USLI

WORCESTER POLYTECHNIC INSTITUTE

G.O.A.T.S.

USLI PROJECT Flight Readiness Review 2018 - 2019

March 4, 2019

Table of Contents

Acronym Dictionary

The Flight Readiness Review (FRR) uses a variety of acronyms. All of them are defined within this section.

- 3D – Three Dimensional
- A – Amps
- ABS – Acrylonitrile Butadiene Styrene
- AGL – Above Ground Level
- AIAA – American Institute of Aeronautics and Astronautics
- APCP – Ammonium Perchlorate Composite Propellant
- BASF – Chemicals company
- CDR – Critical Design Review
- CG – Center of Gravity
- CO_2 – Carbon Dioxide
- CP – Center of Pressure
- CTI – Cesaroni Technology Incorporated
- E-Bay – Electronics Bay
- FAA – Federal Aviation Administration
- FEA – Future Excursion Area
- FN - Foreign National
- FMEA – Failure Modes and Effects Analysis
- FRR – Flight Readiness Review
- ft – Feet
- G.O.A.T.S. – Get Our Apogee to Space
- GPS – Global Positioning System
- GSSS – Garden State Spacemodeling Society
- IMU – Inertial Measurement Unit
- in – Inch
- lbf-ft – Pound Foot (torque)
- lb – Pounds
- LiPo – Lithium Polymer
- LRR - Launch Readiness Review
- mAh – Milliamp Hours
- MHz - Mega Hertz
- MMMSC – Maine Missile Math and Science Club
- MPU – Micro Processing Unit
- MSDS – Material Safety Data Sheets
- mW – Milliwatt
- N/A – Not Applicable
- NAR – National Association of Rocketry
- NASA – National Aeronautics and Space Administration
- PDR – Preliminary Design Review
- PLA – Poly Lactic Acid
- PPE – Personal Protective Equipment
- PWM – Pulse Width Modulation

- RDO – Range Deployment Officer
- RPM – Rotations per Minute
- RSO – Range Safety Officer
- RSSI - Received Signal Strength Indication
- SGA – Student Government Association
- s – Second
- STEM – Science, Technology, Engineering and Mathematics
- TRA – Tripoli Rocketry Association
- UAV – Unmanned Aerial Vehicle
- USLI – University Student Launch Initiative
- V – Volt
- WPI – Worcester Polytechnic Institute

Section 1. Summary

Section 1.1 Team Summary

Section 1.1.2. Team Mentor

Robert Dehate: Team Mentor

President AMW/ProX

NAR L3CC 75918 TRA 9956

robert@amwprox.com

(603) 566-2904

Section 1.2. Launch Vehicle Summary

The final Launch Vehicle design has a diameter of 6.125 in, a length of 131 in. and a theoretical mass plus motors of approximately 11.506kg. The vehicle, named Batman, has been designed to reach an apogee of approximately 4683 ft. The Launch Vehicle will split into four main sections over the course of its decent and each tethered section will have a GPS, totalling 3 GPS devices. The sections are the upper airframe, the lower airframe, the payload retention system, which are all tethered together, and the nose cone. Housed within the upper airframe will be the payload retention system made of airframe tubing dedicated to housing the selected payload for the duration of its flight. The vehicle will have three parachutes, a nose cone parachute, drogue parachute and main parachute. The launch vehicle's flight data was be recorded using a Raven 3 Altimeter that will be housed in the E-bay. On the test launch day, we started with an ejection test, which was successful in separating sections and deploying parachutes. On final visual inspection everything checked out. When we launched the rocket it ascended like we expected, but during the deployment phase the lower airframe sustained some damage.

Section 1.3. Payload Summary

Our selected payload is the deployable UAV beacon delivery system which our team has named Robin. The purpose of the payload system is to deliver a beacon to a Future Excursion Area. This task will be completed using a quadcopter which will be housed within an active retention system contained in the airframe of the launch vehicle during flight with its arms folded. To separate this retention section of the airframe from the main airframe a parachute will deploy after the activation of black powder charges at the appropriate altitude and pull it out. The housing will consist of Blue Tube cut into four separate pieces to allow it to unfold upon landing and orient itself to deploy the UAV to takeoff. Once the launch vehicle is visually confirmed to have landed and having received permission, it will power on and fly to a Future Excursion Area to deliver the beacon. The beacon will be a 3D printed small cube and will be secured to the bottom of the UAV with small linear servo used to drop it when the UAV reaches the Future Excursion Area.

Section 2. Changes Made Since CDR

Section 2.1. Launch Vehicle Changes

The rocket has had very minimal changes in design between the CDR and FRR. We made the decision to increase the weight amount of black powder in the secondary charges. If the first charges went off but were unsuccessful in ejecting the parachutes and separating components it is likely that an equal or lesser charge would also not work. This should not be necessary unless for some reason the primary charge fails to go off. The aluminum plates on the bulk heads are steel in the built rocket. We decided to change this because the steel plates were more widely available.

Section 2.2. Payload Changes

Changes made from the CDR include a redesign of the locking mechanisms for the arms of the UAV and a change of material of the 3D printed base of the retention system. The base was originally like the bulkhead to which it attaches to be made of Matterhackers NylonX 3D printer filament but was instead changed to PLA filament as a high infill print was determined be strong enough to handle flight forces and impact upon landing. Details regarding the UAV arm locking mechanisms can be found in section 5.1.1.

Section 2.3. Project Plan Changes

Funding problems were resolved after submitting another round of funding requests. After presenting to the SGA board, we were given an additional $3149 in funding which is able to cover all travel with the exception airfare. Students attending the launch have payed $390 to purchase plane tickets with the only remaining expense being train tickets which are $12 a person. Additionally by using Go Fund Me the team was able to raise an additional $1,000.

Section 3. Vehicle Criteria

Section 3.1. Design and Construction of Vehicle

Section 3.1.1 Changes in Launch Vehicle Design

The design of the E-Bay sled was altered to accommodate the final design of the GPS antenna which is about 6 in. To do this, the upper E-Bay sled which houses the GPS was extended to 6.5 in and the lower altimeter sled was shortened to 3.9 in. This did not affect mounting for any of the electronics. Additionally, we had initially planned to have a GPS located in every tethered and untethered section of the launch vehicle. This would have placed a tracker in the upper airframe, lower airframe, E-Bay, nose cone, and payload, but in compliance with rule 3.11.1 in the Student Handbook which states, “Any rocket section or payload component, which lands untethered to the launch vehicle, will contain an active electronic tracking device,” we made the decision to reduce the amount of trackers. The new tracker locations are in each the E-Bay, nose cone, and payload retention system only, which makes sure that the tethered main body of the launch vehicle and every untethered section will have a GPS in it.

Section 3.1.2. Design Features
The rocket was designed to ensure that it is able to be safely launched and recovered. The materials and designs of individual parts such as the nose cone, upper airframe, E-Bay, lower airframe, motor, centering rings, fins, payload retention systems, and recovery system will be discussed in detail to explain why our launch vehicle will be successful.

The final nose cone selection has a length of 31.5in, a diameter of 6in, and wall thickness of 0.079in. The team settled upon an ogive shape that is made of fiberglass and weighted with a metal tip.

The team considered multiple other nose cone options throughout the design process with the original launch vehicle design including a fiberglass conical nose cone. This decision was made to move to an ogive shape because of the positive aerodynamic properties compared to conical nose cones, this change was necessary in order to reduce the drag experienced by the launch vehicle.

For transonic speeds, the conical and ogive nose shapes are preferred. In cases of supersonic speed, shapes such as parabolic, spherical blunted, and biconic nose types are preferred. Based on these options for the predicted speeds the launch vehicle will experience, the team felt it best to choose the more aerodynamic option of the two. When ultimately choosing between a fiberglass conical and fiberglass ogive nose cone, the team felt that the material and overall aerodynamic properties of the ogive nose cone made it the best decision for our final launch vehicle.

Specifically, the metal tipped ogive nose cone was chosen to counteract the weight of the launch vehicle's carbon fiber fins and motor. With the original conical nose cone in place, the carbon fiber fins caused the launch vehicles stability to drop significantly due to the added weight. By choosing a metal tipped nose cone we were able to restabilize the launch vehicle as the metal balanced out the gained weight due to the carbon fiber.

The launch vehicle airframe will be constructed out of 6in x 0.074in Blue Tube 2.0. Manufactured by Always Ready Rocketry, Blue Tube is defined as a vulcanized cardboard laminate and is known for its high density and strength. The Blue Tube 2.0 is also heat resistant. Blue Tube was selected for the finalized design because it is highly resistant to abrasion, cracking, shattering and other forms of damage. This is essential in order for the launch vehicle to be recoverable and flown on multiple occasions, ruling out other alternatives such as phenolic for its lack of strength and durability.

In terms of the airframe layout, the upper and lower airframes will be connected by a blue tube tube coupler that will house the altimeter and E-bay of the launch vehicle. The tube coupler serves not only as a form of extra protection for the instruments contained inside but also as a simpler way to access the launch vehicle's electrical components. The coupler is referred to as the E-Bay and houses two Raven 3 altimeters that will act as the primary and secondary flight computers for the launch vehicle.

The height of the launch vehicle was determined due to the stability in correspondence with the moment arm of the vehicle. A taller rocket increased the stability therefore putting the current height of the vehicle at 10’ 11” or 130.9in tall. This height is adequate to house the payload retention system, the payload, the recovery system (including the E-bay) and the payload without any crowding around devices, parachutes, nomex blankets, or energetics that may cause damage or interference to the packed or electrical components contained within the airframe.

The upper airframe of the finalized launch vehicle design houses the selected payload, payload retention system, the nose cone parachute, and main rocket body parachute.

The upper airframe contains a section of airframe inner tube approximately 12.5in in length that will act as the UAV’s active retention system, made of blue tube, a material we continue to use due to its durability and utility. It is pushed out at 700ft AGL with the nose cone, nose cone parachute, and main parachute. The retention system is further detailed in Section 5.

The final E-bay design will be made of an inner tube coupler. The coupler will be composed of Blue Tube with a 1in ring of the outer airframe tubing epoxied in the middle. This is so that the upper airframe and the lower airframe can slide into place and be held together by screws and shear pins. The E-Bay has bulkheads on each side with U-bolts so that when the shock cord pulls the bulkhead the aluminum rod pulls the other bulkhead, which is stuck in place by the Blue Tube ring blocking its movement. There are also bolts on the bulkheads prevent the aluminum rods from sliding through the plywood. The integrity of the bulkheads themselves are sound due to the metal rods, supporting Blue Tube rings and the nuts securing them in place. The upper airframe will be bolted to the E-bay coupler with screws so that when the black powder charge associated with an altitude of 700ft goes off, the coupler will not be pushed out with the parachutes and shock cord.

The lower airframe will be connected to the coupler using shear pins allowing the lower airframe to separate from the rest of the airframe by shearing the shear pins when the apogee black powder charge goes off. However, the lower airframe will still be connected to the rest of the launch vehicle via shock cord. The coupler will have two bulkheads made of 0.25in plywood supported by small rings of Blue Tube. The bulkheads will have two threaded aluminum rods that run through each side. There will be 2 nuts on each side (8 total) of the bulkhead on both rods to secure them. Each bulkhead will have a U-bolt to connect the shock cord. There will be an access point on the main body of the launch vehicle with a toggle switch to turn the Raven 3 altimeter on/off. Charges will also be wired to the outside of the E-bay so that they are easily replaceable or fixable.

Inside the inner tube, a 3D printed Poly Lactic Acid (PLA) sled will house two Raven 3 altimeters, a NEO-6M, a 9V battery, and wires. The sled will be attached to the two aluminum rods. One Raven 3 altimeter will be used for backup charges in case of a failure in the primary altimeter. We will be using the barometer feature of the Raven 3 because it is accurate in detecting the altitude of apogee and dual deployment during flight. It also has an accelerometer feature, but that assumes a vertical path which will throw the altitude value off over time. To counteract this we will be using a discrete Inertial Measurement Unit (IMU) to measure acceleration.

When deciding how the E-bay would be laid out we had the option of fixing a sled to the inside or attaching a wooden block to the center of the inner tube. The sled quickly became the more logical route because it would be hard to support the battery on a flat plane. Screwing components to the wood could cause splits and keeping components vertical would be difficult without physical blocking.

Nothing within the lower airframe was changed between the CDR and the FFR. It houses the motor, drogue parachute, shock cord, and nomex blankets.

The chosen primary motor selection for the final launch vehicle design is the L730-0 with the secondary motor selection being the L1030. The L730-0, manufactured by Cesaroni Technologies proved to be the best option for the team in order to reach our goal apogee while also complying with the 90 second decent time limit set by NASA. The motor tubing will be made from blue tube like the outer airframe of the launch vehicle.

The amount of centering rings located on the motor mount within the lower airframe is five. The centering rings act to help with stability of the motor tube and ensuring its rigidity within the launch vehicle. Centering rings will be laser cut from quarter inch plywood and attached to the motor tubing using epoxy. The bottom most centering ring will have two holes drilled into it for installing the motor retention. The selection motor retention will consist of nuts, bolts, washers, and Z-clips. The upper most centering ring will additionally contain two holes drilled into it for the U-bolt that will connect the shock cord in the lower airframe.

The chosen fin material for the final launch vehicle has been decided to be quarter inch thick carbon fiber. The original design of the launch vehicle included four fins that were going to be made of plywood. The team had originally chosen to work with plywood as it was the chosen material for most fins made by our American Institute of Aeronautics and Astronautics (AIAA) chapter. We quickly realized, however, that with the greater competition USLI offers and with the growing size of the launch vehicle, that the impact speed it would experience upon hitting the ground would be around 26.7ft/s which is a high impact speed for a material like plywood to withstand due to its low durability.

When comparing the weight of carbon fiber to other materials considered for fin design the team found that carbon fiber is lighter than materials such as fiberglass. This was a good sign as we knew with this material being heavier than plywood that changing the fins to this material could have a negative effect on the stability of the launch vehicle. We found that carbon fiber was very strong and could withstand the speed of our ground hit velocity, and that it is a more rigid material, allowing the rocket to experience minimal flex patterns. Due to the fact that at high speeds highly flexible fins can be prone to fluttering we felt that carbon fiber would be a more reliable material in regards to rigidity. In regards to toughness, we found that the shape of carbon fiber will not change when a consistent and constant force is applied to it. Although materials like fiberglass can withstand higher forces for longer amounts of time than carbon fiber due to its flexibility, rigidness was valued more for the following reason. We felt it was important to consider thermal characteristics and the effect weather might have on this material due to our specific location. Since we are located in New England most of our test launches will occur during the colder months. We needed a material that wouldn't deform too much in the cold as we prepared for competition. Ultimately we found that carbon fiber has a negative coefficient of thermal expansion, meaning carbon fiber will shrink or expand less than other comparable materials when exposed to extreme weather conditions. Although carbon fiber is a more expensive material due to its difficulty to manufacture, we felt that the overall benefits it had in regards to thermal characteristics, strength, rigidity, and weight outweighed the negatives of expense and toughness making it our choice of fin material for the final launch vehicle design.

Section 3.1.3. Flight Reliability

A significant amount of our mission criteria success will be ensured through the safety checklists. The prelaunch mission criteria starts by requiring that we ensure that all materials and components necessary for success of the launch vehicle are working and accounted for before attending a test launch or traveling to the competition. We will ensure that this happens through our packing checklist and pre-travel checks. The next criteria is to make sure that all components are placed correctly within the launch vehicle when assembling it for launch. This is easy to do correctly because most parts are fixed either in the E-bay, on it, or in the shoulder of the nose cone. The nose cone shoulder has a GPS fixed onto the side which doesn't need to be moved between flights. The E-bay houses parts fixed to a sled and the E-bay needs to be oriented correctly within the launch vehicle. The bulkhead on the side of E-bay that goes into the upper airframe is marked so that it will be properly attached to that side. The primary and secondary main and drogue parachute charges need to be wired correctly. To make sure this happens the charges are labeled and checked as they are made and checked again before the ebay is closed into the airframes. The shock cord, parachutes, and nomex blankets are packed by properly folding the parachutes and wrapping their cord neatly around it, accordion folding the shock cord, protecting the whole thing with the nomex blanket, which also meets the criteria that nomex blankets will be used to ensure that the black powder charges cause no damage to parachutes or other devices. Recycled newspaper is always to be placed between the nomex blanket and black powder charges when applicable.

Our next criteria to meet is for the Raven 3 Altimeter to be programmed and oriented correctly and safely fastened in the E-bay so that flight data can be received and analyzed after launch. The Raven 3 is another component that will not be moved between every launch or test. When it is placed in it is checked for security and tested and is checked before every launch. The next criteria is to ensure that every section of the launch vehicle along with the payload is equipped with a GPS tracking device that it checked to be successfully transmitting data such that each piece can be easily found after launch. We have three GPS devices in total, one in each the payload, the E-bay, and the nose cone. This will account for every tethered section as required by rules 3.11 and 3.11.1.

Another criteria we must meet is that the launch vehicle will be set up on the launch pad only by members or mentors that have at least a level 2 certification. At the test launch our on-site

mentors, who both had level 3 certifications, set up the rocket and our mentor or school faculty advisor who will be joining us at the competition will be setting up the rocket on the launch pad.
The flight and descent portion of our mission criteria starts with ensuring that our rocket our rocket reach at least 4,500ft AGL. On our test launch day the launch vehicle reached an apogee of 4,031 ft AGL. On the day of our payload launch we aim to reduce the overall weight of our rocket, for example we are considering replacing the steel bulkheads and making a less dense PLA sleds.

The next criterias to be met requires the black powder charge to go off at apogee to deploy the drogue parachute and separate the upper and lower airframe and for the 700ft AGL charges to go off and deploy the main parachute, payload retention system, and nose cone. This is insured with ground tests of the altimeter, ejection tests, and the secondary, larger charges. This process also ensures that sections will properly separate to descend without interference from other parts and for the parachutes to correctly deploy.

Section 3.1.4. Construction Process
We began our construction by cutting the blue tube to their respective lengths. We cut a section for the upper airframe and for the lower airframe, which came to 45.375 in. and 46.25 in. respectively, out of outer tube. A strip of outer tube was also cut to 0.9 in. for a space which is epoxied to the center of the outside of the E-bay. A 11.8 in. of inner tube is E-bay. A .27 in strip of inner tube was cut and we removed an arc length so that it would fit securely inside the E-bay to hold the bulkheads in place. In this step we also cut rectangles out of the lower airframe in which the fins would be located. Our next step was laser cutting the bulkheads and centering rings out of 1/4 plywood. When we got the pieces cut, we drilled holes in the ebay. There were 12 holes drilled in both bulkheads for the U-bolts, threaded rods, and wiring holes for the black powder charges. Around this time we also drilled pressure holes and sanded various parts to refine their dimensions as well as parts that had rough edges. With everything cut we could epoxy the spacer to the E-bay. When the epoxy was set we did our first coats of spray paint on the E-bay and upper and lower airframe.

Shortly after, we went to Hydrocutter to get our carbon fiber fins and parts of the payload cut for assembly. We epoxied in the centering rings, to the motor using the fins to determine the spacing between the rings. After they epoxy set, we were then able to epoxy the combined motor tube and centering rings into the lower airframe and epoxy the fins into place. Around this time we epoxied the U-bolts onto the E-bay, and epoxied the shoulder to the nose cone. The nose cone and shoulder were made to order and are made of fiberglass. The shoulder has a bulkhead with two threaded rods and a U-bolt that is epoxied to the bulkhead for the shock cord.

Thin sheet steel bulkheads were used to isolate the two halves of the E-Bay along with the nose cone electronics. While they were initially constructed by cutting circles with tin snips and a rotary cutting tool and creating the holes for wire and threaded rods with a drill, they proved to be too imprecise, jagged, and hard to work with. A second set of much higher precision bulkheads was created by milling them on a CNC mill.

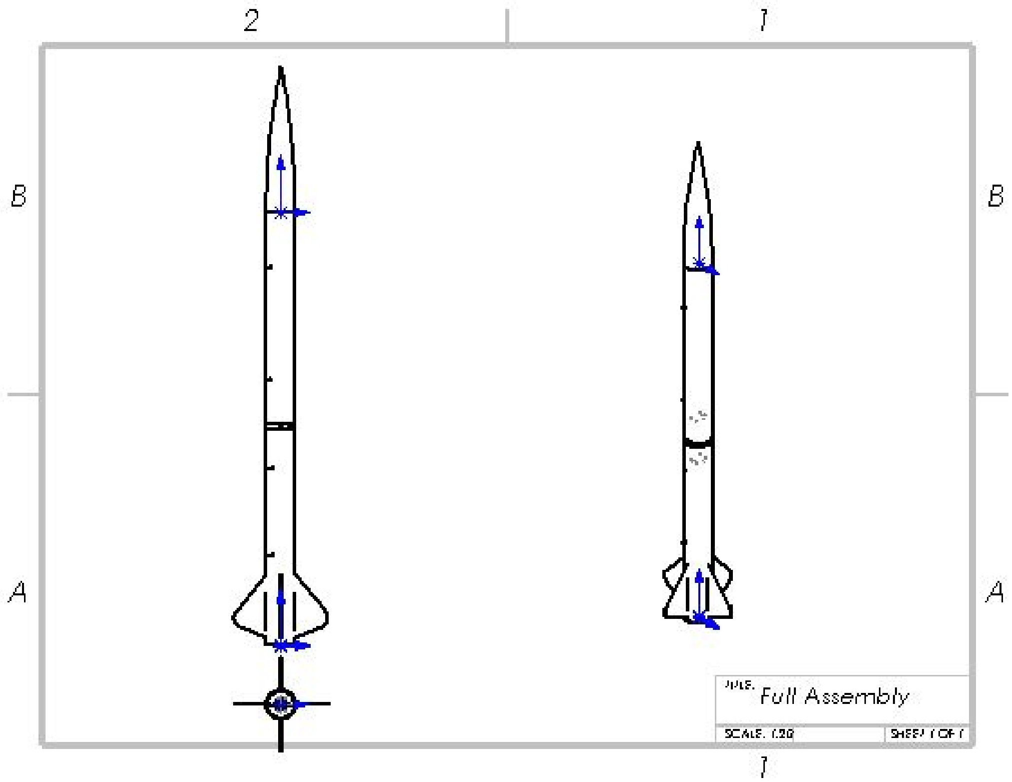
The EBay was constructed form blue tube 2.0, wires, Raven 3 altimeters, 12-volt batteries, and a 3d printed sled retention system with threaded rods and bolts. We connected the main and the apogee charges with wires to the altimeter, the battery and the switch. The same process was followed for the backup altimeter. All wires, altimeters and batteries were neatly zip tied into place.

The last week leading up to the launch, several of the finer details were completed in preparation. The shock cords for the drogue and main parachutes were measured and cut to approximately 188in and 138in, respectively, with each given around an extra 5-6in in order to compensate for the knots that would attach them to their parachutes and u bolts, which was done promptly after. The rail button holes were drilled and the buttons themselves inserted and epoxied into place. Once everything that needed to be epoxied was completed, we sanded the entire rocket because there were several places where epoxy had dripped or pooled, especially around the fins, nose cone and inside the motor tube. This was done to ensure that everything would move smoothly . Once all the epoxy was sanded off, we applied the gloss coats of lead paint.

The day of launch, upon arrival, the E-Bay was taken apart in order to test that the altimeters were working by listening to the sound that each one made which corresponded to each individual charge. The E-Bay was oriented the correct way according to this information. After this, gunpowder for each of the primary and secondary charges were measured out carefully and put into their respective locations. Some sanding was also done on the retention system for the motor due to some epoxy inhibiting the motor’s ability to fit properly. The payload and its retention system were also put into place. Finally, the parachutes were folded into threes and wrapped lightly with their string and packed in their respective locations, thus completing the construction of the rocket.

Section 3.1.5. Schematics

The team has created schematics of the as built launch vehicle. They can be seen in appendix A.1. All dimensions are in inches. The only significant change from the design was that the fin slots were cut 1.8in too long. The extra slot length did not remove any structurally important material and fins were still held in place by the centering rings. The space was filleted with epoxy.



Section 3.1.6. Constructions Differences
When building the rocket we encountered methods of construction that weren't sufficient for what we needed. When we tried cutting the thin sheet steel bulkheads were used to isolate the two halves of the E-Bay along with the nose cone electronics we initially cut circles with tin snips and a rotary cutting tool and creating the holes for wire and threaded rods with a drill, they proved to be too imprecise, jagged, and hard to work with. A second set of much higher precision bulkheads was created by milling them on a CNC mill. When it came to cutting the full scale fins we needed to find a new method because we would not be able to cut them the same way we cut the plywood subscale fins. We were able to get help from a local company, Hydrocutter the has a

Section 3.2. Recovery Subsystem
The launch vehicle will take off in one piece with a predicted apogee at 4683ft AGL. The upper and lower airframes are fastened together with shear pins, as are the upper airframe and nose cone. The E-bay is fastened to the upper airframe with stainless steel screws. It will utilize a primary altimeter, accompanied by a backup altimeter in the event that the primary fails. At apogee, the primary altimeter will trigger the drogue parachute ejection charge (made of black powder), separating the upper and lower airframes by shearing the shear pins connecting the two sections. The two sections will remain connected with a shock cord after deploying the 36 in drogue parachute. One second later, the backup altimeter will trigger its drogue charge,

regardless of whether or not the primary was successful. At this point the launch vehicle will begin its descent.

Upon reaching an altitude of 700 ft AGL, the primary altimeter will detonate the primary main parachute ejection charge (also made of black powder). This will separate the upper airframe and nose cone. The nose cone has its own parachute and is not connected to the upper airframe with shock cord. This parachute as well as the main parachute (72in) will deploy with this primary charge. As with the drogue parachute, the backup altimeter will trigger its main charge one second later, regardless of whether or not the primary was successful. At this point, the launch vehicle is descending in two pieces. The first piece consists of the upper airframe (with the E-bay still fastened), lower airframe, payload, and the drogue and main parachutes (all attached together with shock cord). The second is the nose cone, which descends separately with its own parachute. The two sections will land separately, at which point the payload remains contained in its retention system. In order to comply with the rules NASA has stated in the handbook, every tethered and untethered piece of the launch vehicle that will land separately will be equipped with a GPS device.

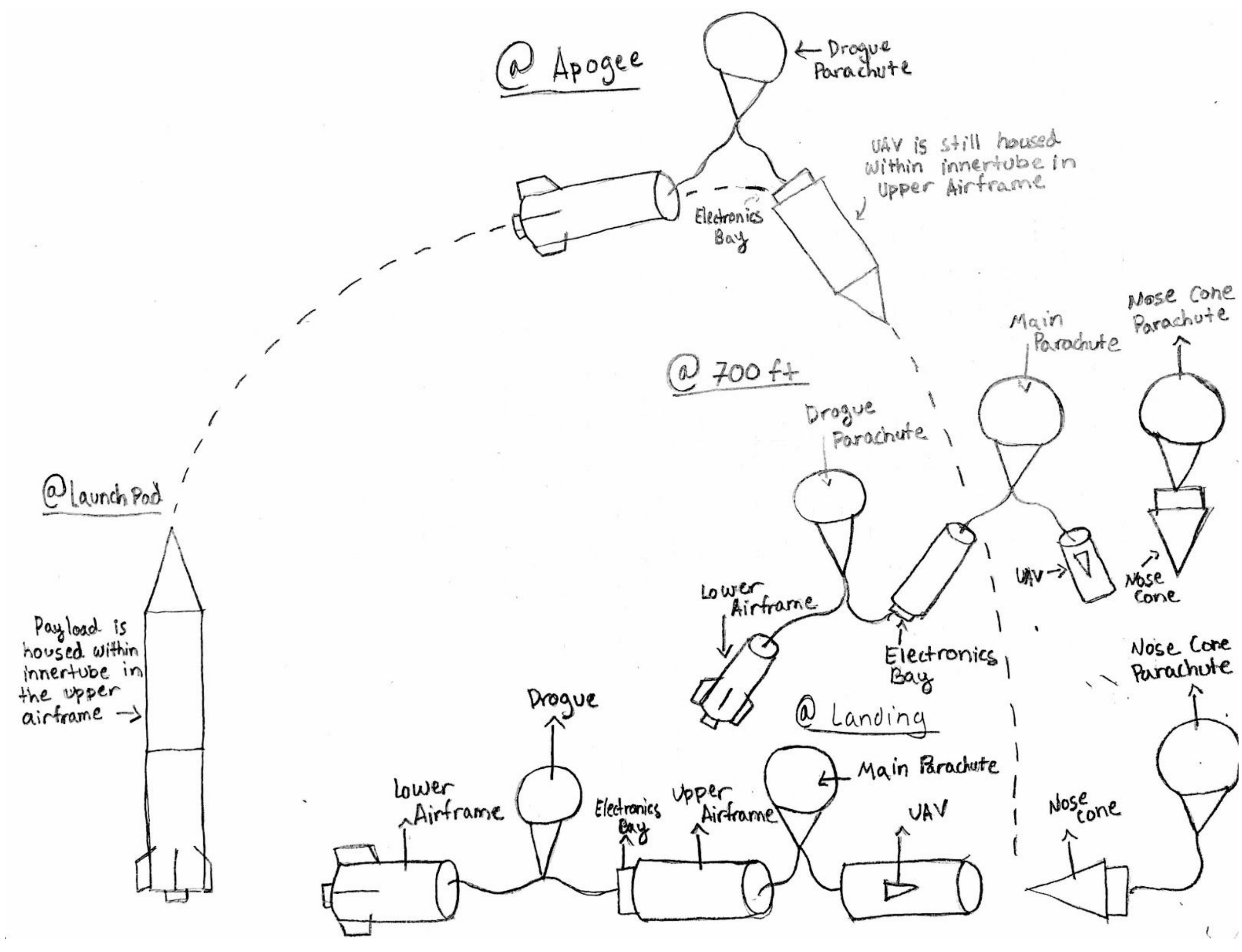


Figure 3.2.1. Flight Plan

In order to reduce the amount of shock inflicted on the parachutes when deployed, a series of layered accordion folds will be made in each of the parachutes' shock cords. The original plan was to use a shock-absorbing system consisting of two buckles with bungee cord in between, however this idea was discarded because it was thought the bungee cord would not be strong enough. By using the accordion folds in the shock cord to further absorb shock, it's guaranteed that the material will be strong enough. All lengths of shock cord are made of 1 in tubular nylon. The shock cord for the drogue parachute will have a length of 138.45 in, and the cord for the main parachute will have a length of 137.55. The bulkheads will be made of 0.25 in plywood and will have a diameter of 5.704 in. All shock cord is attached to the airframe with steel u-bolts.

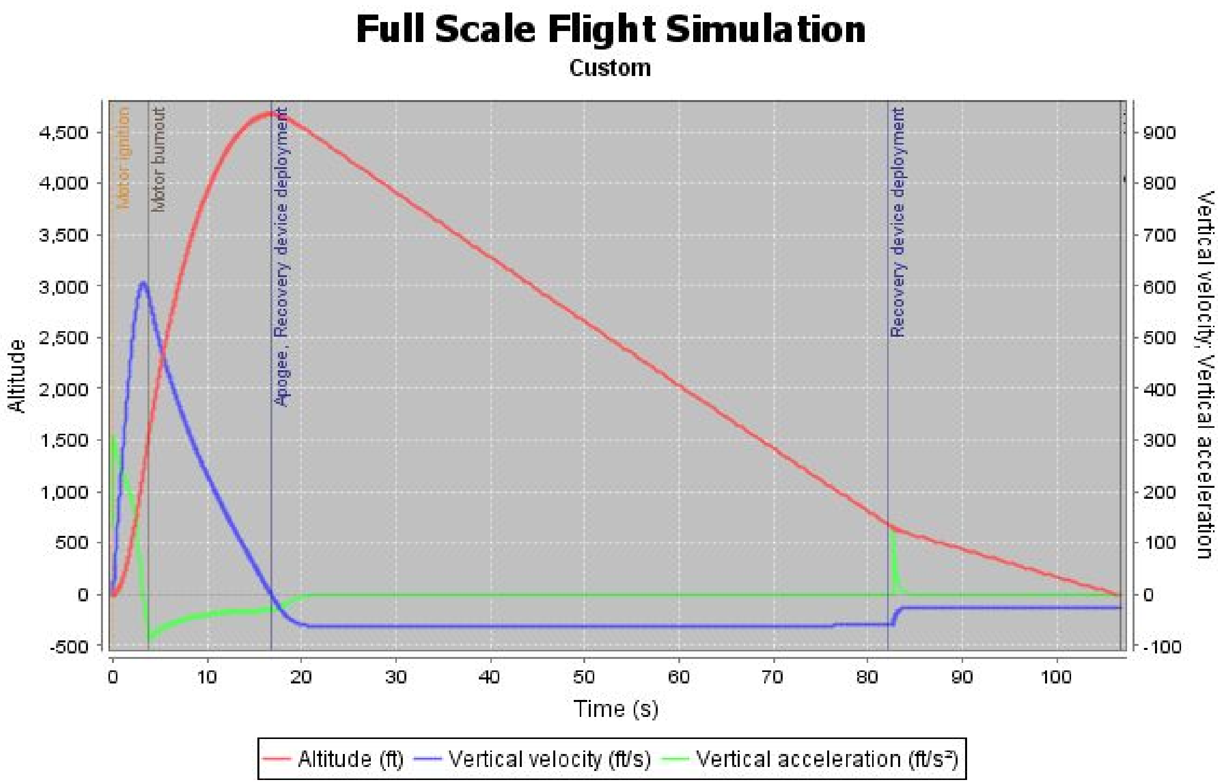


Figure 3.2.2. Flight Simulation Open Rocket

Full Scale Simulation	
Motor Configuration	L730-0
Velocity of Rod	43.2 ft/s
Apogee	4683 ft
Velocity of Deployment	60.6 ft/s
Optimum Delay	13 s

Max Velocity	605 ft/s
Max Acceleration	307 ft/s^2
Flight Time	107 seconds
Decent Time	90.2
Ground Hit Velocity	26.8 ft/s

Table 3.2.3. Flight Plan Simulation Data

Section 3.3. Mission Performance Predictions

Section 3.3.1. Motor Selection

The L730-0 serves as the launch vehicle's main motor. It is 25.6in in length, 2.13in in diameter and has a total impulse of 2763.2100 Ns. The following simulations for this motor were obtained using Open Rocket. The simulation resulted in an apogee of 4704ft AGL and descent time of 92.3 seconds. While this descent time is slightly over the 90 second limit, the simulation does not account for other factors such as the weight of epoxy, quick links, nomex blankets, u-bolts, nuts, bolts, shear pins and screws that will increase the launch vehicle's weight, decreasing the descent time and apogee height. When a theoretical value of this weight was added, the apogee predicted decreased to 4683ft AGL putting our current goal apogee as 4500ft AGL.

Motor Specifications	
Average Thrust	732.9470 N
Class	8% L
Delays	Plugged Seconds
Designation	L730
Diameter	54.0 mm
Igniter	E-Match
Length	6490.0 mm
Letter	L
Manufacturer	CTI

Name	L730
Peak Thrust	1,216.59 N
Propellant	APCP
Propellant Weight	1,351 g
Thrust Duration	3.7700 s
Total Impulse	2763.2100 Ns
Total Weight	2,247.0 g
Type	Reloadable

Table 3.3.1.1. Motor Specifications

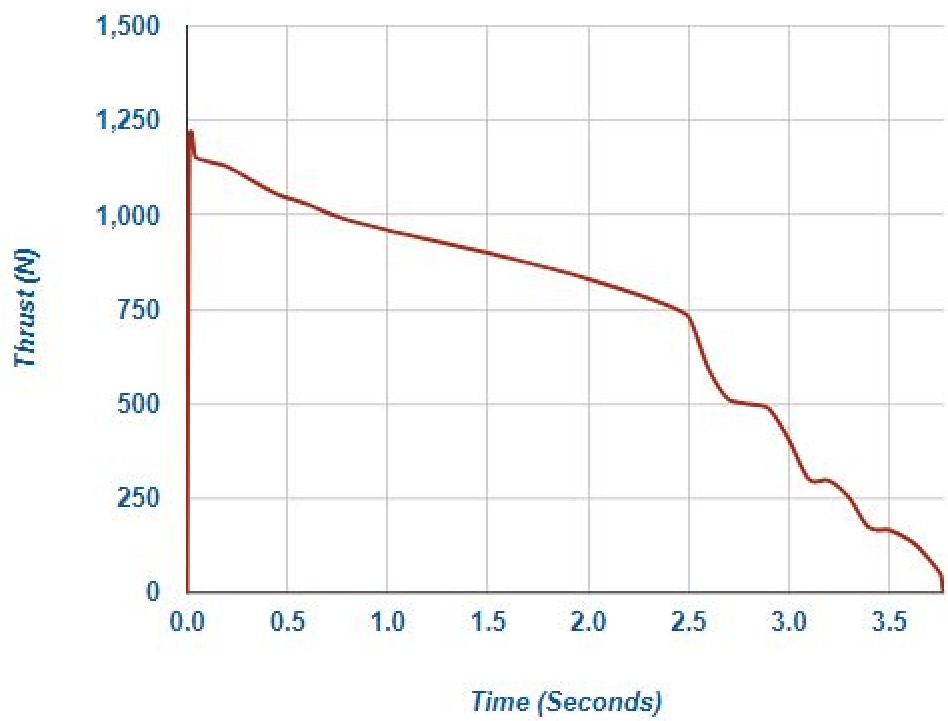


Figure 3.3.1.2. Thrust vs Time

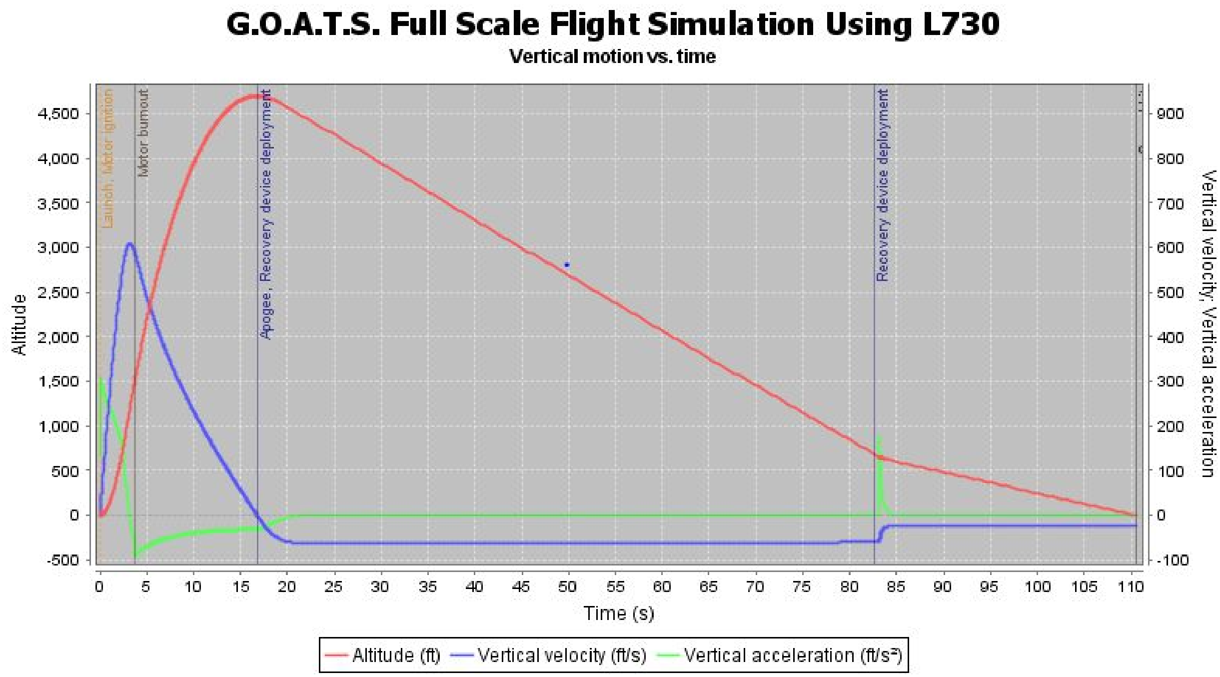


Figure 3.3.1.3. Flight Simulation unweighted

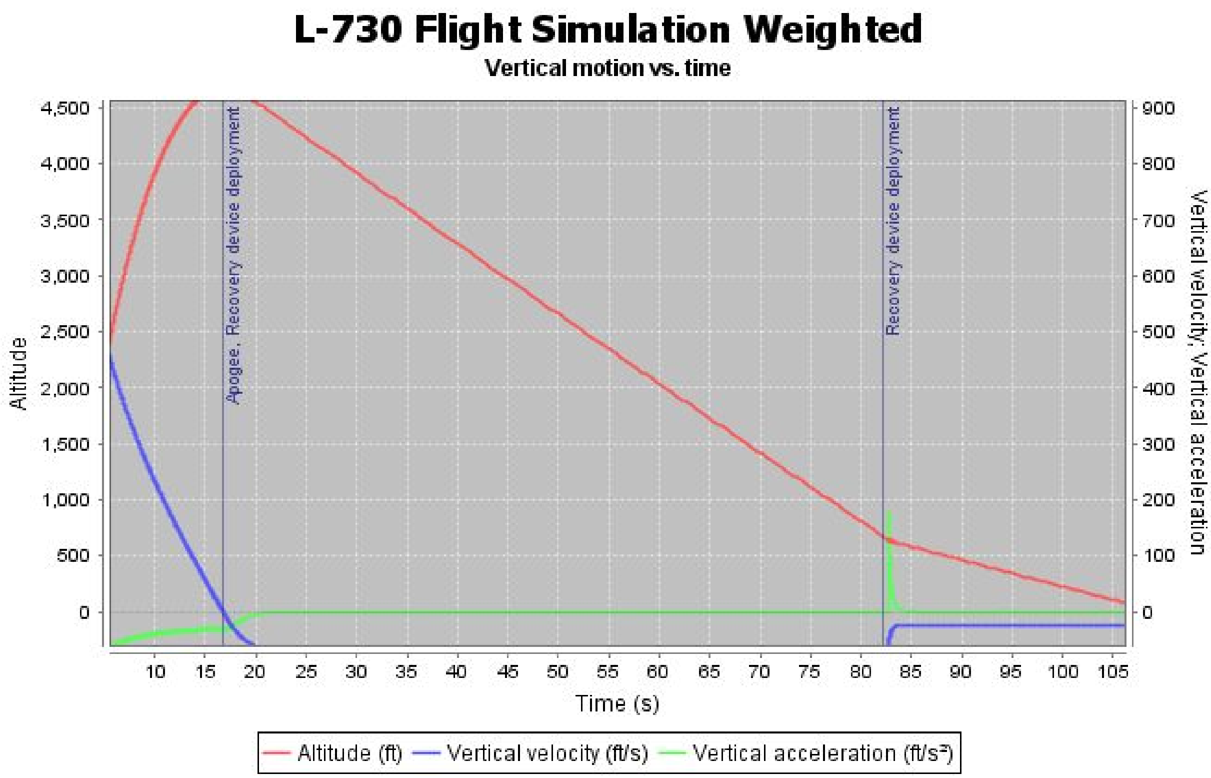


Figure 3.3.1.4. Flight Simulation weighted

The L1030-RL serves as the backup motor. This motor is 25.6in in length, 2.13in in diameter and has a total impulse of 2,781Ns. These values are very similar to the L730-0 motor making it a suitable backup motor. The simulated apogee is 4,679ft AGL with a descent time of 91.5

seconds. While this descent time is slightly over the 90 second limit, the simulation does not account for other factors such as the weight of epoxy, quick links, nomex blankets, u-bolts, nuts, bolts, shear pins and screws that will increase the launch vehicle's weight, decreasing the descent time and apogee height. When a theoretical value of the added weight was added, the apogee predicted decreased to 4669ft AGL.

Motor Specifications	
Average Thrust	1,028.5500 N
Class	9% L
Delays	Plugged Seconds
Designation	L1030-RL
Diameter	54.0 mm
Igniter	E-Match
Length	649.0 mm
Letter	L
Manufacturer	CTI
Name	L1030
Peak Thrust	1,539.44 N
Propellant	APCP
Propellant Weight	1,520 g
Thrust Duration	2.7040 s
Total Impulse	2781.2100 Ns
Total Weight	2,338.0 g
Type	Reloadable

Figure 3.3.1.5. Backup Motor Specifications

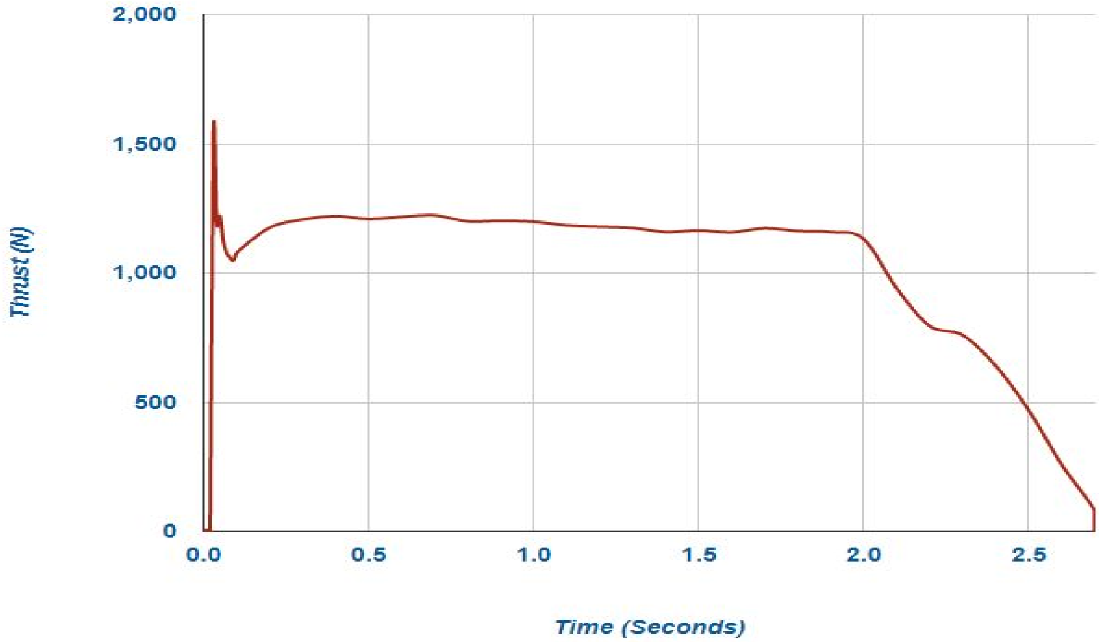


Figure 3.3.1.6. Backup. Thrust vs Time

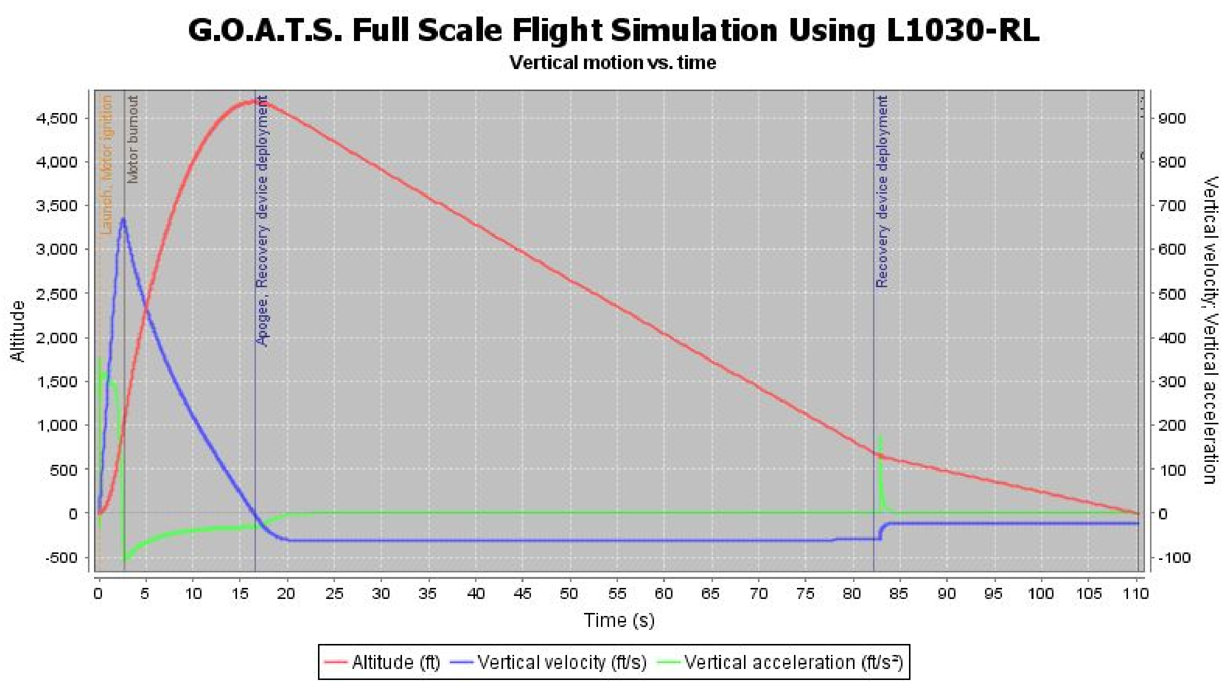


Figure 3.3.1.7. Backup Flight Simulation Unweighted

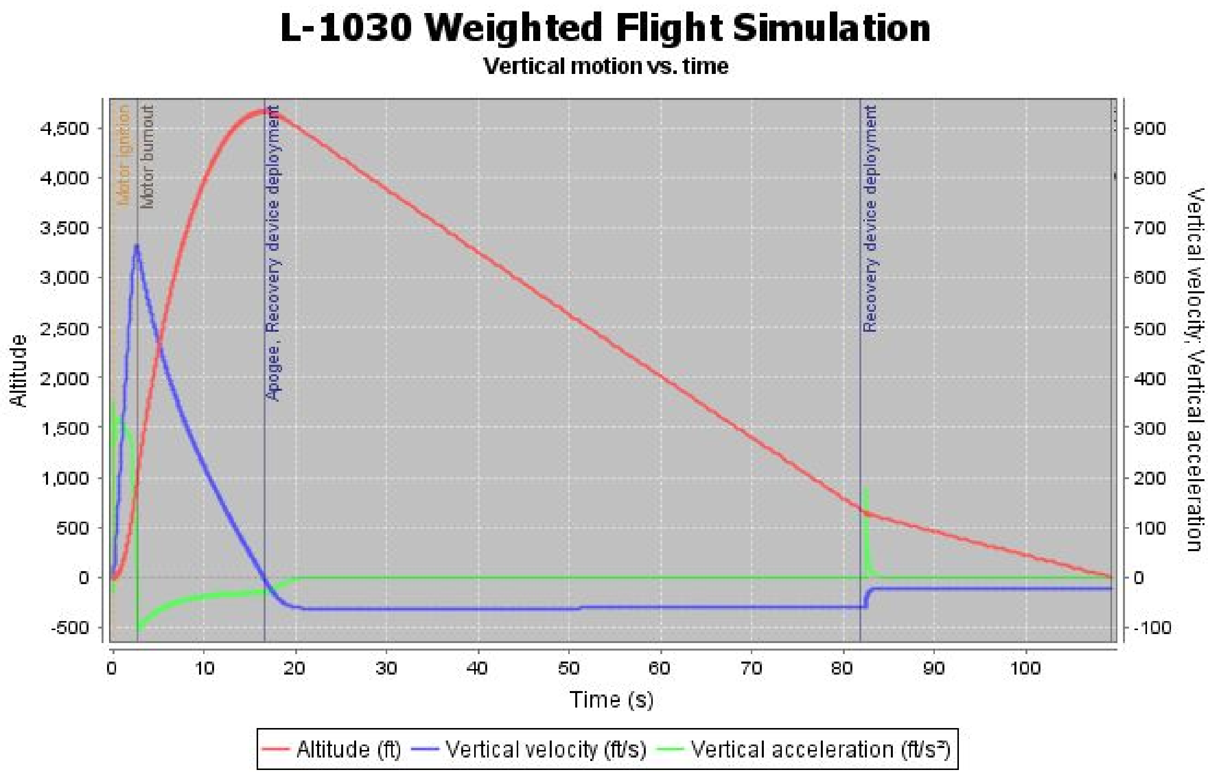


Figure 3.3.1.8. Backup Flight Simulation weighted

Section 3.3.2. Stability Margin and CP/CG Locations

The unweighted launch vehicle's static stability margin on the pad is 3.19 cal. The center of gravity (CG) is located at 82.312 in from the nose cone and the center of pressure (CP) at 101 in from the nose cone. The difference between these two points is 18.828 inches.

The weighted launch vehicle's static stability margin on the pad is 3.52 cal. The center of gravity is located at 80.323 in from the nose cone and the center of pressure at 101 in from the nose cone. The difference between these two points is 20.677 inches.

Note: CG is represented by the blue circle and CP is represented by the red dot in figure 3.5.2.1.


Figure 3.3.2.1. CP and CG location weighted

Section 3.3.3. Matlab Calculations

Recovery Calculations for WPI USLI 2018-19

1) Clear the workspace

```
clear variables; close all; clc;
```

2) Input Constants

```
rho_sl = 0.002377; % Air density at sea level (slug/ft^3)
rho_apo = 0.002067; % Air density at apogee (slug/ft^3)

g = 32.2; % Acceleration due to gravity(ft/s^2)

m1 = 0.07235898; % Section 1 (Payload Rentention) mass (slug)
m2 = 0.1242985; % Section 2 (Nose Cone & Harness) mass (slug)
m3 = 0.291642339; % Section 3 (Lower Airframe) mass (slug)
m4 = 0.219091493; % Section 1 (Upper Airframe) mass (slug)
m5 = m3 + m4;  % Tethered Section (Upper Airframe, Lower Airframe, Payload Retention) mass (slu
m_tot = m1 + m3 + m4;

diameter_drogue = 3; % Drogue chute diameter (ft)
diameter_main = 6; % Main chute diameter (ft)
diammeter_nose = 3; % Nose Cone chute diameter (ft)

Cd = 0.75; % Coefficient of drag for parachutes

apogee_alt = 4574; % Apogee altitude (ft)
main_deploy_alt = 700; % Main chute altitude (ft)

fprintf('Section 1 is the lower airframe, upper aiframe, and payload retainer. Section 2 is the
```

```
Section 1 is the lower airframe, upper aiframe, and payload retainer. Section 2 is the nose cone
```

3) Calculate Descent Times and Velocities

```
% Calculate parachute cross-sectional areas
area_drogue = pi * diameter_drogue^2 / 4; % Drogue chute diameter
area_main = pi * diameter_main^2 / 4; % Main chute diameter
area_nose = pi * diammeter_nose^2 / 4; % Nose cone chute diameter

% Initial descent phase under drogue parachute
v1 = sqrt( (m_tot * g) / (0.5 * rho_apo * Cd * area_drogue) ); % Velocity
t1 = (apogee_alt - main_deploy_alt) / v1; % Flight time

% Second descent phase for main rocket
v2_1 = sqrt( (m5 * g) / (0.5 * rho_sl * Cd * (area_drogue + area_main)) ); % Velocity
t2_1 = (main_deploy_alt) / v2_1; % Flight time

% Second descent phase for nose cone
v2_2 = sqrt( (m2 * g) / (0.5 * rho_sl * Cd * area_nose) ); % Velocity
t2_2 = (main_deploy_alt) / v2_2; % Flight time
```

```
% Calculate total flight time for each section
total_t_1 = t1 + t2_1; % Total flight time for section 1
total_t_2 = t1 + t2_2; % Total flight time for section 2

fprintf('Descent time for Section 1: %0.3f sec\n', total_t_1);
```

```
Descent time for Section 1: 96.816 sec
```

```
fprintf('Descent time for Section 2: %0.3f sec\n', total_t_2);
```

```
Descent time for Section 2: 93.952 sec
```

```
fprintf('Ground hit velocity for Section 1: %0.3f ft/sec\n', v2_1);
```

```
Ground hit velocity for Section 1: 22.848 ft/sec
```

```
fprintf('Ground hit velocity for Section 2: %0.3f ft/sec\n', v2_2);
```

```
Ground hit velocity for Section 2: 25.204 ft/sec
```

4) Calculate Kinetic Energy

```
ke_1 = 0.5 * m1 * v2_1^2; % KE of Section 1
ke_2 = 0.5 * m2 * v2_2^2; % KE of Section 2
ke_3 = 0.5 * m3 * v2_1^2; % KE of Section 3
ke_4 = 0.5 * m4 * v2_1^2; % KE of Section 4

fprintf('Kinetic Energy of Section 1 upon landing: %0.3f lbf*ft\n', ke_1);
```

```
Kinetic Energy of Section 1 upon landing: 18.772 lbf*ft
```

```
fprintf('Kinetic Energy of Section 2 upon landing: %0.3f lbf*ft\n', ke_2);
```

```
Kinetic Energy of Section 2 upon landing: 39.479 lbf*ft
```

```
fprintf('Kinetic Energy of Section 3 upon landing: %0.3f lbf*ft\n', ke_3);
```

```
Kinetic Energy of Section 3 upon landing: 74.857 lbf*ft
```

```
fprintf('Kinetic Energy of Section 4 upon landing: %0.3f lbf*ft\n', ke_4);
```

```
Kinetic Energy of Section 4 upon landing: 56.838 lbf*ft
```

5) Calculate Downrange Drift

```
wind_speeds_mph = [0, 5, 10, 15, 20]; % Wind speeds in mph
wind_speeds = wind_speeds_mph * (5280 / 3600); % Convert to ft/sec

drifts = zeros(3,5); % Set up matrix to hold drift results
```

```
for i = 1:numel(wind_speeds)

    v_wind = wind_speeds(i);

    % Drift = wind speed * descent time
    drift_1 = v_wind * total_t_1;
    drift_2 = v_wind * total_t_2;

    % Put results into results matrix
    drifts(:,i) = [v_wind; drift_1; drift_2];

end
```

6) Plot Downrange drift

```
figure()
plot(wind_speeds_mph,drifts(2,:),wind_speeds_mph,drifts(3,:))
title('Downrange Drift vs Wind Speed');
xlabel('Wind Speed (mph)');
ylabel('Downrange Drift (ft)');
legend('Section 1 (Main Rocket)', 'Section 2 (Nose Cone)');
```

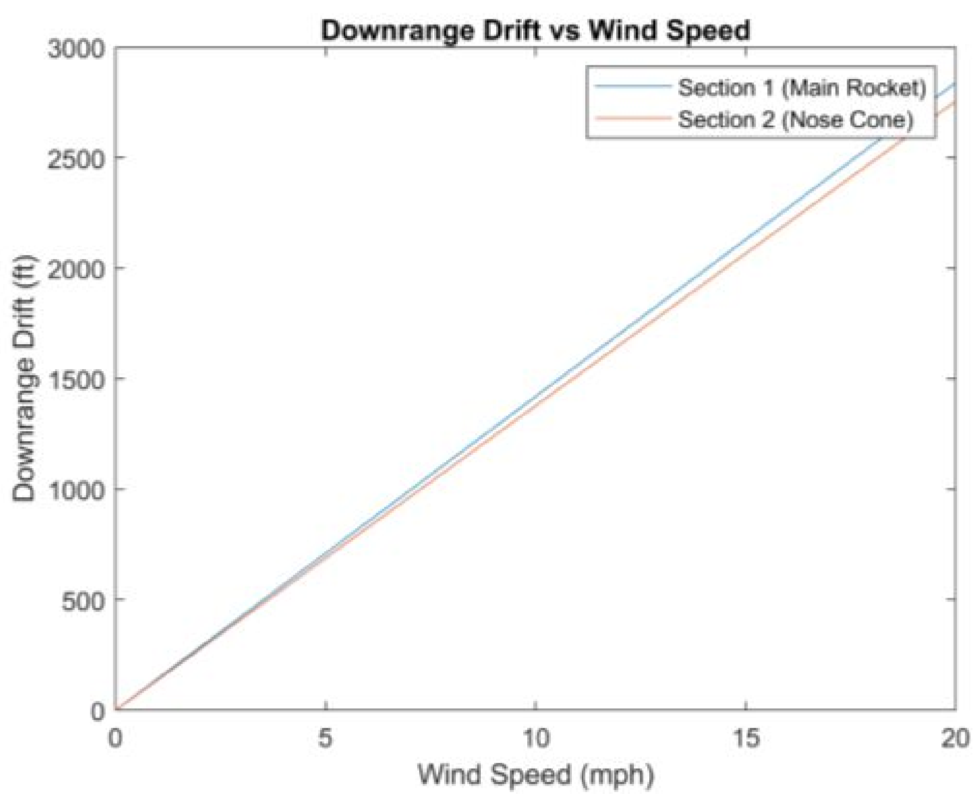


Figure 3.3.3.1. Lateral Drift MatLab

Wind Speed	Section 1 (Main Tethered Section)	Section 2 (Nose cone)
0 mph:	0 ft	0 ft
5 mph:	710 ft	689 ft
10 mph:	1420 ft	1378 ft
15 mph:	2130 ft	2067 ft
20 mph:	2840 ft	2756 ft

Table 3.3.3.1. Drift Parameters

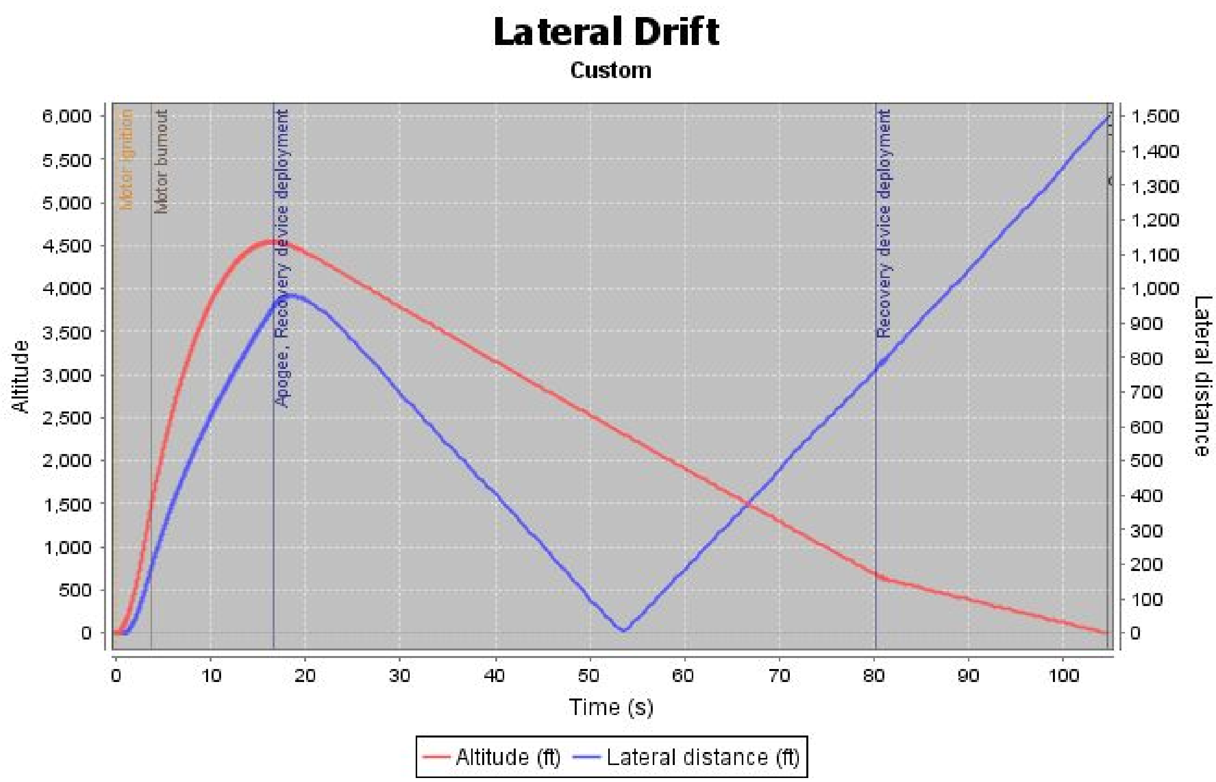


Figure 3.3.3.2. Lateral Drift Open Rocket Graph

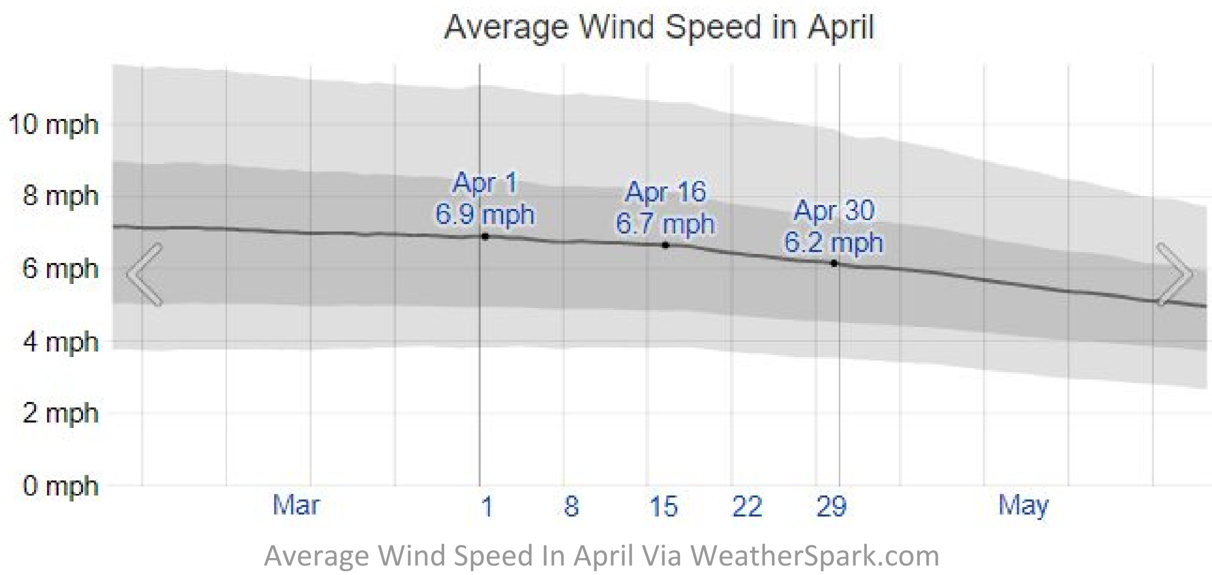
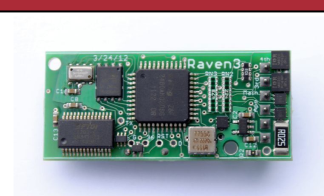


Figure 3.3.3.3. Average Windspeed in Huntsville

Our launch vehicle will not drift outside the range of the recovery area so long as wind speeds remain below 18-20 mph. As shown in the graph above, previous years in Huntsville, Alabama average wind speeds during the time period of the competition are well below that. Therefore we believe this will not be an issue.

Section 3.4. Devices for Mission Performance

3.4.1. Component List

Component	Purpose	Picture
Raven 3 Altimeter 9v	Accurately measures altitude, acceleration, and other parameters necessary for proper deployment.	
GPS NEO-6MV2	Required to locate segments of the rocket using a GPS tracker.	

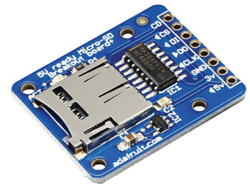
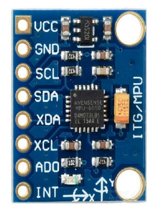
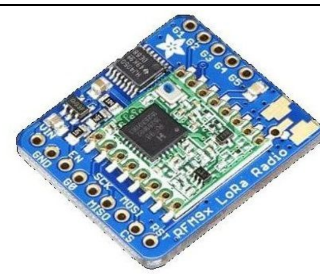
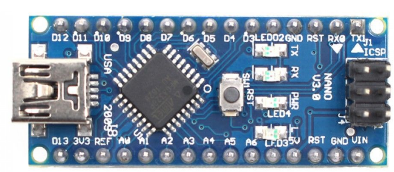
Micro SD card and Breakout Board	Logs gyroscope and accelerometer data.	 
MPU-6050	Senses linear and rotational movement.	
RFM9X LoRa Packet Radio	Transmits and receives GPS data.	
Arduino Nano	Manages the module and makes everything work together.	
Nine Volt Battery	Necessary to power electronics	

Table 3.4.1.1. Devices for Mission Performance

3.4.2. Launch Vehicle Body Tracking System

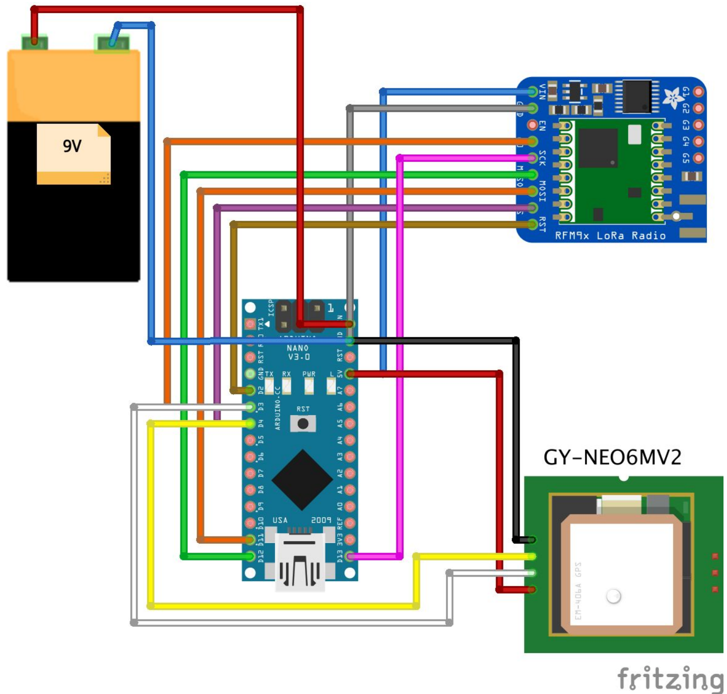


Figure 3.4.2.1. GPS Circuit Diagram

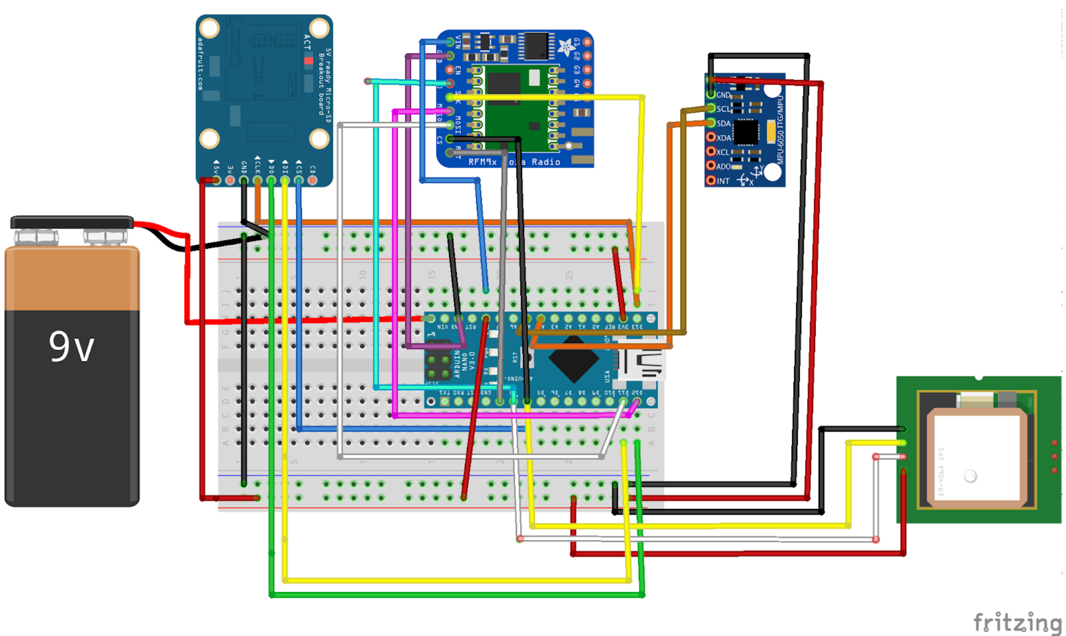


Figure 3.4.2.2. Full GPS Circuit Diagram With E-Bay

The upper airframe, lower airframe, payload, and nose cone will be tracked with the GPS shown in Figure 3.4.2. The UAV will be tracked by the on-board Pixhawk. The upper airframe, in addition to the components in the E-Bay, will include a combined gyroscope and accelerometer chip. These additional components will log data to an sd card.

These tracking modules contain an Arduino Nano, NEO-6MV2, Adafruit RFM95w LoRa radio transceiver, and a 9V battery. The module, contained in a 3D printed shell, will be mounted inside each section of the launch vehicle with epoxy.

All four of the transmissions will be received at the base station by an Adafruit RFM95w LoRa radio transceiver, with the attached antenna. The transceiver is connected to an arduino which outputs data to a laptop.

For the more simplistic module in figure 3.6.2.1, the arduino reads the data from the gps and transmits the longitude and latitude over the transceiver. The arduino is powered by the nine volt battery, the gps and transceiver get power from the arduino's 5V and 3.3V pins respectively. In the upper airframe circuit in figure 3.6.2.2, the same is true with the addition of the the arduino reading the MPU-6050 and writing log data to the sd card. The MPU-6050 and the SD card breakout board are both powered by the arduino 5V pin.

Section 3.5. Vehicle Demonstration Flight

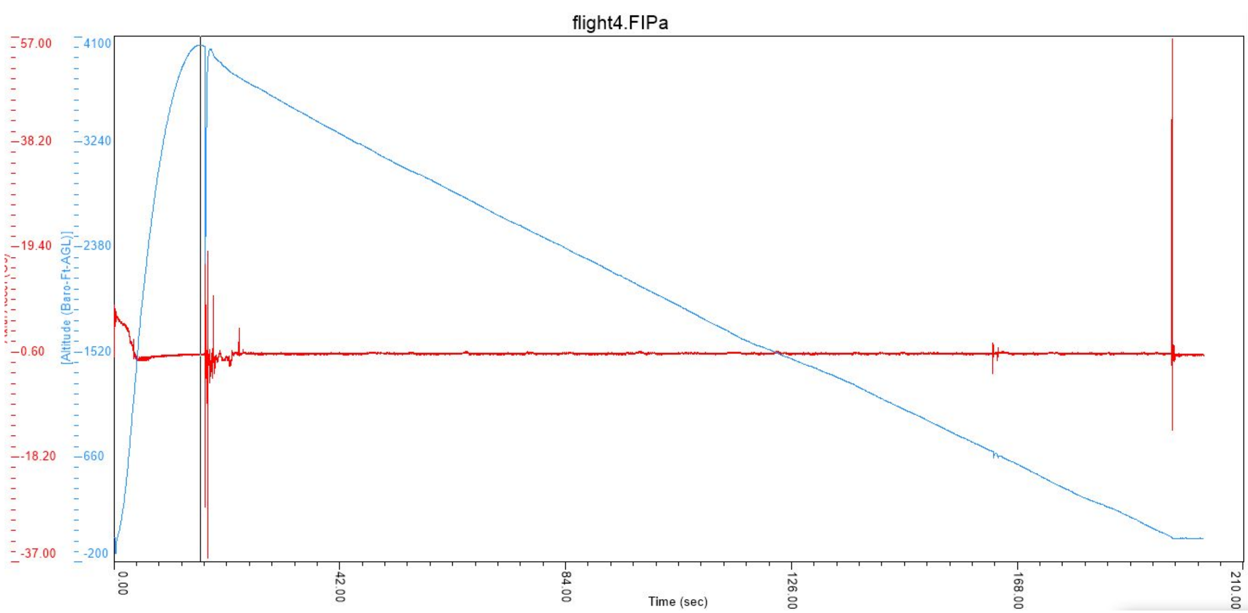


Figure 3.5.1. Altimeter Flight Data

The full scale launch vehicle was launched on lake Winnipesaukee in Gilford New Hampshire on March 3rd, 2019. The lake was determined to be safe to launch on due to the thickness of the ice being measured to be around 26in or slightly more than two feet. This minimum ice thickness able to support a car is 8 inches. With the ice being at 26in this gave us a safety factor of a little over 3 in terms of the ice being safe to drive on. A successful ejection test was performed before proceeding onto the lake for the full scale launch. The launch vehicle was launched around 1:15 p.m., at which point the external temperature was about 30℉, with wind speeds of about 9 mph towards the South-East. On the test launch day, we started with an ejection test. We had 4.0 g apogee charge and 5.4 g main charge, which were successful in separating sections and deploying parachutes. We then proceeded to assemble the launch vehicle for a test launch. That consisted of repacking the parachutes, made and attached the primary and secondary charges, checked the altimeter, went through our safety checklist throughout, and connected the sections with shear pins to fully assemble. Then we moved the launch vehicle to the launch pad and set up for launch. According to the data recovered from the primary altimeter both the apogee and main charges were successful in deploying. The graph in figure 3.5.1. However, due to the force on the top centering ring in the lower airframe when the drogue parachute deployed, the plywood centering ring cracked and in turn was ripped and sheared from the airframe. This led to the lower airframe descending in free fall. However, fortunately the blue tube was recoverable and the fins were unscathed. To counter this issue, we have already prepared a new airframe to have built for competition under the condition we are awarded an extension. The fins are easily transferable to the new airframe and new reinforced centering rings will be made from ¾ in plywood that will be strengthened by a fiberglass coating and heftier layers of epoxy. Additionally due to the same force exerted by the drogue parachute, the nose cone sheared its shear pins prematurely, and although the main charge deployed successfully at 700ft, the nose cone had already deployed at apogee. In order to fix this issue we will be looking into increasing the number of shear pins in the nose cone from two to five and looking into a stronger brand. However it is evident that with these reinforcements the success of the launch vehicle is certain and we hope another flight will be possible.

Another issue to overcome is the weight of the final launch vehicle. Even with our simulated mass the launch vehicle turned out to be heavier than expected. This explains the drop in apogee from our predicted value of 4500 ft to 4031 ft. This is a value that falls just slightly above the 4000 ft height limit. To solve this we are looking into ways the lighten the launch vehicle.

Section 4. Safety and Procedures

This section analyzes the risks associated with the construction with a larger vehicle. Most importantly, these include hazards to safety of personnel, materials, and facilities but they also include risks to the project timeline and the budget. Section 4.1 through 4.4 analyze hazards to personnel, failure modes and effects analysis (FMEA), environmental conditions and rate them by severity and probability. The scales used to rank these are similar to the US Geological Survey's Risk Assessment Codes however they are defined specifically for each section to better rate the risks and hazards being analyzed. Section 4.5. Provides a series of checklists that the team will use at launch events to prevent failures and hazards at the launch.

4.1. Personnel Hazard Analysis

The personnel hazard analysis looks at the possible hazards that may come up throughout the project and analyse them by probability and severity. It focuses on conditions that could be harmful to team members and bystanders.

4.1.1. Probability/Severity Definitions

Personnel Hazard Probability Definitions	
Rating	**Description**
A	The hazard expected to occur if it is not mitigated.
B	The hazard is likely occur if it is not mitigated
C	The hazard may occur if it is not mitigated.
D	The hazard is possible but unlikely to occur.

Table 4.1.1.A. Personnel Hazard Probability Definitions

Personnel Hazard Severity Definitions	
Rating	**Description**
I	Significant chance of death or permanent injury.
II	Possibility of major injuries requiring hospitalization or permanent minor disability.
III	Chance of injury requiring hospitalization or period of minor disability.
IV	May cause minor injury which may require first aid.

Table 4.1.1.B. Personnel Hazard Severity Definitions

4.1.2. Analysis

Personnel Hazard Analysis						
Phase	**Hazard**	**Cause**	**Effect**	**Probability / Severity**	**Mitigation**	**Verification**
Launch	Motor Misfire	Failure of igniter or damage to motor prior to launch	There is a possibility of a delayed ignition which could harm personnel if they approach the launch vehicle too soon.	DII	The motor will only be handled by a certified mentor. The team will wait at least 60 seconds before approaching the launch vehicle and will follow all directions of the RSO.	Motor preparation is included in the Motor Checklist. Team members have been informed of misfire safety procedures in a mandatory safety briefing and will be reminded in mandatory pre-launch safety briefings.

	Premature Motor Ignition	Damage to the motor or exposure to sparks, flames, or heat sources.	Hot motor exhaust can burn nearby personnel. If the vehicle has not been mounted on the launch rail, it's flight will be unpredictable and may hit personnel in its flight path.	DI	New ignitors and motor propellants will be used. The motor will be correctly installed by a certified mentor and ignited by the RSO.	Included in the Launch Checklist.
	Motor Ejected from launch vehicle	Untightened motor retention screws or damage to the motor retention clips.	The motor will go into freefall. If it is still ignited will accelerate to high speeds and fly unpredictably, possibly splitting the vehicle into multiple free falling objects and flying into personnel.	CI	The motor will be correctly installed per manufacturer instructions by a certified mentor. The motor retention system will be inspected prior to launch.	Included in the Motor and Launch Checklists.

	Main Parachute Failure	Not folding the parachute in a way that allows it to unfold easily, using a black powder charges more than 6.5 g, failure of the altimeters to trigger deployment, failure of parachute cords resulting from deployment at speeds greater than 60 ft/s.	If the drogue parachute has deployed, the vehicle will descend at a controlled, but unsafe speed. If it has not, the vehicle will remain in free fall.	BII	Parachutes will be inspected for tears, holes, and burns before launch. Black powder Charges will be measured and weighed with an electronic scale by a mentor. Descent speed under drogue parachute will be less than 60 ft/s. There will be two redundant altimeters to deploy the parachute.	Black powder, altimeter setup, and inspections steps are included in the Recovery and E-Bay Checklists. The descent speed under the drogue parachute will be verified by simulation.

	Drogue Parachute Failure	Not folding the parachute in a way that allows it to unfold easily, using a black powder charges more than 6.5 g, failure of the altimeters to trigger deployment, failure of parachute cords resulting from deployment at speeds greater than 60 ft/s.	The vehicle will enter free fall. If the main parachute deploys, it will likely split the vehicle into many free falling parts.	BI	Parachutes will be inspected for tears, holes, and burns before launch. Black powder Charges will be measured and weighed with an electronic scale by a mentor. The parachute will be deployed at apogee when the vehicle's speed is less than 10 ft/s. Three redundant systems will be capable of deploying the drogue parachute. Those being the primary and secondary	Black powder, altimeter setup, and inspections steps are included in the Recovery and E-Bay Checklists.

					altimeters and the motor ejection charge.	
	Deviation from expected Flight Path	High winds during flight or damage to airframe or fins.	This could cause the launch vehicle to enter undesired areas or potentially hit any personnel in the area.	DI	The launch vehicle will not be flown in inclement weather or when winds exceed 18 mph. Flight path may be adjusted to no more than 20° from the vertical to compensate for wind. The vehicle will be designed to have a stability of at least 3 cal.	The stability will be verified by simulation. Members have been informed that no launches will occur in unsafe conditions at a mandatory safety briefing and will be reminded at a mandatory pre-launch safety briefing.

	Airframe Failure	Structural integrity could be compromised due to poor construction.	Airframe failure during launch or flight could send out debris that could harm personnel. Failure upon landing could cause harm if there are personnel in the area where the launch vehicle lands.	DI	Damaged components will not be used and the vehicle will be packaged to minimize movement during transportation to prevent damage.	The vehicle will be constructed according to the specifications in the design. Safety checklists include the inspection of all airframe components. Packaging will be inspected by the Team Captain and Launch Vehicle Lead before shipping.

	Shock Cord is Severed	Not fully protected with Nomex from black powder charge detonation.	One or more components will enter free fall as they are separated from the parachutes.	DI	A Nomex blanket will protect the shock cord from fire damage. Black powder charges will be measured and packed by a mentor and will be within .1 g of the designed size. Nomex blankets will be inspected prior to launch.	Included in the Recovery, E-Bay, and Assembly Checklists.
	E-bay failure	Loss of power, electrical connectors disconnecting from plugs, breaking of solder joints, or incorrect wiring.	Would prevent the deployment of the main parachute. Drogue parachute may still be deployed by the motor ejection charge. Would cause the vehicle to	CI	The secondary altimeter will have no connection to the primary altimeter and will have its own power source. Wiring will be inspected	Mitigation steps included in the E-Bay Checklist.

			descend at a controlled but unsafe speed.		prior to launch to ensure it follows the design.	
Payload Operation	Loss of Connection	Obscuring terrain, uncharged batteries, or underpowered transmitters.	If lost in flight, there is no way to receive telemetry. There is no way to know if the UAV has deviated from its course or if it is heading towards a populated area..	BIV	Connection will be verified in a pre launch check. Range will be tested prior to launch. The UAV will be capable of completing its mission autonomously.	Included within the Payload Checklist. The UAV's ability to complete the mission autonomously will be tested.
Construction	Tool Accidents	May be caused by negligence, improper training, or damaged tools.	This would cause bodily harm to personnel. This could be anything from minor injuries to disability.	CII	Members will not use tools they are not trained on. Tools will only be used if they are properly maintained.	Members have been informed of tool safety rules in a mandatory safety briefing.

	Inhalation of fumes or dust.	May occur while working with some materials like carbon fiber or when working with chemicals that create fumes such as epoxy.	Can cause damage to the respiratory system.	BII	Any members working with these materials will wear proper PPE and work in a well ventilated area.	Members have been informed of PPE rules in a mandatory safety briefing.
	Accidental Ignition of energetics.	Exposure to sparks, flame, or heat or mistakenly connecting a live wire to an ignitor.	The detonation will be harmful to anyone near it, especially if they are working on the charges with their hands. If it is the motor that is ignited, it will become uncontrollable, possibly hitting people.	CI	Energetics will only be handled by certified mentors in a dedicated staging area. They will be inhibited until the launch vehicle is put on the launch pad.	Included in the Motor and Launch Checklists.

	Overheating of electronics	During operation, electronics generate heat, particularly processors.	Could result in minor burns if personnel do not expect electronics to be hot.	CIV	Members will not touch electronics for at least a minute after operation.	Members have been informed of electronic safety rules in a mandatory safety briefing.
	Debris	While cutting parts or fitting pieces together, it is possible that parts may break and create potentially dangerous debris	This debris could hit personnel and cause harm depending on the debris.	BIII	All personnel in the area when parts are being worked on will be required to wear all necessary PPE in order to ensure safety	Members have been informed of PPE rules in a mandatory safety briefing.

Table 4.1.2.A. Personnel Hazard Analysis

4.2. Failure Modes and Effects Analysis

The FMEA ranks possible failure modes by probability and severity with a focus on the hardware itself. Their causes and effects are also considered along with how they might be mitigated.

4.2.1. Probability/Severity Definitions

FMEA Probability Definitions	
Rating	**Description**
A	The failure is expected to occur if it is not mitigated.
B	The failure is likely occur if it is not mitigated
C	The failure may occur if it is not mitigated.

D	The failure is possible but unlikely to occur.

Table 4.2.1.A. FMEA Probability Definitions

FMEA Severity Definitions	
Rating	**Description**
I	Complete loss of the item or system.
II	Significant damage to the item or system. Item requires major repairs or replacement before it can be used again.
III	Damage to the item or system which requires minor repairs or replacement before it can be used again.
IV	Damage is negligible.

Table 4.2.1.B. FMEA Probability Definitions

4.2.2. Analysis

Failure Modes and Effects Analysis

Item	Failure Mode	Cause	Effect	Probability/ Severity	Mitigation	Verification
Launch Vehicle	Drogue parachute does not deploy.	Using too small an ejection charge, fitting the airframe too tightly, or improperly packing the drogue parachute.	The launch vehicle will enter free fall. The vehicle is likely to be lost when the main parachute deploys at 700 ft AGL, creating	CI	The primary charge will be 4g. A second altimeter will be set to detonate a redundant 4.5g black powder charge at apogee plus 1 second. All altimeters will have their programming and wiring double checked.	Included in the E-Bay Checklist.

			multiple free falling objects posing a dangerous hazard to personnel.			
	Main parachute does not deploy.	Using too small an ejection charge, fitting the airframe too tightly, or improperly packing the main parachute.	The launch vehicle will descend at a controlled but fast rate leading to minor damage. While slower than free fall, this still poses a danger to personnel.	CII	The primary charge will be 5.5g. A second altimeter will be set to detonate a redundant 5.7g black powder charge at 700 ft AGL plus 1 second. All altimeters will have their programming and wiring double checked.	Included in the E-Bay Checklist.
	Motor misfire	Improperly installing the igniter, damage to the ignitor, or damage to the motor.	The rocket may still launch creating a dangerous situation when approached by personnel.	AIV	The motor will only be handled by a certified mentor. The team will wait at least 60 seconds before approaching the launch vehicle and will follow all directions of the	Included in a mandatory safety briefing for team members. This will be repeated in pre-launch safety breings.

					RSO.	
	Motor ejected from launch vehicle	Failure to fully tighten motor retention screws.	The ejected motor becomes a free falling object. The motor casing is unlikely to be found.	CI	The motor will be properly installed per manufacturer instructions by a certified mentor. The motor retention system will be inspected prior to launch.	Motor installation is included in the Motor Checklist. Final inspection is included in the Launch Checklist.
	Shock Cord is Severed	Loosening of improperly tied knots or not being fully protected by Nomex blankets.	The recovery system will be compromised leading to one or more free falling objects .	DI	A Nomex blanket will protect the shock cord from fire damage. The black powder charges will be measured percicley by a Mentor before use.	Included in the Recovery and Assembly Checklists.

	Mistimed Deployment	Improperly programing or wiring of an altimeter or damage to the altimeter.	If the deployment of the main parachute is affected, the rocket may either drift too far or not decelerate enough before landing. If the drogue parachute is affected, it is likely to cause significant damage to the vehicle as it will deploy at unsafe speeds. High probability of creating one or more free falling	CI	A second altimeter will be set to detonate redundant black powder charges at apogee plus 1 second and 700 ft AGL plus 1 second. All altimeters will have their programming and wiring double checked.	Included in the E-Bay Checklist.

			objects.			
UAV	Motor failure	Damage to the UAV either before or in flight which may result from mishandling of the UAV or improperly securing it within the retention system. May also result from the force experienced on landing.	Either failure to lift off or loss of control.	CII	Motors will be properly installed per manufacturer instructions and secured with motor retention clips.	Drop tests will be performed to ensure that the retention system offers sufficient protection from landing forces. Pre-flight checks are included in the Payload Checklist.

	Airframe Failure	Damage to the UAV either before or in flight which may result from mishandling of the UAV or improperly securing it within the retention system. May also result from the force experienced on landing.	Either failure to take off or loss of control and possible loss of the UAV.	CI	The airframe will be constructed out of carbon fiber and designed to withstand forces expected in flight, launch, and landing.	Drop tests will be performed to ensure that the retention system offers sufficient protection from landing and flight forces.
	Electronics failure	Electronics may become damaged, disconnected, or not configured for flight when being handled prior to installatio	Failure to take off or a significant effect on control.	CII	The electronics will be properly secured with screws. Connections will either be made with solder or ports that can withstand the vibrations of the vehicle. The system will be configured for	Drop tests will be performed to ensure that the retention system offers sufficient protection from landing and flight forces.

		n. Vibrations in flight may cause wires or ports to disconnect.			flight and tested before being integrated into the vehicle.	
	Beacon retention system failure	The system may be damaged by mishandling during installation or by landing and launch forces	The UAV will not be able to deploy the payload.	CIV	The system will be demonstrated prior to launch. Care will be taken not to damage or block moving parts	Included in the Payload Checklist.
Payload Retention System	Failure to Deploy	Part of the airframe may land on top of the system, it may fail to eject from the airframe.	The UAV will not be able to deploy.	DIII	The shock cord will be at least x3 the length of the airframe to ensure that the airframe does not land near the system.	Included in the E-Bay Checklist.

	Premature Deployment	Controller triggers prematurely.	The UAV will be dropped into a free fall.	DI	The deployment will only be triggered manually by the RSO.	All tests and demonstrations of the retention system will demonstrate manual control. Members will be instructed to wait for the RSO's permission before deployment in a mandatory pre-launch briefing.
	Parachute lands on Top of the System	Possible result of the launch vehicle landing in a particular orientation with the parachute too close to the payload.	Will prevent the payload from deploying. If the payload is deployed, the UAV and parachute will likely be damaged.	CIII	The parachute will be attached to the shock cord rather than directly to the payload segment to increase distance from the payload to the parachute.	This will be verified by the full-scale launch demonstration.

Table 4.2.2.A. FMEA

4.3. Environmental Conditions

Environmental concerns ranks possible hazards that may occur in the launch with their probability and severity. The effects on safety, hardware, and the environment are considered along with mitigation strategies.

4.3.1. Probability/Severity Definitions

Environmental Conditions Probability Definitions	
Rating	**Description**
A	The condition is expected to have negative effects if it is not mitigated.
B	The condition is likely have negative effects if it is not mitigated
C	The condition may have negative effects if it is not mitigated.
D	The condition is possible but unlikely to have negative effects.

Table 4.3.1.A. Environmental Conditions Probability Definitions

Environmental Conditions Severity Definitions	
Rating	**Description**
I	The condition may cause death or permanent disability to personnel or loss of the system.
II	The condition may cause major injuries or significant damage to the system.
III	The condition may cause injury or minor damage to the system.
IV	The condition may cause minor injury or negligible damage to the system.

Table 4.3.1.B. Environmental Conditions Severity Definitions

4.3.2. Analysis

Environmental Hazards Analysis					
Phase	**Environmental Condition**	**Effect**	**Probability / Severity**	**Mitigation**	**Verification**
Launch	Birds	If the launch vehicle hits a bird, it could damage the launch vehicle and alter its trajectory depending on the size of the bird. Bird will likely die.	DII	The launch vehicle will not be launched while there are birds too close to it.	The RSO is responsible for the final decision to launch. In the Launch Checklist, arming the launch vehicle is the final step.
	Strong winds	Unsafe alterations to launch vehicle's trajectory. Will cause the vehicle to land outside the allowable recovery zone.	BIII	The rocket will not be launched if wind speed exceeds 18 mph. The vehicle's launch angle may be adjusted slightly to compensate for wind.	The RSO is responsible for the final decision to launch and may call for a delay if winds are too high. The 18 mph limit is based off drift calculations. Launch angle adjustment is included in the Launch Checklist.

	Inclement weather	Unsafe alterations to launch vehicle's trajectory and launch vehicle itself.	AI	The team will not launch in inclement weather.	The RSO is responsible for the final decision to launch. In the Launch Checklist, arming the launch vehicle is the final step. Based on the local weather forecast, the officers may decide to cancel the team's launch if inclement weather is expected.
	Trees	Due to winds or an unpredicted flight path caused by a component failure, the launch vehicle or payload could end up hitting or landing in a tree.	CI	The rocket will not be launched if wind speed exceeds 18 mph. The vehicle's launch angle may be adjusted slightly to compensate for wind.	The RSO is responsible for the final decision to launch and may call for a delay if winds are too high. The 18 mph limit is based off drift calculations. Launch angle adjustment is included in the Launch Checklist.
	Plants and animals.	High temperature exhaust from the motor has can ignite flammable material nearby,	BIV	The vehicle will be launched on a launch rail with a blast deflector. The area will be cleared of flammable materials.	The team will only launch at launch events with an FAA Waiver hosted by NASA, GSSS, and MMMSC. The Launch Checklist explicitly states to mount the vehicle

		such as grass.			on a launch rail.
Payload Operation	Plants and animals.	Losing control of the UAV could result in it damaging plants and possibly any animals in the area.	CIII	High temperature exhaust from the motor can ignite flamable material nearby, such as grass.	This ability will be demonstrated.
	Obstruction.	A plant, rock, or other object could get in the way of the retention system opening and get damaged or prevent the system from functioning.	DIV	The retention system will be designed to open slowly in order to minimize potential damage to any surroundings.	Retention system actuation speed is limited by the gear ratio of 150 of the linear servos. This will be demonstrated in all tests of the retention system.

Table 4.3.2.A. Environmental Concerns

4.4. Project Risks

Project risks analyzes the probability and severity of risks to the project as a whole. Where applicable, the quantitative effects on the schedule, budget, and overall design are considered along with mitigation strategies.

4.4.1. Probability/Severity Definitions

Project Risk Probability Definitions	
Rating	**Description**
A	The risk is expected to have negative effects if it is not mitigated.
B	The risk is likely have negative effects if it is not mitigated
C	The risk may have negative effects if it is not mitigated.
D	The risk is possible but unlikely to have negative effects.

Table 4.4.1.A. Project Risk Probability Definitions

Project Risk Severity Definitions	
Rating	**Description**
I	Irrecoverable failure.
II	Significant loss of money, time, or major design overhaul.
III	Minor loss of money, time, or minor design overhaul.
IV	Negligible effect to design, timeline, and budget.

Table 4.4.1.B. Project Risk Severity Definitions

4.4.2. Analysis

Project Risks Overview						
Risk	**Probability/ Severity**	**Schedule Impact**	**Budget Impact**	**Design Impact**	**Mitigation**	**Verification**
Launch Cancellation	BII	Launch delayed until next available date. If another suitable date cannot be found in	None	None	The team will finish construction well before competition deadlines to ensure there are multiple launches that can be attended. The	The team has these buffers built into the Gantt Chart.

		time, the required tests will not be able to be performed.			team also has GSSS as a back up launch organizer.	
Destruction of Full Scale	CII	The launch vehicle will need to be rebuilt over the course of two to three weeks. In addition to this, time will be needed to correct design flaws.	May cost upwards of $1600 depending on how much of the launch vehicle is salvageable.	Will likely require a major design overhaul to prevent such a failure in the future.	All checklists will be completed before launch. All aspects of the design will be looked over by multiple members and mentors to catch any possible errors. The launch vehicle will be constructed to the specifications of the design.	Completing all checklists requires the approval by all officers who are responsible for validating that all steps have been completed. throughout its construction, the vehicle's dimensions will be inspected to ensure they remain within tolerance.

Failure to secure travel funding	CII	None	Because SGA does not cover airfare, if funding is not secured members would only be able to attend if they paid $650 out of pocket. This will significantly limit the number of members who can attend the competition.	None	Outreach officer will reach out to multiple companies well in advance of the competition. Other funding methods will be explored as well. Members have been informed that they may need to pay up to $650 to attend the competition.	After presenting an additional funding request to SGA, the team has secured funding for every part of travel aside from thee flight and travel to Logan Airport. This cut the price per student down to $388 which has been paid by all members attending the competition. The only additional charges will be for the train to the airport which is $12.
Damaged or delayed during shipping	CI	Would cause a delay would likely be impossible to make as it would be too close the the actual competition on time. If	If damage is repairable, it may cost some to purchase materials.	Very small alterations to the design may be permitted if they are the only way to fix the vehicle. These will not be made	The launch vehicle will be packed safely and shipped with a via a reputable shipping company to arrive slightly ahead of the team.	The package will be reviewed by the officers before shipping to verify that the motion of all components is safely restricted.

		damage is minor enough, it can be repaired there.		without first consulting with NASA safety personnel.		
Damage to construction material.	BIII	May cause a delay to order new components from one day to two weeks depending on what was broken.	Will cost the team the amount needed to purchase the replacement unless spare parts are already available.	Small design changes could be made to avoid long wait times. For example, using a differently sized quicklink. Officers will consult with NASA safety personnel to verify the safety of the changes.	Extra components will be ordered where budget allows. There is a section of the budget that covers unexpected expenses such as these.	The team will keep an inventory to track materials purchased. All members have had a safety briefing to ensure they know how to protect the materials during construction.

Destruction of payload.	CI	Likely two to three weeks to reorder parts, rebuild, and fix design flaws.	May cost up to $749. Actual value is likely to vary as many components may be salvageable.	Large design changes are likely required to resolve the issue with the payload or the launch vehicle, depending on which one was the source of the issue.	Before launching, the payload will be thoroughly tested in a safe environment. The launch vehicle will undergo its own testing before they are tested together.	The full-scale test will not occur until all preliminary tests have been completed.
Injury	BI	One or two days will be required to determine the cause of the injury and how it can be prevented in the future. In the case of a serious injury or death, the project is unlikely to	None	None	The team will follow all safety procedures and proper tool use. All members are required to attend a safety briefing and pre-launch briefing and sign a form indicating their understanding of the safety requirements.	Team members have been informed of safety procedures in a mandatory safety briefing and will be reminded in mandatory pre-launch safety briefings.

		recover before the competition and may prevent the team from participating in future competitions.				

Table 4.4.2.A. Project Risk Overview

4.5. Launch and Assembly Checklists

In order to ensure the success of the flight and the safety of personnel, the team will use checklists to ensure all operations are successful. The launch vehicle will not be launched until all tasks on every checklist has been verified as complete. Required personnel are listed who must be the one to complete a step either due to safety purposes or because the task is their specialization. PPE are listed where appropriate. Explicit hazard warnings are given for dangers that may occur if a step is done incorrectly or omitted. They are either Setup Hazards, which pose a danger to personnel completing the step, or Operation Hazard, which may not threaten personnel completing the step but will threaten the safe operation of the vehicle.

4.5.1. Payload Launch Checklist

Payload Checklist	
Task	**Required Personnel**
Ensure payload has charged batteries. ⚠Setup Hazard: Not using a proper battery charger or creating short circuits may cause combustion.	
Perform an electronics systems check.	
Ensure communications are functional.	

Verify the structural and mechanical components are in working order including the retention system, joints, and the payload deployment system. ⚠Operation Hazard: If the retention system is not structurally sound, it could break upon ejection releasing free falling objects.	
Configure electronics for flight.	Payload Lead
Pack payload within the retention system. ⚠Operation Hazard: Improperly packing the payload will prevent the main parachute from deploying leaving the vehicle at unsafe speeds.	Payload Lead

Table 4.5.1.B. Payload Checklist

4.5.2. Motor Checklist

Motor Checklist	
Task	**Required Personnel**
SAFETY GLASSES REQUIRED Take motor out of package. ⚠Setup Hazard: Motor should not be taken out until it is ready to be used. Keep away from heat sources to prevent premature ignition.	Mentor
SAFETY GLASSES REQUIRED Ensure all components are in working condition and has been tampered with. ⚠Operation Hazard: If the motor shows any sign of tampering or damage it may not fire correctly and should not be flown.	Mentor
SAFETY GLASSES REQUIRED Confirm with the RSO that the motor is safe. ⚠The RSO has the final say on the safety of the motor.	Mentor, RSO
SAFETY GLASSES REQUIRED Use CTI Delay Drill Bit to adjust motor deployment charge delay time. ⚠Operation Hazard: An improperly timed delay will cause premature or late deployment from the redundant ejection charge possibly leading damage from aerodynamic forces creating free falling objects.	Mentor

Table 4.5.2.A. Motor Checklist

4.5.3. EBay Checklist

E-Bay Checklist	
Task	**Required Personnel**
Secure the two 9V batteries.	
Plug each altimeter into a computer and test that the main altimeter is programmed for dual deployment at apogee and 700 ft AGL and that the secondary altimeter is programmed for dual deployment at apogee plus one second and 700 ft AGL plus one second. ⚠Operation Hazard: Verify that the second deployment at 700 ft AGL occurs after apogee. Misprogrammed altimeters could cause premature or late deployment, destroying the launch vehicle.	Team Captain Launch Vehicle Lead Safety Officer
Slide the sled into e-bay coupler.	
Make sure apogee and main charges are oriented in the correct direction for deployment. Double check that they are connected to the correct altimeter channel. ⚠Operation Hazard: Switching the charges will cause the main parachute to deploy at apogee leading to excessive decent times.	
Connect terminal blocks to apogee and main. ⚠Operation Hazard: Improperly securing the wires may prevent deployment.	
SAFETY GLASSES REQUIRED Pack black powder charges. ⚠Setup Hazard: All energetics must be kept away from heat sources.	Mentor
SAFETY GLASSES REQUIRED Connect black powder charges to the other end of the terminal blocks. ⚠Setup Hazard: Ensure that the the terminal blocks is not live before connecting the charges to prevent premature detonation.	Mentor
SAFETY GLASSES REQUIRED Make sure black powder charges are oriented correctly and secured. ⚠Operation Hazard: Switching the charges will cause the main parachute to deploy at apogee leading to excessive decent times.	Mentor
SAFETY GLASSES REQUIRED Place e-bay in the launch vehicle. Be careful to ensure apogee and	

main charges are still oriented correctly. ⚠Operation Hazard: Switching the charges will cause the main parachute to deploy at apogee leading to excessive decent times.	

Table 4.5.3.A. EBay Checklist

4.5.4. Recovery Checklist

Recovery Checklist	
Task	**Required Personnel**
Put nomex blankets on shock cord. ⚠ Operation Hazard: If blankets are not fastened correctly, parachutes could be damaged leading to the rocket free falling.	
Ensure all bodies are secured with shock cord. ⚠Operation Hazard: If a body is not connected properly, it could separate and free fall.	Launch Vehicle Lead
Verify all parachutes are in working condition without holes, tears, or burns. ⚠Operation Hazard: If parachutes are damaged, the vehicle could fall fast enough to damage itself or personell.	Launch Vehicle Lead
Pack all parachutes properly. ⚠Operation Hazard: If parachutes are not packed properly, they may not deploy, causing the vehicle to free fall.	
Secure parachutes to their mounting points. ⚠Operation Hazard: If parachutes are not secured properly, they could come detached from the shock cord and the vehicle will free fall.	

Table 4.5.4.A. Recovery Checklist

4.5.5. Structural Checklist

Structural Checklist	
Task	**Required Personnel**
Make sure the upper and lower airframes are in working condition with no dents or fractures. ⚠Operation Hazard: If the airframe is dented or fractured, parts could break upon launch and turn into several free falling objects.	Launch Vehicle Lead
Make sure the fins are in working condition with no bending or	Launch Vehicle

fractures. ⚠Operation Hazard: If the fins are bent or fractured, they could break off upon launch and turn into free falling objects.	Lead
Make sure the nose cone is in working condition with no dents or fractures. ⚠Operation Hazard: If the nose cone is dented or fractured, it may break in flight, creating free falling objects, or cause the vehicle to deviate from its predicted flight path.	Launch Vehicle Lead
Check that the EBay is properly secured to the upper airframe with screws. ⚠Operation Hazard: If the EBay is not secured it could cause the upper and lower airframes to separate in flight likely resulting in multiple free falling objects and the loss of the vehicle.	Launch Vehicle Lead

Table 4.5.5.A. Structural Checklist

4.5.6. Assembly Checklist

Assembly Checklist	
Task	**Required Personnel**
Fit Nomex blankets into the launch vehicle. ⚠Operation Hazard: If blankets are not fitted properly, deployment may not occur and the rocket will free fall.	
Fit parachutes, ensuring they stay packed and are not tangled in shock cord. Ensure they are adequately protected from energetics by the Nomex blankets. ⚠Operation Hazard: If parachutes are not fitted properly or become tangled in the shock cord, they may not deploy and the rocket will free fall.	
Fit the payload retention system. ⚠Operation Hazard: If retention system is not properly fitted, the payload could separate in flight.	
Fit the upper and lower airframes together. ⚠Operation Hazard: Improperly fitting the airframes may lead to a deviation from the expected flight path and could cause them to separate in flight, endangering the vehicle and personnel.	
Insert shear pins. ⚠Operation Hazard: If shear pins are not inserted, the airframes may separate in flight.	

Table 4.5.6.A. Assembly Checklist

4.5.7. Launch Vehicle Troubleshooting Checklist

The troubleshooting checklist is the only exception to the rule. As it is not mandatory to complete before launch. It is intended as a guide to fix the rocket electronics in case they are nonfunctioning.

Launch Vehicle Troubleshooting Checklist
Task
Connect both altimeters to a computer to check that the primary altimeter is set to deploy first at apogee then at 700 ft AGL and the secondary altimeter is set to deploy first at apogee plus one second and 700 ft AGL plus one second.

Power on the altimeters with a 9V battery. On startup, they will beep once per volt they are receiving. 9 beeps indicates 9V.
The altimeters can be tested by manually connecting the wires to simulate being connected to an ejection charge. If the altimeter emits one low beep every two seconds, it either does not detect any charges connected, is receiving less than 3.85V, or is not oriented vertically. Otherwise, it will emit a series of 4 beeps every two seconds. Each beep indicates the continuity of a channel. For example one low beep, followed by on high beep, then two low indicates that only channel 2 has continuity.

Table 4.5.7.A. Launch Vehicle Troubleshooting Checklist

4.6. Full Scale Test Flight Safety Assessment

This section assesses the safety concerns resulting from the full scale test flight. This includes a flight timeline of all important events and an analysis of the state of all components. From this, failure modes are determined along with mitigation plans, verification, and budgetary and schedule effects.

4.6.1. Flight Timeline

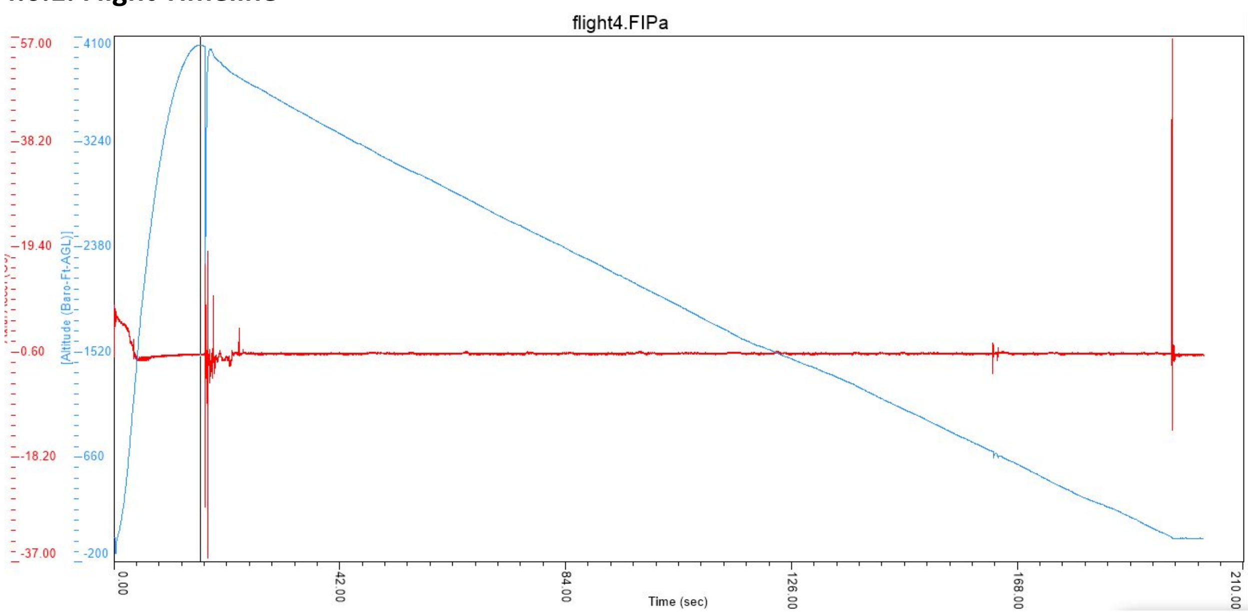


Figure 4.6.1.A. Graph of Altimeter Data

Full Scale Test Event Timeline	
Time	Event
T + 0s	Motor Ignition
T + 16s	Vehicle Reaches Apogee at 4031 ft

T + 16.9s	Deployment of Drogue Parachute and Destruction of Lower Airframe Shock Cord Mount Bulkhead. Premature deployment of Main and Nose Cone parachute.
Approx. T + 100s	Lower Airframe lands and fractures.
T + 163.5s	Main parachute deployment charge fired by altimeter.
T + 196.7s	Upper Airframe, E-Bay, and Retention System lands at approximately
Approx. T + 215s	Nose Cone Parachute lands.

Figure 4.6.1.B. Full Scale Test Timeline

4.6.2. Component State Summary

Despite the main deployment charge being fired at the correct time, the nose cone was ejected early. This likely occurred due to premature shearing of the shear pins after apogee. On landing, it sustained no damage.

The upper airframe functioned nominally and sustained no damage.

The E-Bay functioned nominally and sustained no damage. All charges deployed at the programmed altitudes.

The Lower Airframe did not perform as expected. When the deployment charge fired .9 s after apogee, force applied via the shock cord sheared the shock cord mount centering ring. This caused the lower airframe to separate from the other tethered section and go into free fall. The lower airframe tumbled, slowing its decent. It landed on the fins, breaking parts of the blue tube as the fins shifted. The fins did not detach or sustain damage from the impact. Motor retention functioned nominally despite the shearing of the shock cord mount centering ring.

Because the nose cone deployed prematurely, both parachutes deployed shortly after apogee. This, combined with the lighter weight without the lower airframe, caused the vehicle to descend far slower than expected.

The payload retention system functioned nominally and sustained no damage. The linear servos successfully held the system together.

4.6.3. Failure Mode Analysis and Mitigation Plan

Based on observations at launch and analysis during the post flight checklist, the following two failure modes are determined.

The premature deployment of the main parachute and the nose cone was due to insufficient strength of the 2 shear pins. The weight of the nose cone combined with the force experienced during the deployment of the drogue parachute deployment prematurely sheared the pins.

The team plans to mitigate this by adding 3 more shear pins to a total of 5 shear pins. This will be verified by performing another deployment test to verify that 5 shear pins will not inhibit deployment. The team will demonstrate the ability of the shear pins to hold the full weight of the nose cone.

The second failure mode was the shearing of the shock cord mount centering ring. The .25 in plywood was not strong enough to decelerate the upper airframe after deployment. The offset U-bolt broke off with about half for the centering ring while the other half remained fixed.

This failure mode will be mitigated primarily by increasing the thickness of the centering rings. All structural centering rings will be swapped out for .5 in centering rings. Bolts will be fixed with washers to further spread out the load and epoxy fillets will be increased to better transfer the loads into the airframe.

4.6.4. Budget and Schedule Impact of Mitigation Plan

The mitigation plan for the shear pin failure will have no impact on the budget as the team already has extra shear pins and black powder for the additional deployment tests. Schedule impact is also minimal as drilling new holes for shear pins only takes a few minutes while deployment testing takes about one hour.

The mitigation plan for the centering ring failure will have no impact on the budget as the team already has the materials required to construct a new lower airframe. The team already has the Blue Tube, wood, U-bolts, and epoxy required and the fins and motor tube can be salvaged from the previously flown lower airframe. Construction of a new lower airframe will take at most one week to cut new centering rings and blue tube and to assemble it.

Section 5. Payload Criteria

Section 5.1. Payload Design and Testing

Our selected payload design of a quadrotor UAV is housed within a cylindrical retention system composed of Blue Tube and a 3D printed base and bulkhead. Upon activation, the four quarter pipe sections of the tube will open, being actuated by strong linear servos, and right the system from any initial landing configuration in order to deploy the UAV. The UAV has arms which fold up to place it in flight configuration and are driven down by springs and magnets to lock a buckle and prevent them from moving during the flight of the UAV. The UAV along with other electronics will be securely mounted inside and protected with shock-absorbing foam.

Section 5.1.1. Payload Changes

After further review of the quadrotor UAV locking arms, it was calculated that magnets would not hold the arms securely in flight. To resolve this we brainstormed other “clipping” mechanisms. We decided to explore the use of a snap buckle, with some research we found a design manual about snap-fit produced by BASF. This manual gave several equations to create the geometry of snap-fit prong, as well as the forces needed for the snap-fit to engage, the equations are shown in the following figures. For our design we were limited by the resolution of the 3D printer, as such limiting t to a multiple of 0.4 mm. We were also limited by the total arc length of the swing of the buckle, this is set by the flat angle of the UAV arms and body, 180° and the distance between the inside edge of the hinge and the inside diameter of the retention system, resulting in a value of L of 0.375 in. The manufacturer of NylonX published a few material properties such as the flexural modulus, however other properties were estimated conservatively based off the value given for nylon, properties such as allowable strain and coefficient of friction were determined this way. Using excel to make several iterations of our calculations, we calculated the total final push-on force of 3.14 pounds. The clips we created have two snap-fit progs giving us a total force of 6.29 pounds to clip the mechanism. To assist the weight of the falling UAV arm the clips have a total of four magnets with a pull of seven pounds each. The resulting design should be sufficient to secure the UAV quadrotor arms. The resulting CAD model can be seen in Figure 5.1.1.5.

MAXIMUM STRAIN (@ BASE)

$$\epsilon = 1.5 \frac{tY}{L^2 Q}$$

MATING FORCE

$$W = P \frac{\mu + \tan\alpha}{1 - \mu \tan\alpha}$$

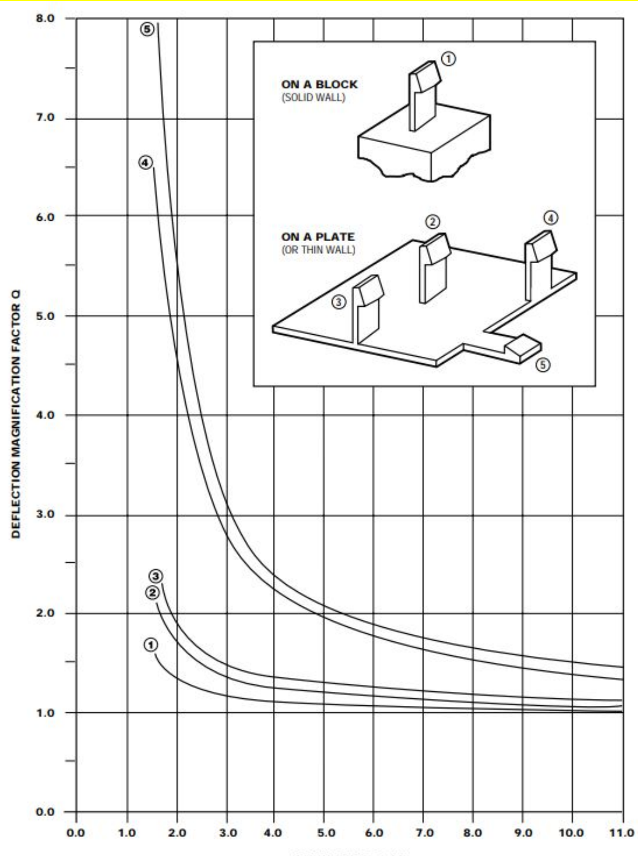
$$P = \frac{b t^2 E \epsilon}{6L}$$

Figure 5.1.1.1 Equations need for snap-fit fitting

Where:

W = Push-on Force
W' = Pull-off Force
P = Perpendicular Force
μ = Coefficient of Friction
α = Lead Angle
α' = Return Angle
b = Beam Width
t = Beam Thickness
L = Beam Length
E = Flexural Modulus
$\in$ = Strain at Base
$\in_o$ = Allowable Material Strain
Q = Deflection Magnification Factor (refer to Figure IV-2 for proper Q values)
Y = Deflection

Figure 5.1.1.2. Variables for Equations



Uniform Beam, Q Factor
Figure IV-1

Figure 5.1.1.3. Graphs for Determining Q

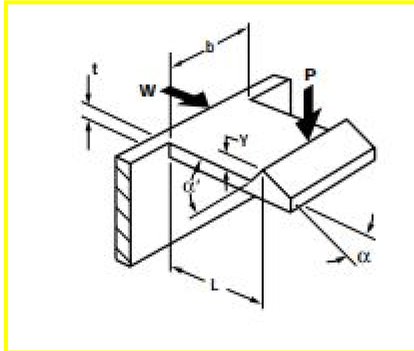


Figure 5.1.1.4. Geometric Relations to Variables

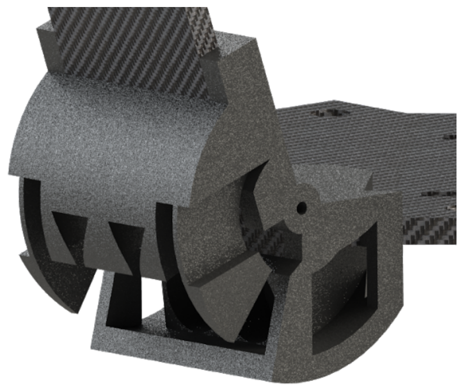


Figure 5.1.1.5. SolidWorks Render of Clip Design

Describe any changes in the payload design from CDR and explain why those changes are necessary. Describe unique features of the payload. Include the following: Structural elements and Electrical elements

Section 5.1.2. Flight Reliability Confidence

Our retention system was designed with reliability in mind, being composed of Blue Tube and PLA and Matterhackers NylonX 3D printer filaments. Blue Tube 2.0 is our selected material for protecting our payload due to its strength and proven reliability as airframe material along with it's smooth integration with the launch vehicle being made from the same material. The internal support structure is 3D printed out of NylonX, a carbon-fiber infused nylon filament designed for strength and durability. The design is simplistic and contains few moving parts in order to minimize potential points of failure. The active retention system has four linear servos to strongly hold the Blue Tube quarterpipe pieces down, connected to the integrated tracking and activation system. As the system unfolds the arms of the UAV are driven passively down by torsion springs and will be held in place by locking clips 3D printed from NylonX, pulled together by neodymium magnets. Our organization has used the design of an ejectable inner tube system from an outer airframe and it has proven to be effective and reliable. The finalized retention system dimensiones did not change from manufacturing and can be seen in the drawings below.

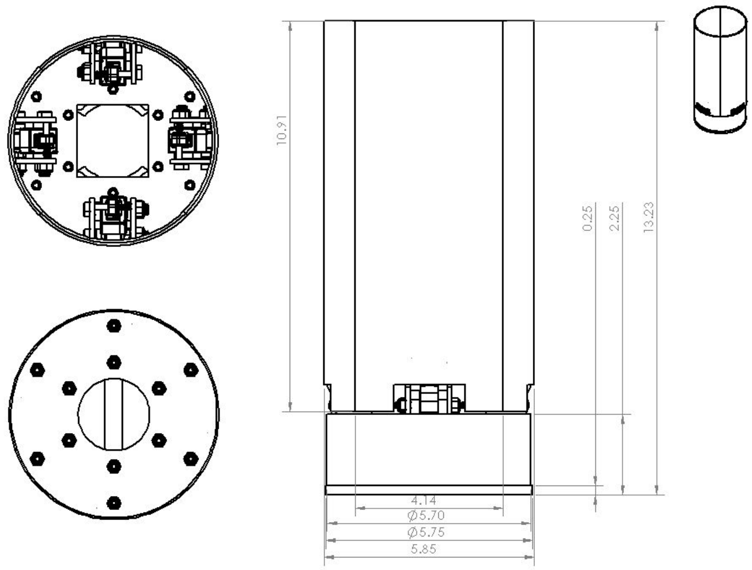


Figure 5.1.2.1.Retention System Dimensioned Side View

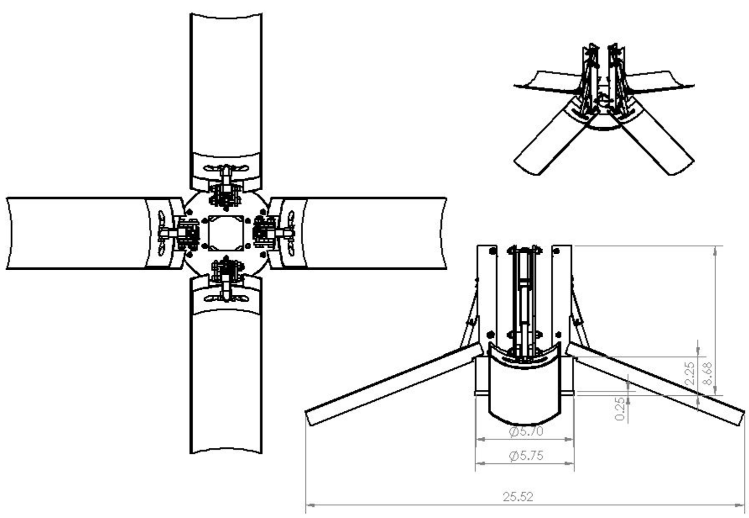


Figure 5.1.2.2. Retention System Dimensioned Top View

As the frame of the UAV will be made from carbon fiber and contain 3D printed parts from NylonX filament it will already be highly durable to strong forces and possess secure mounting for the components it must carry to function. Additionally, foam padding will be placed in the retention system to aid in damping quick accelerations to the UAV which showed to work sufficiently with the mass simulator launched with the retention system in the full scale launch. The final payload will be ready to launch on the designated scheduled date which is described in section 5.1.5

Section 5.1.3. Payload Construction

The payload construction began with the manufacturing of all of the necessary payload components. For the quadcopter the arms and baseplate were cut out of ⅛in carbon fiber with other components being 3D printed out of NylonX or PLA. The mass simulator used in the full scale flight consisted of these carbon fiber frame pieces secured together along with the largest and heaviest components of the UAV such as the two lithium polymer batteries and latching relay. The bulkhead of the retention system took about two days to print using fifty percent infill and a slow print speed to ensure a strong and successful print. The Blue Tube inner tube was carefully cut into four sections by hand using a dremel and sanded to ensure a good fit. The flap pieces for mounting the linear servos to the four Blue Tube sections were carefully epoxied and clamped along with the top quarter-inch plywood divided circle sealing the top of the retention system and set to cure for three days to guarantee a strong bond.

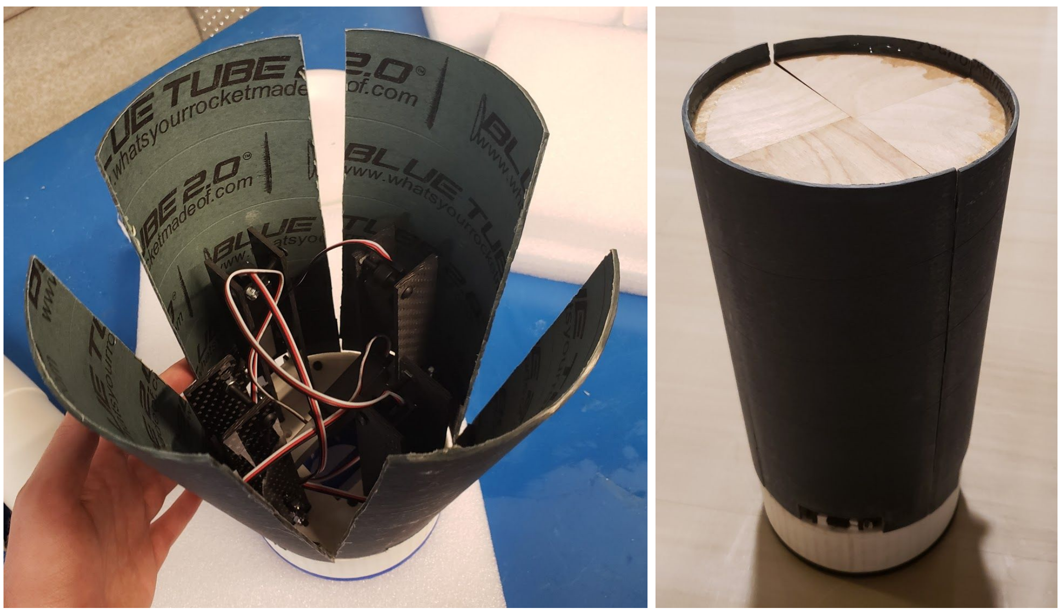


Figure 5.1.3.1. Construction of Retention System (Left) and Completed Retention System (Right)

For the electrical components, which include the rocket trackers and payload retention system printed circuit board were created to ensure a sturdy and safe way to mount these systems. The current model for the circuit designs of the rocket trackers were interfaced with the component footprints in a PCB software. These boards were laid out to be 3in by 4in using single sided traces and a rocker switch for safety and the ability to be conveniently power-cycled. These boards were manufactured in a school facility. The components for the rocket trackers were then attached by soldering female pin headers to the traces and attaching the components all possessing male pin headers. Finally, the LoRa radio was attached to a strip of copper tape of about 15 centimeters in length tuned to the 915MHz as a dipole antenna.

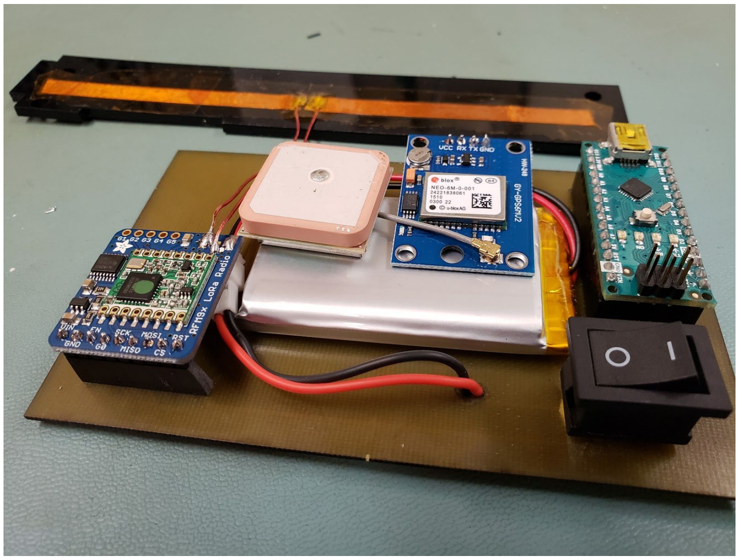


Figure 5.1.3.2. GPS Electronics

All components of the UAV are in house and ready to be tested and assembled. 3D printed components such as the beacon releasing mechanism and arm locking buckles are nearing readiness to be fully printed, allowing suitable time for additional testing of software and structural soundness in preparation for the full payload launch.

Section 5.1.4. Earlier Models

The earliest design of the payload featured a four-sided pyramid retention system that would fall separately from the launch vehicle. The arms of the UAV were aligned with sides of the pyramid such that they would open together and the UAV would have clearance for flight. This design ended up being changed due to space issues and concerns of it falling separately acting out of accordance with the competition regulations. Ultimately we decided on a cylindrical retention system that would be housed in Blue Tube inner tube. This is space efficient, being a cylinder inside of another, and is connected via shock cord to the airframe. With this design the four quarter pipes will fold open and the arms of the UAV will fit between their lowering mechanisms and allow for a vertical liftoff from the base, exactly like the original design from the proposal. Though many necessary iterations have been made to this system due to misinterpretation of the rules, concerns of space efficiency, and sizing iterations from continued prototyping, the original idea of unfolding to right itself has persisted as this system is highly reliable, elegant, and mechanically simple.

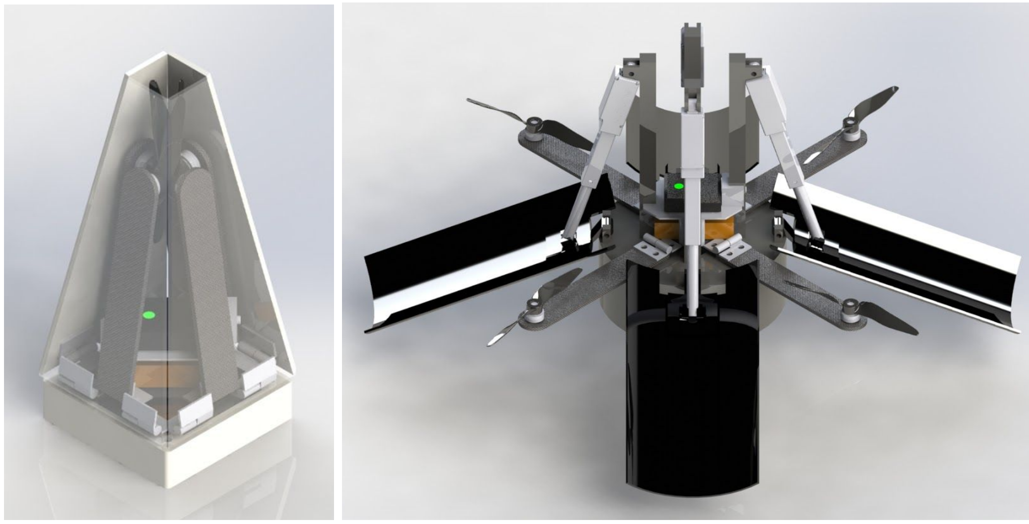


Figure 5.1.4.1. Previous Designs of Payload and Retention System

Section 5.1.5. Payload Demonstration Flight
The full scale test launch conducted on March 3rd using the retention system and payload mass simulation was deemed a successful flight of these systems, determined by a completed ejection from the launch vehicle, full retention of the mass simulation, and undamaged status of the retention system and payload upon landing. During this launch the retention system effectively ejected from the airframe and the UAV mass simulation remained protected inside. Upon visual inspection after landing it was confirmed that the payload and its retention system remained intact, structurally sound and performed as desired. Our launch of the completed payload is scheduled to be March 16th, with success determined by the ability of the retention system to perform as it did in the full scale test launch, actuate to unfold, right itself, power on, and release the UAV. The UAV must be able to become airborne and fly to it's designated coordinates using its autonomous flight system and drop the beacon when required.

The GPS tracker system housed within the launch vehicle worked exactly as desired when flown in the full scale launch and were observed to remain functional throughout the entirety of the flight and after landing, demonstrating their functionality, durability, and sufficient mounting.

Section 6. Project Plan

Section 6.1. Testing

Tests that were run on the rocket trackers consisted of position and distance tests. The first tests were done to establish the distance the LoRa transceivers could reach. This was done by setting up a ground station and a receiver, then moving the receiver away from the ground station. It was observed that they could go over half a mile while maintaining a good connection with an average RSSI of -80. The ability of the LoRa to communicate through trees and some walls was also demonstrated in a similar manner, showing their robustness when implemented with the intention of line of sight communication. Additionally the accuracy of the GPS signal from the NEO was tested and observed to remain within a 10ft radius of the exact location of the tracker.

The payload retention system was additionally manipulated to observe its functionality and durability. It was drop tested onto grass from up to 5 meters The linear servos were tested to successfully open the retention system and right itself in the process. The retention system also was able to survive a 5 meter drop, which results in it falling at speeds greater and hitting the ground with a larger impulse than in an actual flight procedure.

Section 6.2. Requirements Compliance

In order to ensure a successful year requirements had to be met and verified. This has been completed for both handbook requirements and team derived requirements. All requirements have been verified through one of the four methods. Testing is used for checking specific characteristics and parameter. Analysis is used to explain or interpret a methodic and detailed test. Inspection is used to determine conditions and status through investigation. Demonstration is used to check the future success of a task.

Section 6.2.1. Handbook Requirements

General Requirements			
NASA Requirements	**How we Plan to Meet Them**	**Method**	**Verification**
1.1. Students on the team will do 100% of the project, including design, construction, written reports, presentations, and flight preparation with the exception of assembling the motors and handling black powder or any variant of ejection charges, or preparing and installing electric matches (to be done by the team's mentor).	We will make sure that the work is completed by students and not mentors.	Inspection	We will verify this by making sure that no mentors work on the paperwork.

1.2 The team will provide and maintain a project plan to include, but not limited to the following items: project milestones, budget and community support, checklists, personnel assignments, STEM engagement events, and risks and mitigations.	We will include all of the listed requirements for the project plan	Inspection	We will use a Gantt chart and stick to a rigid schedule to make sure that everything is completed and done on time.
1.3. Foreign National (FN) team members must be identified by the PDR and may or may not have access to certain activities during launch week due to security restrictions.	We will make sure our Foreign Nationals are identified by the PDR.	Inspection	We will verify this by asking the team multiple times.
1.4. The team must identify all team members attending launch week activities by the Critical Design Review (CDR). Team members will include:	We will make sure that all members are identified by the CDR.	Inspection	We will verify this by creating a checklist.

1.5. The team will engage a minimum of 200 participants in educational, hands-on STEM activities, as defined in the STEM Engagement Activity Report, by FRR.	We will participate in multiple outreach event throughout the year.	Inspection	We will verify that we are completing these task by looking at the Gantt chart and taking numbers of participants at event.
1.6. The team will establish a social media presence to inform the public about team activities.	We will create multiple social media platforms and continually update them.	Demonstration	We will verify this looking at the amount of followers we have.
1.7. Teams will email all deliverables to the NASA project management team by the deadline specified in the handbook for each milestone.	We will email and submit our documents a day before the deadline in order to limit risks of submitting late.	Inspection	We will verify this by checking with the handbook and the Gantt Chart
1.8. All deliverables must be in PDF format.	We will make sure to convert them for submission.	Demonstration	We will varitying by making sure all finalized documents are saved in PDF form.
1.9. In every report, teams will provide a table of contents including major sections and their respective sub-sections.	Every document will have a Table of Contents	Demonstration	We will verify that there is a table of content before submitting.

1.10. In every report, the team will include the page number at the bottom of the page.	Page numbers will be programmed to be at the bottom of every page	Demonstration	We will verify that there is a page number at the bottom of every page before submitting.
1.11. The team will provide any computer equipment necessary to perform a video teleconference with the review panel. This includes, but is not limited to, a computer system, video camera, speaker telephone, and a sufficient Internet connection.	We will make sure to get everything ahead of the due date.	Demonstration	We will verify everything by making a checklist that we will follow
1.12. All teams will be required to use the launch pads provided by Student Launch's launch services provider. No custom pads will be permitted on the launch field. Eight foot 1010 rails and 12 ft 1515 rails will be provided. The launch rails will be canted 5 to 10 degrees away from the crowd on launch day.	We will build our launch vehicle for the appropriate launch pad design.	Testing	We will verify this by testing the vehicle with the proper launch pad.

1.13. Each team must identify a "mentor." A mentor is defined as an adult who is included as a team member, who will be supporting the team (or multiple teams) throughout the project year, and may or may not be affiliated with the school, institution, or organization. The mentor must maintain a current certification, and be in good standing, through the NAR or Tripoli Rocketry Association (TRA) for the motor impulse of the launch vehicle and must have flown and successfully recovered (using electronic, staged recovery) a minimum of 2 flights in this or a higher impulse class, prior to PDR. The mentor is designated as the individual owner of the rocket for liability purposes and must travel with the team to launch week.	We have found a mentor that has all of the prior experience we need.	Demonstration	We will verify this by routinely communication.

Table 6.2.1.A. General Requirements

Vehicle Requirements			
NASA Requirements	**How we Plan to Meet Them**	**Method**	**Verification**
2.1. The vehicle will deliver the payload to an apogee altitude between 4,000 and 5,500 feet AGL. Teams flying below 3,500 feet or above 6,000 feet on Launch Day will be disqualified and receive zero altitude points towards their overall project score	Our launch vehicle will have an apogee of 4683 feet, within the acceptable range.	Demonstration	We will use an on-board Raven 3 Altimeter to verify our altitude during test launches.
2.2. Teams shall identify their target altitude goal at the PDR milestone. The declared target altitude will be used to determine the team's altitude score during Launch Week.	We will base our target altitude on the value of our expected apogee. This value is currently 4683ft AGL.	Analysis	We will use the data from the altimeter during test launches to confirm our expected apogee.
2.3. The vehicle will carry one commercially available, barometric altimeter for recording the official altitude used in determining the	Our launch vehicle will have 2 Raven 3 barometric altimeters on board.	Inspection	Before launching both altimeters will be double checked that they are programmed correctly and then after flight we will acquire the data off of them in order to

Altitude Award winner.			determine our final altitude.
2.4. Each altimeter will be armed by a dedicated mechanical arming switch that is accessible from the exterior of the rocket airframe when the rocket is in the launch configuration on the launch pad.	We will be using an external switch for the altimeters.	Inspection	Holes will be drilled into the coupler for the switches to fit in snuggly. They will be secured such that they won't come out during flight.
2.5. Each altimeter will have a dedicated power supply.	Each Altimeter will be supplied with a 9V battery.	Inspection	As part of the launch checklist we will make sure all batteries are fresh and securely connected to its corresponding altimeter.
2.6. Each arming switch will be capable of being locked in the ON position for launch (i.e. cannot be disarmed due to flight forces).	The arming switch we have chosen can only be switched on and off using a precision screwdriver.	Demonstration	The switch will be left in the on position and then the screwdriver will be put away so that there's no worry of the switch being accidently shut off.
2.7. The launch vehicle will be designed to be recoverable and reusable. Reusable is defined as being able	We will use materials durable enough to withstand the forces of flight and landing	Testing	The Sub-scale and test launches will help to determine whether or not a stronger material

to launch again on the same day without repairs or modifications.			needs to be looked into.
2.8. The launch vehicle will have a maximum of four independent sections. An independent section is defined as a section that is either tethered to the main vehicle or is recovered separately from the main vehicle using its own parachute.	We have limited our design to four independent sections.	Inspection	Our four sections will be defined as the nose cone, upper airframe, lower airframe and payload retention system.
2.8.1. Coupler/airframe shoulders which are located at in-flight separation points will be at least one body diameter in length.	All coupler shoulders will be at least 6in long.	Inspection	The coupler for the e-bay is 6in on either side.
2.8.2. Nosecone shoulders which are located at in-flight separation points will be at least ½ body diameter in length.	The nose cone shoulder will be at least 6in long.	Inspection	The nose cone shoulder is 7.13in.
2.9. The launch vehicle will be limited to a single stage.	Our Launch Vehicle will only have one stage.	Inspection	Only one motor will be used in the design and flight of the launch vehicle.

2.10. The launch vehicle will be capable of being prepared for flight at the launch site within 2 hours of the time the Federal Aviation Administration flight waiver opens.	All materials necessary for the rocket's success will be prepared in advance.	Inspection	There will be a launch day checklist to ensure everything that can be prepared beforehand is ready to go.
2.11. The launch vehicle will 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.	The ability of the vehicle to stay in launch-ready mode for a minimum of two hours will be tested before competing in the competition.	Demonstration	Using brand new batteries we will use the test launches as a way to ensure the vehicle can stay in launch-ready mode for two hours.
2.12. The launch vehicle will be capable of being launched by a standard 12-volt direct current firing system. The firing system will be provided by the NASA-designated launch services provider.	We plan to meet this by using the igniter supplied with the motors	Analysis/Testing	We will verify this at our test launches.
2.13. The launch vehicle will require no external circuitry or special ground support equipment to	We will only use the igniter that came with the specific motor and what's supplied at the launch pad to initiate launch.	Demonstration	We will verify this at test launches.

initiate launch (other than what is provided by the launch services provider).			
2.14. The launch vehicle will use a commercially available solid motor propulsion system using ammonium perchlorate composite propellant (APCP) which is approved and certified by the NAR and TRA.	We will only be using motors manufactured by CTI	Inspection	We will check and verify these motors are approved and certified by the NAR before ever placing them in the launch vehicle
2.14.1. Final motor choices will be declared by the CDR milestone.	A final design of the launch vehicle will be finished by the CDR in order to determine the best appropriate motor		there will be no further changes of the launch vehicle design or motors by the CDR
2.14.2. Any motor change after CDR must be approved by the NASA Range Safety Officer (RSO) and will only be approved if the change is for the sole purpose of increasing the safety margin. A penalty against the team's overall score will be incurred when a motor change is made after the CDR	We will take all precautions to accurately choose the best and most safe motor for our launch vehicle. This is in order to avoid having to change the motor after the CDR with the final design is submitted.	Analysis/Testing	calculations and simulations will be used to confirm the efficiency of the motor in our launch vehicle before submitting the CDR so it never has to be changed.

milestone, regardless of the reason.			
2.15. Pressure vessels on the vehicle will be approved by the RSO and will meet the following criteria:	N/A-We will not be using pressure vessels	N/A	N/A
2.15.1 The minimum factor of safety (Burst or Ultimate pressure versus Max Expected Operating Pressure) will be 4:1 with supporting design documentation included in all milestone reviews.	N/A-We will not be using pressure vessels	N/A	N/A
2.15.2. Each pressure vessel will include a pressure relief valve that sees the full pressure of the tank and is capable of withstanding the maximum pressure and flow rate of the tank.	N/A	N/A	N/A
2.15.3.Full pedigree of the tank will be described, including the application for which the tank was designed, and the history of the tank, including the number of pressure cycles put	N/A	N/A	N/A

on the tank, by whom, and when.			
2.16. The total impulse provided by a College or University launch vehicle will not exceed 5,120 Newton-seconds (L-class). The total impulse provided by a High School or Middle School launch vehicle will not exceed 2,560 Newton-seconds (K-class).	We have only been looking at L-class and K-class motors throughout the design process	Inspection	We will calculate the chosen primary and backup motor's impulse in order to ensure they fit within the L-class limit. Our launch vehicle currently has an L730 as its primary motor
2.17. The launch vehicle will have a minimum static stability margin of 2.0 at the point of rail exit. Rail exit is defined at the point where the forward rail button loses contact with the rail.	We will use Open Rocket to simulate the stability of the launch vehicle.	Demonstration	Our current launch vehicle design has a stability of 3.36.
2.18. The launch vehicle will accelerate to a minimum velocity of 52 ft/s at rail exit.	We will use Open Rocket to ensure the launch vehicle will accelerate to at least 52 ft/s at rail exit	Demonstration	Our launch vehicle currently has a rail exit velocity of 60ft/s
2.19. All teams will successfully launch and recover a subscale model of their rocket	We will scale our full scale design down and build a smaller version of it for the subscale.	Testing/Analysis	Our sub-scale launch vehicle was built early due to limited launches

prior to CDR. Subscales are not required to be high power rockets.			during the winter months in New England. Its launch was on Oct. 20th in Berwick Maine and was successful.
2.19.1. The subscale model should resemble and perform as similarly as possible to the full scale model, however, the full scale will not be used as the subscale model.	The subscale model was designed to match the full scale launch vehicle as accurately as possible.	Demonstration	The subscale was divided into 4 main pieces just like the full scale with a piece of aluminum tethered to the launch vehicle to simulate the weight of the UAV
2.19.2. The subscale model will carry an altimeter capable of recording the model's apogee altitude.	The Subscale model had an E-bay housing a Raven 3 altimeter.	Analysis	Using this altimeter we were able to get the apogee altitude and flight data for the subscale.
2.19.3. The subscale rocket must be a newly constructed rocket, designed and built specifically for this year's project.	All new parts will be ordered for the subscale test.	Inspection	The subscale was built completely from scratch with new materials.
2.19.4. Proof of a successful flight shall be supplied in the CDR report. Altimeter data output may be used to meet this requirement.	The subscale launch vehicle's altimeter will be used to recover flight data	Inspection/Analysis	We were able to successfully receive flight data from the raven 3 altimeter located in the E-bay of the subscale

2.20. All teams will complete demonstration flights as outlined below.	Demonstration flights will be scheduled for the team	Demonstration	These will be mandatory for all members
2.20.1. Vehicle Demonstration Flight - All teams will successfully launch and recover their full scale rocket prior to FRR in its final flight configuration. The rocket flown must be the same rocket to be flown on launch day. The purpose of the Vehicle Demonstration Flight is to validate the launch vehicle's stability, structural integrity, recovery systems, and the team's ability to prepare the launch vehicle for flight. A successful flight is defined as a launch in which all hardware is functioning properly (i.e. drogue chute at apogee, main chute at the intended lower altitude, functioning tracking devices, etc.).	Test flights will be held in Berwick, Maine at their launch site. The team intends to work with MMMSC for test launches. The launch vehicle will not be changed after test flights. All hardware will be thoroughly checked after flight to ensure everything is in good condition and working properly.	Inspection	Test flights are scheduled according to launch dates for the Berwick Maine launch site. The launch vehicle will be built such that any damage is negligible and it can be launched again at the competition.

2.20.1.1. The vehicle and recovery system will have functioned as designed.	The launch vehicle recovery system will be assembled as described in all designs and simulations.	Inspection	Extra care will be taken to ensure parachutes are placed in the correct packing order and each tethered or piece landing separate will be equipped with its own GPS system
2.20.1.2. The full scale rocket must be a newly constructed rocket, designed and built specifically for this year's project.	All components have been designed for the USLI launch vehicle. No designs will be used from previous launch vehicles made by the WPI AIAA chapter.	Demonstration	The full scale will be constructed using all new materials specified in the budget
2.20.1.3. The payload does not have to be flown during the full scale Vehicle Demonstration Flight. The following requirements still apply:	N/A	N/A	N/A
2.20.1.3.1. If the payload is not flown, mass simulators will be used to simulate the payload mass.	If the payload is ready to be flown by test launches mass simulators will be measured just in case.	Testing/Demonstration	Mass simulators will be brought to the test launch regardless of whether or not the payload is ready to fly just in case.
2.20.1.3.2. The mass simulators will be located in the same approximate location on the rocket as the missing payload mass.	Mass simulators will be secured within the payload retention system so that they are located in the same place the payload would be	Inspection	We will ensure we have the necessary materials to ensure the mass simulators are placed in the best position to

			simulate as if the actual UAV was there.
2.20.1.4. . If the payload changes the external surfaces of the rocket (such as with camera housings or external probes) or manages the total energy of the vehicle, those systems will be active during the full scale Vehicle Demonstration Flight.	N/A	N/A	N/A
2.20.1.5. Teams shall fly the launch day motor for the Vehicle Demonstration Flight. The RSO may approve use of an alternative motor if the home launch field cannot support the full impulse of the launch day motor or in other extenuating circumstances.	We will use the motor in our design for our test launches	Demonstration	We will make sure the simulations continue to check out with the motor we are chosen and that we have it on hand when we go to launch
2.20.1.6. The vehicle must be flown in its fully ballasted configuration during the full scale test flight. Fully ballasted refers to the same amount of ballast that will be flown during	We will not make any changes to the launch vehicle or its flight configuration after the CDR submission	Inspection	The launch vehicle will be flown in identical configurations for the test and competition flights

the launch day flight. Additional ballast may not be added without a re-flight of the full scale launch vehicle.			
2.20.1.7. After successfully completing the full scale demonstration flight, the launch vehicle or any of its components will not be modified without the concurrence of the NASA RSO.	The launch vehicle will not be changed after the successful test flight	Inspection	We will make sure we are satisfied with our final design before we go to launch to ensure we won't need or want to make any changes after
2.20.1.8. Proof of a successful flight shall be supplied in the FRR report. Altimeter data output is required to meet this requirement.	The launch vehicle will provide data for the FRR with its E-bay and raven three altimeter during flight	Testing	We will receive data from the altimeter for the FRR after the launch vehicle has landed
2.20.1.9. Vehicle Demonstration flights must be completed by the FRR submission deadline. If the Student Launch office determines that a Vehicle Demonstration Re-flight is necessary, then an extension may be granted. This extension is only valid for re-flights, not first-time flights.	Demonstration flights will be completed before the FRR	Demonstration	We will take extra care to make sure our launch vehicle and payload are both working in top order to avoid have to redo our demonstration flights

Teams completing a required re-flight must submit an FRR Addendum by the FRR Addendum deadline.			
2.20.2. Payload Demonstration Flight - All teams will successfully launch and recover their full scale rocket containing the completed payload prior to the Payload Demonstration Flight deadline. The rocket flown must be the same rocket to be flown on launch day.	Demonstration flights will be completed prior to the payload demonstration flight	Demonstration	We will make sure our Gantt chart accounts for this so that the launch vehicle is ready to fly and complete its demonstration flight prior to that of the payload
2.20.2.1. The payload must be fully retained throughout the entirety of the flight, all retention mechanisms must function as designed, and the retention mechanism must not sustain damage requiring repair.	The payload will be housed in its own retention system that will stay within the launch vehicle for the duration of its flight	Inspection	We will verify that the payload has stayed contained safely within the payload retention system once it has landed.
2.20.2.2. The payload flown must be the final, active version.	The payload will be the final active version proposed in the CDR	Inspection	No changes will be made to the UAV after the CDR to ensure it’s the final active version

2.20.2.3. If the above criteria is met during the original Vehicle Demonstration Flight, occurring prior to the FRR deadline and the information is included in the FRR package, the additional flight and FRR Addendum are not required.	N/A	N/A	N/A
2.20.2.4. . Payload Demonstration Flights must be completed by the FRR Addendum deadline. No extensions will be granted.	Payload demonstration flights will be completed by the FRR	Demonstration	The payload will be finished with building in time to get the demonstration flights done before the FRR deadline
2.21. An FRR Addendum will be required for any team completing a Payload Demonstration Flight or NASA required Vehicle Demonstration Re-flight after the submission of the FRR Report.	N/A	N/A	N/A
2.21.1. Teams required to complete a Vehicle Demonstration Re-Flight and failing to submit the FRR	N/A	N/A	We will make sure to submit the FRR on time

Addendum by the deadline will not be permitted to fly the vehicle at launch week.			
2.21.2. Teams who successfully complete a Vehicle Demonstration Flight but fail to qualify the payload by satisfactorily completing the Payload Demonstration Flight requirement will not be permitted to fly the payload at launch week.	N/A	N/A	N/A
2.21.3. Teams who complete a Payload Demonstration Flight which is not fully successful may petition the NASA RSO for permission to fly the payload at launch week. Permission will not be granted if the RSO or the Review Panel have any safety concerns.	N/A	N/A	N/A

2.22. Any structural protuberance on the rocket will be located aft of the burnout center of gravity.	The only protuberance, the E-bay switch will be located aft of the burnout center of gravity	Inspection	Multiple team members will check to confirm the switch is located in the correct place
2.23. The team's name and launch day contact information shall be in or on the rocket airframe as well as in or on any section of the vehicle that separates during flight and is not tethered to the main airframe. This information shall be included in a manner that allows the information to be retrieved without the need to open or separate the vehicle.	The Teams name and contact information will be written on the side of the launch vehicle	Inspection	Permanent marker will be used to ensure the name and contact information of the team doesn't fade or get wiped off during the duration of the competition
2.24. Vehicle Prohibitions	N/A	N/A	N/A
2.24.1. The launch vehicle will not utilize forward canards. Camera housings will be exempted, provided the team can show that the housing(s) causes	We will not be using canards or camera housings on the launch vehicle	Inspection	These components will not be included in the design of the launch vehicle

minimal aerodynamic effect on the rocket's stability.			
2.24.2. The launch vehicle will not utilize forward firing motors.	The launch vehicle will not use forward firing motors	Inspection	The launch vehicle will be designed using Cesaroni Tech motors approved and certified by the NAR
2.24.3. The launch vehicle will not utilize motors that expel titanium sponges (Sparky, Skidmark, MetalStorm, etc.)	The launch vehicle will not use motors that expel titanium sponges	Inspection	The launch vehicle will be designed using Cesaroni Tech motors approved and certified by the NAR
2.24.4. The launch vehicle will not utilize hybrid motors.	The launch vehicle will not be designed for hybrid motors	Inspection	The launch vehicle will be designed using Cesaroni Tech motors approved and certified by the NAR
2.24.5. The launch vehicle will not utilize a cluster of motors.	The launch vehicle will not be designed for a cluster of motors	Inspection	The launch vehicle will be designed using Cesaroni Tech motors approved and certified by the NAR
2.24.6. The launch vehicle will not utilize friction fitting for motors.	We will not use friction fitting for motors instead we will use a motor retention system	Inspection	The motor retention system will be put together using screws, clips to hold on the motor, and a screwdriver

2.24.7. The launch vehicle will not exceed Mach 1 at any point during flight.	The launch vehicle will be designed in Open Rocket to not exceed Mach 1 at any point during flight	Inspection	The launch vehicle's simulated speed is Mach .55.
2.24.8. Vehicle ballast will not exceed 10% of the total unballasted weight of the rocket as it would sit on the pad (i.e. a rocket with and unballasted weight of 40 lbs. on the pad may contain a maximum of 4 lbs. of ballast).	Any ballast incorporated into the launch vehicle will not exceed 10% of the unballasted weight	Analysis	Calculations will be condoned to confirm any ballast is within the 10% margin
2.24.9. Transmissions from onboard transmitters will not exceed 250 mW of power.	The GPS tracking transmitters we plan to use are rated for less power than the specified output maximum	Analysis	We will ensure the output power of all transmitters does not exceed this limit prior to their integration into the launch vehicle
2.24.10. Excessive and/or dense metal will not be utilized in the construction of the vehicle. Use of lightweight metal will be permitted but limited to the amount necessary to ensure structural integrity of the airframe under the expected operating stresses.	The amount and type of metal will be limited in the design of the launch vehicle. There will be no excessive use of metal.	Inspection	The only metal components currently incorporated in our launch vehicle design involves quick links, u-bolts, nuts, bolts, screws, and a metal tipped ogive nose cone.

Table 6.2.1.B. Vehicle Requirements

Recovery Systems Requirements			
NASA Requirements	**How we Plan to Meet Them**	**Method**	**Verification**
3.1. The launch vehicle will stage the deployment of its recovery devices, where a drogue parachute is deployed at apogee and a main parachute is deployed at a lower altitude. Tumble or streamer recovery from apogee to main parachute deployment is also permissible, provided that kinetic energy during drogue-stage descent is reasonable, as deemed by the RSO.	The launch vehicle will have a 36in drogue parachute programmed to deploy at apogee, a 72in main parachute and 36in nose cone parachute programmed to deploy at 700ft	Inspection	A Raven 3 Altimeter will be used to program the dual deployment system on the launch vehicle ensuring the drogue parachute deploys at apogee, and the main and nose cone parachute deploys at 700ft
3.1.1. The main parachute shall be deployed no lower than 500 feet.	The main parachute will be deployed at 700ft	Inspection	The Raven 3 Altimeter will be programmed to deploy the main parachute at 700ft

3.1.2. The apogee event may contain a delay of no more than 2 seconds.	The primary altimeter will release the drogue parachute at apogee and the secondary altimeter will release the drogue parachute at apogee plus one	Inspection	We will use software to ensure both altimeters are programmed to accurately follow these guidelines
3.2. Each team must perform a successful ground ejection test for both the drogue and main parachutes. This must be done prior to the initial subscale and full scale launches	A ground ejection test will be done before the subscale and full scale launches	Testing	Ground ejection tests will be scheduled in the Gantt chart in order to ensure they are planned accordingly
3.3. At landing, each independent section of the launch vehicle will have a maximum kinetic energy of 75 ft-lbf	Each independent section will have its kinetic energy calculated to confirm it is below 75 lbf-ft.	Analysis	All kinetic energy values are below this limit
3.4. The recovery system electrical circuits will be completely independent of any payload electrical circuits.	Launch vehicle electrical components will be kept separate from payload electrical components	Inspection	Launch vehicle electrical components will be housed in its E-bay whereas payload electrical components will be housed within the payload

3.5. All recovery electronics will be powered by commercially available batteries.	Recovery electronics such as the gps system and Raven 3 Altimeter will be powered with commercially available batteries	Inspection	Electronics will be powered using 9V batteries
3.6. The recovery system will contain redundant, commercially available altimeters. The term “altimeters” includes both simple altimeters and more sophisticated flight computers.	The launch vehicle will be using two raven three altimeters one primary and one secondary.	Testing	We will verify both altimeters are working as they are supposed to before launch
3.7. Motor ejection is not a permissible form of primary or secondary deployment.	The motor will not be used as a form of primary of secondary deployment	Inspection	Deployment will be triggered using the primary and secondary Raven three altimeters.
3.8. Removable shear pins will be used for both the main parachute compartment and the drogue parachute compartment.	Shear pins will be placed on both the upper and lower airframes	Inspection	The launch vehicle will be checked before launching to ensure shear pins are where they need to be.
3.9. Recovery area will be limited to a 2,500 ft. radius from the launch pads	To ensure the launch vehicle lands within this radius it has been designed to fit the 90s decent limit	Analysis	Using Open Rocket simulations we are able to monitor our descent time

			during the construction of the launch vehicle.
3.10. Descent time will be limited to 90 seconds (apogee to touch down).	The launch vehicle's design takes this into account adjusting parachute sizes to fit in this descent time limit	Analysis	Using Open Rocket simulations we are able to monitor our descent time during the construction of the launch vehicle. Additionally the launch vehicles descent time will be timed when we go to test launches.
3.11. An electronic tracking device will be installed in the launch vehicle and will transmit the position of the tethered vehicle or any independent section to a ground receiver.	A GPS tracking device will be located on each independent piece of the launch vehicle	Inspection	The GPS tracking device will be checked before launch to ensure it is transmitting data correctly
3.11.1. Any rocket section or payload component, which lands untethered to the launch vehicle, will contain an active	Any untethered piece of the launch vehicle will contain its own GPS tracking device	Inspection	The nose cone and the rest of the launch vehicle body along with the payload will have

electronic tracking device.			their own GPS tracking device
3.11.2. The electronic tracking device(s) will be fully functional during the official flight on launch day.	GPS tracking devices will be bought new to ensure there is no damage done to them and to ensure they will work properly	Inspection	GPS tracking devices will be checked before launch to ensure they are transmitting data correctly
3.12. The recovery system electronics will not be adversely affected by any other on-board electronic devices during flight (from launch until landing).	The GPS devices will be wired such that they are not affected by the other electronics on the launch vehicle	Inspection	All wiring will be checked more than once and tested to ensure there is no interference
3.12.1. The recovery system altimeters will be physically located in a separate compartment within the vehicle from any other radio frequency transmitting device and/or magnetic wave producing device.	The e-bay will be divided into two separate compartments. One will house the altimeters for recovery the other will house the gps tracking device	Inspection	The altimeters will be checked to ensure there is no interference between it and the gps device
3.12.2. The recovery system electronics will be shielded from all onboard	Recovery system electronics will be shielded from onboard transmitting devices	Inspection	Recovery system devices will be checked to ensure there is no interference

transmitting devices to avoid inadvertent excitation of the recovery system electronics.			due to other transmitting devices
3.12.3. The recovery system electronics will be shielded from all onboard devices which may generate magnetic waves (such as generators, solenoid valves, and Tesla coils) to avoid inadvertent excitation of the recovery system.	Recovery system electronics will be shielded from other onboard devices	Inspection	Recovery system devices will be checked to ensure there is no interference due to other devices
3.12.4. The recovery system electronics will be shielded from any other onboard devices which may adversely affect the proper operation of the recovery system electronics.	Recovery system electronics will be shielded from other onboard devices	Inspection	Recovery system devices will be checked to ensure there is no interference due to other devices

Table 6.2.1.C. Recovery System Requirements

Payload Requirements			
NASA Requirements	**How we Plan to Meet Them**	**Method**	**Verification**
4.2 College/University Division – Each team will choose one experiment option from the following list.	We will select only one experiment option.	N/A	We selected the UAV experiment option.
4.2.1 An additional experiment (limit of 1) is allowed, and may be flown, but will not contribute to scoring.	N/A	N/A	N/A
4.2.2 If the team chooses to fly an additional experiment, they will provide the appropriate documentation in all design reports so the experiment may be reviewed for flight safety. Option 1 — Deployable Rover/Soil Sample Recovery Option 2 — Deployable UAV/Beacon Recovery	N/A	N/A	N/A

4.3 Deployable Rover / Soil Sample Recovery Requirements	N/A	N/A	N/A
4.3.1 Teams will design a custom rover that will deploy from the internal structure of the launch vehicle.	N/A	N/A	N/A
4.3.2 The rover will be retained within the vehicle utilizing a fail-safe active retention system. The retention system will be robust enough to retain the rover if atypical flight forces are experienced.	N/A	N/A	N/A
4.3.3 At landing, and under the supervision of the Remote Deployment Officer, the team will remotely activate a trigger to deploy the rover from the rocket.	N/A	N/A	N/A
4.3.4 After deployment, the rover will autonomously move at least 10 ft. (in any direction) from the	N/A	N/A	N/A

launch vehicle. Once the rover has reached its final destination, it will recover a soil sample.			
4.3.5 The soil sample will be a minimum of 10 mL.	N/A	N/A	N/A
4.3.6 The soil sample will be contained in an onboard container or compartment. The container or compartment will be closed or sealed to protect the sample after collection.	N/A	N/A	N/A
4.3.7. Teams will ensure the rover's batteries are sufficiently protected from impact with the ground.	N/A	N/A	N/A
4.3.8. The batteries powering the rover will be brightly colored, clearly marked as a fire hazard, and easily distinguishable from other rover parts	N/A	N/A	N/A

4.4 Deployable Unmanned Aerial Vehicle (UAV) / Beacon Delivery Requirements	N/A	N/A	N/A
4.4.1. Teams will design a custom UAV that will deploy from the internal structure of the launch vehicle.	We will design our own UAV and internal retention system.	N/A	The UAV will be of our own design and built alongside the launch vehicle team to ensure an internal retention structure.
4.4.2. The UAV will be powered off until the rocket has safely landed on the ground and is capable of being powered on remotely after landing.	We will have our UAV powered off until it is confirmed landed by a visual confirmation and powered on after that.	Inspection	We will verify that the launch vehicle has landed and power on the rover remotely.
4.4.3. The UAV will 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.	The UAV retention system will be encased within the body of the launch vehicle and designed to be robust enough to handle any forces it might experience in flight.	Inspection	The UAV retention system will be carefully inspected prior to installation and installed with care to keep it within the launch vehicle.

4.4.4 At landing, and under the supervision of the Remote Deployment Officer, the team will remotely activate a trigger to deploy the UAV from the rocket.	At launch, we will wait until the RDO gives us a go-ahead to activate the UAV.	N/A	We will communicate with the RDO to ensure proper methods are followed
4.4.5. After deployment and from a position on the ground, the UAV will take off and fly to a NASA specified location, called the Future Excursion Area (FEA). Both autonomous and piloted flight are permissible but all reorientation or unpacking maneuvers must be autonomous.	Our UAV retention system will unpack and prepare the UAV for launch autonomously. After unpacking, the UAV will be teleoperated to deliver the beacon.	Demonstration	After anRDO confirms the landing of our retention system, we will send the signal to autonomously unpack the UAV and proceed to pilot it.
4.4.6 The FEA will be approximately 10 ft. x 10 ft. and constructed of a color which stands out against the ground.	N/A	N/A	N/A
4.4.7 One or more FEA's will be located in the recovery area of the launch field. FEA samples will be provided to teams	N/A	N/A	N/A

upon acceptance and prior to PDR			
4.4.8 Once the UAV has reached the FEA, it will place or drop a simulated navigational beacon on the target area.	Our UAV will have a retention system for the beacon that will release once it has reached the FEA.	Inspection	We will have an onboard camera that will be used to verify the UAV is over the FEA.
4.4.9 The simulated navigational beacon will be designed and built by each team and will be a minimum of 1 in W x 1 in H x 1 in D. The school name must be located on the external surface of the beacon.	Our beacon will be a 1 inch cube with the WPI seal on it.	Inspection	We will measure the cube and store it within the UAV and launch vehicle in such a way it maintains shape and design.
4.4.10 Teams will ensure the UAV's batteries are sufficiently protected from impact with the ground.	We will have the batteries placed within the UAV such that they are protected from punctures and direct impacts should the UAV fail.	Testing	The UAV will be tested prior to launch to verify battery safety.
4.4.11 The batteries powering the UAV will be brightly colored, clearly marked as a fire hazard,and easily distinguishable from other UAV parts.	The batteries will be colored brightly and marked as fire hazards, clearly visible as its own part.	Inspection	We will make sure with multiple people that the batteries are clearly visible and marked.

4.4.12 The team will abide by all applicable FAA regulations, including the FAA's Special Rule for Model Aircraft (Public Law 112-95 Section 336; see https://www.faa.gov/uas/faqs).	We will be aware of and abide by all FAA regulations that apply.	Inspection	We will verify the rules defined by the FAA are followed by the final design and our intentions of use.
4.4.13 Any UAV weighing more than .55lbs will be registered with the FAA and the registration number marked on the vehicle.	If the payload is greater than .55lbs, the team will register it with the FAA and ensure it is clearly marked with its registration number.	Inspection	Based on our final design of the UAV, we will determine the weight and follow through with registration if necessary.
4.5 Team-Designed Payload Requirements (High School/Middle School Division)	N/A	N/A	N/A
4.5.1 Team-designed payloads must be approved by NASA. NASA reserves the authority to require a team to modify or change a payload, as deemed necessary by the Review Panel, even after a proposal has been awarded.	N/A	N/A	N/A

4.5.2. Data from the science or engineering experiment will be collected, analyzed, and reported by the team following the scientific method.	N/A	N/A	N/A
4.5.3. The experiment must be designed to be recoverable and reusable. Reusable is defined as being able to be launched again on the same day without repairs or modifications.	N/A	N/A	N/A
4.5.4. Any experiment element that is jettisoned during the recovery phase will receive real-time RSO permission prior to initiating the jettison event.	N/A	N/A	N/A
4.5.5. Unmanned aerial vehicle (UAV) payloads, if designed to be deployed during descent, will be tethered to the vehicle with a remotely controlled release mechanism until the RSO has given	N/A	N/A	N/A

permission to release the UAV.			
4.5.6 Teams flying UAVs will abide by all applicable FAA regulations, including the FAA's Special Rule for Model Aircraft (Public Law 112-95 Section 336; see https://www.faa.gov/uas/faqs).	N/A	N/A	N/A
4.5.7 Any UAV weighing more than .55 lbs. will be registered with the FAA and the registration number marked on the vehicle.	N/A	N/A	N/A

Table 6.2.1.D. Payload Requirements

Safety Requirements			
NASA Requirements	**How we Plan to Meet Them**	**Method**	**Verification**
5.1. Each team will use a launch and safety checklist. The final checklists will be included in the FRR report and used during the Launch	The team will write detailed checklists. They will cover all tasks that are required to launch the launch vehicle safely.	Inspection	At launch events, the Safety Officer will check off tasks on a physical or digital copy of the checklists.

Readiness Review (LRR) and any launch day operations.			
5.2. Each team must identify a student safety officer who will be responsible for all items in section 5.3.	The team captain will appoint the safety officer.	Inspection	The information of the safety officer is included on relevant documents.
5.3.1. The safety officer will monitor team activities with an emphasis on Safety during design of vehicle and payload, construction of vehicle and payload, assembly of vehicle and payload, ground testing of vehicle and payload, subscale launch tests, full scale launch tests, launch day, recovery activities, and	The safety officer will attend all the events. They will actively advise members on safety matters.	N/A	When planning events, the availability of the safety officer will be confirmed in advance.

STEM engagement activities.			
5.3.2. The safety officer will implement procedures developed by the team for construction, assembly, launch, and recovery activities.	The safety officer will host safety briefings for members. Attendance is required to participate in building and launch activities.	N/A	Members must sign a form indicating their understandin g of safety procedures.
5.3.3. The safety officer will manage and maintain current revisions of the team's hazard analyses, failure modes analysis, procedures, and MSDS/chemical inventory data.	Hazard analysis, FMEA, procedures, and MSDS will be made available to all members and will be updated regularly.	N/A	Members will be made aware they have access to these materials as part of a safety briefing.
5.3.4. Assist in the writing and development of the team's hazard analyses, failure modes analysis, and procedures.	The safety officer will organize the writing of these sections by delegating tasks to specific members and overseeing the sections completion.	Inspection	The safety officer's sections will be validated by the captain.

5.4. During test flights, teams will abide by the rules and guidance of the local rocketry club's RSO. The allowance of certain vehicle configurations and/or payloads at the NASA Student Launch does not give explicit or implicit authority for teams to fly those vehicle configurations and/or payloads at other club launches. Teams should communicate their intentions to the local club's President or Prefect and RSO before attending any NAR or TRA launch.	Prior to the launch of any vehicles, the RSO will be informed of how the launch vehicle is intended to perform. This includes the expected apogee, recovery method, payload, and any other details they request. The team will follow all rules set forth by the club running the event.	N/A	No launch vehicle will be flown until the RSO has been explicitly told how the craft is intended to perform and the RSO has given explicit permission to launch.

5.5. Teams will abide by all rules set forth by the FAA.	Members will be briefed on FAA regulations. The Safety Officer will attend all launch events to advise members and ensure compliance with all laws.	Inspection	The team will only launch rockets at launch events organized by a rocketry club with a FAA waiver.

Table 6.2.1.E. Safety Requirements

6.2.2. Team Derived Requirements

Vehicle Requirements			
Requirement	Justification	Method	Reference
There must be at least one successful full scale launch before competition	The team will aim for the opportunity to conduct multiple full scale test launches	Testing	The data for these test launches will be available by the FRR
All components cut or dremeled will be sanded to ensure edges are smooth such that all pieces fit together as designed	Every object that needs it will be sanded as needed	Inspection	The launch vehicle will be checked for sharp or rough edges during construction
The rotary switch will only be switched on by, the rocket lead, director of system integration, mentor, payload lead, or team members familiar with the e-bay	The team aims to prevent any tampering or accidents when it comes to the devices in the e-bay and ensuring they are all programmed and working correctly	Inspection	Only certain members will be able to use the arming switch or check devices in the e-bay
The e-bay will be organized such that devices and wiring are neatly placed and easy to access	The E-bay has been designed with two compartments to keep everything organized	Inspection	This will be verified visually by the rocket lead and payload lead.
Energetics and Motors	The team wants to	Inspection	This will be verified

will only be handled during travel by first and foremost the team mentor, and then the faculty advisor.	ensure the safety of its members especially if they have less experience in handling energetics		visually and verbally by the team mentor, and faculty advisor.
All members will wear all required safety garments if they desire to participate in the construction of the launch vehicle	The team wants to ensure the safety of its members. If someone does not comply with these rules they will be asked to leave	Inspection	This will be verified visually and verbally by the team faculty advisor, mentor, and officer board
All dimensions will be checked with the rocket lead or Director of System Integration before cutting into any component	This limits the amount of errors and ensures the integrity and accuracy of the final design	Inspection	This will be confirmed visually and verbally by the rocket lead or Director of System Integration

Table 6.2.2.1 Team Derived Vehicle Requirements.

Recovery Requirements			
Requirement	Justification	Method	Reference
All parachutes will be checked for correct sizes	This is to avoid errors that may affect lateral drift of descent time	Inspection	This will be verified using the parachute sizing in simulations as well as by the team members assigned to recovery
Shock cord will be accordion folded and secured using a piece of tape such that it can easily rip apart	To absorb more shock	Inspection	This will be verified visually by team members assigned to recovery and can be found in section 3.4
Parachutes will be packed with nomex blankets for protection	To avoid damage due to energetics during flight	Inspection	This will be verified visually by recovery team members and tested during test launches.
Altimeters will be	To avoid any errors in	Inspection	This will be verified by

triple checked for correct programming and orientation	orientation or programming that may cause the launch vehicle to, deploy parachutes incorrectly, or sustain damage		the team mentor and rocket lead as well with multiple simulated tests and checks
Kinetic Energy of each individual section shall not exceed 75 lbf-ft.	Values have been calculated to ensure this	Analysis	Verified via calculations and data

Table 6.2.2.2. Team Derived Recovery Requirements.

Payload Requirements			
Requirement	Justification	Method	Reference
There must be at least one successful full scale test before competition	The team will aim for the opportunity to conduct multiple full scale tests	Testing	The data for these tests will be available by the FRR
The UAV will be organized such that all components and electronics are easily accessible	The UAV has been designed to have a minimal form factor and easy access to all parts	Inspection	This will be verified visually by payload lead.
Ensure all components of UAV are functioning as desired	The UAV must have all components working to complete beacon delivery	Testing	A systems check will be run to ensure all parts are in working order
UAV and beacon will be securely mounted within the retention system	The UAV and beacon must remain undamaged during launch vehicle flight in order to successfully complete beacon delivery	Inspection	This will be verified visually by payload lead
The UAV will have a maximum of at least twice the flight time estimated to be needed to complete	Should any abnormalities in the flight of the UAV occur, sufficient time will be allowed for	Analysis/testing	Sections 5.4 and 6.1.2 provide details regarding the processes by which components were

the mission	analysis and corrective measures applied by a human operator to aid in the mission		selected to ensure this requirement was met

Table 6.2.2.3. Team Derived Payload Requirements.

Section 6.3. Budgeting and Timeline

In this section there is an in depth budget cost ranging from every expense made or will be mader for the success of the competition. Alongside with a funding plan in order the make sure that it is as realistically as possible and to make sure that this is logistically possible. The timeline has been used over the year to make sure all deadline are met and that nothing is done out of order.

Section 6.3.1 Budget

Full Scale & Sub-Scale Rocket:						
Component	**Specific Item**	**Quantity**	**Price**	**Total**	**Vendor**	**Comments**
Nose Cone	6” Fiberglass Metal Tipped Nose Cone	1	$149.95	$149.95	Madcow Rocketry	-
Main Tube	Blue Tube 2.0 6”x0.074”x72”	2	$105.95	$211.90	Always Ready Rocketry	Airframe
Centering Rings	Plywood ½”x2’x4’	0	$15.50	$0.00	Home Depot	Already Owned
Fins	Carbon Fiber Sheets	1	$342.75	$342.75	Dragon Plate	-
Motor Tube	Blue Tube 2.0 54mmx.062”x 48”	1	$23.95	$23.95	Always Ready Rocketry	Airframe
Inner Tube	Blue Tube 2.0 6’x0.077”x48”	1	$66.95	$66.95	Always Ready Rocketry	Coupler
Motor Case	Cesaroni 29mm	1	$143.27	$143.27	Apogee Components	-

	6XL-Grain Case					
Flight Computer	Raven 3 Altimeter	0	$155.00	$0.00	Feather weight Altimeters	Already Owned
Full Scale Battery	Turnigy Graphene 65C LiPo	0	$15.69	$0.00	Hobby King	-
Arming Switch	Full Scale Rocket Rotary Switch	1	$10.33	$10.33	Apogee Components	-
Wiring	Wiring	0	$5.00	$0.00	WPI	Already Owned
Main Engine	L730CL 54-6GXL Reload Kit	2	$182.60	$365.20	AMW ProX	-
Backup Engine	L1030 RL	0	$175.00	$0.00	AMW ProX	Will buy as needed
Separation Charges	Black Powder Charges	0	$0.00	$0.00	WPI	Already Owned
Shear Pins	2-56x1/2" Nylon Screws	0	$10.64	$0.00	McMaster-Ca rr	Package of 100
Rail Buttons	1515 Rail Buttons	2	$6.00	$12.00	AMW ProX	-
Nomex Blankets	Sunward 18in Nomex Blanket	0	$10.49	$0.00	Apogee Rockets	Already Owned
Igniter	Full Scale Igniter	0	Free	Free	WPI	Already Owned
Parachutes	36" Drogue	1	$35.50	$35.50	Spherachutes	Already Owned
Parachutes	72" Hemisphere	1	$82.50	$82.50	Spherachutes	Already Owned
Parachutes	36"	1	$30.00	$30.00	Spherachutes	Already

	Hemisphere					Owned
Shock Cord	BlueWater 1" Tubular Webbing (130 ft.)	130	$0.45	$58.50	REI	130 in, $0.45/in, 4000 lb breakforce
U-Bolts	U-Bolts	0	Free	Free	WPI	Already Owned
Motor Retention	Hanger Wire	0	Free	Free	WPI	Already Owned
Quick Links	316 Stainless Steel Quick Link	0	$5.08	$0.00	McMaster-Carr	Already Owned
Swivel Mounts	Swivel 12/0 1500 lb	0	$4.00	$0.00	AMW ProX	Already Owned
Nuts/Bolts/ Washers	Assorted	0	$15.00	$0.00	McMaster-Carr	Already Owned
Blue Tape	ScotchBlue 1.88"x60yds	0	$6.58	$0.00	Home Depot	Already Owned
Gorilla Tape	Gorilla 1-7/8x35yds	0	$8.98	$0.00	Home Depot	Already Owned
Subscale						
Main Tube	2.15"x0.062"x 48"	2	$23.99	$47.90	Always Ready Rocketry	Airframe
Nose Cone	54mm Plastic Nose Cone	1	$14.80	$14.80	Apogee Components	Nose Cone
Motor Tube	1.15"x.062"x2 4"	1	$6.25	$6.25	Always Ready Rocketry	Motor Tube
Inner Tube	2.15"x0.062"x 8"	1	$8.95	$8.95	Always Ready Rocketry	Inner Tube
Motor Casing	Pro-29 4G	1	$26.00	$26.00	AMW ProX	Motor Casing
Flight	Raven 3	0	$155.00	$0.00	Feather	Already

Computer	Altimeter				weight Altimeters	Owned
Battery	9V Battery	0	$11.55	$0.00	Amazon	Already Owned
Arming Switch	Sub Scale Arming Switch	1	$9.93	$9.93	Apogee Components	-
Wiring	Wiring	1	$5.00	$0.00	WPI	-
Parachutes	30” Hemisphere	1	$26.75	$26.75	Spherachutes	Already Owned
Parachutes	18” Hemisphere	1	$14.00	$14.00	Spherachutes	Already Owned
Parachutes	18”Drogue	1	$21.50	$21.50	Spherachutes	Already Owned
Main Engine	H118CL	0	Free	Free	AMW ProX	Already Owned
Separation Charges	Black Powder Charges	0	Free	Free	WPI	Already Owned
Full Scale Total	$1,532.80					
SubScale Total	$176.08					
Total	$1,708.88					

Table 6.3.1.1. Launch Vehicle Budget

Payload:						
Component	**Specific Item**	**Quantity**	**Price**	**Total**	**Vendor**	**Comments**
Processor	Arduino Nano	2	$22.00	$44.00	Arduino	Capsule Processor
Processor	Pix Hawk Mini	1	$164.99	$164.99	Amazon	UAV Processor
LiPo Battery	3.7v 2000mAh	6	$12.50	$75.00	Adafruit	-
ESCs	Lumenier 30A BLHeli_S OPTO	4	$13.00	$54.00	GetFPV	-
Brushless Motor	RotorX RX1404B	4	$15.00	$60.00	GetFPV	-
Servos	L16-R	2	$70.00	$140.00	Spektrum	-

Transceiver	NRF24L01	3	$19.95	$59.85	Amazon	-
3D Printer Filament	Nylon X	1	$136.24	$136.24	-	-
Carbon Fiber	1ftx1ft sheet	1	$136.24	$136.24	Dragon Plate	-
GPS NEO 6MV2	NEO 6M	3	$8.55	$25.65	-	-
Overhead	Cover for additional components	1	$50.00	$50.00	-	-
Payload Total	$945.97					

Table 6.3.1.2. Payload Budget

Logistics:						
Component	**Specific Item**	**Quantity**	**Price**	**Total**	**Vendor**	**Comments**
Test Launch	Participation Fee	10	$5.00	$50.00	MMMS C	-
Certifications	Level 1 and 2	4	$25.0 0	N/A	MMMS C	-
Hotel Rooms	(4 nights) 2 Double Beds	5	$90	$1,800	Host Hotel	-
Shipping to Competition	Full-scale Rocket	1	$300	$300	UPS	-
Flights	Flight Tickets	18	$326	$5,868	-	Flights will be paid for by students or sponsors
Logistics Total	$7,718					

Table 6.3.1.3. Logistics Budget

	Preferred Option:	AIAA Selected and Current Option:
Total With Logistics:	Total With Logistics Minus Flight Cost:	Total Without Logistics:
$10,373	$4,505	$2,655
Total With Logistics accounting for shipping:	Total With Logistics Minus Flight Cost+shipping:	Total Without Logistics Plus Shipping:

$10,673	$4,505	$2,955

Table 6.3.1.4. Combined Budget

Section 6.3.2 Funding Plan

Our primary funding requirements have been met. The majority of our funding has been awarded by the WPI SGA. Including an additional award, requested for travel expenses in February 2019. Additional funding has been achieved through the use of personal donations and fundraising. This includes the use of door-to-door requests, as well as more traditional fundraising via social media. A Go-Fund-Me fundraiser raised the team an additional $1,000, which helped pay for carbon fiber for both the payload and the rocket fins. After the test launch, any remaining funds will be considered for the use of WPI USLI branded material, such as jackets, shirts or hats.

Section 6.3.3. Timeline

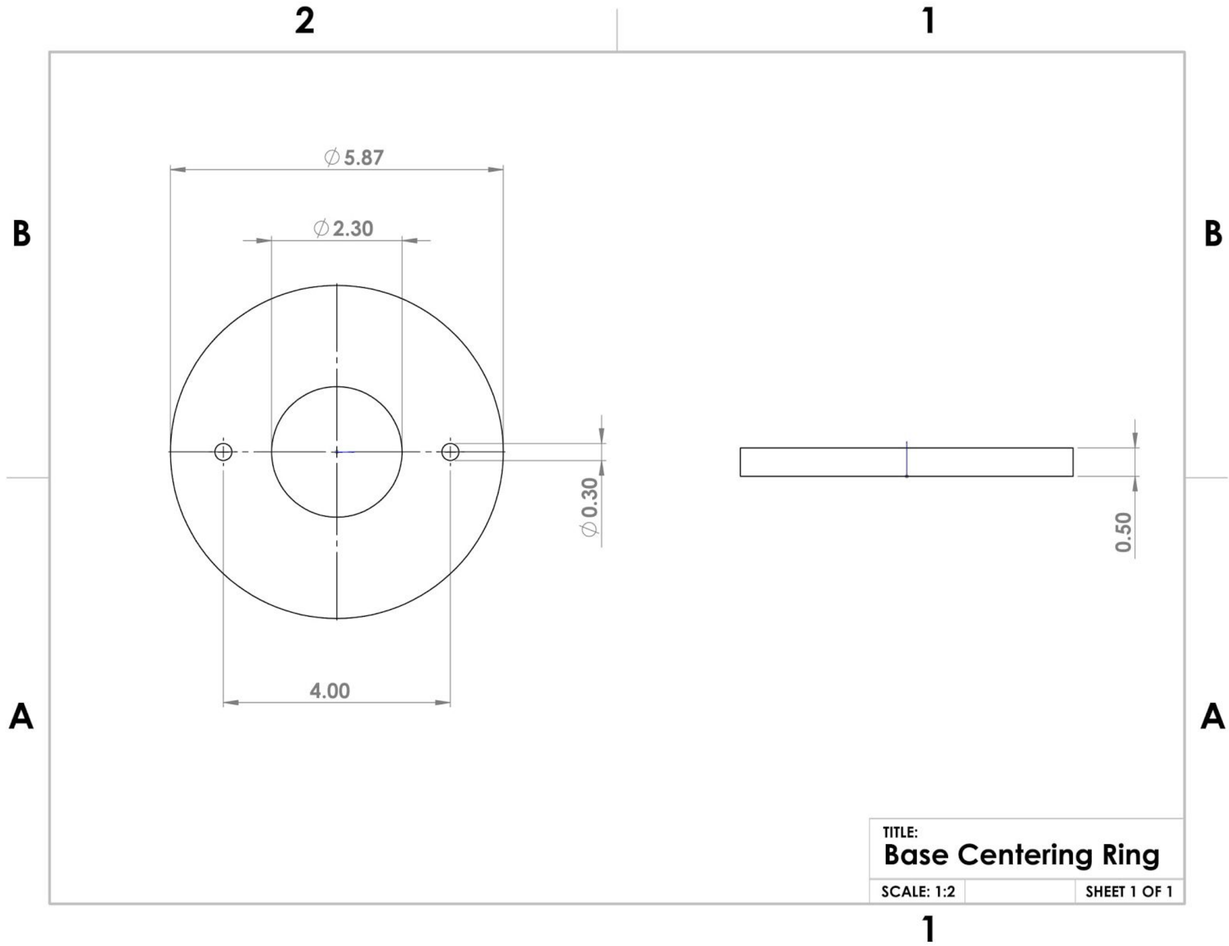
Two timeline has been created. The first one is a brief series of milestones and event to help the success of the team. The The second one in depth Gantt chart that is broken up into sections consisting of a proposal, logistics/sponsorship, vehicle, payload, preliminary design review, critical design reviews, flight readiness review, and competition. The burgundy colored cells are used for milestones, the gray is for meetings and the time worked on, and the peach is for college breaks.

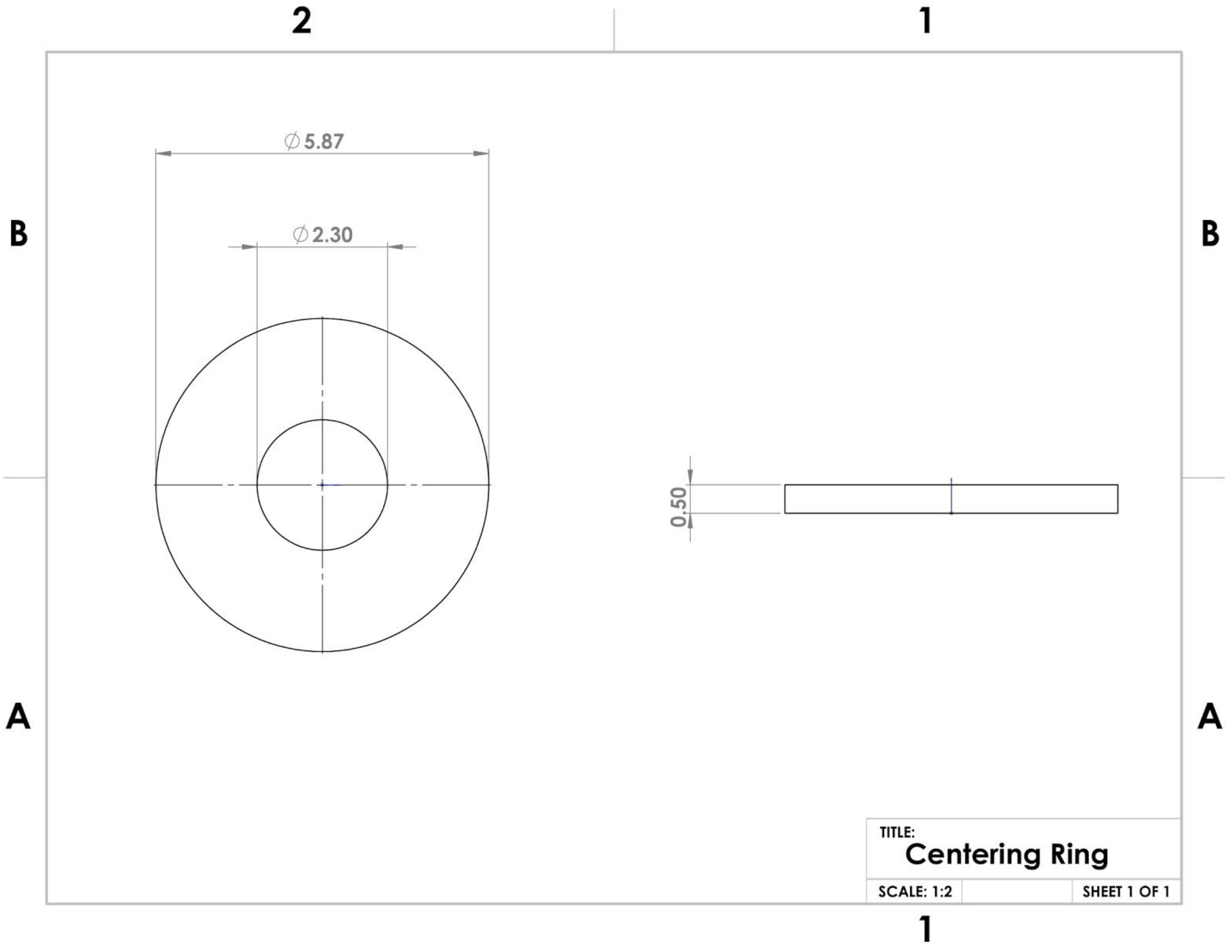
Task	Start	Duration	Aug. 22	Sep. 5	Sep. 19	Oct. 3	Oct. 17	Oct. 31	Nov. 14	Nov. 28	Dec. 12	Dec. 26	Jan. 9	Jan. 23	Feb. 6	Feb. 20	Mar. 6	Mar. 20	Apr. 3	Apr. 17
Request for Proposal	Aug. 23	N/A																		
Team Interest Meeting	Aug. 28	1 Meeting																		
Discussion of the Proposal	Aug. 31	1 Meeting																		
Design Launch Vehicle and Payload	Sep. 5	1 Meeting																		
Write up Proposal	Sep. 7	1 Meeting																		
Revise Proposal	Sep. 11	2 Meetings																		
Design Subscale Launch Vehicle	Sep. 13	1 Meeting																		
Submit Proposal	Sep. 19	N/A																		
Proposal Submission Celebration	Sep. 20	1 Meeting																		
Supply Order	Sep. 21	1 Meeting																		
Begin Working on PDR	Sep. 24	2 Meetings																		
Payload Prototyping Begins	Sep. 25	4 Meetings																		
Create Subscale Rocket	Sep. 26	4 Meetings																		
Finish PDR Rough Draft	Oct 1	2 Meetings																		
Awarded Proposals Announced	Oct. 4	N/A																		
Work on Copprate Sponsorship Package	Oct. 3	3 Meeting																		
Payload Design Testing	Oct. 9	5 Meetings																		
Fall Break	Oct. 12 to Oct. 22	N/A																		
Do Ground Ejection Test for Subscale Rocket	Oct. 19	1 Meeting																		
Launch Subscale Rocket	Oct.20	1 Meeting																		
Revise Rough Draft	Oct. 24	2 Meetings																		
Plan out the flight tickets and hotel rooms	Nov. 1	5 Meetings																		
PDR (report, presentation, and flysheet) Due	Nov. 2	N/A																		
Submit Corporate Sponsorship Package	Nov. 9	1 Meeting																		
Finialize List of Potential Sponsors	Nov. 16	1 Meeting																		
PDR video teleconferences	Nov. 19	1 Meeting																		
Post PDR Review	Nov. 20	1 Meeting																		
Continue Payload Design	Nov. 22	2 Meetings																		
Finalize Launch Vechicle Full Scale Design	Nov. 23	1 Meeting																		
Finalize Payload Design	Nov. 26	1 Meeting																		
Send out Sponsership Letter	Nov. 26	1 Meeting																		
Prepair for Engament Event	Nov. 26	2 Meetings																		
CDR Q&A	Nov. 27	N/A																		
CDR Rough Draft	Nov. 29	3 Meeting																		
Begin Launch Vechicle Full Scale Build	Nov. 30	3 Meetings																		
Begin Payload Construction	Nov. 30	3 Meetings																		
Finalize CDR	Dec.7	2 Meetings																		
Winter Break	Dec. 15 to Jan. 8	N/A																		
Final Colection of Sponsership Money	Jan.1	N/A																		
CDR (report, presentation, and flysheet) Posted on Webs	Jan. 4	N/A																		
Prepair for Engament Event	Jan. 6	2 Meetings																		
CDR video teleconference	Jan. 7 to Jan.22	1 Meeting																		
Post CDR review	Jan. 23	1 Meeting																		
Finish Launch Vechicle Full Scale	Jan. 24	2 Meetings																		
Finish Payload	Jan. 24	2 Meetings																		
FRR Q&A	Jan. 25	N/A																		
FRR Rough Draft	Jan. 25	2 Meetings																		
Prepair For Engament Events	Jan. 28	2 Meetings																		
Robokids- Engagment Event	Feb. 7	1 Meeting																		
Book Hotel Rooms	Feb. 7	1 Meeting																		
Purchace Tickets	Feb. 15	1 Meeting																		
Engineering on the Go- Engagment Event	Feb. 18	1 Meeting																		
Introduce a Girl to Engineering- Engagment Event	Feb. 19	1 Meeting																		
Finalize FRR	Feb. 24	3 Meetings																		
Friendly House- Engagment Event	Feb. 26	1 Meeting																		
Spring Break	Mar. 2 to Mar. 10	N/A																		
Launch Vechicle Full Scale Launch	Mar. 3	1 Meeting																		
Full Scale ground ejection test	Mar. 3	1 Meeting																		
Vehicle Demonstration Flight Deadline	Mar. 4	N/A																		
FRR (report, presentation, and flysheet)	Mar. 4	N/A																		
FRR video teleconference	Mar. 8 to Mar. 21	1 Meeting																		
Prepare for Competition	Mar. 23	3 Meetings																		
Ship Parts to Huntsville Alabama	March 25	1 Meeting																		
Travels to Huntsville, AL	Apr. 3	N/A																		
Launch Readiness Reviews (LRR)	Apr. 3	N/A																		
Launch Day	Apr. 6	N/A																		
Award Ceremony	Apr. 6	N/A																		
Backup Launch Day	Apr. 7	N/A																		
Send Follow up to Sponsors	Apr. 15	N/A																		
Post-Launch Assessment Review (PLAR)	Apr. 26	N/A																		
End of the Year Celebration	Apr. 30	1 Meeting																		

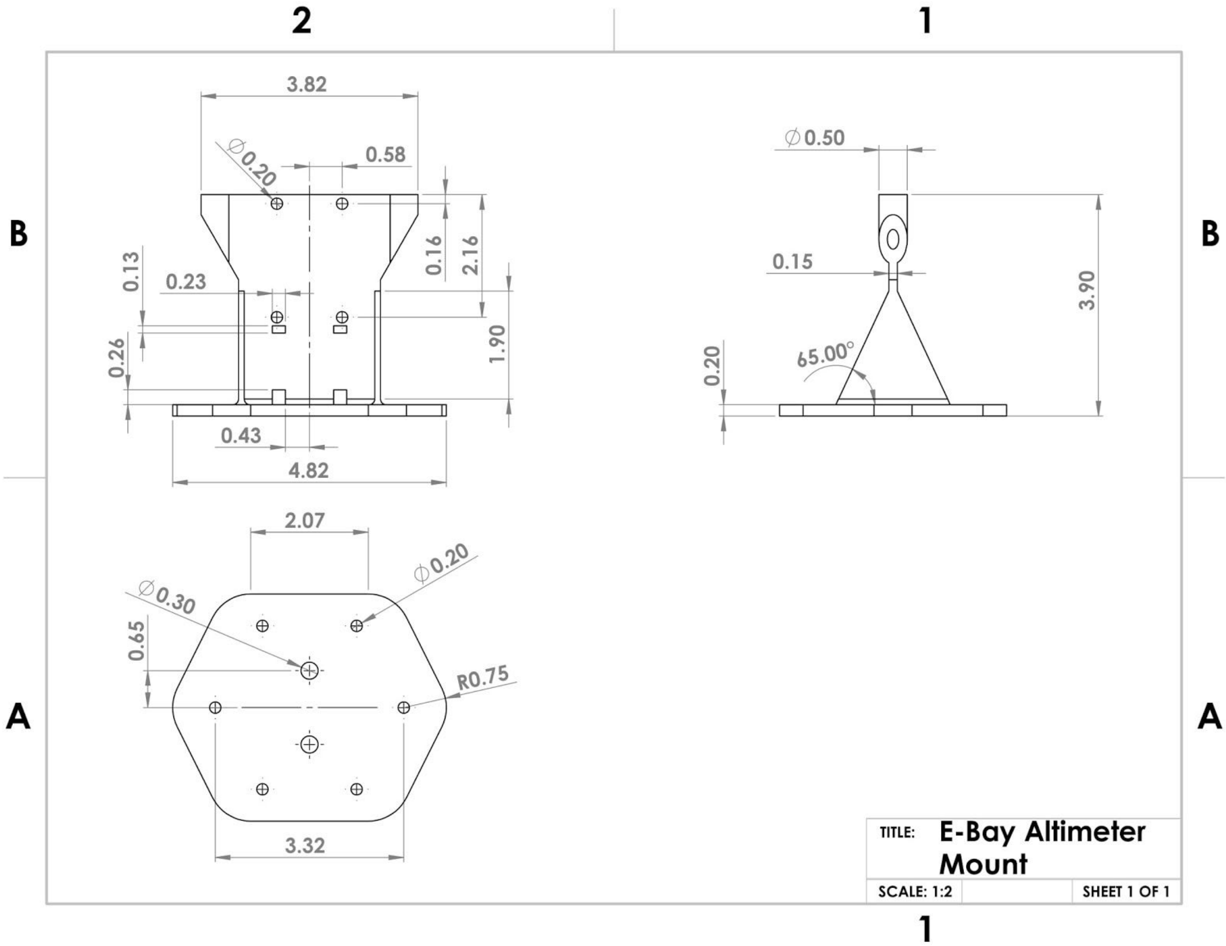
Due dates
Meetings
On Break

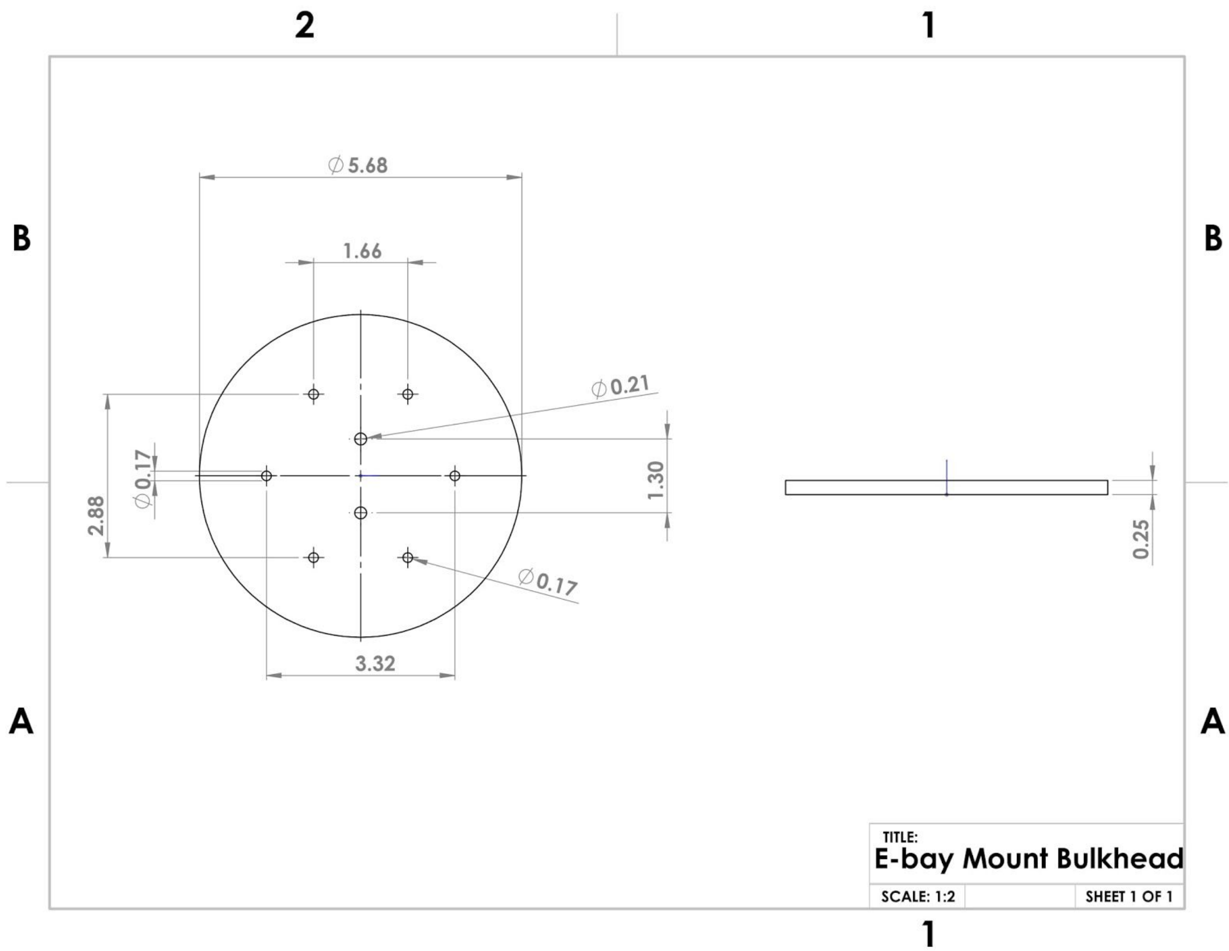
Appendix

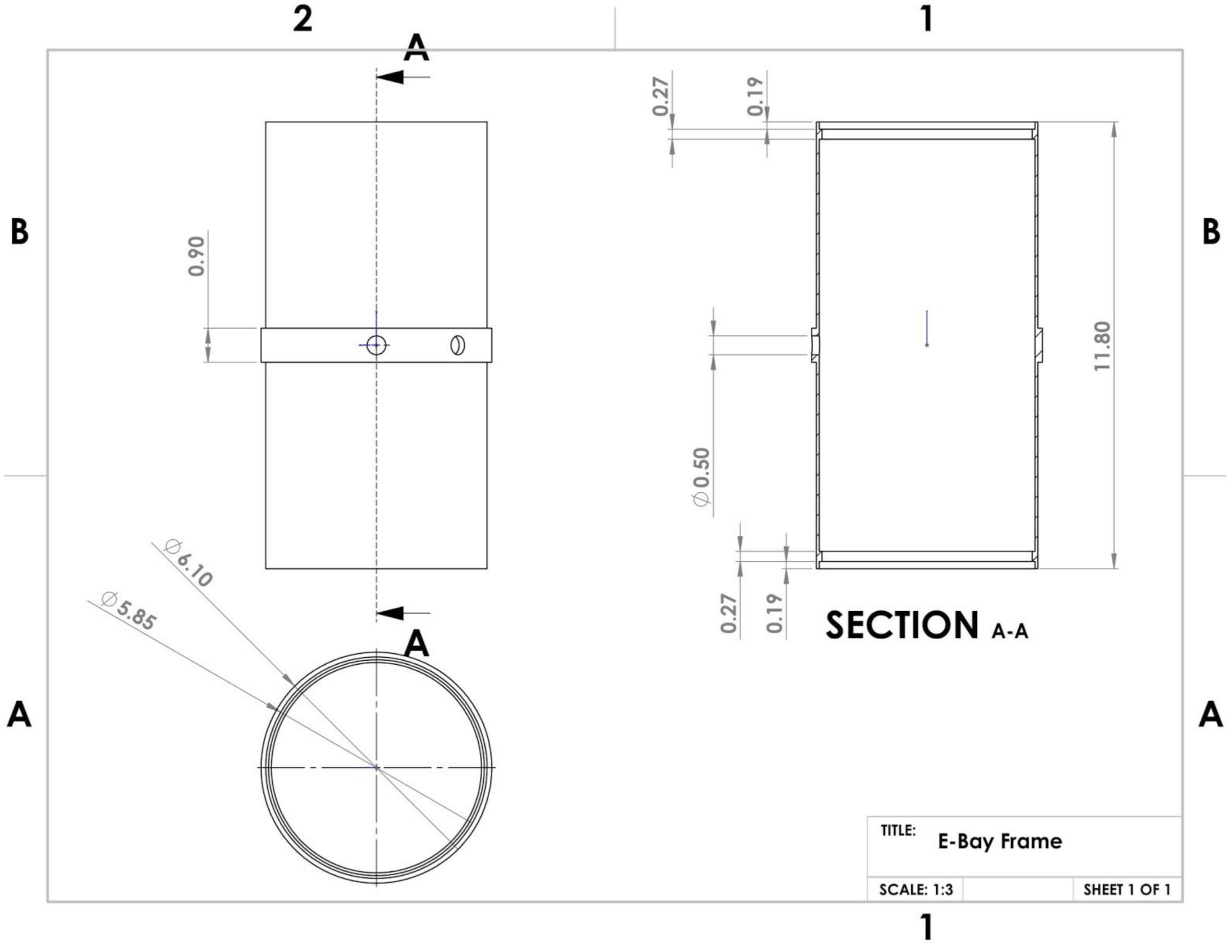
A.1. As Built Rocket Schematics

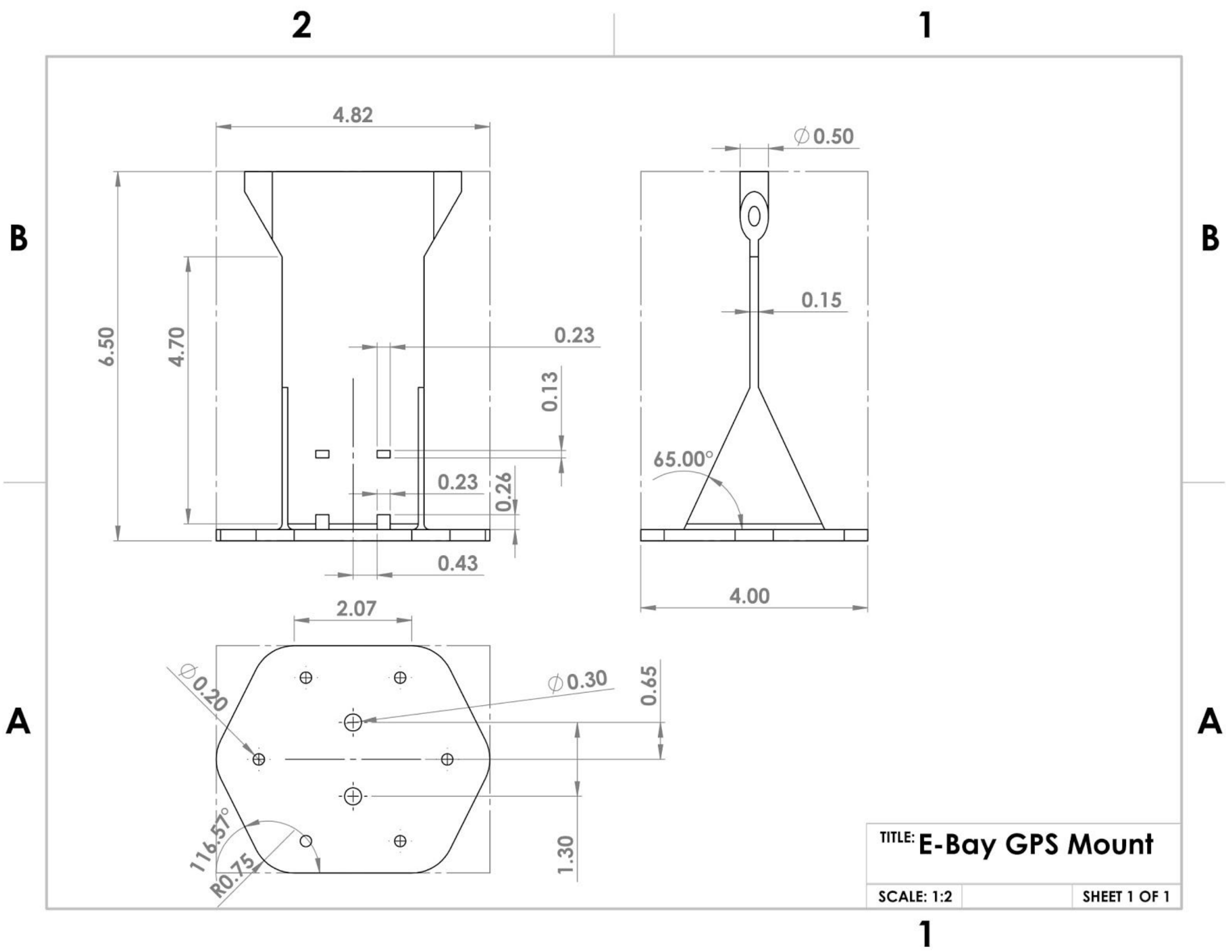


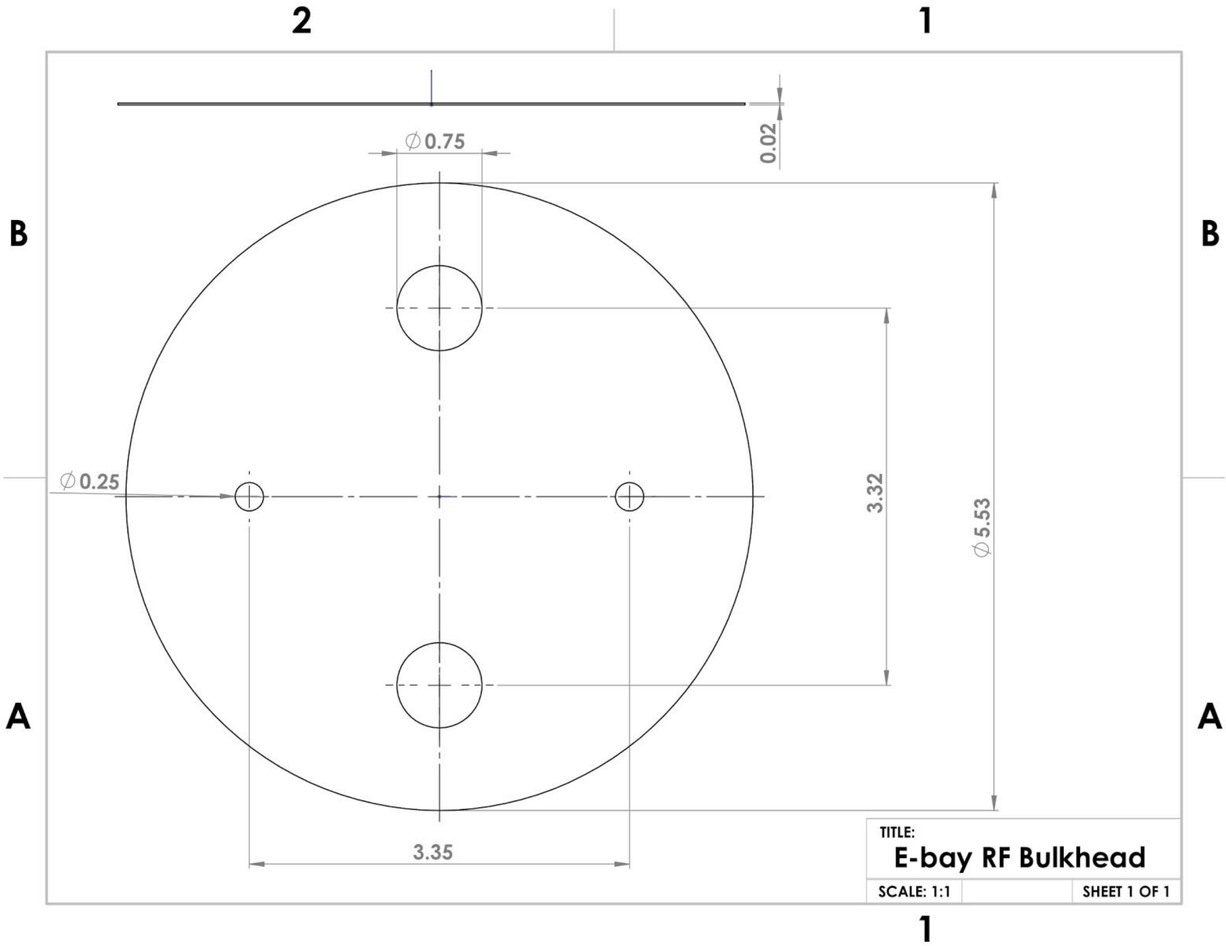

2
1
B
A
∅5.87
∅2.30
0.50
TITLE:
Centering Ring
SCALE: 1:2
SHEET 1 OF 1

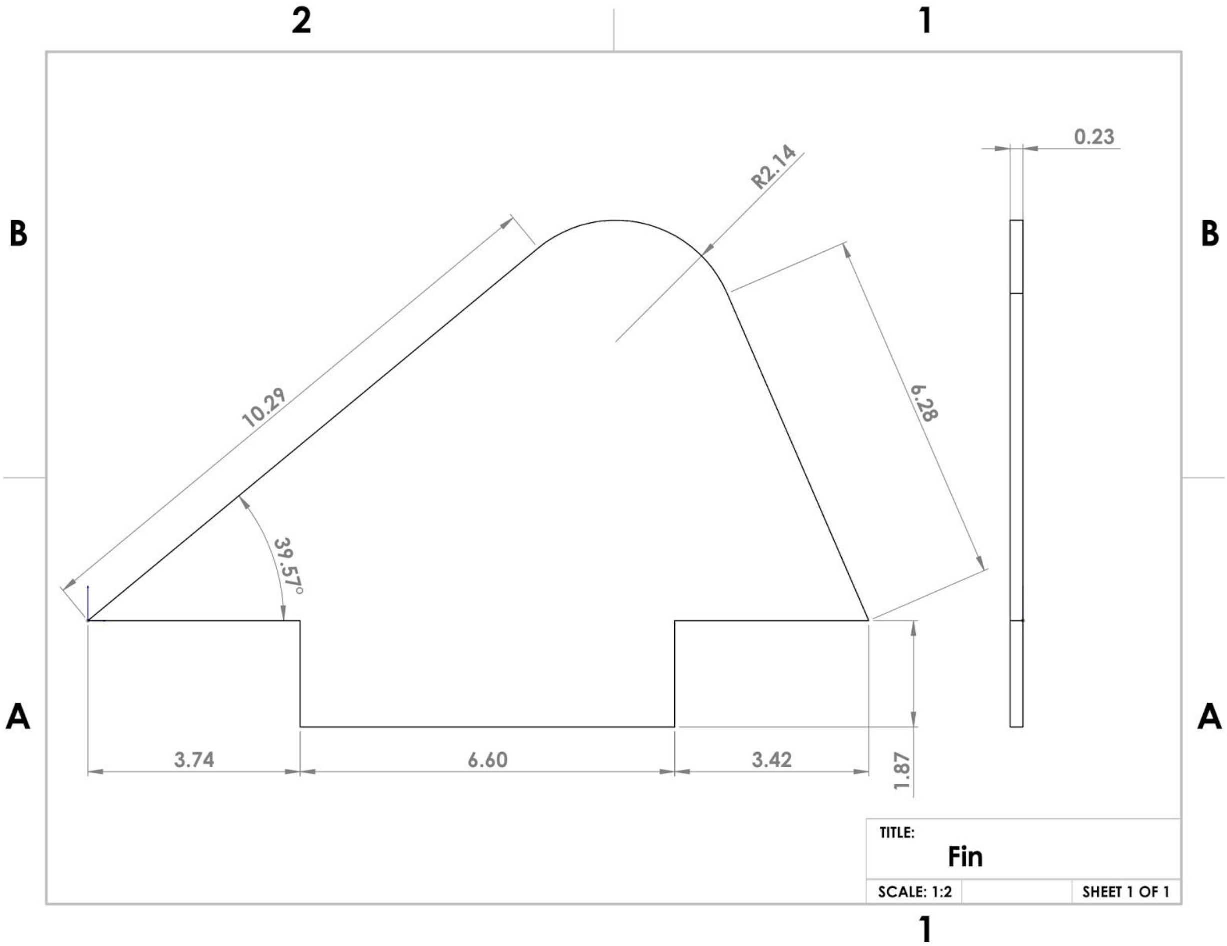

2
1
B
A
3.82
Ø0.20
0.58
0.16
2.16
0.13
0.23
1.90
0.26
0.43
4.82
Ø0.50
0.15
3.90
0.20
65.00°
2.07
Ø0.20
Ø0.30
0.65
R0.75
3.32
TITLE: E-Bay Altimeter Mount
SCALE: 1:2
SHEET 1 OF 1

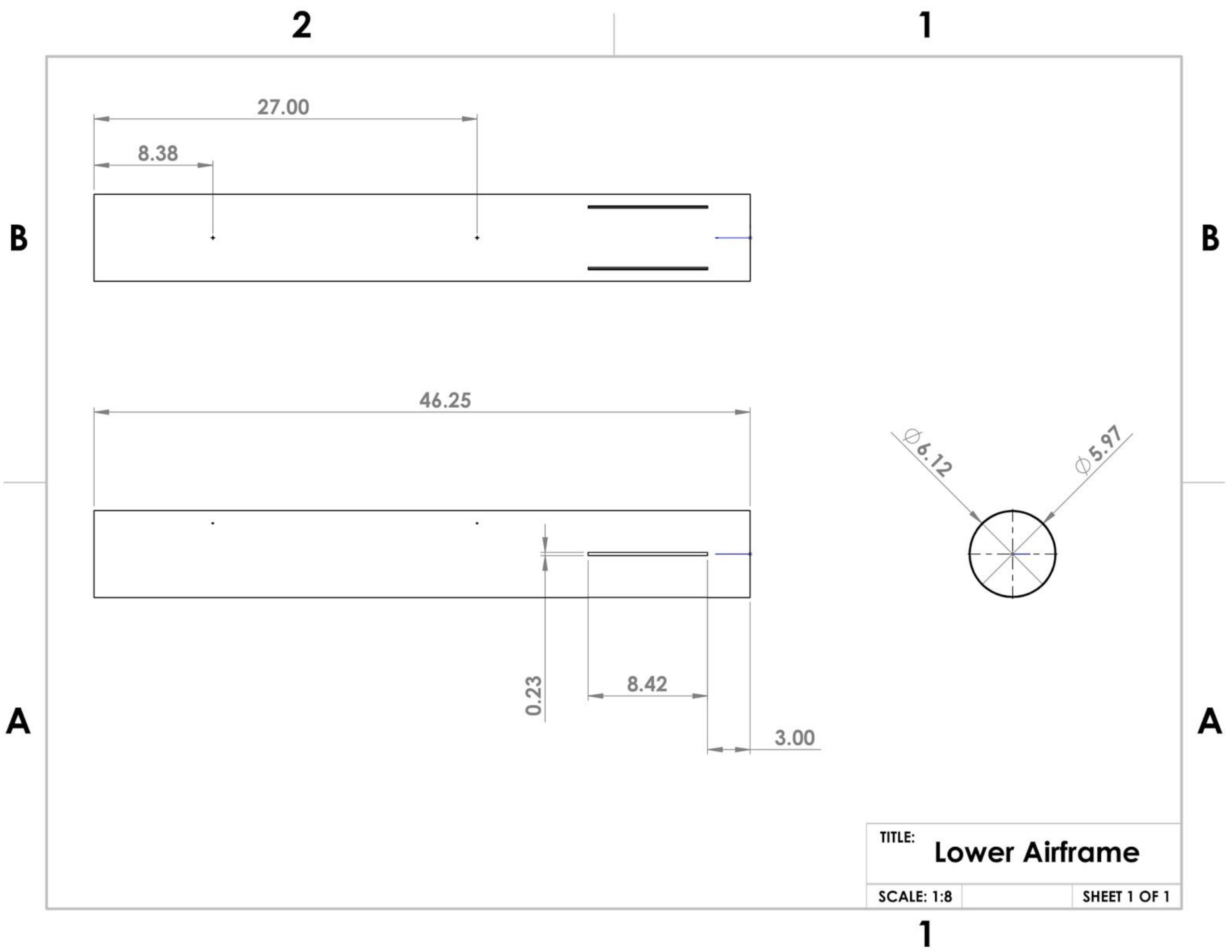

2
1
B
A
∅5.68
1.66
∅0.21
∅0.17
2.88
1.30
∅0.17
3.32
0.25
TITLE:
E-bay Mount Bulkhead
SCALE: 1:2
SHEET 1 OF 1

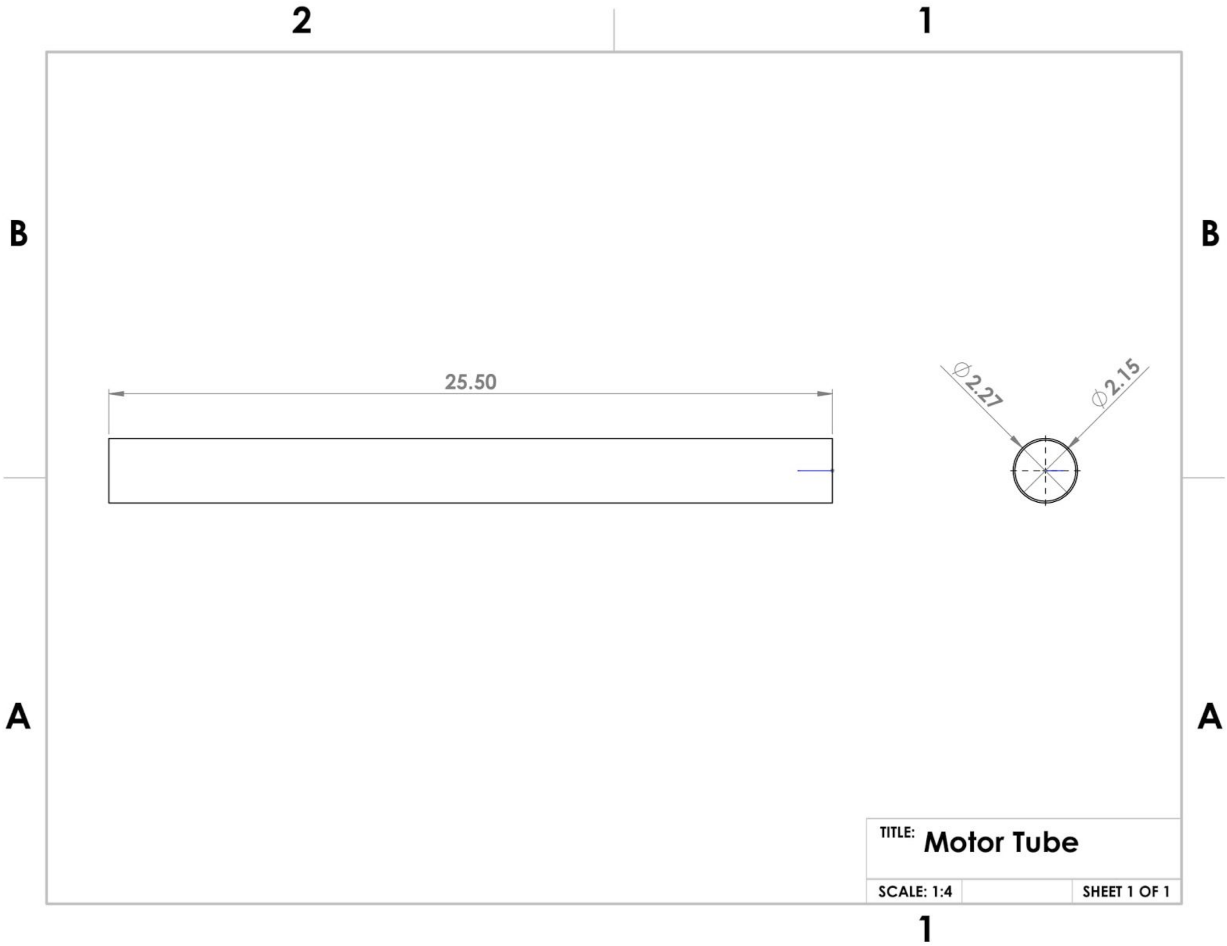

2
1
A
B
B
0.90
0.27
0.19
11.80
∅0.50
0.27
0.19
∅6.10
∅5.85
SECTION A-A
A
A
A
TITLE: E-Bay Frame
SCALE: 1:3
SHEET 1 OF 1
1

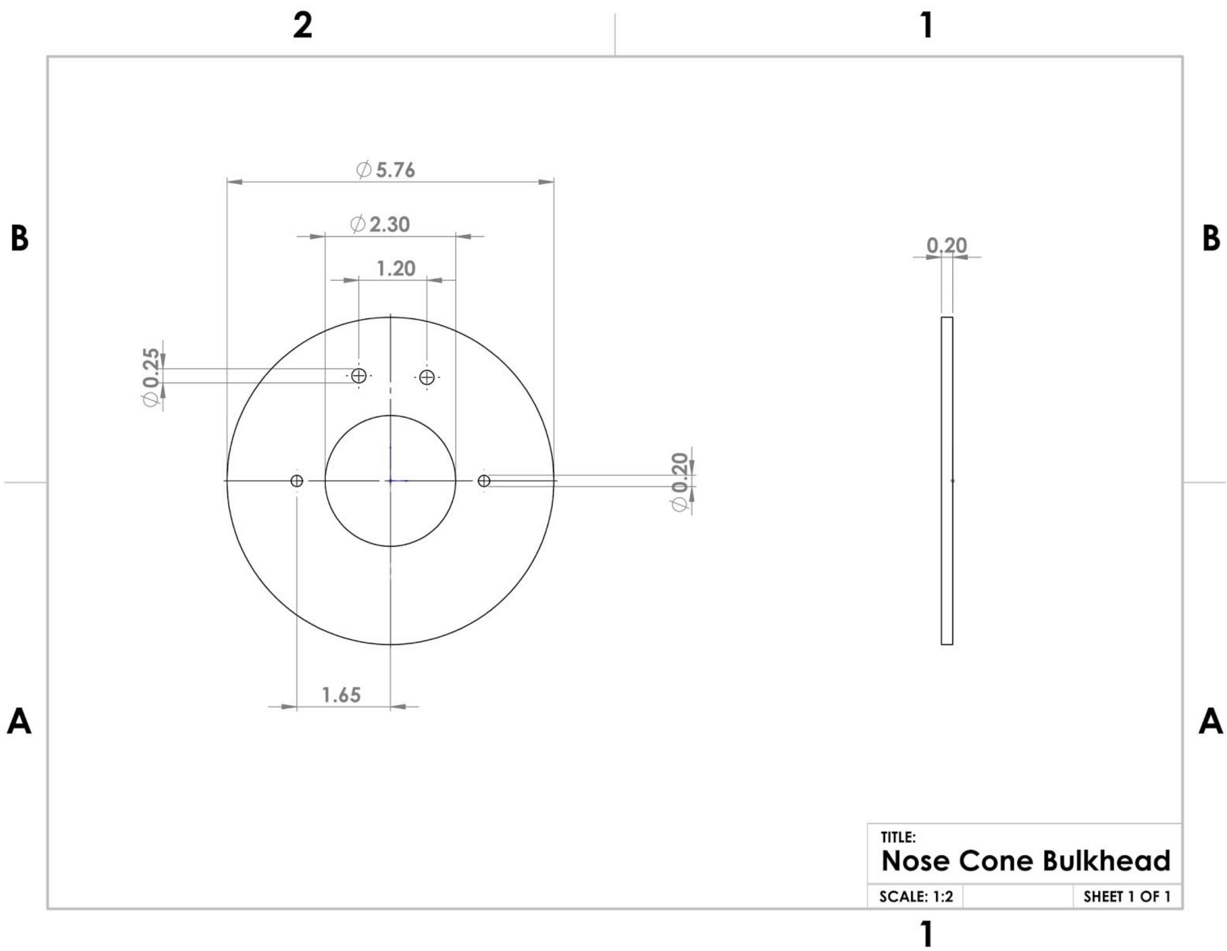

2
1
B
A
4.82
6.50
4.70
0.23
0.13
0.23
0.26
0.43
∅0.50
0.15
65.00°
4.00
2.07
∅0.20
∅0.30
0.65
1.30
116.57°
R0.75
TITLE: E-Bay GPS Mount
SCALE: 1:2
SHEET 1 OF 1

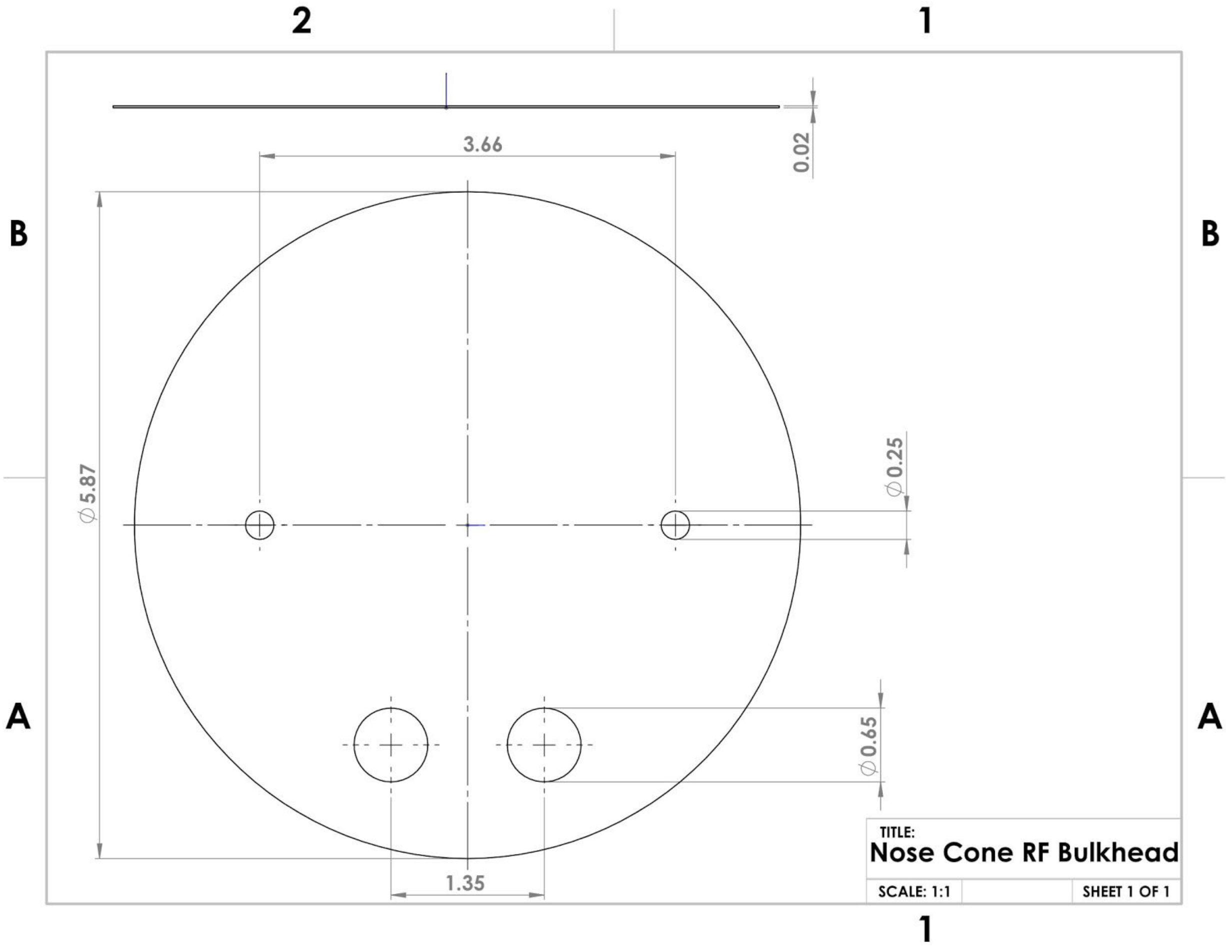

2
1
B
B
A
A
1
∅0.75
0.02
∅0.25
3.32
∅5.53
3.35
TITLE:
E-bay RF Bulkhead
SCALE: 1:1
SHEET 1 OF 1


2
1
B
A
0.23
R2.14
10.29
6.28
39.57°
3.74
6.60
3.42
1.87
TITLE:
Fin
SCALE: 1:2
SHEET 1 OF 1

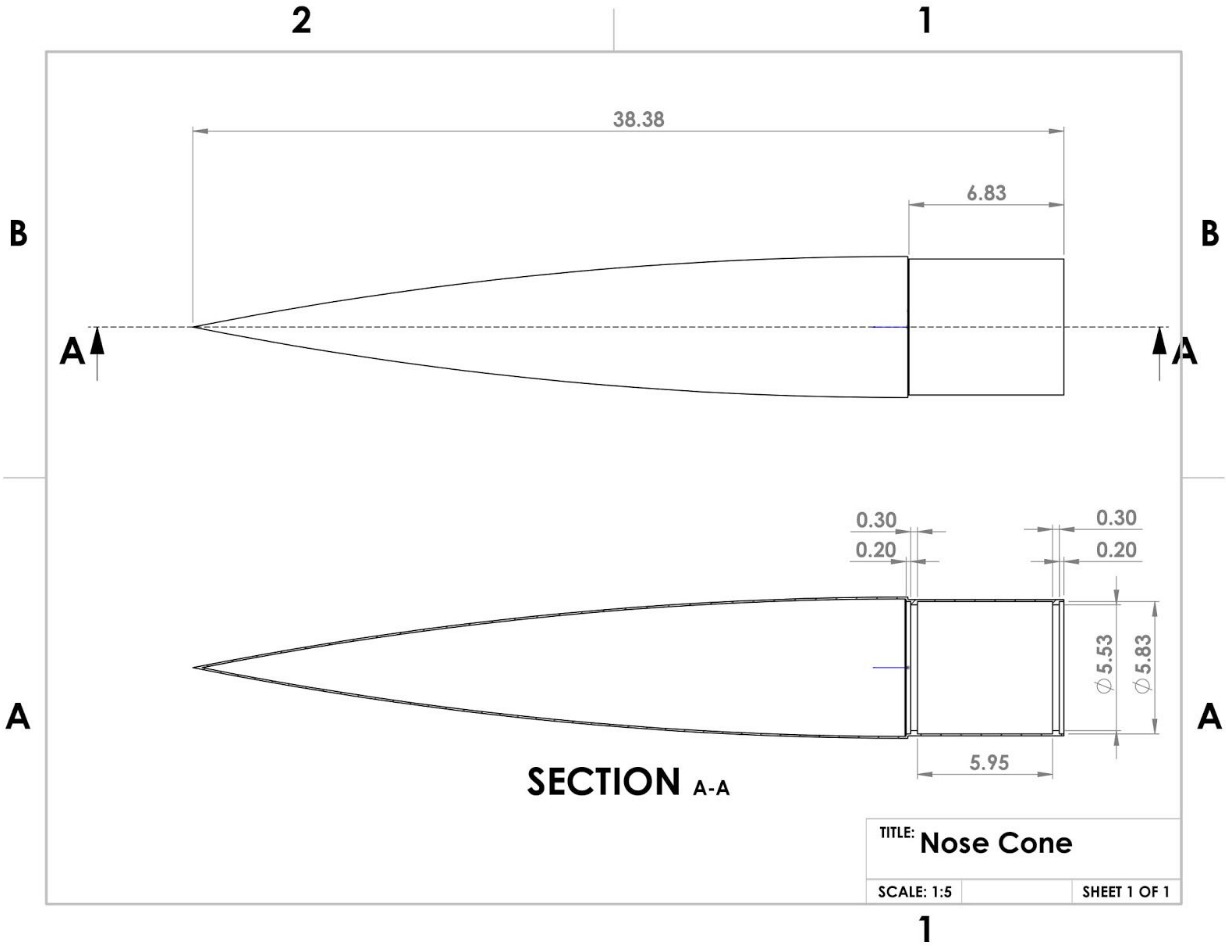

2
1
B
B
A
A
1
27.00
8.38
46.25
⌀6.12
⌀5.97
0.23
8.42
3.00
TITLE:
Lower Airframe
SCALE: 1:8
SHEET 1 OF 1

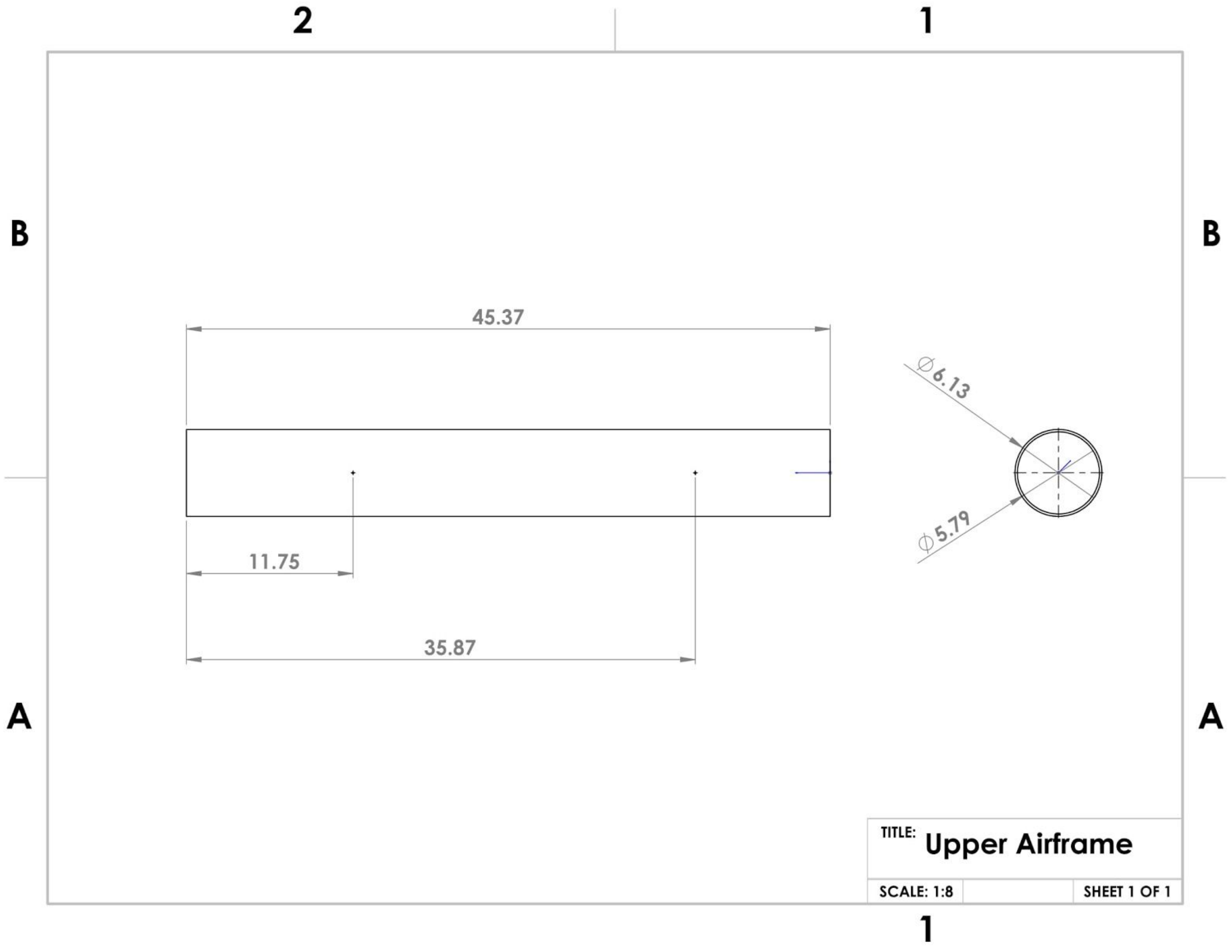

2
1
B
B
25.50
⌀2.27
⌀2.15
A
A
TITLE: Motor Tube
SCALE: 1:4
SHEET 1 OF 1
1


2
1
B
B
A
A
∅5.76
∅2.30
1.20
∅0.25
∅0.20
1.65
0.20
TITLE:
Nose Cone Bulkhead
SCALE: 1:2
SHEET 1 OF 1
1



2
1
B
A
3.66
0.02
∅0.25
∅5.87
∅0.65
1.35
TITLE:
Nose Cone RF Bulkhead
SCALE: 1:1
SHEET 1 OF 1


2
1
38.38
6.83
B
B
A
A
0.30
0.20
0.30
0.20
Ø 5.53
Ø 5.83
A
A
5.95
SECTION A-A
TITLE: Nose Cone
SCALE: 1:5
SHEET 1 OF 1
1


2
1
B
B
A
A
45.37
⌀6.13
⌀5.79
11.75
35.87
TITLE: Upper Airframe
SCALE: 1:8
SHEET 1 OF 1
1