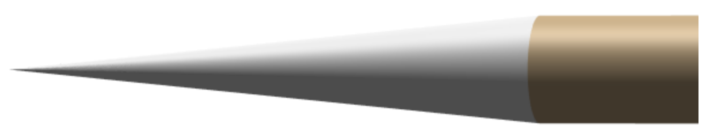


Figure 3-10 5:1 Conical Nosecone

3.1.3.7(b) 4:1 Ogive Nosecone

Ogive nosecones of various ratios are also popular amongst hobbyist for their availability and aesthetic design. At speeds above Mach 1, ogive nosecones provide low drag coefficients. However, this trait is not relevant to the competition as handbook requirement 2.24.7 prohibits the launch vehicle from exceeding speeds of Mach 1.

At a ratio of 4:1, the ogive nosecone is lighter than the 5:1 conical alternative and allows for a larger portion of the weight budget to go to payload and recovery components. Figure 3-10 below is an illustration of the 4:1 ogive nosecone.

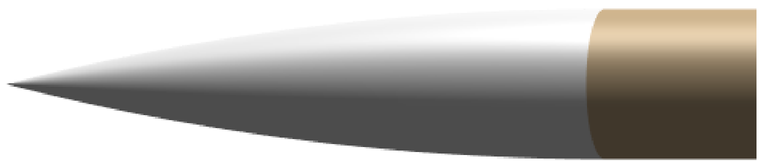


Figure 3-11 4:1 Ogive Nosecone

3.1.4 Leading Design

A dimensioned drawing of the leading launch vehicle design is shown in Figure 3-12. As shown, the leading configuration consists of a 22 inch nose cone with a 2.75 inch coupler, a 14.5 inch payload bay, 22.5 inch main parachute bay, 2 inch AV bay band, a 35 inch fin can, and a 22 inch motor tube. All body tubes are 5.5 inches in diameter. The payload bay and main parachute bay are joined by a 11 inch 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. 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.

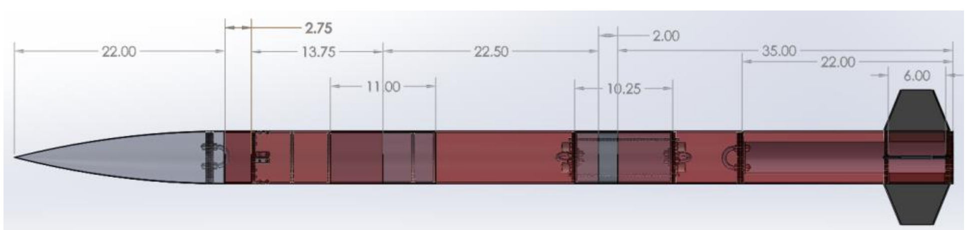


Figure 3-12: Leading Design Dimensions

This configuration is the payload forward layout described in Section 3.1.3.2(b). While this configuration doesn't allow for predicting the orientation of the payload at landing, the current leading payload deployment system does not rely on this. Because of this and due to the benefits to the kinetic energy and applied loads at parachute deployment, this layout is the current leading configuration of the launch vehicle.

3.1.4.1 Material

Though G12 Fiberglass is heavier and more expensive than other available materials, it is currently the top choice for launch vehicle body material. Even with fiberglass, our current leading configuration is a total of 43.4 lbm, which is a reasonable mass and will not cause any issues with reaching our apogee target. Due to unpredictable field conditions in North Carolina, having an airframe material that is immune to moisture is crucial. While Blue Tube can be sealed to be resistant to moisture, this will add to the fabrication time of the rocket and will be more difficult to execute properly. None of the team have sealed body tubes before, which means there is large room for error, and this has been deemed unacceptable. Fiberglass will ensure that our launch vehicle is as durable as possible so that it will be reusable and is therefore worth the added weight and cost.

3.1.4.2 Nose Cone

The nose cone design is shown in Figure 3-13 with a bulkhead and U-bolt mounted in it. This bulkhead will be attached to a shock cord which will be routed through the payload bay and attached to the main parachute. The bulkhead will be recessed four inches into the nose cone from the edge of the coupler.

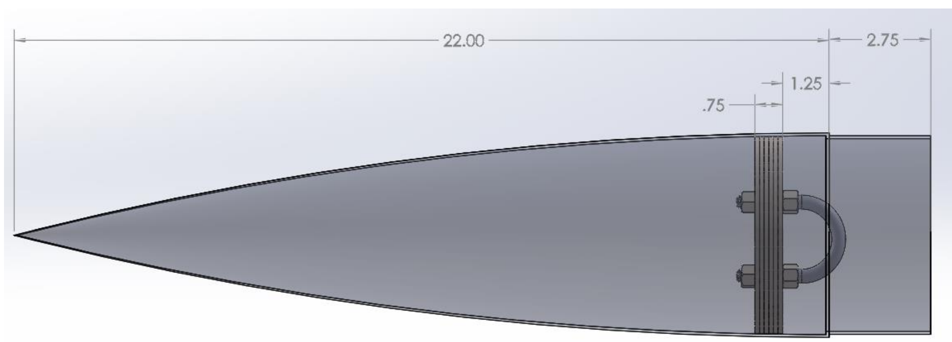


Figure 3-13: Nose Cone Dimensions

This design will make fabrication more difficult as it will require the bulkhead diameters to match the contours of the inside of the nose cone. However, the added benefits to payload accessibility are worth the added manufacturing time as discussed in Sections 3.1.3.3(b) and 3.1.4.3.

The nosecone shape is a 4:1 ogive design. As discussed in Section 3.1.3.7(b) the 4:1 ogive nosecone is lighter than the alternative. However, its fiberglass construction makes it heavy enough that nose ballasting is not necessary to maintain a static stability margin above 2.0 calibers. Additionally, its shape provides a larger interior space in which payload deployment electronics can be stored. This space may become necessary as the payload deployment electronics are designed and integrated into the launch vehicle.

3.1.4.3 Payload Bay

A dimensioned drawing of the payload bay is shown in Figure 3-14. The leading design is the configuration with a removable bulkhead, discussed in Section

3.1.3.3(b). The removable bulkhead would be supported by L-brackets on the interior of the payload bay such that the outer layer of the bulkhead is two inches from the edge of the body tube, which will place it in contact with the nose cone coupler. There will be four centering rings spread throughout the length of the payload bay to support the payload deployment pod, including one that is flush with the edge of the coupler, as shown. The centering rings will be 0.25 inches thick in order to save weight as they will not have to support high loading. The weight of this section without the payload or payload deployment system is 4.975 lbm.

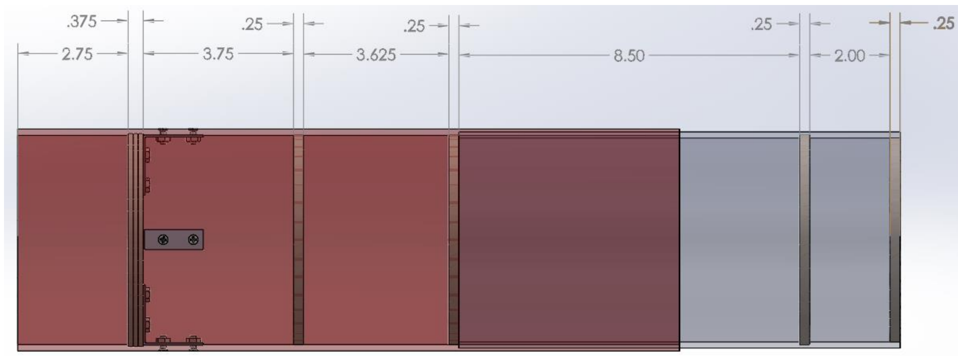


Figure 3-14: Payload Bay Dimensions

Though mounting a bulkhead in the nose cone is not ideal, the benefits of space on the bulkhead, easier manufacturing, no disruptions on the outer body of the launch vehicle, and even better access than is provided by the hatch design are significant enough that this configuration is the current leading design for the payload bay.

3.1.4.4 AV Bay

A dimensioned drawing of the current leading AV bay design is shown in Figure 3-15. The leading design is the configuration discussed in Section 3.1.3.4(b) which is contained within a section of coupler. The coupler section containing the AV bay will be 10.25 inches long with a 2 inch long band of body tube placed such that the coupler length in each of the adjacent sections is sufficient per requirement 2.8.1. The coupler will be closed on either end by bulkheads which have layers of both the coupler inner diameter and the body tube inner diameter. This bulkhead design allows the couplers to be secure against the edge of the coupler and to seal the AV bay from the ejection charges. The blast caps are mounted to the outside of each bulkhead and there is a U-bolt on each bulkhead to attach to a shock cord. Two 0.25 inch threaded rods span the length of the AV bay coupler, which will both secure the bulkheads to the coupler as well as support the AV bay sled within. The mass of this section without the AV bay sled is 3.15 lbm.

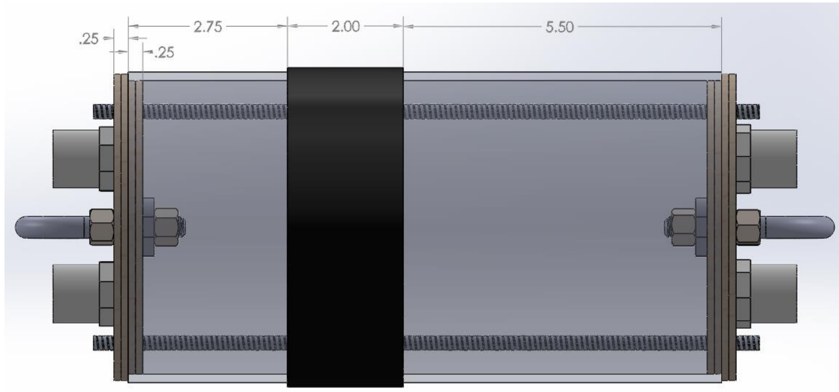


Figure 3-15: AV Bay Dimensions

While this configuration may make last minute fixes more difficult, these issues are less common than launch day preparation. The time that will be saved by being able to prepare the AV bay at the same time as the payload, parachutes, etc. as well as the greater ease of access to the blast caps and U-bolts as well as the better air flow and airframe strength is significant enough that it greatly outweighs the potential downside of more difficult access should anything need fixing after the launch vehicle is assembled. For these reasons, this configuration is the leading design.

3.1.4.5 Fin Can

A dimensioned drawing of the fin can leading configuration is shown in Figure 3-16. The fin can houses the motor tube which is secured by the engine mount at the aft end of the fins. There will be a centering ring at the forward end of the fin tabs to support the motor tube and to help locate the fin tabs properly. Finally, a bulkhead will be placed at the forward end of the motor tube. This bulkhead will have one layer that will have the outer diameter of the motor tube cut out so that the motor tube will rest within the bulkhead. This design is intended to help support the motor tube during fabrication rather than to distribute loads from the motor. This bulkhead will have a U-bolt which will secure the drogue parachute which will be housed within the fin can. The mass of the fin can is 10.2 lbm.

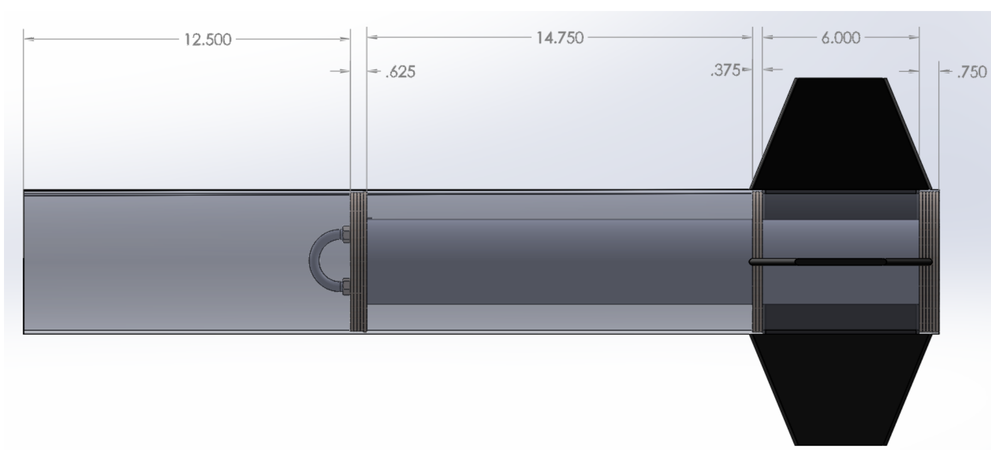


Figure 3-16: Fin Can Dimensions

While this configuration will add weight to this system, the weight addition is determined to be negligible and worth the added benefit of having the U-bolt to secure the drogue parachute. This will allow the shock cord to be interchangeable if necessary, thus increasing the reusability of the launch vehicle. In addition, this will not require as much shock cord length, which means that shock cords that are currently owned by the team can be used. Finally, this reduces the chance of failure because the shock cord attachment does not have just a single point of failure. For these reasons, this configuration is the current leading design for the fin can.

3.1.4.6 Bulkhead Sizing

The bulkhead thicknesses given in the dimensioned drawings of the nose cone, AV bay, and fin can are approximations. Once the design is finalized and the final weights can be obtained, the bulkhead thicknesses will be calculated to withstand the loads using hand calculations and simulations in ANSYS. The hand calculations will be done using plate bending equations found in Roark's Formulas for Stress and Strain[2]. These equations assume that the load is applied over a small circular area; since the load is actually applied over the two U-bolt flanges, this assumption will make the calculation conservative. The following equation, which assumes a thin circular plate which is fixed around the edge with the load centered, is used for solid bulkheads with a centered U-bolt:

$$M_r = \frac{W}{4\pi}\left[(1+\nu)ln\frac{a}{r} - 1 + \frac{(1-\nu){r'_0}^2}{4r^2}\right] \qquad (4)$$

Where W is the applied load, $\nu = 0.426$ is the Poisson's ratio of the birch plywood[3], a is the distance from the edge of the bulkhead to the circular area the load is being applied over, r is the radius of the bulkhead, and $r'_o = \sqrt{1.6{r_o}^2 + t^2} - 0.675t$, where r_o is the radius of the load application circle. For solid bulkheads with the U-bolt not centered, the following equation is used:

$$M_{max} = \frac{-W}{8\pi}\left[2 - \left(\frac{r'_o}{a-p}\right)^2\right] \qquad (5)$$

Where a is the radius of the bulkhead and p is the distance between the center of the bulkhead and the area where the load is being applied. Finally, for the engine block which will be fixed on the edges and the load is applied to the edge of the inner circular cutout, the moment is calculated as:

$$M = -Wa\left(L_9 - \frac{C_8 L_6}{C_5}\right) \qquad (6)$$

[2] (Roark, Budynas and Young 2002)
[3] (Green, Winandy and Kretschmann 1999)

Where

$$C_5 = \frac{1}{2}\left[1 - \left(\frac{b}{a}\right)^2\right] \tag{7}$$

$$C_8 = \frac{1}{2}\left[1 + \nu + (1 - \nu)\left(\frac{b}{a}\right)^2\right] \tag{8}$$

$$L_6 = \frac{r_o}{4a}\left[\left(\frac{r_o}{a}\right)^2 - 1 + 2ln\frac{a}{r_o}\right] \tag{9}$$

$$L_9 = \frac{r_o}{a}\left\{\frac{1 + \nu}{2} ln\frac{a}{r_o} + \frac{1 - \nu}{4}\left[1 - \left(\frac{r_o}{a}\right)^2\right]\right\} \tag{10}$$

Using the moments calculated, the stress is calculated using the following:

$$\Sigma = \frac{My}{I} \tag{11}$$

Where y is half the thickness of the bulkhead and I is the moment of inertia of the bulkhead. Using this stress value, and yield stress values of birch plywood, it can be ensured that the bulkhead will be able to withstand the force being applied at parachute deployment.

In addition to these calculations, ANSYS analysis will be performed since the hand calculations make several assumptions that could affect the results. The hand calculations will be used to validate that the ANSYS model results are reasonable and the bulkhead thicknesses will be determined with a factor of safety included.

3.1.4.7 Fin Configuration

To improve roll stability, the team selected a 4-fin configuration for the current leading launch vehicle design. This design will require a longer manufacturing process, but because the current leading design also places the payload forward of the AV bay, the fin can is capable of being made in parallel with the payload section. As discussed in Section 3.1.3.6(b), the teams' manufacturing equipment is better suited to constructing fins at 90 angles to each other. Furthermore, smaller fins are less likely to strike the ground on landing. This increases the reusability factor of the current leading launch vehicle design.

3.1.5 Motor Alternatives

The size and mass of the leading design require the use of an L-class motor. Team possesses an Aerotech RMS 75/3840 motor casing which will fit in the motor tube of the leading design. There are commercially available motors that can fit this casing: The L850W, L1150, L1390, and L1520. Data from each of these motors was used to simulate launches in Rocksim. All launches were simulated at the latitude and field elevation of the competition launch site. Furthermore, each motor configuration was simulated at wind conditions of 20 mph sustained winds and 0mph sustained winds using the assumption that these conditions would yield the highest and lowest possible apogees for each motor. In all cases, the launch vehicle was able to reach a rail exit velocity of more than 52 fps and a thrust to weight ratio of greater than 5:1. Since all 4 motors satisfied the above criteria, apogee became the deciding factor. The team is permitted to select a target apogee between 4000 ft and 5500 ft. During the design of the recovery subsystem it was determined that an apogee closer to 4000 ft is desirable to achieve drift and decent times that comply with competition requirements. With this goal in mind, the team examined the data in Table 3-1 to select the leading motor configuration.

Table 3-1 Simulated Apogee Limits for Motor Alternatives

Motor	Lowest Apogee (ft.)	Highest Apogee (ft.)
L850W	3788	4209
L1150R	3591	3902
L1390G	4282	4792
L1520T	4586	4812

The L1150R Achieves an apogee nearest to 4000ft of any option, but its range is not within the permitted target range. This disqualifies it for use in the current leading design configuration. The L850W provides a window that encompasses the 4000ft limit. The L1390G has an apogee window, window slightly above the L850W.This makes it a good alternative should the launch vehicle mass increase. The L1520T has the narrowest apogee range of the sample and its range is well centered in the permitted target range. Like the L1390G, it is an acceptable alternative should the current leading design become heavier. The data in Table 3-1 suggests that the L850W is the best option for the current leading design.

3.2 Recovery Subsystem

3.2.1 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 an apogee altitude, 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 3.2.10 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. For redundancy, 1 second later, 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, from the avionics bay, the main altimeter 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 rocket, releasing the main parachute deployment bag, which 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. For redundancy, one second later, the redundant altimeter will send a signal through the 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 3.2.10 Black Powder Sizing 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.

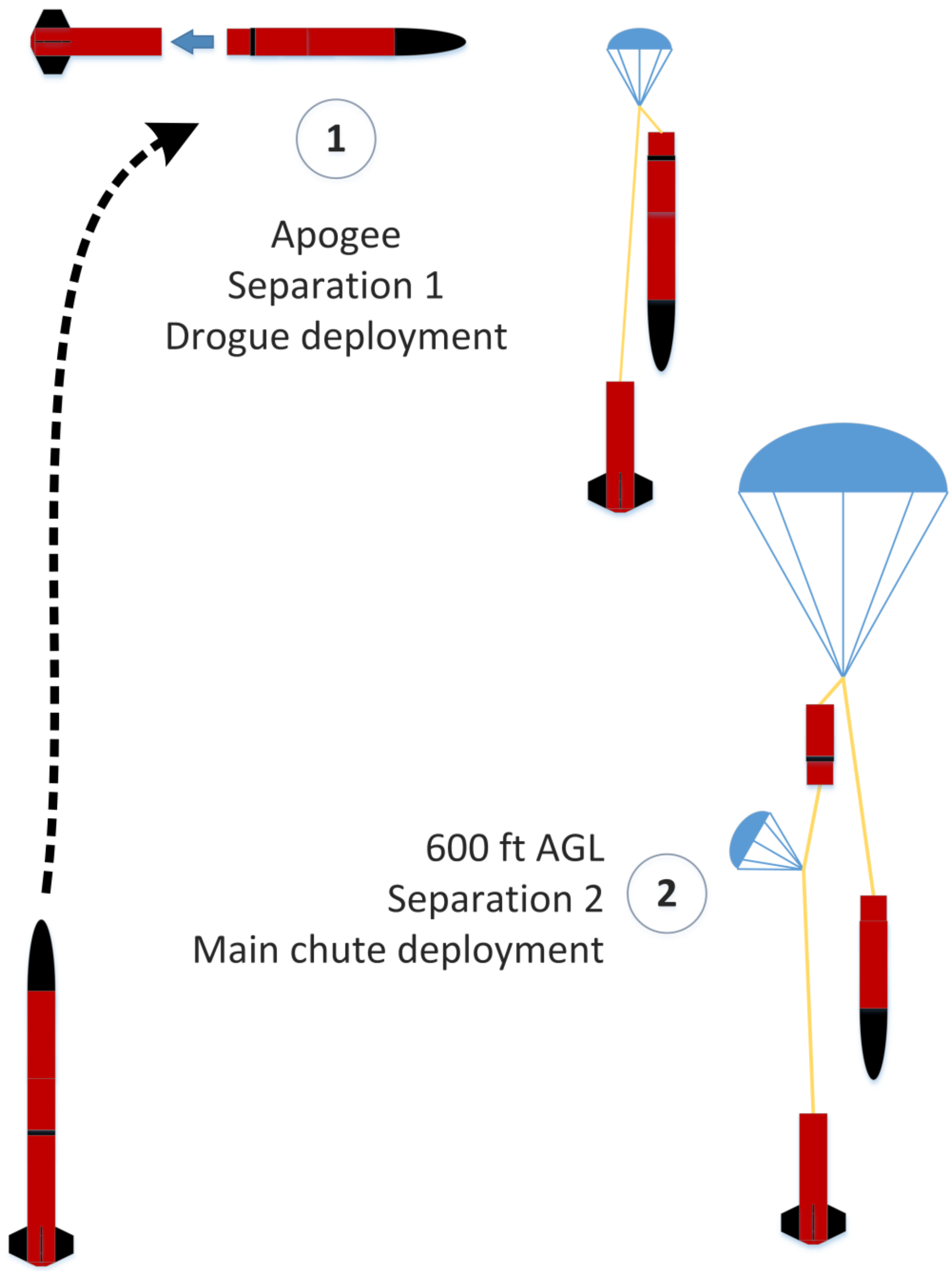


Figure 3-17 Recovery Events Overview

At each joint between separable sections, four nylon shear pins will be used to ensure no pre-mature separations of sections occur during flight. Following the competition rules, the team will always conduct ground tests of black powder ejection events to confirm the quantity necessary to confidently separate rocket sections without damaging any components before each flight.

3.2.2 Avionics Alternatives

Three commercially-available altimeters were considered for use in the vehicle's recovery system. The Adept22, Entacore AIM 3.0, and PerfectFlite StratoLoggerCF. For the purposes of the NASA Student Launch competition, the primary parameters to consider are form factor, ease of wiring, measurement precision, battery life, and ability to customize the main deployment altitude. Table 3-2, below, compares the three altimeter alternatives and was compiled from manufacturer data and data gathered from Apogee Rockets.

Table 3-2 Comparison of Altimeter Alternatives

Altimeter	Adept22	Entacore AIM 3.0	StratoLoggerCF
Main Deployment Altitude Adjustability	300 ft intervals 1800-300 ft	1 ft interval 100-9999 ft	1 ft interval 100-9999 ft
Delay Charge after Apogee	No delay, output 1 only fires at apogee	Yes	Yes, 0-5 sec
Max Altitude	25000 ft AGL	38615 ft MSL	100000 ft MSL
Minimum Apogee	300 ft AGL	N/A	100 AGL
Altitude Resolution	1 ft	1 ft	1 ft if < 38000 ft MSL
Battery Life (reported)	48 hrs	30 min recording per flight	18 mins recording per flight
Dimensions	22.86mm x 15.24mm x 71.12mm	70mm x 25mm x 15mm	50.8mm x 21.336mm x 12.7mm
Data Logged	Apogee	Continuity, voltage, temp, alt	Alt, temp, voltage

The Entacore AIM 3.0 has the ability to delay the drogue black-powder charge after apogee, making it suitable for use as a redundant altimeter. One downside to the Entacore AIM 3.0 is the lack of battery life compared to the Adept22; however, the Entacore AIM 3.0's battery life is enough to meet the pad stay time and flight time requirements of the competition. Team experience has found that the Entacore AIM 3.0's design makes properly connecting the altimeter before flight challenging. The single battery input with no integral switch terminal connection requires additional wiring connections to be made in on avionics sled to accommodate the altimeter's arming switch. This increases the space and number of components required for the avionics sled. Additionally, the Entacore AIM 3.0's use of a common ground terminal for the main and drogue charges presents a challenge to ensuring the connection within that terminal is secure. The presence of two wires within a single screw terminal can be less secure than if only a single wire is present, thus this design increases the chance of failure of the main and drogue ejection charges. This is not acceptable to the team. The Adept22's similar design, where the battery and both charges share a positive terminal, also presents the same increased chance of failure.

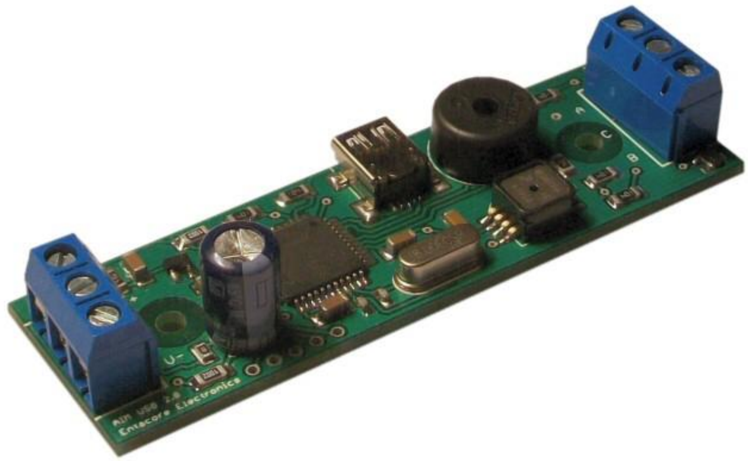


Figure 3-18 Entacore AIM USB 3.0 Altimeter

The biggest advantage of the StratoLoggerCF over both the Entacore and Adept22 altimeters is its compact size and reliability, which allows for more flexibility in mounting the altimeter and sizing the payload sled.

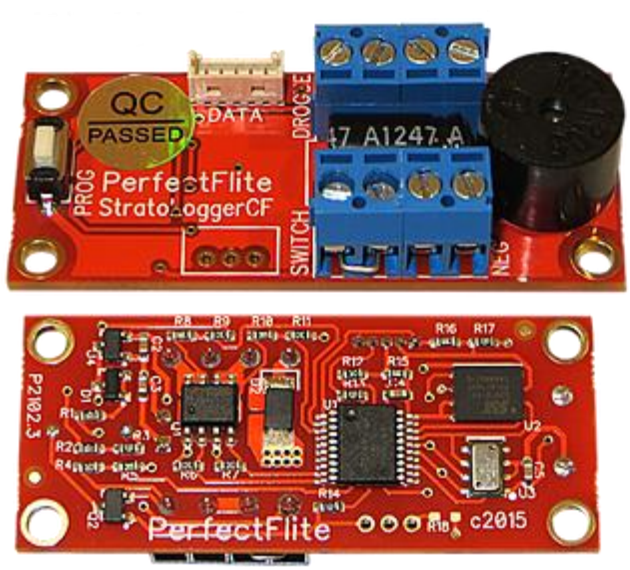


Figure 3-19 PerfectFlite StratoLoggerCF Altimeter

The Adept22, although a reliable device that performs well, is limited by a lack of adaptability. The limited main parachute deployment altitudes pose issues while attempting to meet kinetic energy and wind drift requirements. Secondly, because there is no function to detonate charges on a time-delay after apogee, the Adept22 cannot be used as a secondary altimeter. Finally, team experience has found that wiring the Adept22 is challenging in the field. The design is susceptible to being improperly wired in a manner that causes poor connection to one of three mission-critical components, namely the e-matches and altimeter power supply.

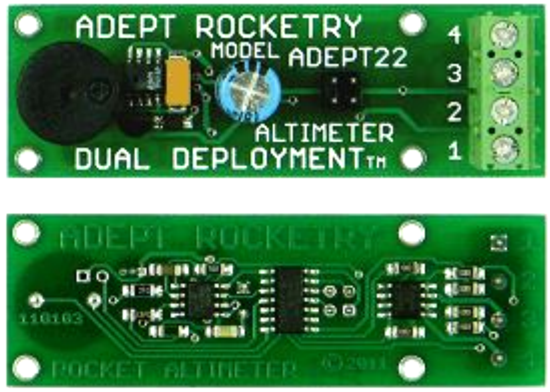


Figure 3-20 Adept22 Altimeter

The human-factors and reliability considerations surrounding the wiring methods required by the Entacore AIM 3.0 make it less suitable as an alternative. The Adept22 does not provided the necessary capabilities for use as the vehicle’s primary and secondary altimeter. Based on the results of this analysis, the PerfectFlite StratoLoggerCF was selected as the leading altimeter alternative based on its adaptability and ease of wiring.

The rocket will be equipped with a BigRedbee 900 GPS tracker which will transmit the rocket’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 rocket. 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 need to be connected to the laptop computer. This provides a redundant method of tracking the rocket in case the laptop malfunctions or is otherwise inoperable.

The GPS tracker within the rocket 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 rocket. The device will be powered on during the assembly of the AV sled and closure of the AV bay within which it is mounted. This will give the device time to acquire satellite signal and establish its location prior to flight.

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 rocket during and after flight: visually tracking the rocket 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 completely contained within the midsection of the rocket. 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 rocket 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.

3.2.3 Electrical Schematic of Recovery System

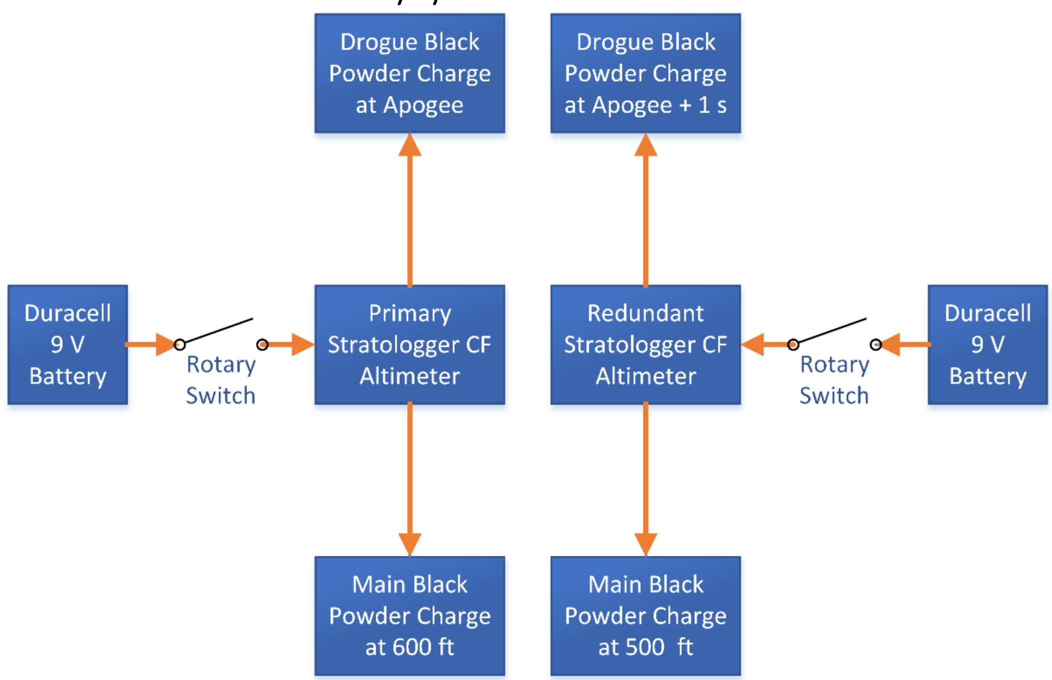


Figure 3-21 Electrical Schematic of Leading Alternative for Recovery System

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.

3.2.4 Avionics Sled Alternatives

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 rotary switches will be mounted to the body tube of the rocket, flush with the external airframe, to allow the altimeters to be powered on using a flathead screwdriver or other similar device. 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. Rotary 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 rocket 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 rocket and mitigates risks associated with the recovery system. For these reasons, the team selected the non-key-activated rotary 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 by connecting an LED in place of the electronic match in the circuit and sealing them within a vacuum chamber. The vacuum chamber will then be depressurized and re-pressurized in a manner roughly analogous to the pressure changes experienced in the flight profile of the rocket to confirm that the LED is powered on at the pressure it was programmed to. Following these tests, the team will review the pressure and altitude data from the altimeter collected during the test to further ensure the device functioned properly.

3.2.5 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:

$$H = D^2 * L * 0.0008\ in^{-2} \tag{12}$$

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.

3.2.6 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-lbs of kinetic energy. The kinetic energy of each section at landing can be calculated using the following equation:

$$KE = \frac{1}{2} m v^2 \tag{13}$$

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 (13, above, can be re-arranged to calculate the maximum allowable descent rate for each independent section of the vehicle using the following equation:

$$v_{max} = \sqrt{\frac{2\ KE}{m}} \tag{14}$$

Where v_{max} is the maximum allowable descent velocity of the section, *KE* is the maximum allowable kinetic energy of the section, 75 ft-lbs, and *m* is the mass of the section. The results of Equation (14 were plotted in Figure 3-22, below, to demonstrate how the mass of the section affects the maximum allowable descent rate of that section.

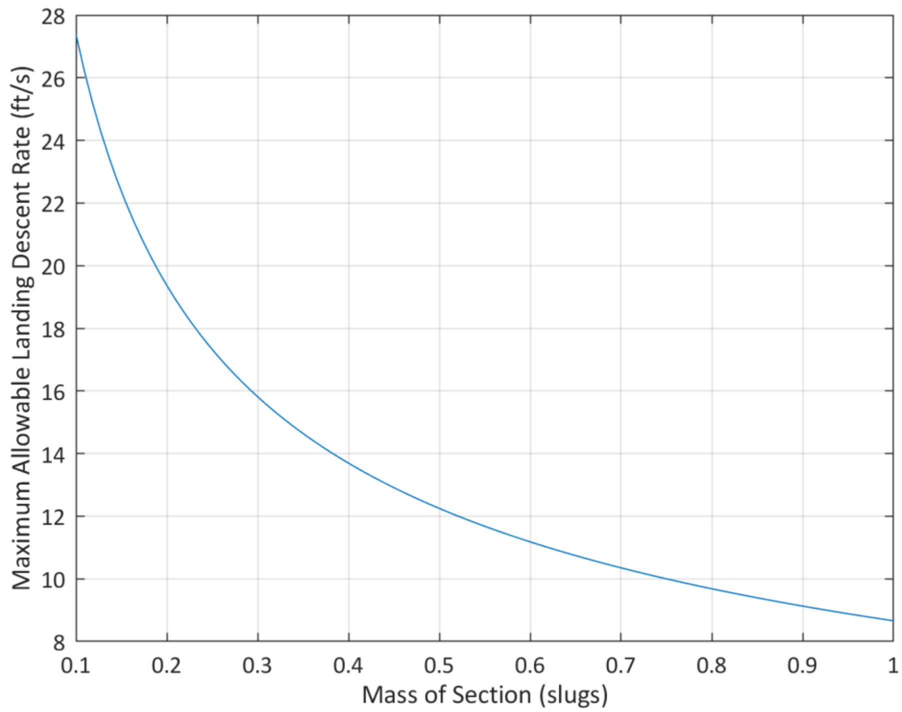


Figure 3-22 Plot of Maximum Landing Descent Rate vs. Section Mass

Equation (14 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 3-3.

Table 3-3 Maximum Descent Rate to Achieve Landing Kinetic Energy Requirement for Each Independent Section of the Leading Design Alternative

Section	Mass	Maximum Descent Velocity
Nosecone	0.4594 slugs	18.1 ft/s
Midsection	0.3046 slugs	22.2 ft/s
Fin Can	0.4432 slugs	18.4 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 3-3, above, if the system is to meet the landing kinetic energy requirement. The implications of this are discussed further in Section 3.2.7 Main Parachute Alternatives.

Table 3-4, below, lists the masses and landing kinetic energy of each section, calculated using Equation (13) and the calculated descent rate of the leading alternative vehicle design under the leading main parachute alternative detailed in Section 3.2.7 Main Parachute Alternatives. The results of these calculations demonstrate the leading design alternative meets the required performance to achieve the required landing kinetic energy.

Table 3-4 Kinetic Energy at Landing of Independent Sections of Leading Design Alternative

Section	Mass	Kinetic Energy at Landing
Nosecone	0.4594 slugs	45.4 ft-lbs
Midsection	0.3046 slugs	30.1 ft-lbs
Fin Can	0.4432 slugs	43.8 ft-lbs

3.2.7 Main Parachute Alternatives

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

$$v = \sqrt{\frac{W}{2\,\rho\, C_D\, \pi \left(\frac{D}{2}\right)^2}} \tag{15}$$

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.

For the main parachute, three options were considered. First, the Fruity Chutes Iris Ultra parachute, which is advertised as having a higher C_d than a non-reefed parachute for a given parachute diameter. This is advantageous as it requires the team to allocate less space in the rocket body for parachutes. Additionally, the parachute gives a higher drag for less material, which helps to reduce cost. To provide a more traditional alternative, the Fruity Chutes Elliptical parachutes and the Spherachutes Spherical parachutes were also analyzed. The Fruity Chutes Elliptical parachutes have a much lower C_d that is usually around 1.5 as opposed to the approximately 2-2.5 for Spherachutes or Iris Ultra parachutes. 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 combination of high drag with less weight and volume for given performance characteristics, in addition to the fact the none of the Spherachutes parachutes meet the team-derived requirement that the selected main parachute alternative shall already be owned by the team, led the team to conclude that the Fruity Chutes Iris UltraCompact parachute product line was the only suitable alternative for performance evaluation and further consideration. The performance of the four main parachute alternatives, alongside a Spherachutes offering for reference, most-closely suited to the leading launch vehicle alternative is presented below in Table 3-4.

Table 3-5 Comparison of Main Parachute Alternatives

Parachute	Drag Coefficient	Descent Velocity	Maximum Section Kinetic Energy	Descent Time from Main Deployment Altitude
Fruity Chutes 84 inch Iris UltraCompact	2.13	19.9 ft/s	91.4 ft-lbf	30.1 s
Fruity Chutes 96 inch Iris UltraCompact	2.09	17.6 ft/s	71.5 ft-lbf	34. s
Fruity Chutes 120 inch Iris UltraCompact	2.11	14.1 ft/s	45.4 ft-lbf	42.7 s
Fruity Chutes 144 inch Iris UltraCompact	2.12	11.7 ft/s	31.3 ft-lbf	51.4 s
144 inch Spherachutes	2.48	17.0 ft/s	66.1 ft-lbf	35.4 s

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 120-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 120-inch Iris UltraCompact parachute is the leading alternative main parachute.

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.

3.2.8 Drogue Alternatives

An analysis of Fruity Chutes Classic Elliptical, Fruity Chutes Compact Elliptical, and Spherachutes parachutes was undertaken to select the most appropriate leading alternative drogue parachute for the launch vehicle. The Fruity Chutes Classic Elliptical and Fruity Chutes Compact Elliptical parachute product lines are very similar; however, the Compact Elliptical parachutes are lighter and have lower pack volume than the Classic Elliptical parachutes. Although this weight and volume savings comes with a slight performance penalty, the performance of the same-diameter parachutes from each product line is still very similar, especially in the range of diameters less than 24 inches.

The drogue alternatives were evaluated based on the rate at which the leading alternative launch vehicle design would descend under each. This performance was analyzed to determine whether the drogue would enable the leading alternative launch vehicle using the leading alternative main parachute (presented in Section 3.2.7) to meet the drift distance and descent time limits required by the competition. The performance of the six alternatives most closely suited for use on the leading alternative launch vehicle is presented below in Table 3-6 Comparison of Drogue Alternatives.

Table 3-6 Comparison of Drogue Alternatives

Parachute	Drag Coefficient	Descent Velocity	Descent Time from Apogee to Main Deployment	Time from Apogee to Landing
Fruity Chutes 15 inch Classic Elliptical	1.37	139.4 ft/s	25.8 s	68.4 s
Fruity Chutes 18 inch Classic Elliptical	1.43	113.8 ft/s	31.6 s	74.2 s
Fruity Chutes 24 inch Classic Elliptical	1.47	84. ft/s	42.7 s	85.4 s
Fruity Chutes 24 inch Compact Elliptical	1.41	86. ft/s	41.7 s	84.4 s
24 inch Spherachute	2.47	101.8 ft/s	34.2 s	69.6 s
30 inch Spherachute	2.44	82 ft/s	42.4 s	77.8 s

It was decided that the drogue alternative which provided by the slowest descent velocity while still meeting the drift distance and descent time requirements would be selected. This is to minimize the forces experienced by the launch vehicle and recovery system upon main parachute deployment. In general, the greater the difference between the rates of descent of the vehicle under main and drogue parachute, the greater the acceleration the launch vehicle will experience during the main parachute deployment sequence. Thus, it was determined that the Fruity Chutes 24-inch Compact Elliptical parachute is the leading alternative drogue parachute.

3.2.9 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 particular type of shock cord successfully in the past for rockets 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 3-23 shows the shock cord sizing with respect to the separated sections of the leading alternative design.

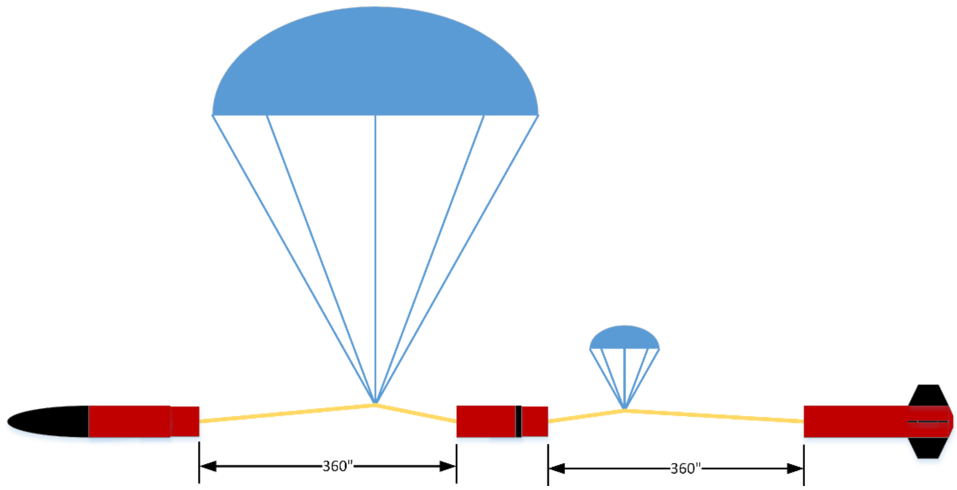


Figure 3-23 Shock Cord Sizing Diagram

3.2.10 Black Powder Sizing

The two separations of the recovery system will be conducted by the detonation of black powder charges. We 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:

$$m = L * D^2 * 0.006 \quad (16)$$

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.

For redundancy, we will use two different altimeters wired to two different black powder charges per stage. The redundant black powder charge will go off approximately 1 second after the main is set to go off to account for failure in the first system. In order to prevent one charge detonating the other, over-pressurizing the compartment, we house the charges in PVC tubing and cover the ends with paper towel for a controlled detonation. During preliminary design discussion, two arguments were considered in the sizing of the redundant charge. One suggests a slightly larger size black powder charge in the redundant system in case the first is not strong enough to overcome frictional forces. The other suggests the same size black powder charge, predicting the failure is more likely in the wiring systems than sizing and that too large of a black powder charge would be a larger risk. We decided on the second option, reasoning that if the redundant black powder charge were too large and damaged the rocket, it would be more likely to damage the altimeter system, disabling the main parachute, and causing the rocket to go ballistic.

3.3 Mission Performance Predictions

3.3.1 Target Altitude Declaration

Based on Rocksim simulations described in Section 3.3.2, the team has decided that the target altitude for the full-scale launch vehicle will be 4090 ft.

3.3.2 Flight Profile Simulation

The Rocksim model of the current leading design was the subject of launch simulations in Rocksim to determine the target altitude. Figure 3-24below shows the flight profile of the current leading design using the parameters outlined in Table 3-7

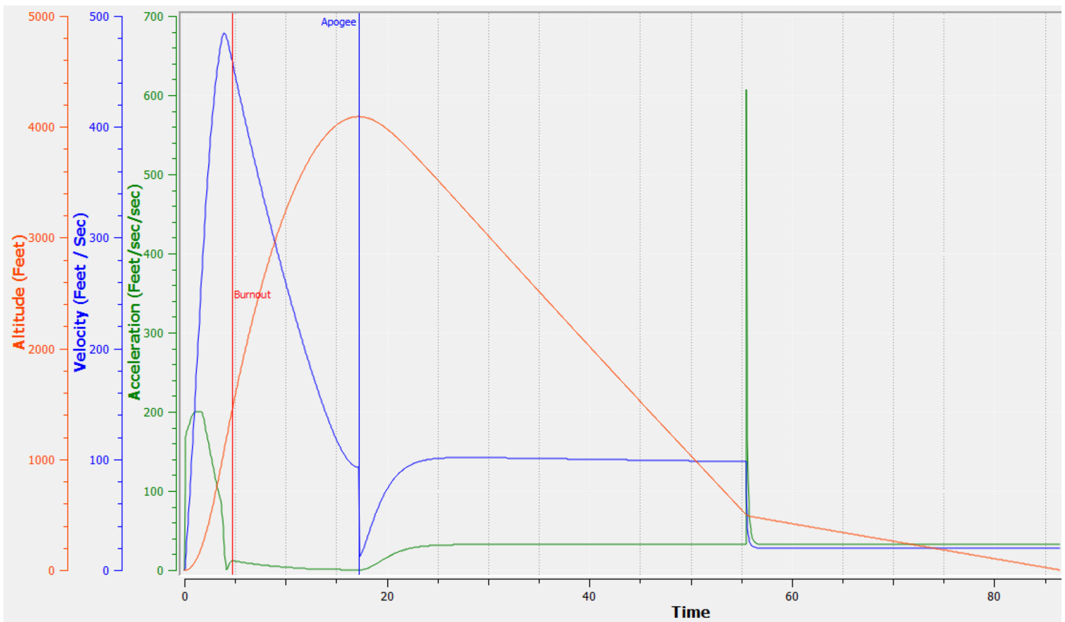


Figure 3-24 Flight Profile of Current Leading Design

Table 3-7 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[4]
Launch direction	Into wind	Prevailing wind at launch site[5]

While the thrust curve of the L850W is readily available online, the team felt it better to examine the thrust curve from the flight simulation above. Figure 3-25 below illustrates the thrust curve of the L850W used by Rocksim.

[4] (Weather Spark n.d.)
[5] (Weather Spark n.d.)

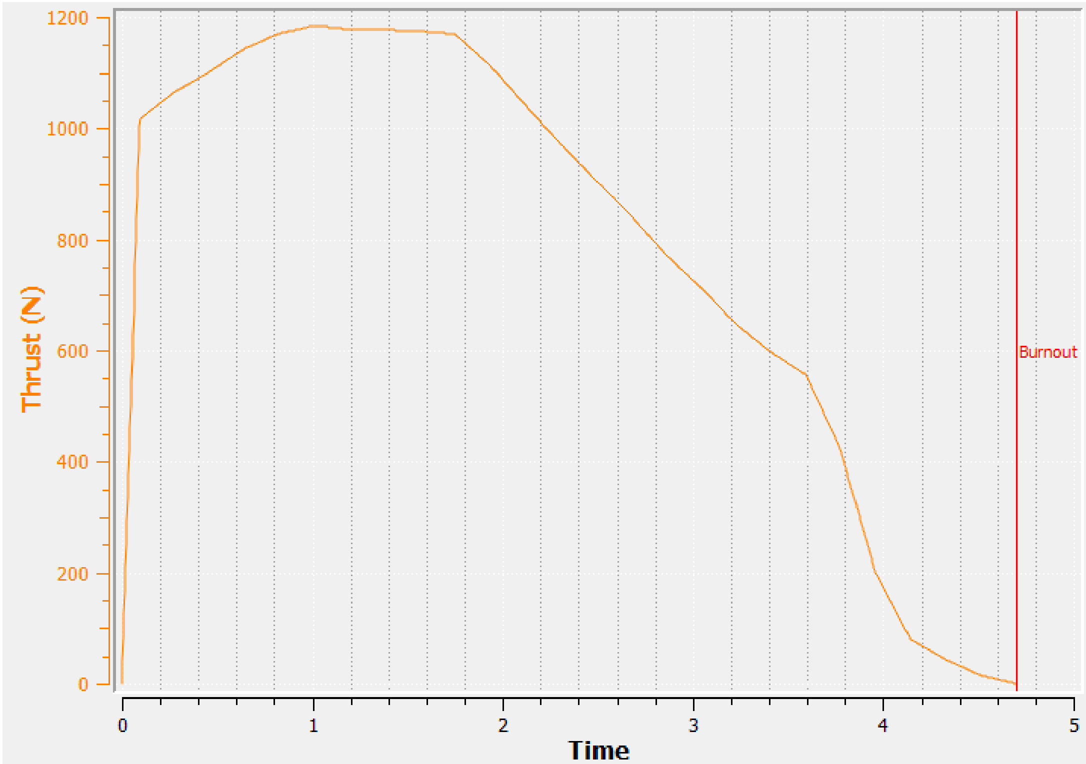


Figure 3-25 Thrust Curve of Aerotech L850W

3.3.3 Stability Margin Simulation

According to the Rocksim model, the CP location of the rocket in the current leading design configuration is at a point 71.43 inches from the nosecone tip. This value was computed automatically by the software at M = 0.3, which corresponds to the approximate average Mach number of the rocket from launch to apogee. The Barrowman's Method, which defines a simple algebraic method for calculating the CP position on a subsonic rocket, was applied to confirm the Rocksim prediction for CP position. Barrowman's Method allows the rocket to be split into three parts: nosecone, transition, and fins. Since the rocket 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:

$$X_N = 0.446 * L_N \tag{17}$$

where L_N is the length of the nosecone. Using L_N = 22 inches., X_N was calculated to be 9.812 inches. The coefficient for fins C_F can be defined as:

$$C_F = \left(1 + \frac{R}{S+R}\right)\left[\frac{4N\left(\frac{S}{d}\right)^2}{1 + \sqrt{1 + \left(\frac{2L_F}{C_R + C_T}\right)^2}}\right] \tag{18}$$

where R is the radius of the rocket body, S is the fin semi-span length, N is the number of included fins, d is the diameter of the rocket 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 in., S = 4.2 inches, N = 4, d = 5.5 inches, L_F = 5.25 inches, C_R = 7.0 inches, and C_T = 3.5 inches, C_F was calculated to be 5.3939. The equation for the arm length of the fins X_F can be defined as:

$$X_F = X_B + \frac{X_R}{3}\frac{C_R + 2C_T}{(C_R + C_T)} + \frac{1}{6}\left[(C_R + C_T) - \frac{C_R C_T}{(C_R + C_T)}\right] \quad (19)$$

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 rocket body. Using X_B = 90.5 inches, X_R = 1.75 inches, C_R = 7.0 inches, and C_T = 3.5 inches, X_F was calculated to be 92.6389 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:

$$X_{CP} = \frac{(C_N X_N + C_F X_F)}{C_N + C_F} \quad (20)$$

The CP position was calculated to be 70.23 inches from the nosecone tip, which is 1.20 inches. FWD of the CP position from Rocksim. This difference equates to a decrease of .16 cal 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 rocket stability margin and determining the amount of ballast necessary for stable flight. The equation for the stability margin of a rocket S_M can be defined as:

$$S_M = \frac{X_{CP} - X_{CG}}{d} \quad (21)$$

Where X_{CP} and X_{CG} are the distances from nosecone tip to the rocket CP and CG, respectively, and d is the rocket outside diameter. Stability margin is measured in calibers, where one caliber is equal to the rocket outside diameter. Using the results from Rocksim, X_{CP} = 71.43 inches and X_{CG} = 57.93 inches, the stability margin was calculated to be 2.44 cal. Since this value is the stability margin of the rocket after full assembly and before launch, it exceeds the handbook requirement that the rocket 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 3-26 movement of the Stability margin, CG, and CP locations throughout the flight profile discussed in Section 3.3.2.

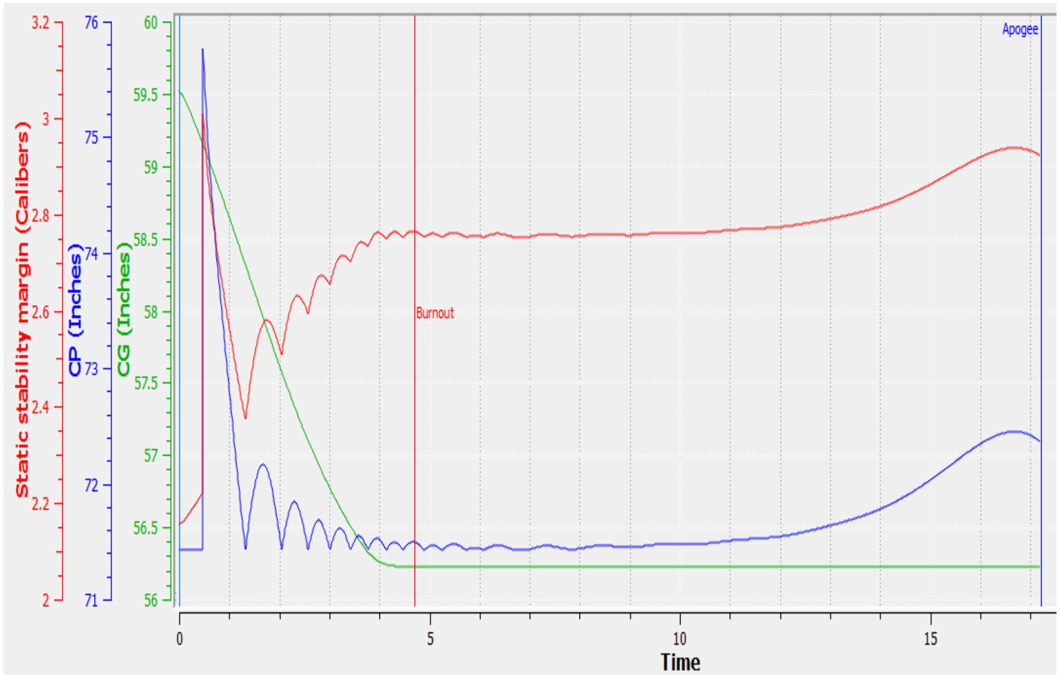


Figure 3-26 Stability Margin/CP/CG vs. Time

As component weights are updated throughout the remainder of the project, ballast will be modified in the Rocksim model to ensure that the CG is located such that the Stability Margin remains greater than 2.0.

3.3.4 Kinetic Energy Calculations

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

$$KE = \frac{1}{2}mv^2 \tag{22}$$

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 (13, above, can be re-arranged to calculate the maximum allowable descent rate for each independent section of the vehicle using the following equation:

$$v_{max} = \sqrt{\frac{2\,KE}{m}} \tag{23}$$

Where v_{max} is the maximum allowable descent velocity of the section, *KE* is the maximum allowable kinetic energy of the section, 75 ft-lbs, and *m* is the mass of the section. The results of Equation (14 were plotted in Figure 3-22, above, to demonstrate how the mass of the section affects the maximum allowable descent rate of that section.

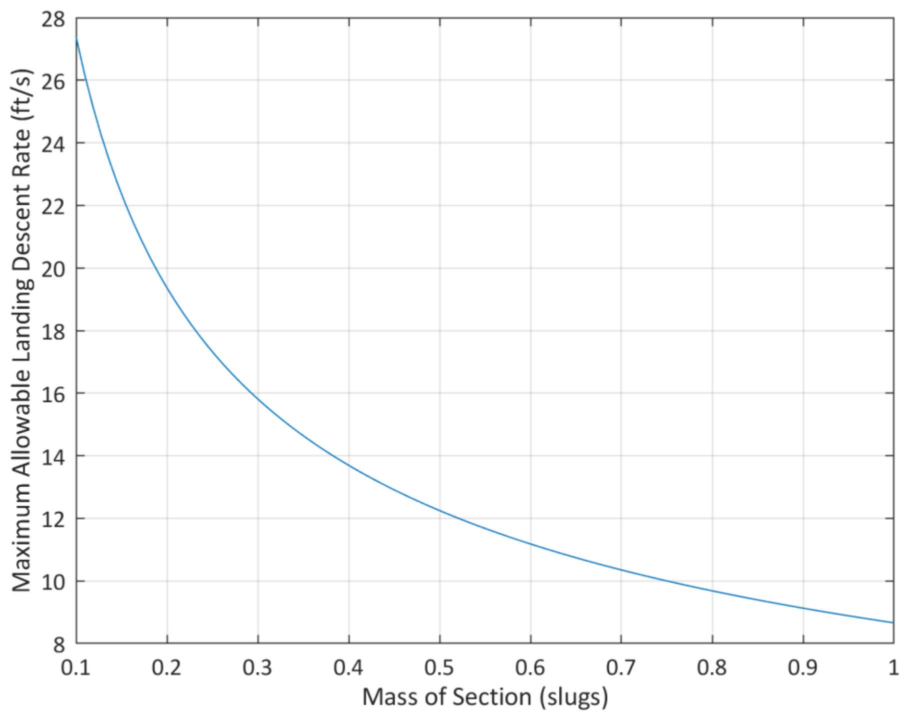


Figure 3-27 Plot of Maximum Landing Descent Rate vs. Section Mass

Equation (14) 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 above in Table 3-3.

Table 3-8 Landing Kinetic Energy per Independent Section

Section	Mass	Maximum Descent Velocity
Nosecone	0.4594 slugs	18.1 ft/s
Midsection	0.3046 slugs	22.2 ft/s
Fin Can	0.4432 slugs	18.4 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 3-3, above, if the system is to meet the landing kinetic energy requirement. The implications of this are discussed further in Section 3.2.7 Main Parachute Alternatives.

Table 3-4, above, lists the masses and landing kinetic energy of each section, calculated using Equation (13) and the calculated descent rate of the leading alternative vehicle design under the leading main parachute alternative detailed in Section 3.2.7 Main Parachute Alternatives. The results of these calculations demonstrate the leading design alternative meets the required performance to achieve the required landing kinetic energy.

Table 3-9 Kinetic Energy at Landing of Independent Sections of Leading Design

Section	Mass	Kinetic Energy at Landing
Nosecone	0.4594 slugs	45.4 ft-lbs
Midsection	0.3046 slugs	30.1 ft-lbs
Fin Can	0.4432 slugs	43.8 ft-lbs

3.3.5 Descent Time Calculations

Descent times were calculated to determine wind drift and are shown in Table 3-10.

3.3.6 Wind Drift Calculations

Table 3-10 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 3-10 Wind Effect on Apogee and Drift

Wind Speed	Apogee	Descent Time	Drift Distance
0 mph	4259 ft AGL	85 s	0 ft
5 mph	4245 ft AGL	85 s	624 ft
10 mph	4199 ft AGL	85 s	1240 ft
15 mph	4119 ft AGL	84 s	1839 ft
20 mph	4006 ft AGL	82 s	2414 ft

3.3.6.1 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 3-11. The results of these simulations are significantly lower than the results of the hand calculations.

Table 3-11 RockSim Simulation Results for Wind Drift

Wind Speed	Apogee	Landing Distance from Launch Pad
0 mph	4259 ft AGL	0 ft
5 mph	4245 ft AGL	169 ft
10 mph	4199 ft AGL	335 ft
15 mph	4119 ft AGL	493 ft
20 mph	4006 ft AGL	671 ft

3.3.6.2 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 3-11 are significantly lower than the results of the hand calculations presented in Table 3-10 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 rocket 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 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 rocket 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 rocket 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 rocket 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 rocket retrieval process to ensure safety of the crew.
	Unpredictable rocket flight and descent paths	High velocity cross-winds	Ground crew and spectators at risk of descending rocket components Injury of recovery sub-team members in the process of retrieving separated rocket 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, rocket assembly will be carried out in whatever shelter provided by the RSO or a team member's vehicle. 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 rocket 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.
		Severe humidity	Ground crew and spectators at risk of descending rocket components	2	3	

	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 rocket 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 rocket 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 rocket after descent	Severe humidity affecting altimeter calibration	Injury of recovery sub-team members in the process of retrieving the separated rocket components.	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 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 rocket 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	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.

4.2 Failure Modes and Effects Analysis (FMEA)

See Appendix A 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.

4.3 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 rocket	Heavy precipitation	Water exposure to electronics components could result in failure to launch the rocket, failure to separate the rocket, 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 rocket 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 rocket – possibly resulting in a significantly lower apogee, violent parachute deployment and	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

		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.			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, rocket assembly will be carried out in whatever shelter provided by the RSO or a team member's vehicle.
Post-descent dynamic separated rocket 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 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.	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.
Torn parachutes and tangled	Proximity to wooded area	Trees within the rocket descent path can damage parachutes and shroud lines,	1	2	Choose a launch site that has a large proximity away from wooded areas. If the rocket is

shroud lines during descent		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 rocket components are out of reach for the recovery sub-team.			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.

4.4 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	Casual 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 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	The electronics lead, or safety officer, will verify that no wires are exposed in the launch vehicle prior to full vehicle integration. Electronics will be stored in a secure environment devoid of extreme temperature	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 determined by the safety officer to be in good physical condition will be used in the vehicle.

					fluctuations or contact with other components that may inflict damage.	
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 not properly secured to components leading to freefall.	Components of the launch vehicle may be strewn across the ground, leaving material in the environment which may be 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.	2	4	Redundant ejection charges as well as a redundant altimeter, secondary to the primary altimeter and ejection charges, will be implemented in the launch vehicle. The redundant system will activate following a delay after the primary system,	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 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

					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.	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 they're in suitable condition. If a battery is not operable it will be disposed of according the MSDS standards.	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.

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.

4.5 Logistical Project Risks

Risks to project timeline, their likelihood and impact levels, and mitigation methods are presented in Table 4-9.

Table 4-9 Logistical Project Risks

Risk	Likelihood	Impact	Mitigation	Mitigation Cost
Overspending	Low	Medium	Sticking to a strict budget	Fundraising may become more necessary
Delays	Medium	High	Rigid and realistic time management	Loss in flexibility for unforeseen challenge
Lack of Resources	Low	High	Clearly communicated needs for materials	Unexpected costs and subsequent delays
Improper Design	Medium	High	Cooperative review of the rockets systems on a regular basis	Need for an expensive and time-consuming redesign late in the competition
Motor Failure	Low	High	Buy reputable and quality motors	An increase in cost of motors
UAV Integrated System Failure	Low	High	Rigorous testing and troubleshooting	An accelerated development cycle
Power Supply Failure	Low	High	Using a large power supply	Rocket has a higher weight

5. Payload Criteria

5.1 Payload Objective

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 defined a successful payload mission completion as one that deploys from the payload bay, arms the motors, and can be safely flown to the nearest Future Excursion Area (FEA) via first person view flight.

5.2 Summary of Alternate UAV Designs

5.2.1 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 possible 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 modifiable to meet the team's requirements. However, this presents obvious special issues, as an 8.66 inches frame would not easily fit inside the leading design rocket diameter of 5.5 inches.

5.2.1.1 "Folding-X" Arm Design

One considered alternate design for the UAV had two 8.66-inch arms in an x-shape hinging from their center with UAV motors attached on the end of each of these arms. While inside the rocket, the UAV would cross with one arm on top of the other, which resulted in a width of about 4.4 inches. Upon deployment, the arms would unfold so that the distance between the left and right arm tips measures 8 ¼-inches.

One issue the team found with this design was that the hinge at the center made it necessary that one arm would be stacked on top of the other within the rocket and, upon deployment, one arm would be 0.16 inches above the other. This would cause the four motors to be on unequal planes, which necessitated a specialized motor program as the default program for quadcopter motors assumes that all four of them are on the same plane. Alternatively, padding on each of the lower arms would artificially elevate the motors.

Designing a way for these crossing arms to open was another challenge. One approach that was considered was unfolding the arms using a compressed spring that converted its stored potential energy to kinetic energy and pushing the UAV open. The team would have to mount the spring on the UAV in such a way that the spring can slide across the arms. To maintain a constant x-position and changing y-position for a point on a rotating body, there must be some sliding motion along the length of the radius of rotation. With these considerations, the team opted for a simpler design involving fewer parts and less custom programming.

5.2.1.2 Arms on Hinges

Such a large diameter wheelbase contradicts one of the main problems the team anticipated: payload compartment size. The smaller UAV's could easily mount in the rocket 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 rocket diameter of over 8 inches, which the team was reluctant to pursue, due to past teams' challenges in dealing with large diameter rockets, 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 of radius 0.3 inch on the rotating corner so that the arm does not stop itself from rotating.

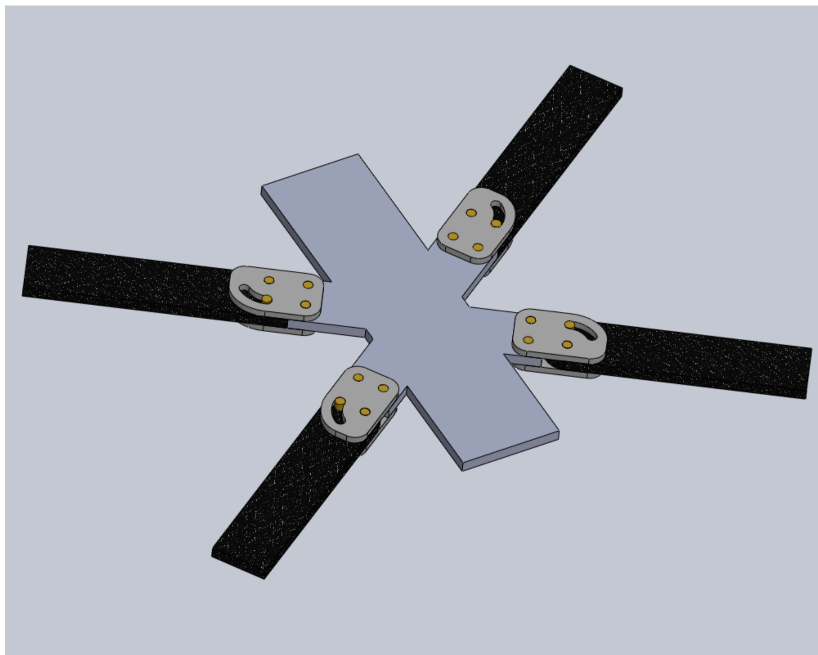


Figure 5-1 Open arm configuration for quadcopter

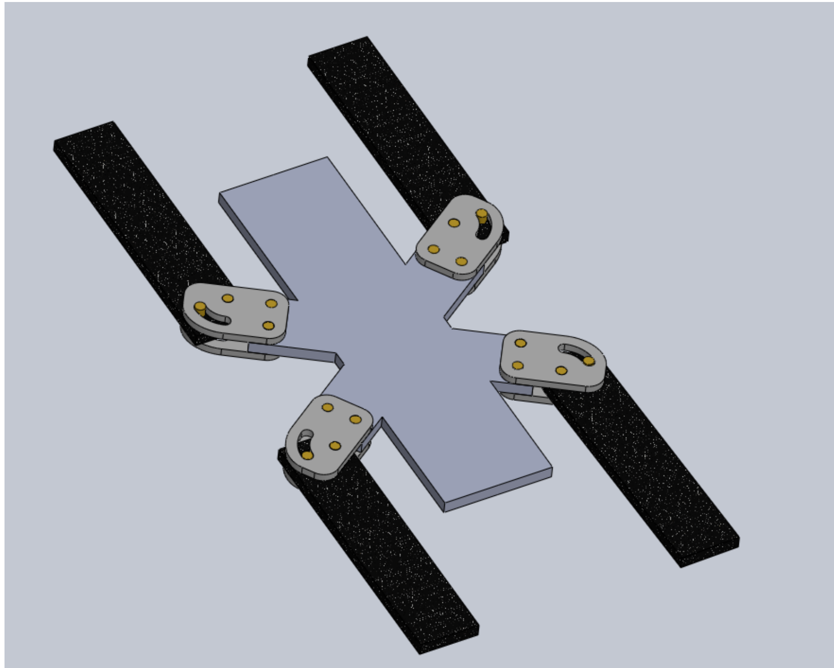


Figure 5-2 Closed arm configuration for quadcopter

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.

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 sufficient to do so.

5.2.2 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 typical 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.

5.2.2.1 Servo and Friction Fit Wire

One option that was considered for deploying the payload was to attach the SNB loosely to a wire and have the wire hooked to a servo on one end and a friction fitting slot on the other. The primary advantage to this system would be its simplicity. The servo only needs to be powered during activation, which would pull the wire out of the friction fit and allow the beacon to fall. A 3D printed mount would be affixed to the UAV body, and the servo would be bolted to it. However, this design has several flaws.

During launch, the vehicle and its subsystems will experience up to ten times the normal force of gravity which puts this system at higher risk of the wire disconnecting from the friction fitting. When the UAV would deploy, this weakened connection becomes a risk to both individuals on the ground and mission success. In addition, this is fitting is limited and does not restrict the movement of the beacon during flight. This lack of restriction in movement would impact the UAV flight control with the beacon not being secured. Due to these serious safety issues and reliability issues, this option will not be considered further.

5.2.2.2 Solenoid

An alternative design for the payload release mechanism used a solenoid instead of a servo to release the payload from the UAV. The solenoid directly works with a 5V source, of which a compatible connection is included on the proposed 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 6mm 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 cut. The team considered this method because it would be more stable with the large amounts of force experienced by the rocket during launch. One downside to this payload release mechanism is that the solenoid must receive power until the drop of the payload, meaning that we must find a battery that doesn’t add too much weight, but can still provide the necessary amount of power to keep the solenoid activated for the entire flight.

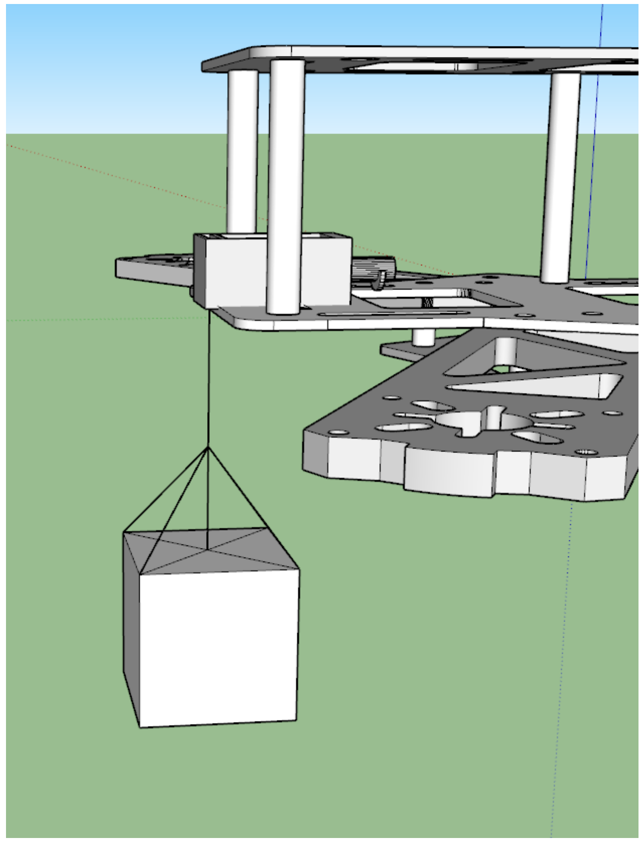


Figure 5-3 Google Sketch-up model demonstrating Solenoid design

5.3 Summary of UAV with Leading Designs

With the aforementioned design alternatives fully considered, the team has chosen the designs detailed in section 5.2.1.2 and 5.2.2.2 as the leading alternatives. These two systems have been identified as having the least number of failure modes and most likely chances for success. The folding hinge design is slightly more involved to implement, 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 leading alternative as it is the most secure SNB deployment system considered thus far. While it does have a similar downfall to the servo system, being that the beacon is not rigidly held in place, the team has decided that the solenoid would considerably lower the risk of the beacon being prematurely deployed.

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 leading payload deployment system. The deployment system, detailed in section 5.5.2.2, 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 housed underneath the UAV in a specially constructed cradle. This cradle will shield the battery from ground impact and also introduce a set of landing gear for the UAV that 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.

While the folding arm and beacon deployment systems have alternatives considered, the electronic components have not seen similar treatment. This is because the team has decided that picking electronic components that will power the quadcopter regardless of structural modifications would be advantageous to the both the 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 55 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 5.4. 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 56 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.

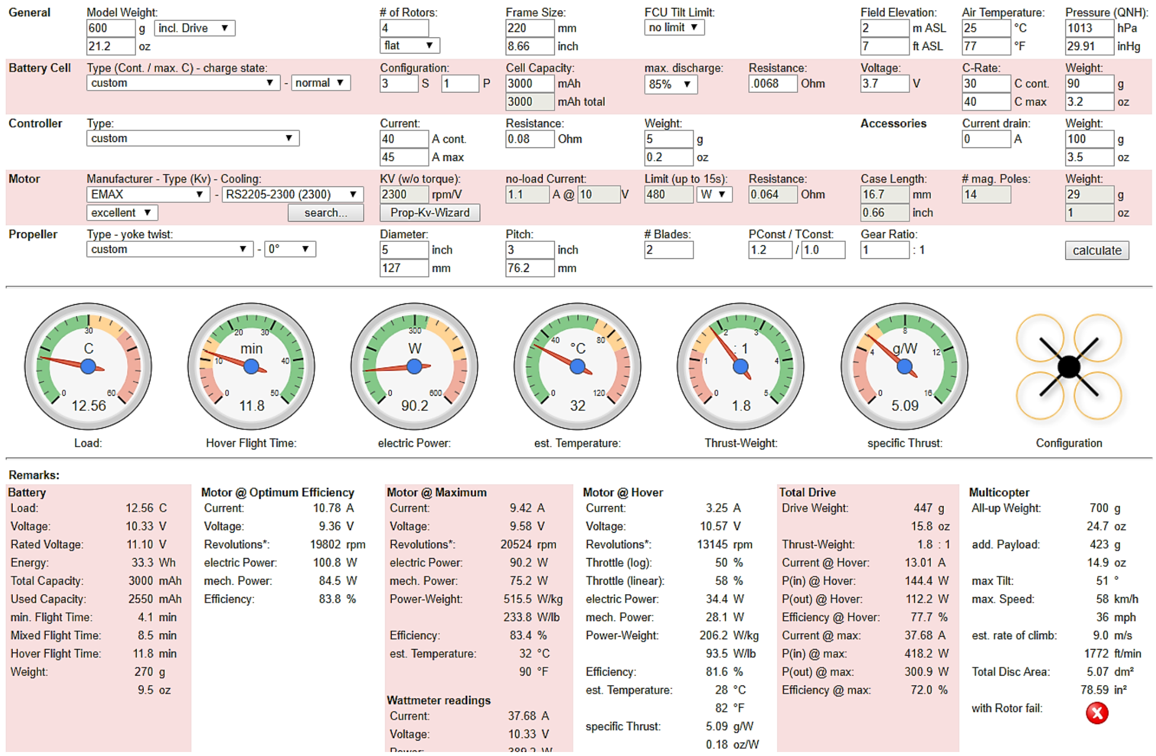


Figure 5-4 eCalc performance estimations based on leading design

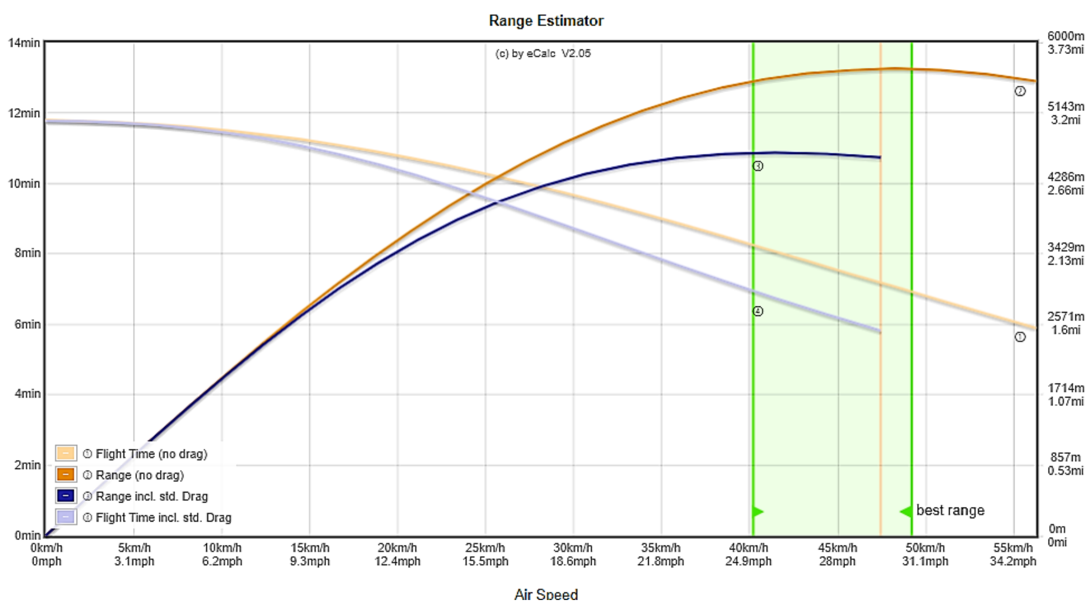


Figure 5-5 eCalc Range Estimator showing best range of operation for quadcopter

5.4 Electrical Schematics and Estimated Masses

The payload deployment system shall be remotely triggered via a long-range transmitter connected to a microcontroller. This configuration will allow for the integration of multiple output devices into one circuit, including an electronic latch to secure the payload deployment pod during flight and motor to deploy the pod from the rocket payload bay. To attach the components to the airframe, a removable bulkhead shall be utilized onto which the electronic components will be fastened before launch and the secured inside the payload bay. The configuration and installation of electronic hardware in the payload bay will be accomplished with the structure seen in Figure 5-6.

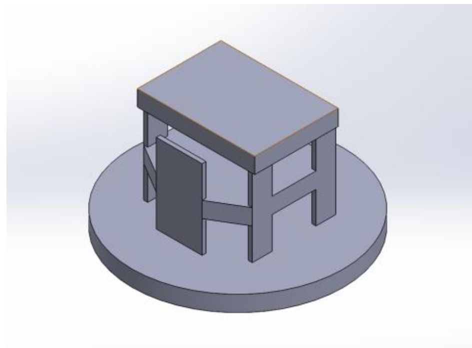


Figure 5-6 Payload Electronics Mounting System

The slots are intended for securing the battery packs (blue) with a top platform for attachment of standoffs to mount the microcontroller (green), and this configuration is seen in Figure 5-7

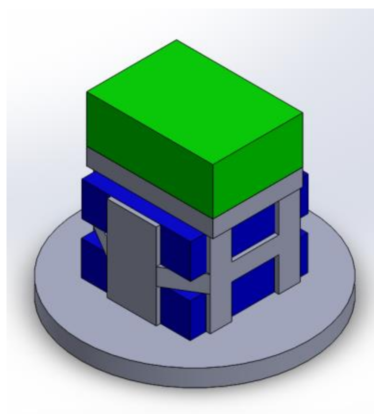


Figure 5-7 Payload Electronics Mounting System with Components

The battery packs will then be secured in place with zip-ties to prevent the packs from coming loose during flight. This configuration is the leading design because it places a barrier between the sensitive microcontroller and battery components and the remainder of the payload bay. Using a latch and stepper in that compartment is acceptable from a risk standpoint as the aforementioned devices are more capable of withstanding flight forces from the payload pod and its contents. In order to connect all components, a microcontroller shield will be utilized for simplification of the intermediary circuitry.

An alternate design is to place all electronic components onto a permanent bulkhead with a cradle placed farther into the payload bay to support the electronic latch and a small access hatch built for access to the other components. The advantage of this design is that the bulkhead is permanently secured, and components can be directly secured into it; however, this also comes with the disadvantage of requiring another hatch in the airframe which brings numerous other complications in terms of aerodynamic stability, feasibility, and structural integrity.

The UAV will utilize a basic set of components in order to accomplish four tasks which make up the process of transporting the SNB to the FEA. First, the UAV will utilize a flight controller and transmitter capable of two operation states—a low-power mode that disengages all other components except those communicating with the transmitter and a full-power mode that allows the UAV to deliver power to the motors and fly to the FEA. This is the leading option to fulfill the requirement for disengaging the UAV while inside the rocket, as it requires no additional mechanisms and thus has the lowest count of failure modes. Second, the UAV will take off once safely deployed from the rocket and locate the FEA. Though there are two ways to locate the FEA, either with human observation or remote sensing, the UAV will carry a small FPV camera and video transmitter to transmit a real-time video feed from the UAV that will allow the human pilot to find the nearest FEA quickly and efficiently, conserving weight with regards to onboard components and endurance. Third, the UAV will fly to the FEA and release the simulated beacon using a mechanism detailed in Section 5.2.2. Finally, the UAV will safely land for recovery, which requires the UAV to possess sufficient endurance to have the longevity to do this, which is covered in Section 5.3.

Though there are many options for both transmitter and flight controller, the respective leading choices are the Taranis X-Lite Transmitter and FrSky OmniNXT F7 flight controller, seen in Figure 5-8and Figure 5-10. The X-Lite transmitter is preferred as it provides the necessary performance while being in a portable and ergonomic container which can accommodate a screen to display the video from the FPV camera, which will be key factors for mission completion as it must be carried to the RDO at the launch field. The OmniNXT F7 offers an integrated radio receiver compatible with the X-Lite transmitter that can utilize all available inputs of the transmitter, with an OmniNXT F7 pin map and wiring schematic included in Figure 5-10and [Figure 5-11.

Figure 5-8 Taranis X Lite Radio Trnasmitter

Figure 5-9 FrSky OmniNXT F7 Flight Controller

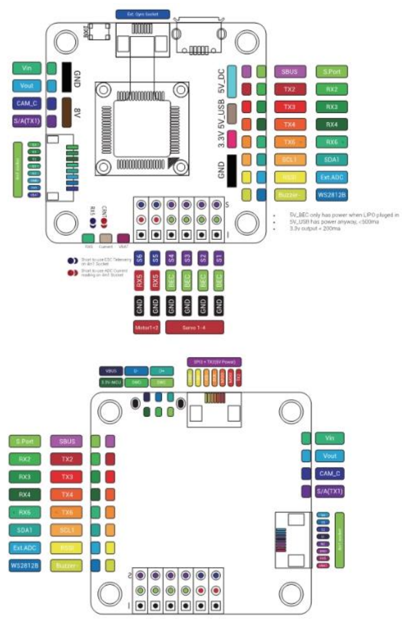


Figure 5-10 OmniNXT F7 Flight Controller Pin Map

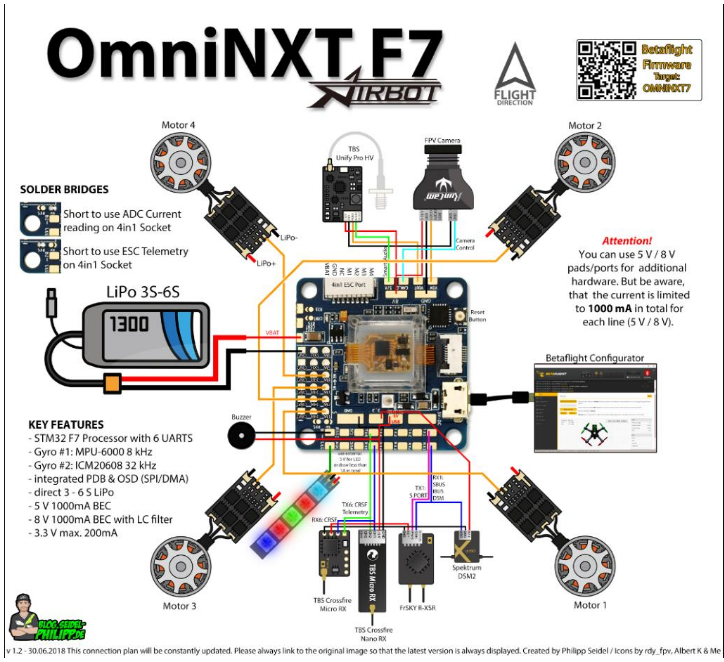


Figure 5-11 Flight Controller Electrical Schematic

5.5 Preliminary Interfaces Between Payload and Launch Vehicle

5.5.1 Payload Bay Overview

The goal of the payload bay is to protect and secure the payload during flight, and ensure the drone is deployed and flight-ready on command. In order to accomplish the first task, both alternate designs include a form of “pod” to protect the UAV during flight and deployment. The other similarities the designs share is the use of plywood centering rings to restrict the motion of the pod, a lead screw system to push the pod out of the rocket body, and a latch at the forward side of the payload bay to hold and eventually release the pod. The following alternate designs describe how the payload bay/pod accomplishes the tasks of protecting the UAV, orienting the UAV, and leaving the UAV vertically unrestricted.

5.5.2 Summary of Alternate Designs

5.5.2.1 Self-Righting, Unfolding Pod

The first design is to enclose the UAV in a pod capable of unfolding or opening from any orientation. By enclosing the UAV in a pod, it is protected from the ground. Then, regardless of orientation, the pod unwraps or unfolds, leaving the UAV exposed and ready to fly. Regardless of orientation, after unfolding, the inside of the pod will be facing up, ensuring the pod is correctly oriented. The energy for this unfolding is provided by elastic potential energy provided either by attached surgical tubing or by properties of the pod material itself. For a rigid pod energized by external elastic, the shape of the pod could assist with self-righting. For a flexible pod providing its own elastic potential, the ends of the pod flaps could overlap to ensure the pod does not open upside down.

Table 5-1 Pros and Cons for Self-Righting Pod

Pro	Con
Few Moving parts	Danger of perfectly upside-down deployment causing dropped UAV
If the pod opens from any orientation, the payload *will* deploy if the pod exits the rocket	Pod must be tall in addition to wide (explained below)
Works on a sloped surface	Stored potential energy could cause extra friction and reduce re-usability
Works if pointed a few degrees into the ground	Elastics are most efficient acting linearly, not for opening a cylinder.
Few electronic parts and communications required	Relies heavily on dry ground conditions
	When pod is 90% out of the rocket, the potential energy must be contained by a single centering ring.
	No known material for flexible self-opening wrap design

One of the primary reasons this design is infeasible is because of space restrictions. In meeting many handbook requirements, a small rocket diameter is advantageous. The article *The Geometry and self-righting of turtles* published in the *Proceedings of the Royal Society B,* analyzes shapes capable of self-righting to one specific orientation without outside energy. According to the article, in order for a shape to be capable of having one stable equilibrium point, the height/width ratio must be between 0.9 and 1.1[6]. Using a perfect cylinder as an average, a 4.5-inch diameter pod takes up 79% of the total cross-sectional area of a coupler, leaving very little room for stepper motors and the shock cord to be properly positioned.

5.5.2.2 Pod Suspended off Cantilevered Rod (Leading Design)

The biggest issue with a self-righting pod is that the ground conditions can have a major effect on the forces on the pod and UAV. This alternate design proposes suspending the pod on a cantilevered rod attached to the lead screw and centered within the rocket. Once the pod is clear of the final centering ring, it will be held above the ground, able to freely rotate until the pod orients its heaviest direction downwards. The cantilevered rod will then retract back into the payload bay,

[6] (Domokos 2008)

potentially bringing the pod with it. However, elastic straps are stretched across the final centering ring, allowing the rod to retract, while the pod is caught outside and drops to the ground. Finally, two flaps on the top of the pod, previously held shut by the presence of the rod, will open, revealing the UAV and leaving it unrestricted to fly. The flaps of the pod will be pushed open by levers elastically pulled down from the inside.

Table 5-2 Pros and Cons for Cantilevered Rod Design

Pro	Con
Does not rely on ground conditions	Possibility of jamming pod into the ground while the rod is present.
No high potential forces required.	Possibility of rod bending preventing all movement and rotation
May be able to work a few degrees pointed into the ground	More moving parts creates more potential for failure
Pod shape can be small to fit in smaller diameter rocket	
Few electronic parts and communications required	

5.5.3 Leading Alternate Design Deployment Process

1. The Signal is sent from the RSO Tent and is received by the RF receiver discussed in section 5.4.

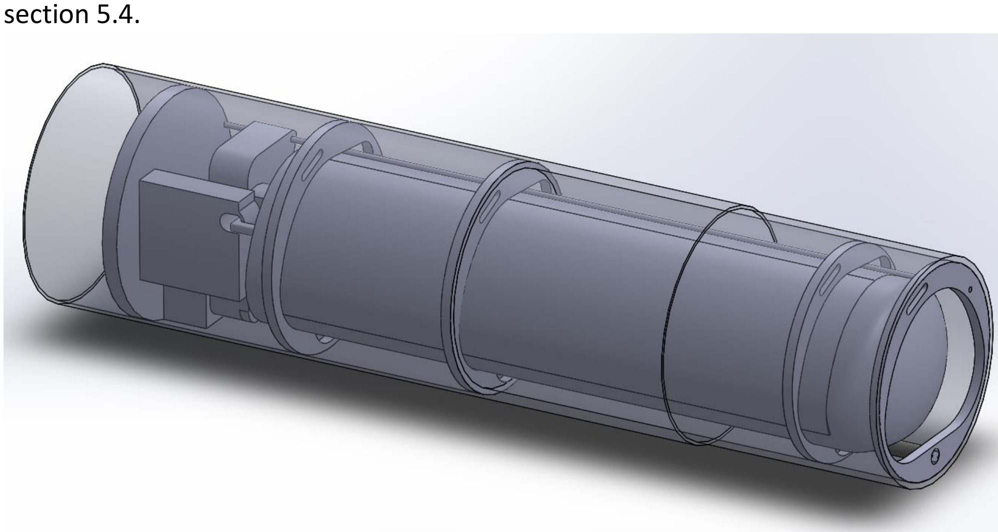


Figure 5-12Payload Bay in Flight Configuration

2. The Arduino releases the Latch, and after a delay, begins spinning the stepper motor.

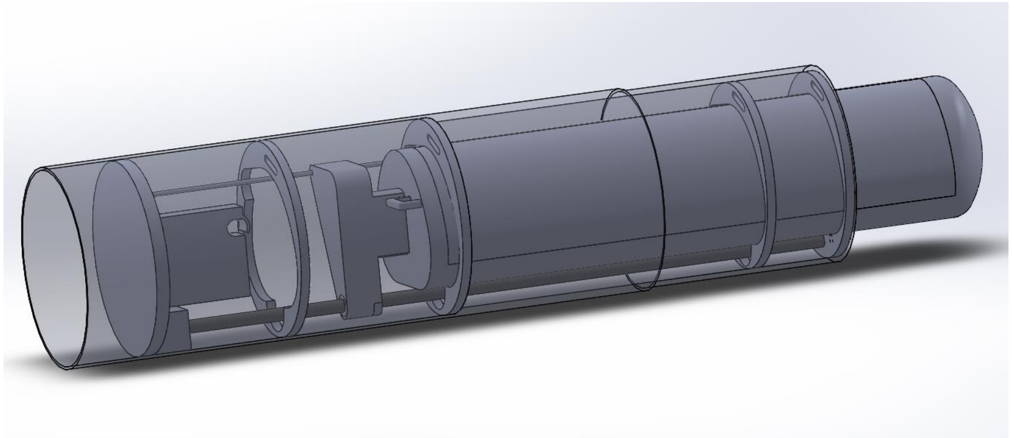


Figure 5-13 Latch Opened, Pusher Partially Extended

3. The Pusher slides along the lead screw until the pod has completely cleared the final centering ring. The pod is now entirely suspended by the cantilevered rod.
4. The Pod rotates heavy side down, leaving the drone in the pod correctly oriented.

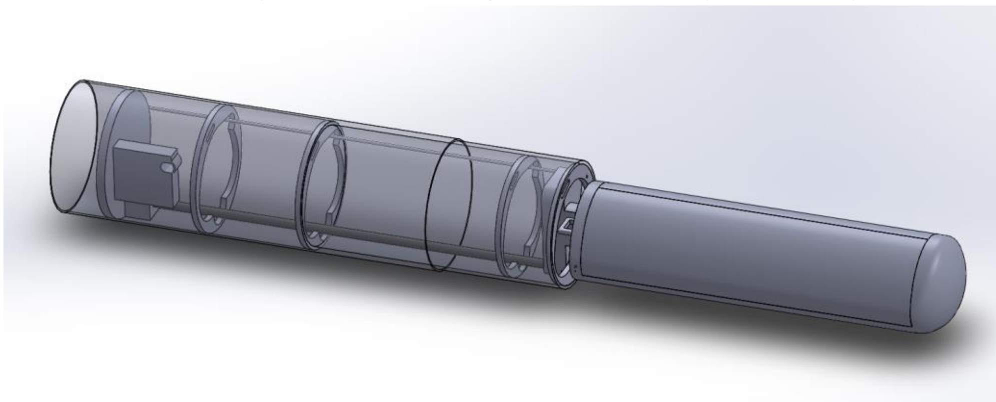


Figure 5-14 Pod Fully Extended, Suspended from Cantilever

5. The pusher and rod retract. If the pod rotates at all, it will be unable to retract into the body tube. If the tube lands perfectly, the pod will get caught on a piece of elastic stretched over the opening, previously pushed out of the way by the front of the pod.

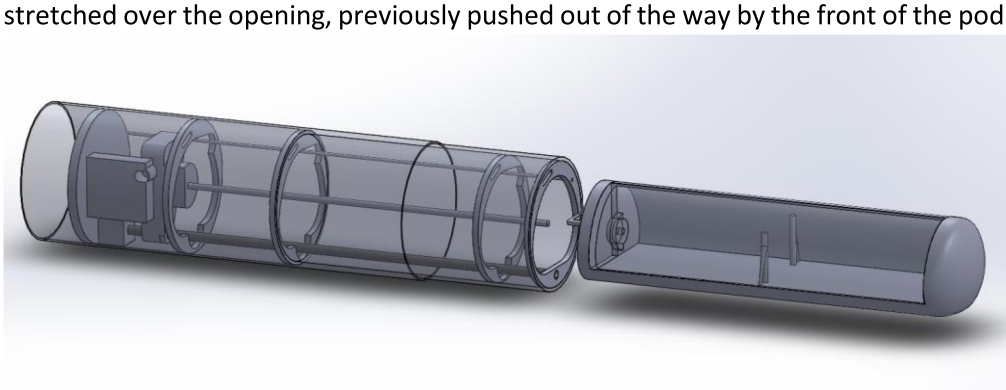


Figure 5-15 Rod Retracted, Pod Resting on Ground

6. Once the rod is retracted, the pod falls to the ground, and the standing levers in the pod which are pulled down by elastic, push the flaps open.

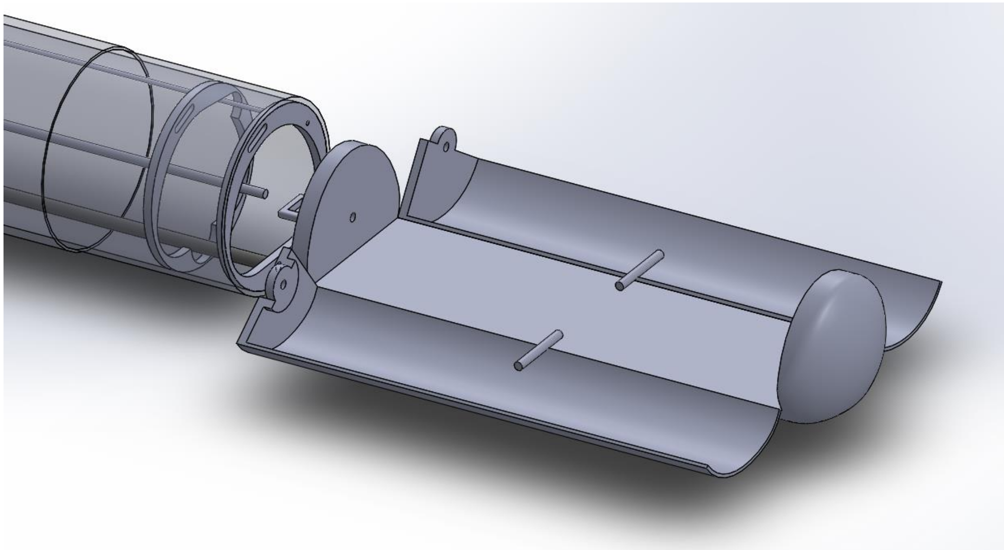


Figure 5-16 Pod Opens, Revealing the UAV (Not Pictured)

7. With the pod walls moved away, the UAV arms extend as explained in section 5.2.1.2, readying it for flight.

6. Project Plan

6.1 Requirements Verification

Table 6-1 Requirements Verification Table

Handbook Item	Compliance	Method of Verification	Verification Plan
1.1	Team members shall complete 100% of the project, including design, construction, written reports, pre-sentations, 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, checklists, personnel assignments, STEM engagement events, and risk and mitigation.	Inspection	Executive Board Members shall collaborate to produce an updated project plan with each milestone report.
1.3	The Team shall not be bringing any Foreign Nationals to launch week activities.	Demonstration	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	Demonstration	The Team Outreach Coordinator shall organize STEM engagement events such that the team reaches 750 participants by FRR.

	Engagement Activity Report, 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.	Demonstration	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 rocket to launch on a 1515 rail.	Test	The Structures lead shall use the team's 1515 rail to slide the assemble rocket into place to verify alignment and fit.
1.13	The team shall identify two mentors, Alan Whitmore and Jim Livingston.	Demonstration	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 rocket 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 shall be declared in Section 3.3.1 of this document.

2.3	The team shall design a vehicle to carry two commercially available barometric altimeters. One altimeter shall be chosen as the primary altimeter.	Analysis	The recovery and avionics lead shall use two PerfectFlite StratoLogger CF altimeters in the fabrication of the team's rocket.
2.4	The team shall design a vehicle with two altimeters armed by an external arming switch.	Analysis	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 rocket 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) sections as described in Section 3.1.4.
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 as described in Section 3.1.4.
2.8.2	The nosecone shoulder shall be at least ½ body diameter in length.	Inspection	The nosecone shoulder shall be 2.75 inches 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 L850W 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	Demonstration	The team shall practice launch vehicle assembly prior to launch day to verify assembly fits within the time constraints.

	Administration flight waiver opens.		
2.11	The launch vehicle shall be capable of remaining in launch-ready configuration on the pad for a minimum of 2 hours without losing the functionality of any critical on-board components.	Test	The team shall test each of the electronic systems to verify functionality for a minimum of two hours.
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 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.	Demonstration	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 L850W motor produced by Aerotech.
2.14.1	The team shall make final decisions on motor choice by the Critical Design Review Milestone.	Demonstration	The motor choice shall be finalized by the Critical Design Review Milestone.
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 L850W motor with a total impulse of 3,646.2 Newton-seconds.
2.17	The team shall design a motor with a minimum static stability margin of 2.0	Inspection	The launch vehicle shall be 2.17 calibers based on the current design.

	at the point of rail exit.		
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 rocket.	Demonstration	The subscale model shall be launched on November 17th, 2018.
2.19.1	The subscale model shall resemble and perform aerodynamically similar to the full-scale rocket.	Demonstration	The subscale model shall be 73% of the size of the full-scale rocket.
2.19.2	The subscale model shall carry an altimeter capable of recording the model's apogee altitude.	Demonstration	The subscale shall carry two StratoLogger altimeters to record altitude.
2.19.3	The subscale model shall be a newly constructed rocket, 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 the CDR report.
2.20.1	The team shall launch its full-scale rocket in final flight configuration prior to FRR.	Demonstration	The team shall design an rocket that is recoverable and sustainable enough to survive multiple launches in final flight configuration.
2.20.1.1	The vehicle and recovery system shall have functioned as designed.	Test	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 rocket shall be a newly constructed rocket, designed and built specifically for this year's project.	Demonstration	The team shall construct a new rocket in preparation for the full-scale qualification launch.
2.20.1.3.1	If the payload is not flown, mass simulators shall be used to simulate the payload mass.	Test	The team shall design the payload bay to accept a mass simulator if necessary.

2.20.1.3.2	The mass simulators shall be located in the same approximate location on the rocket as the missing payload mass.	Test	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 and 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 L850W 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.	Test	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	Demonstration	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	Demonstration	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 mid-February.
2.20.2.1	The payload shall be fully retained throughout the entirety of the flight,	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

	all retention mechanisms must function as designed, and the retention mechanism must not sustain damage requiring repair.		payload is retained throughout all regimes of flight.
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 by mid-February.
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 rocket 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 rocket 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 such 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.
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.	Demonstration	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.	Demonstration	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.	Test	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.
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.
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 commercially available batteries.	Demonstration	The Avionics and Recovery Subteam shall utilize altimeters that are powered by commercially available batteries.
3.6	The recovery system shall contain redundant,	Analysis	The Avionics and Recovery Subteam shall select the optimal altimeters after ananalyzing several brands.

	commercially available altimeters.		
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.	Demonstration	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 rocket 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.
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.
4.4.1	The team shall design a custom UAV that will deploy from the internal structure of the launch vehicle.	Demonstration	The Paylaod 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 rocket 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.
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 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%.
4.4.4	The UAV shall be deployed from the launch vehicle under the supervision of the RDO.	Demonstration	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.	Demonstration	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	Demonstration	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.	Demonstration	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.	Demonstration	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.	Demonstration	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.	Demonstration	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.	Demonstration	The UAV Subteam shall register the UAV with the FAA.

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.	Demonstration	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 rockets 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 Team Derived Requirements

Throughout the preliminary design process, the team found that the requirements described in Table 6-1 were mostly sufficient to guide the team towards a viable design. To define additional requirements the team conducted an examination of requirements derived by previous teams. Furthermore, the team treasurer conducted a review of the current budget. Once completed, the results of these two exercises were used to decide on the requirements listed in Table 6-2.

Table 6-2 Team Derived Requirements Table

Subteam	Description of Requirement	Reason for Requirement	Method of Verification	Verification Plan
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.

Vehicle	The launch vehicle shall not exceed a velocity of Mach 0.7.	At speeds over Mach 0.7, fin flutter occurs, increasing the risk of fin cracking. This would make 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.

6.3 Project Budget

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

Table 6-3 List of Club Officers for 2017-18 School Year

	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**
Travel	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**

6.4 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**

6.5 Project Timeline

Figure 6-1 shows the project timeline for the 2018-2019 competition year.

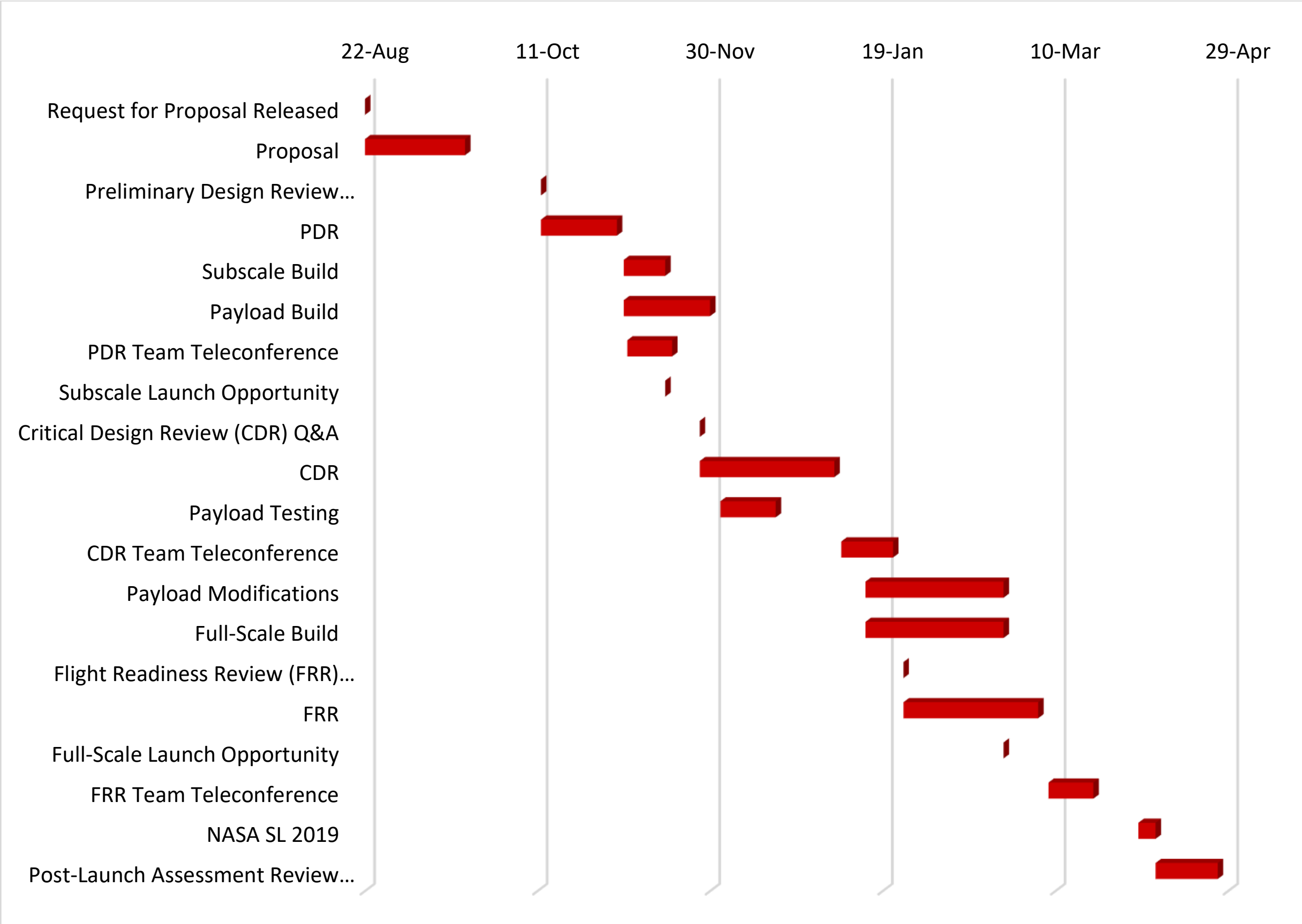
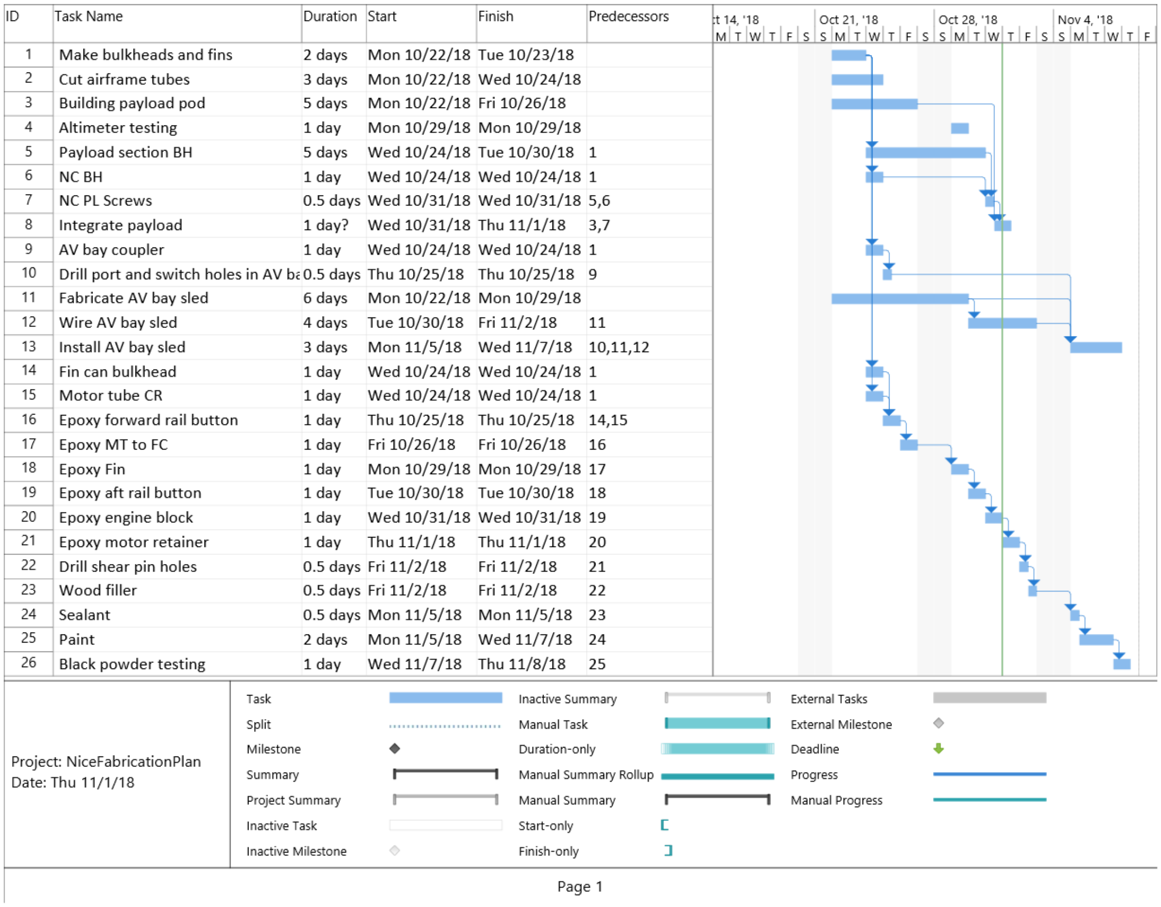


Figure 6-1 2018-19 NASA SL Competition Gannt Chart

Additionally, the team has developed a timeline for fabricating the subscale rocket. This timeline will be updated as the build progresses and used as a baseline to develop a schedule for the full-scale launch vehicle construction.



ID	Task Name	Duration	Start	Finish	Predecessors
1	Make bulkheads and fins	2 days	Mon 10/22/18	Tue 10/23/18	
2	Cut airframe tubes	3 days	Mon 10/22/18	Wed 10/24/18	
3	Building payload pod	5 days	Mon 10/22/18	Fri 10/26/18	
4	Altimeter testing	1 day	Mon 10/29/18	Mon 10/29/18	
5	Payload section BH	5 days	Wed 10/24/18	Tue 10/30/18	1
6	NC BH	1 day	Wed 10/24/18	Wed 10/24/18	1
7	NC PL Screws	0.5 days	Wed 10/31/18	Wed 10/31/18	5,6
8	Integrate payload	1 day?	Wed 10/31/18	Thu 11/1/18	3,7
9	AV bay coupler	1 day	Wed 10/24/18	Wed 10/24/18	1
10	Drill port and switch holes in AV ba	0.5 days	Thu 10/25/18	Thu 10/25/18	9
11	Fabricate AV bay sled	6 days	Mon 10/22/18	Mon 10/29/18	
12	Wire AV bay sled	4 days	Tue 10/30/18	Fri 11/2/18	11
13	Install AV bay sled	3 days	Mon 11/5/18	Wed 11/7/18	10,11,12
14	Fin can bulkhead	1 day	Wed 10/24/18	Wed 10/24/18	1
15	Motor tube CR	1 day	Wed 10/24/18	Wed 10/24/18	1
16	Epoxy forward rail button	1 day	Thu 10/25/18	Thu 10/25/18	14,15
17	Epoxy MT to FC	1 day	Fri 10/26/18	Fri 10/26/18	16
18	Epoxy Fin	1 day	Mon 10/29/18	Mon 10/29/18	17
19	Epoxy aft rail button	1 day	Tue 10/30/18	Tue 10/30/18	18
20	Epoxy engine block	1 day	Wed 10/31/18	Wed 10/31/18	19
21	Epoxy motor retainer	1 day	Thu 11/1/18	Thu 11/1/18	20
22	Drill shear pin holes	0.5 days	Fri 11/2/18	Fri 11/2/18	21
23	Wood filler	0.5 days	Fri 11/2/18	Fri 11/2/18	22
24	Sealant	0.5 days	Mon 11/5/18	Mon 11/5/18	23
25	Paint	2 days	Mon 11/5/18	Wed 11/7/18	24
26	Black powder testing	1 day	Wed 11/7/18	Thu 11/8/18	25

Figure 6-2 2018-19 NASA SL Subscale Build Gannt Chart

Throughout the preliminary design process the team has been experimenting with different planning and organizational tools. Figure 6-1 was generated using MS Excel and Figure 6-2 was generated using MS Project. Additionally, the team is making use of Asana, an online Kanban board tool, to assign tasks to subteams. The team plans to continue to utilize these tools for the duration of the competition year.

7. References

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Appendix A

System	Subsystem/ Component	Failure Mode	Causal Factors	Failure Effects		Severity	Likelihood	Recommendations
				Subsystem	System			
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 rocket component during descent and recovery		Damage to itself and other rocket 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 grounded ejection tests of the calculated black powder charge masses to verify separation of

								sections, and functionality of altimeter system. Periodically conduct grounded 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			2	2	Conduct grounded ejection tests of the

					Failure to launch			calculated black powder charge masses to verify separation of sections, and functionality of altimeter system. Periodically conduct grounded 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 1.5 during all regimes of flight.
			Damaged during handling and fabrication within the lab, or handling and assembly prior to launch			1	2	Inspect each body tube component for cracks, bends, warping, or other damage 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 rocket 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 rocket prior to launch to measure the stability margin. Mass distribution within the rocket 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, and establish preventative measures to reduce error frequency.
			Fin flutter			2	3	Rocket 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	Rocket 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 contamination	Rocket fails to launch	Reduced performance of rocket motor	Rocket 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 flame and hazards storage cabinet. Periodically inspect storage compartment.
			Over-oxidized reaction			2	2	
			Reduced fuel efficiency			3	2	

	Bulkheads	Bulkhead separation from airframe during motor burn	Manufacturing defect	Reduced performance of rocket motor and severe damage to other rocket 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 1.5 during all regimes of flight.
			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	Possible 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 rocket 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 grounded 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	Rocket 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			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	Rocket 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, rocket is not recovered safely	1	2	Conduct grounded ejection tests of the calculated black powder charge masses to verify separation of sections, and functionality of altimeter system. Periodically conduct grounded 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		Rocket 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		Rocket 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 grounded ejection tests of the calculated black powder charge masses to verify separation of sections, and functionality of altimeter system. Periodically conduct grounded 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 rocket to separate and deploy parachutes	1	2	Conduct grounded ejection tests of the calculated black powder charge masses to verify separation of sections, and functionality of altimeter system. Periodically conduct grounded 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 grounded ejection tests of the calculated black powder charge masses to verify separation of sections, functionality of altimeter system, and minimal damage to separated rocket components.
		Charge ignites but fails to cause separation	Charge is too small	No ejection	Failure of rocket to separate and deploy parachutes	1	2	Conduct grounded 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 grounded ejection tests of the calculated black powder charge masses to verify separation of sections, and functionality of altimeter system. Periodically conduct grounded 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 grounded ejection tests of the calculated black powder charge masses to verify separation of sections, and functionality of altimeter system. Periodically conduct grounded 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 grounded ejection tests of the calculated black powder charge masses to verify separation of sections, and functionality of altimeter system. Periodically conduct grounded 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 grounded ejection tests of the calculated black powder charge masses to verify separation of sections, and functionality of altimeter system. Periodically conduct grounded 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 rocket 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 rocket 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 reducing 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	Team Mission Failure (failure to deliver beacon)	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 ball-and-socket latches			4	2	Ball-and-socket latches will be tested prior to launch under numerous angular acceleration conditions.
		Failure to secure UAV arms into a fully deployed position				4	2	Ball-and-socket latches 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 disconnection	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 additive 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.
		Do 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.