University of Central Florida – 2023 – CDR – Report

4000 Central Florida Blvd, Orlando, FL 32816

Knights of Experimental Rocketry

10/28/2023

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1 Summary

1.1 Team Summary

Team name: Knights Experimental Rocketry

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NAR Number: #21735

Certification Level: 3

Hours Spend: 260

Social Media:

Instagram @ucf_rocketry

Twitter: @KnightsRocketry

YouTube: Knights Experimental Rocketry

Travel Plans:

We plan on driving out to Huntsville Alabama on April 12 to compete on the 15th at Braggs Farm.

1.2 Launch Vehicle Summary

Vehicle Name	Asclepius
Target Altitude	5507’
Motor Selection	Aerotech Rocketry K1000T-P
Vehicle Predicted Mass	22.558 lbs
Vehicle Outer Diameter	5.1”
Vehicle Length	87”
Vehicle Independent Sections	4
Vehicle Recovery System	Dual Deployment: Apogee and 600’

1.2.1 Target Altitude

As discussed in PDR, our target altitude is 5570'. We determined that altitude by using OpenRocket and doing many different simulations for apogee with varying different launch angles and wind speeds and we took the mean. We used the mean because we feel that gives us the best chance of hitting our altitude because the mean can account for varying conditions and gives us some leeway.

1.2.2 Final Motor Choice

For our final motor choice, we decided to go with an Aerotech K1000T. In-depth analysis and justification for this motor choice is provided in section 3.4.3.

Aerotech Rocketry K1000T	
Total Impulse	25111.5 Ns
Max Thrust	376.33 lbs
Burn Time	2.4 s
Propellant	Blue Thunder

1.2.3 Size and Mass of Launch Vehicle

Asclepius	
Expected Mass	22.558 lbs
Length	87in
Outer Diameter	5.1in
Rail size	1515 144in

1.2.4 Recovery System

Our recovery team has focused their efforts towards achieving a fast descent time and safe impact velocity. To achieve both the needed requirements and the bonus objectives for the competition, we have chosen a dual deploy mechanism that uses a 1' drogue parachute and an 8' main parachute to allow for a faster descent while also safely recovering the rocket. The 1' drogue will be deployed at apogee with a redundant charge going off 1 second after apogee and the main parachute will be deployed at 49 seconds after apogee with redundant floating charges to ensure deployment. The drogue is so small for the sole of purpose of receiving the extra bonus points on section 3.11. Furthermore, whilst this would suggest larger snatch forces – which is true – the use of aluminum, black oxide steel, and shaft guards make it so we need not worry about any bulkheads tearing.

1.3 Payload Summary

The payload system's main goal is to achieve the experiments deliverables described by the NASA 2023 Handbook. That being landing a payload capable of self-orienting parallel to the horizon and taking imagery as denoted by a series of RAFCO. The payload system is also in charge of other self-imposed requirements. Disregarding the primary experiment, the payload system is also planning to launch a camera system that could possibly be adapted for live video. Additionally, the payload system is designing its own custom flight computer and PCB, housed in the nose cone; this custom flight computer would also be streaming live telemetry which will be reflected in a student-made ground station.

1.3.1 Primary Payload

The primary payload is a self-orienting camera system designed to meet NASA's experiments deliverables. This payload - dubbed the P.I.L.L. (Payload Integrated Launch Log) - is a 3D-printed assembly comprised of three cylindrical sections. One of the outer sections contains important electronics, while the other is solely for structural support. The center section contains a wide-angle camera attached to a linear elevator mechanism. The center and outer sections are connected via a bearing interface, allowing them to spin independently. Due to the weight distribution of the internal components of the PILL, the center section is always aligned by gravity, keeping the camera level with the horizon. The PILL is attached adjacent to the shock cord, allowing it to exit the rocket behind the main parachute. Upon landing, the PILL self-orients to keep the camera upright then raises the camera out of the center section using the linear elevator mechanism. The PILL can then receive radio commands from NASA and execute all possible commands, including rotating the camera 360 degrees with a servo motor and using OpenCV on a Raspberry Pi to record and manipulate images.

1.3.2 Secondary Payload

The secondary payload is a Run Cam Split, a COTS camera that can function independent of all avionics and need only an SD card and battery source to record video. The secondary payload, however, may also be replaced with an ESP32 Cam which would allow for live video streaming for furthering the teams STEM Engagement initiative - whilst not inherently required, the idea would be useful for member enrichment, as well as garnering interest in student led rocketry. The location of the secondary payload remains in the one-inch band of the Von Karman nose cone; however, it will now draw power from the same LiPO batteries powering the custom flight computer.

2 Changes Made Since PDR

2.1 Changes Made to Vehicle Criteria

2.1.1 Vehicle

There have been a few changes from PDR to the vehicle. We changed the thickness of the tubes from .1 inch to .060 inches due to Ansys analysis on prepreg. We decided to change the thickness because with our analysis we save we are able to save weight and still have a safety factor on our tubes that is acceptable. We also decided to go with a commercial coupler instead of manufacturing our own coupler. We made this decision because if we built our own coupler, it would be difficult to get the tolerances required and it would end up costing more because we would need to buy another metal mandrel in order to build the coupler. We also changed from carbon fiber coupler to a fiberglass coupler because it was easier and cheaper to buy a fiberglass coupler that matched our dimensions.

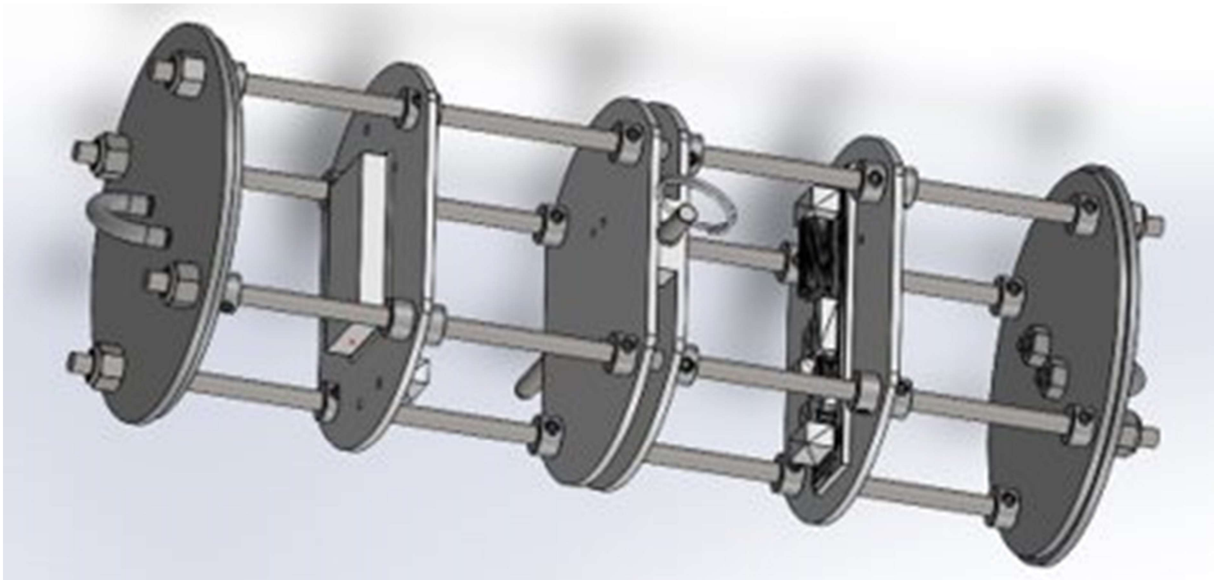
2.1.2 Recovery

Design changes for recovery have been minimal since PDR. The choice of altimeters, bolts, fasteners, and materials has stayed largely the same. Discourse has been held over the use of threaded rods, or flush aluminum rods. As in PDR, we've opted to only thread the ends of aluminum rods for ease of use. That said, since the center is not threaded, we have the choice of shaft guards or collars; thus, the only change has been the mounting system.

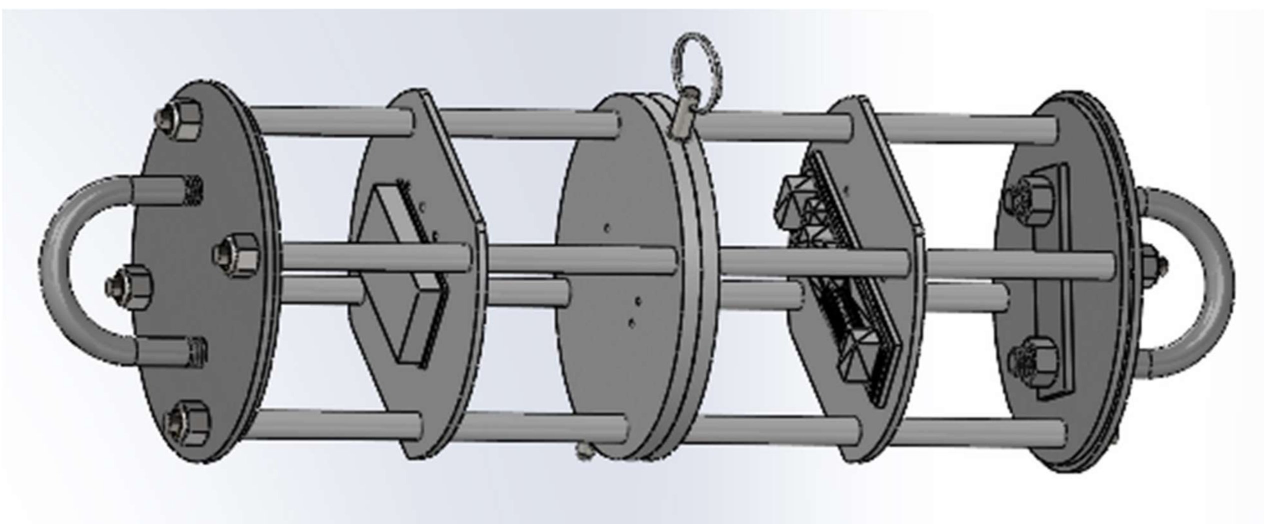
2.1.2.1 Mounting System for Plates

Shaft guards were used to replace shaft collars for the purpose of efficiency and for a reduced cost. Since the shaft collars needed to be evenly spaced throughout the recovery design, manufacturing the recovery would take far more precision as we would need to screw all 32 of the shaft collars evenly and would take time out of our manufacturing period. With the shaft guards, the recovery system will be easy to manufacture as no screws are needed to hold them in place as they will be compressed in the system. The cost of using the shaft guards is $2.65 while the cost of using shaft collars is $109.76 – unless we were to manufacture our own in the UCF machine shop. This is a huge decrease in cost and will allow us to use the money elsewhere for this project. The idea for the shaft guards came about in discussion when the concept of ¼" ID PVC pipe could be used to compress the plates between the bulkheads extremely cheaply. Resources online as well as recovery tests suggest the idea is viable. Further testing will be conducted, but currently, shaft guards will be used for the sake of cost-efficiency.

Shaft Collars



Shaft Guards

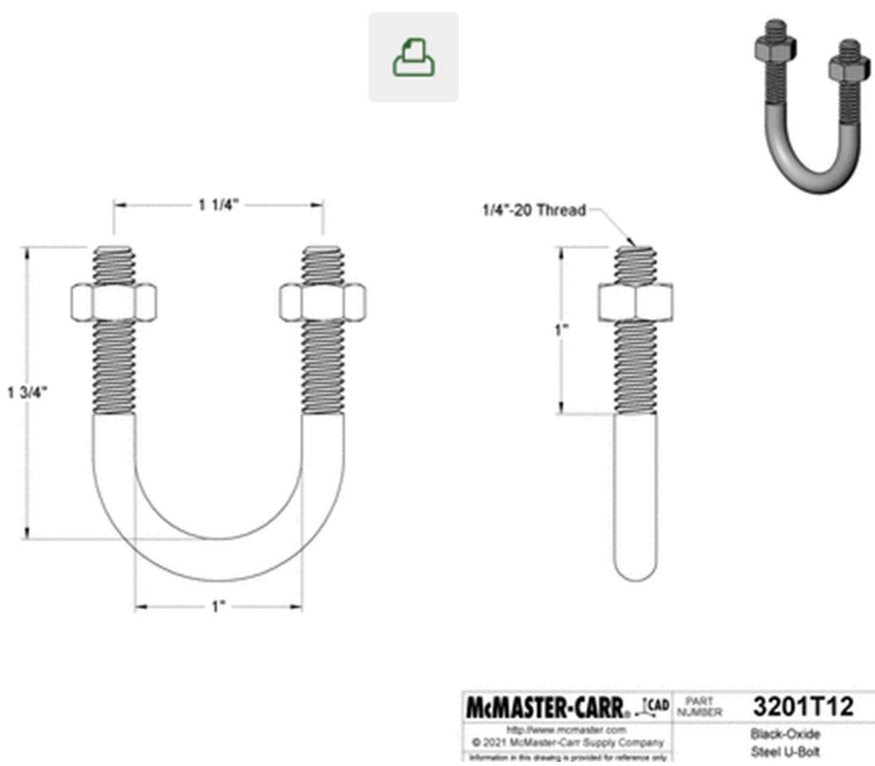


It is worth noting that shaft guards would inherently weigh more than shaft collars. However, since the guards would be made out of PVC, the difference would be minimal, and in fact favorable, as we've greatly underestimated the weight of our components to make sure we can adjust for our specific apogee later.

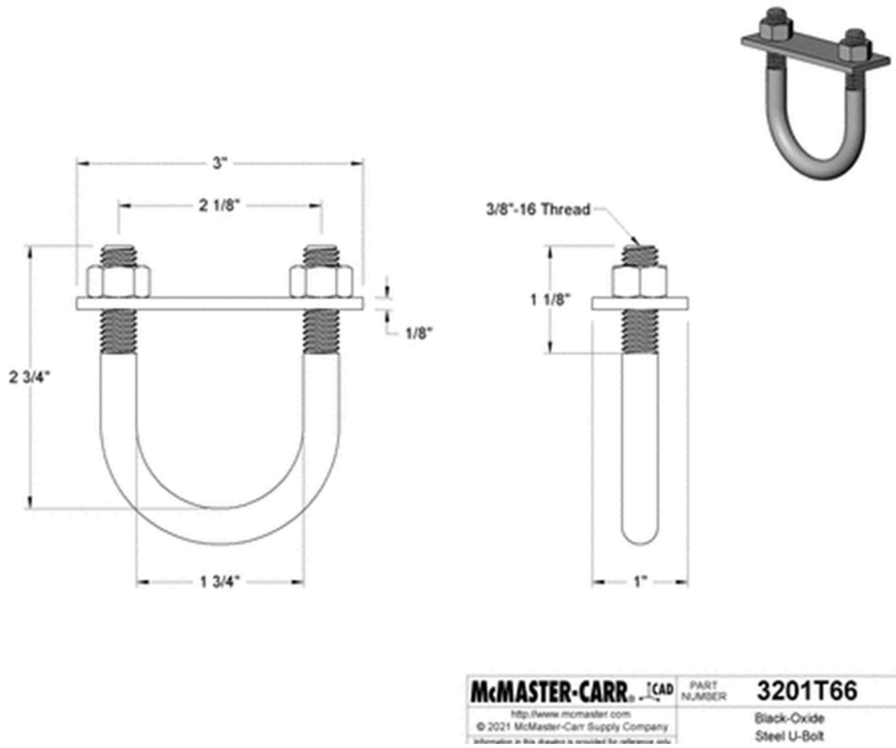
		RATINGS	
Criterion	Weight	Shaft Collars	Shaft Guards
Stability	5	3	5
Manufacturability	4	5	5
Disassembility	1	1	4
Protection	1	1	1
Cost	4	1	5
Total		41	70

2.1.2.2 U-bolt

The preliminary design U-bolt diameter was below safety standards. To counteract this, we decided to pick a different U-bolt. Our original U-bolt had a ¼"diameter whilst our new U-bolt's has a diameter of 3/8". The new U-bolts ratings exceed the estimated max snatch force of 718lbf. The original U-bolt was rated for only 425 lbf; however, the new U-bolt is rated for 1,075 lbf. resulting in a safety factor of approximately 1.5 – this is assuming the max snatch force however, so it can be argued the safety factor is higher.



Original U-bolt



Updated U-bolt

		RATINGS	
Criterion	**Weight**	**3/8" U-Bolt**	**1/4" U-Bolt**
Strength	4	4	3
Cost	3	3	3
Safe	5	5	1
Stability	3	5	3
Reliability	5	4	2
Total		**85**	**45**

2.1.2.3 Coupler Material

The coupler material in the preliminary design was carbon fiber. After discussion with our team, we had decided to challenge that idea. We had fiberglass readily available which would provide the team with more money for other parts of the project. Another concern that arose was safety concerns with manufacturing carbon fiber. A lot of preparation would have to be made before the manufacturing process was to begin, which would take up a lot of manufacturing. All dimensions of the coupler remain the same.

		RATINGS	
Criterion	**Weight**	**Fiberglass**	**Carbon fiber**
Cost	5	5	2
Weight	4	4	5
Stability	4	5	5
Reliability	3	5	5
Manufacturing Ease	3	4	1
Total		88	68

2.2 Changes Made to Payload Criteria

In order to maximize the points we may receive, we've opted to keep the same general concept of a self-orienting rolling cage, custom flight computer, and secondary experiment restricted to the nose cone's one inch band. That being said, changes to most aspects of the payloads system have stayed largely the same. With that in mind, the PILL has given up an access of orientation to solve the issues of height and distortion, while the flight computer has changed the components as the original design was already completed and viewed as limited.

2.2.1 Primary Payload

The original primary payload design (PILL v1) utilized a self-orienting camera system contained entirely within an outer polycarbonate tube. The camera and all electronics were held on a 3D-printed sled which would rotate within the outer tube. The outer tube was transparent, allowing light transmissibility for the camera. Nylon shock absorbers were placed on the outside of the PILL v1 to lessen the impact of landing. Several issues were identified with the PILL v1 design.

(1) Distortion caused by polycarbonate – refraction index of 1.59,
(2) Visibility concerns with the shock absorbers
(3) Height limitations,
(4) Manufacturing difficulties

The new payload design (PILL v2) solves these problems by adding a linear elevator mechanism that lifts the camera outside the PILL housing through a hatch. Moving the camera outside the PILL eliminates all distortion concerns and adds additional height to avoid any tall grass. This also removes the need for the outer housing to be transparent: meaning the outer housing need only be RF transparent, so other plastics, fiberglass, and 3D printing can now be considered. The exterior of the PILL v2 will be coated in an impact and heat resistant rayon or fiberglass reinforced epoxy, eliminating the need for shock absorbers – this is being in conjunction with UCF's research pavilion nanotechnology lab. The PILL v2 housing will be entirely 3D-printed, greatly simplifying the manufacturing process; polycarbonate filament will likely be used, however, since there will be visible threads, we originally couldn't use this method as there would be far too much distortion, however, that is no longer a concern. To align the linear elevator mechanism with the hatch, the PILL v2 is divided into three sections connected by ball bearings, allowing the center section to self-orient with gravity; it is worth noting that we do lose an access of orientation with this design, but the benefits of fixing height, manufacturability, and distortion was deemed more important – given the terrain as well, it is unlikely the PILL does not land parallel along the y-axis regardless. The new electronics sled spans the entire length of the PILL and is tied to the center section. The design changes made to the primary payload solve multiple issues and allow for a far simpler design.

		RATINGS	
Criterion	**Weight**	**PILL V2**	**PILL V1**
Manufacturability	5	5	3
Distortion	3	3	2
Height	5	5	3
Self-Orientation	4	2	4
Total		**67**	**52**

2.2.2 Secondary Payload

The secondary payload still consists of a Run Cam Split, the purpose of said secondary payload being to record promotional material for STEM Engagement. With that in mind, the simplicity of the design means there have been no changes since PDR. Regardless, changes can still be made as this payload exists outside of the expectation of the NASA 2023 Handbook. However, the system will be the same in concept as to avoid any "major changes." The location of the secondary payload will always remain in the one-inch band of the Von Karman Nose Cone. The only plausible change is the choice of camera; the alternative – which remains in debate – is an ESP32 Cam, which combined with a Lora radio module, could provide live video streaming – this would mean another radio band being used, which could cause conflicts on launch day.

		RATINGS	
Criterion	**Weight**	**Run Cam Split**	**ESP32 Cam**
Cost	5	5	2
Simplicity	3	5	2
Live Video	2	2	5
Total		**44**	**26**

2.3 Project Plan Modifications

2.3.1 Funding plans

Our USLI team was previously under the impression we would receive funds from The Florida Grant Consortium, however, as of January 8th we have yet to hear a concrete answer. Thus, we are under the assumption we will not be receiving their funds. To compensate for our losses, we will be utilizing liquid funds from our sponsorship from Blue Origin ($3000) as well as funds from the Daytona 500 ($2000-$6000). Blue Origin alone compensates for the FSGC if need me, and the Daytona 500 allows us more leeway.

2.3.2 Manufacturing timeline

Due to the launch dates available to us at the local Palm Bay launch site, we must have our vehicle demonstration flight take place on February 18th, to allow for the completion of FRR. Thus, vehicle design must now be done with manufacturing before February 18th. Similarly, our payload demonstration flight will be March 18th, meaning our Payload will also have to be done before March 18th.

3 Vehicle Criteria

3.1 Design and Verification of Launch Vehicle

3.1.1 Mission Statement and Mission Success Criteria

The vehicle's primary purpose is to safely deliver the payload to the ground after reaching an altitude of 5507 feet. For the mission to be consider a success the launch vehicle will perform a stable accent, reaches 5507 feet, main and drogue deploys at designated heights, payload safely reaches the ground, and the launch vehicle recovers in a state of flight ready condition with no significant damage.

3.1.2 Vehicle Design

3.1.2.1 Chosen Design from PDR

The design we chose to go with is a 5 inch inner diameter rocket. The vehicle features a Von Karman nose cone shape, which protects our telemetry and our live video camera. The length of the rocket will be 87 inches. The length is made up of a nose cone that is 16 inches long, 35 inch long upper airframe, 2 inch long switch band on the coupler, 30 inch long lower airframe, and a tailcone that is 4 inches long. The vehicle will use 4 trapezoidal fins, with a root cord of 7 inches, a height of 5.5 inches, a tip cord of 3 inches, and a sweep length of 5 inches. The expected mass of the final launch vehicle is 22.558 lbm.

3.1.2.1.1 Nose Cone

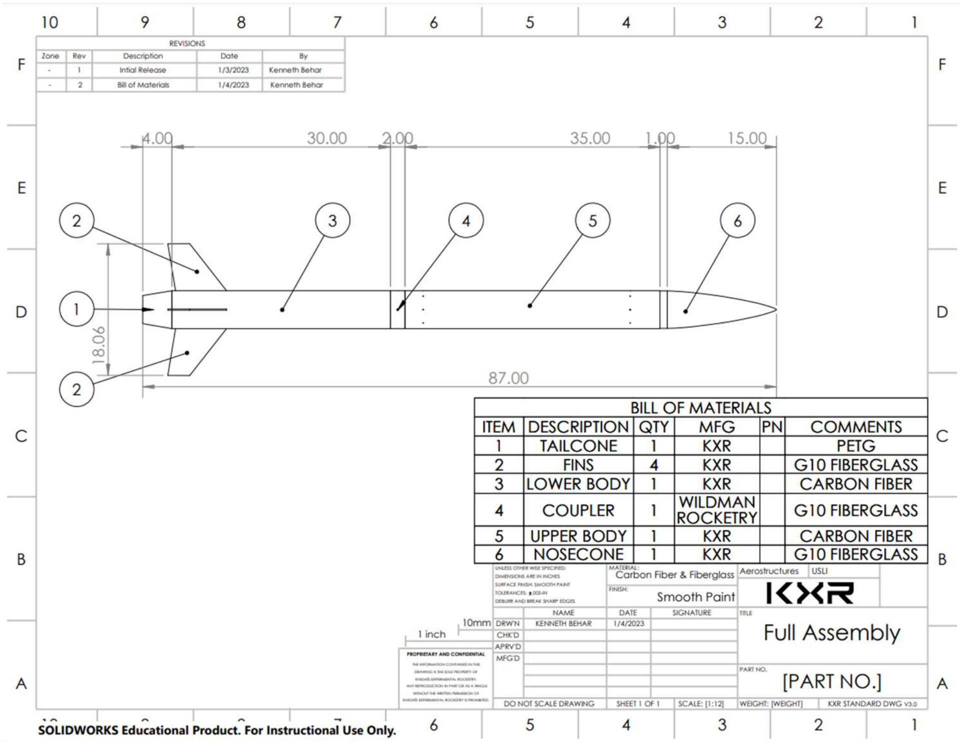
The nosecone design we have chosen is an uncapped fiberglass Von Karman nosecone with an aluminum nosecone tip. We have chosen a Von Karman nosecone due to it being one of the most aerodynamic design concepts with also having a sizable amount of usable volume for our telemetry sleds. Due to how laying fiberglass into a female mold, we cannot guarantee having a tip that is within spec. This can be resolved by machining a steel tip that will be threaded into the tip of the uncapped nosecone. The length of this nosecone will be 15 inches and will have a base outer diameter of 5.1 inches and base inner diameter of 5 inches. The nosecone tip will be blunted as that is best for flying at subsonic speeds. The length of the nosecone tip will be 2.5 inches long, with a shoulder 1.41 inches in diameter and 0.5 inches long. The base of the tip above the shoulder has an outer diameter of 1.52 inches and an inner diameter of 1.41 inches.

3.1.2.1.2 Airframe Material

The primary material we will use for the airframe will be carbon fiber. Both the upper and lower body tubes will be carbon fiber due to its high strength-to-weight ratio compared to fiberglass, previous experience with carbon fiber, and not having a need for radio transparency beyond the nosecone. The coupler will fiberglass. The upper body tube will have a length of 35 inches, and the lower body tube will have a length of 30 inches. Both will have an outer diameter of 5.1 inches and an inner diameter of 5 inches. The coupler will be 12 inches long and have an outer diameter of 5 inches.

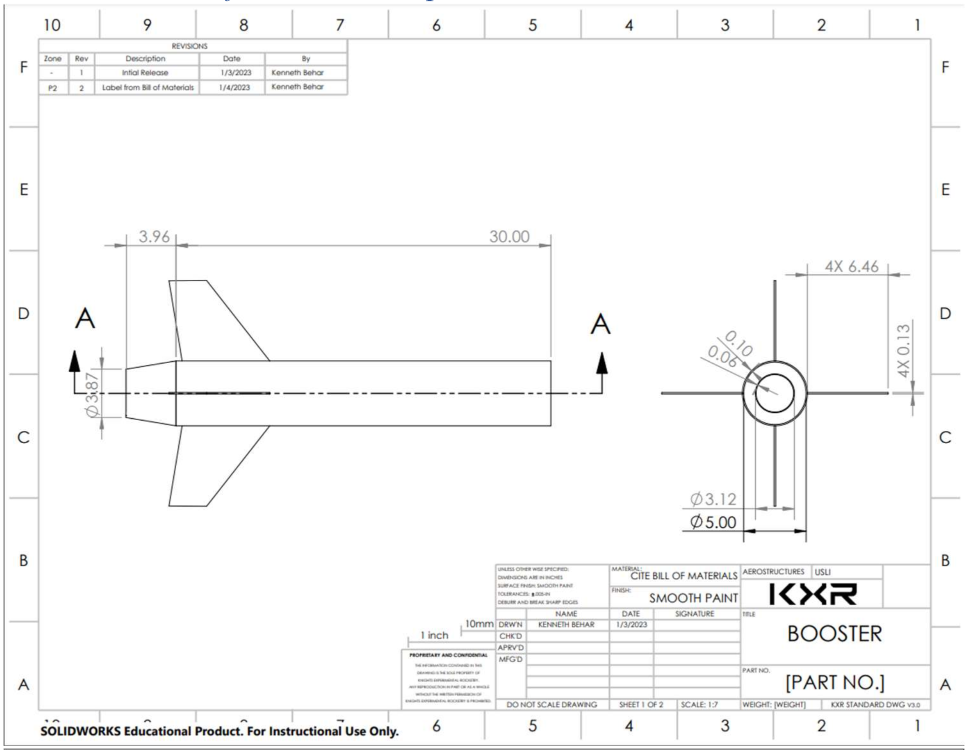
3.1.3 Dimensional Drawings

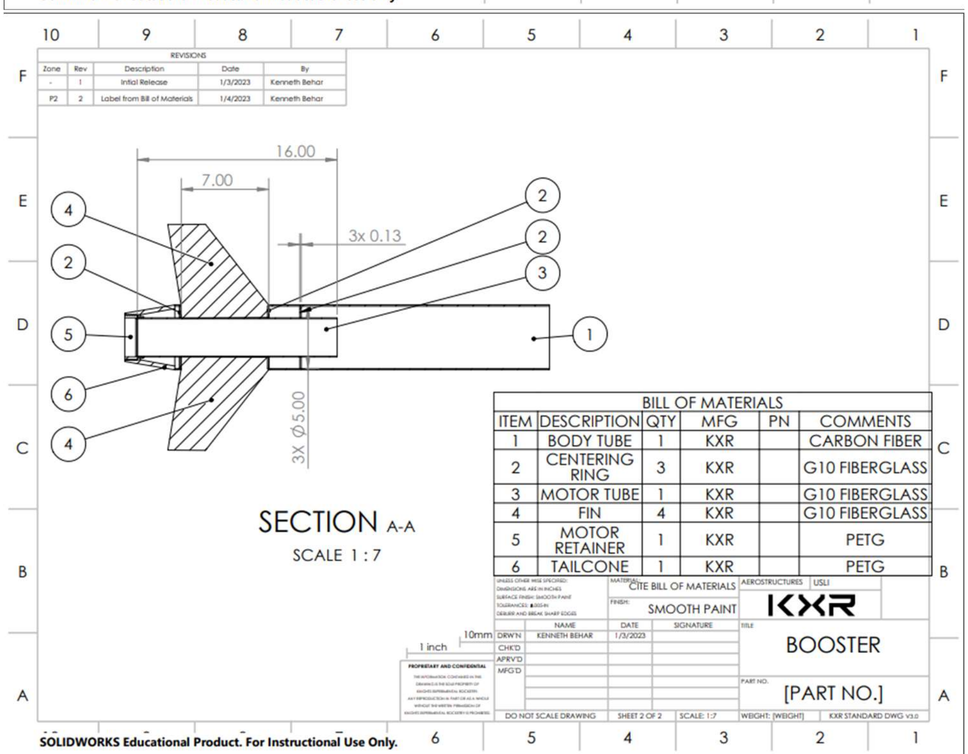
3.1.3.1 Assembled Launch Vehicle



The full assembly shown is primarily made of carbon fiber and G10 fiberglass. There are three primary sections: the lower body, upper body, and nosecone. The lower body and upper body are connected by a G10 fiberglass coupler. The lower body has connections for four fiberglass fins and a PETG 3D printed tailcone. This drawing only shows external components and their dimensions.

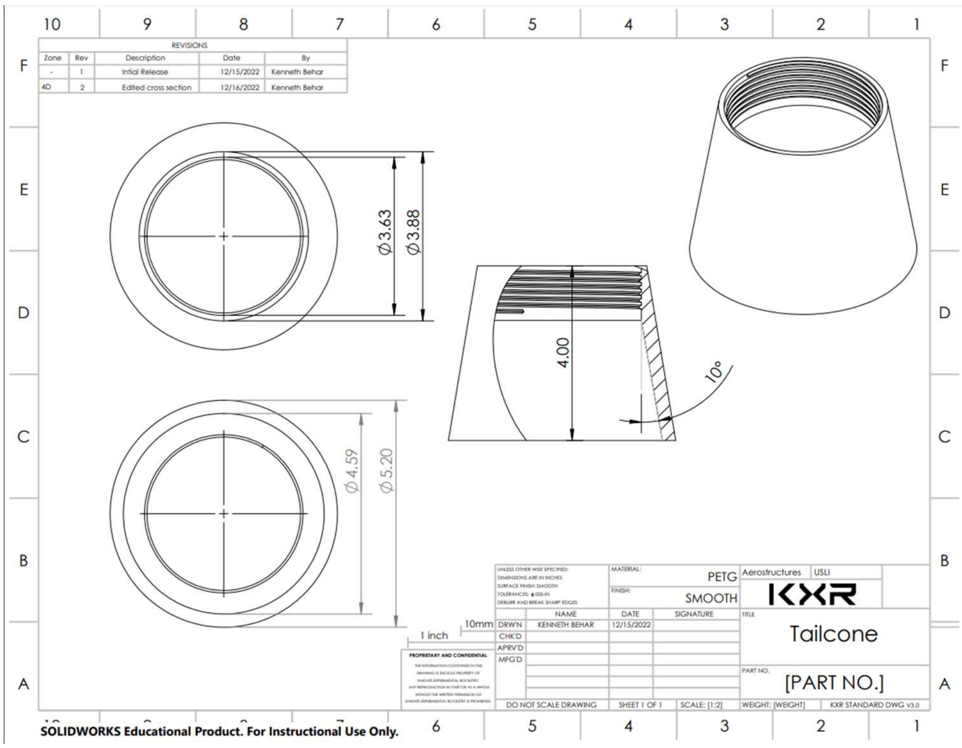
3.1.3.2 Lower Airframe and Components





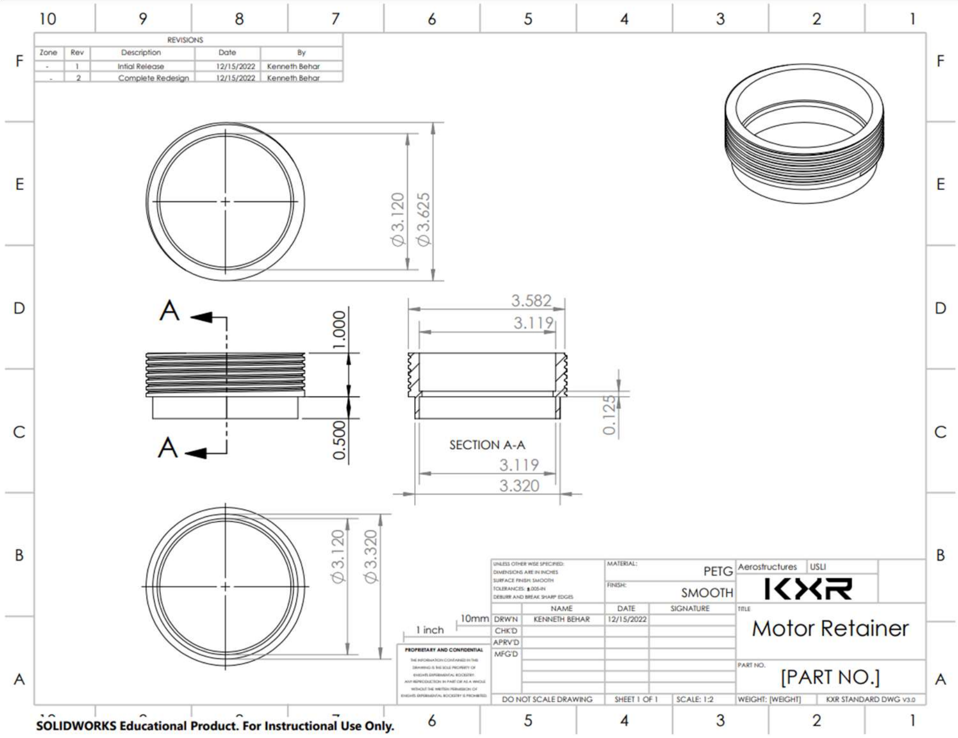
The booster, or lower airframe, is composed of a combination of the lower body, fins, and tailcone. The tailcone connects with the motor retainer to ensure the motor will stay inside. The motor tube is kept in place by three G10 fiberglass centering rings. The four fins slot in within allocated space between the first two centering rings, with a third centering ring slightly further up the tube. The fin slots are located quadrangularly around the tube.

3.1.3.2.1 Tailcone



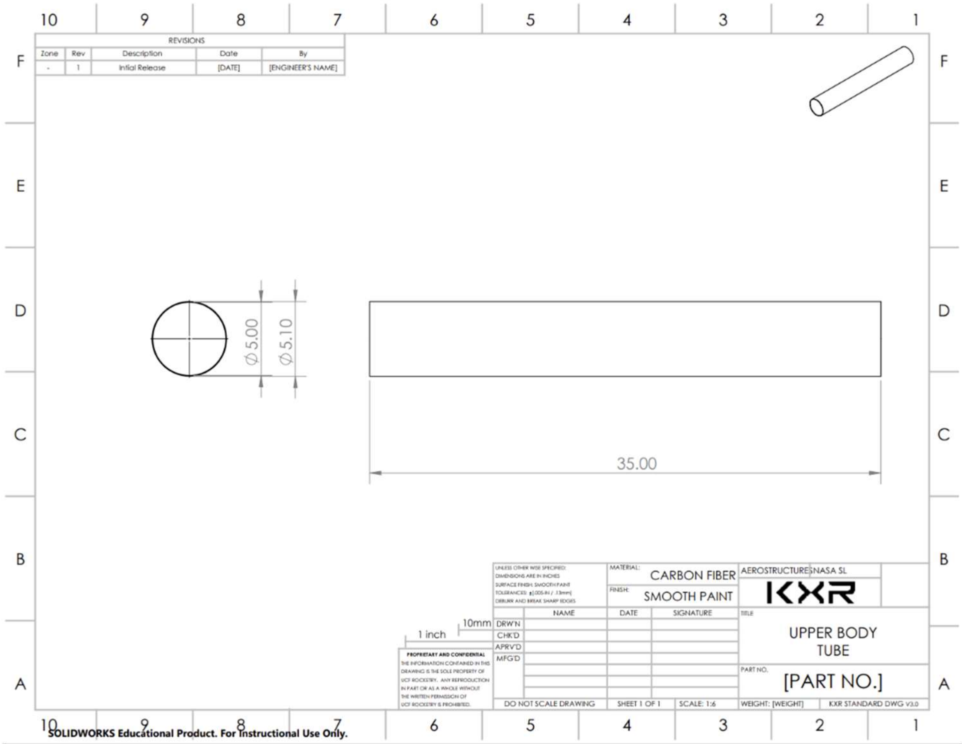
The tailcone can be bolted and unbolted to the lower body tube. It is 3D printed from PETG. The end is threaded to allow for a connection with the motor retainer.

3.1.3.2.2 Motor Retainer



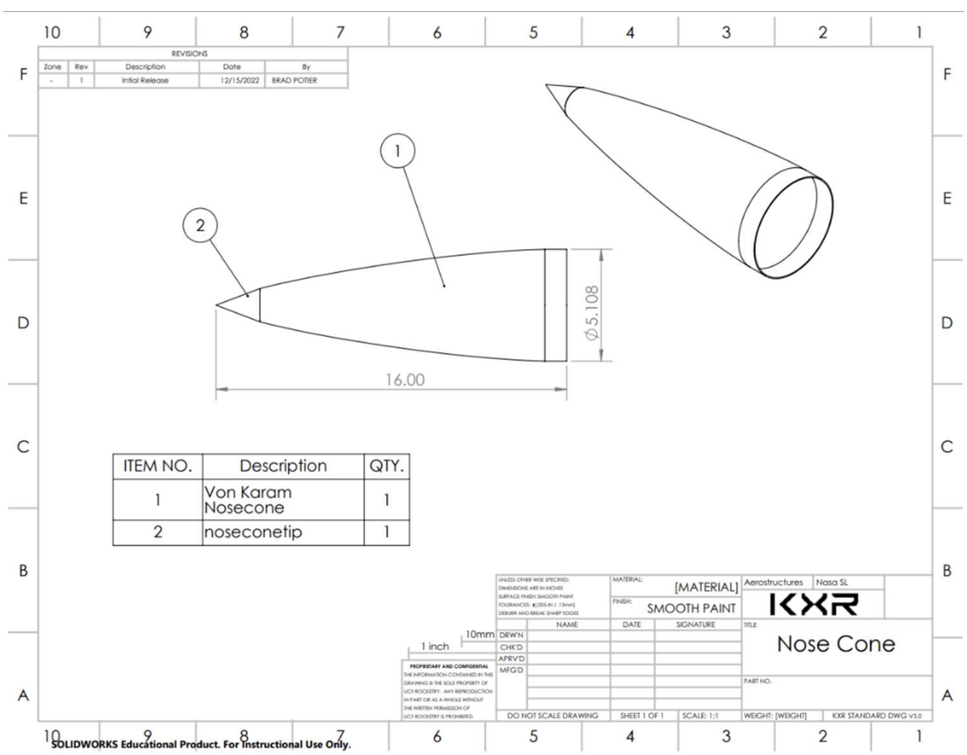
The motor retainer is screwed into the tailcone. It is 3D printed from PETG. The end is threaded to allow for it to connect to the tailcone. The motor will meet the motor retainer at the lip seen in the center of the cross-section view.

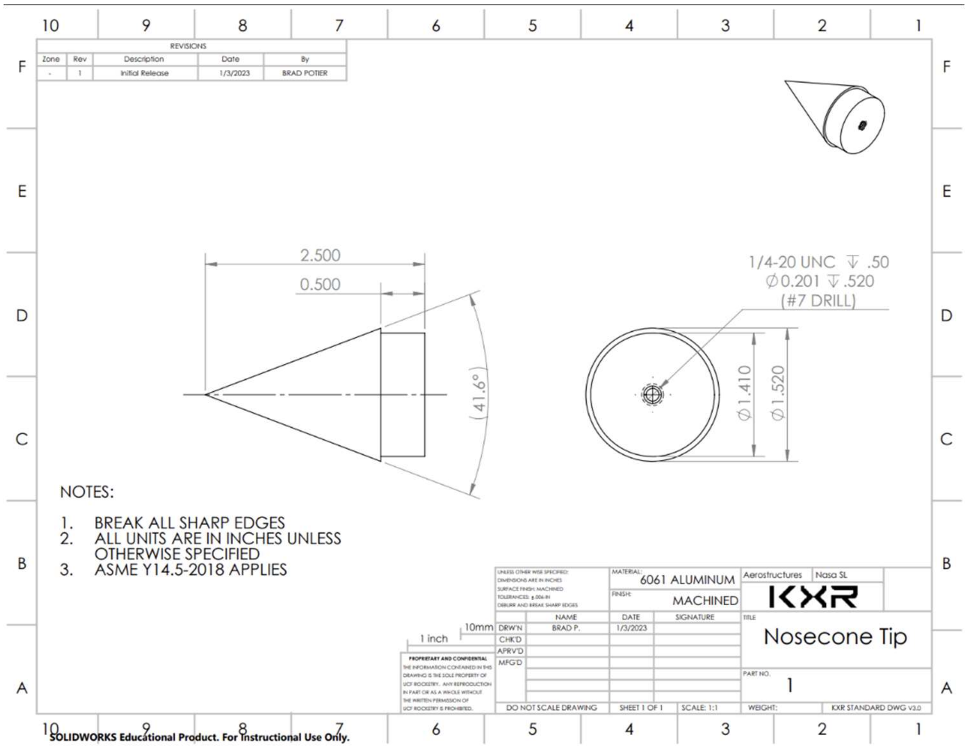
3.1.3.3 Upper Airframe and Components



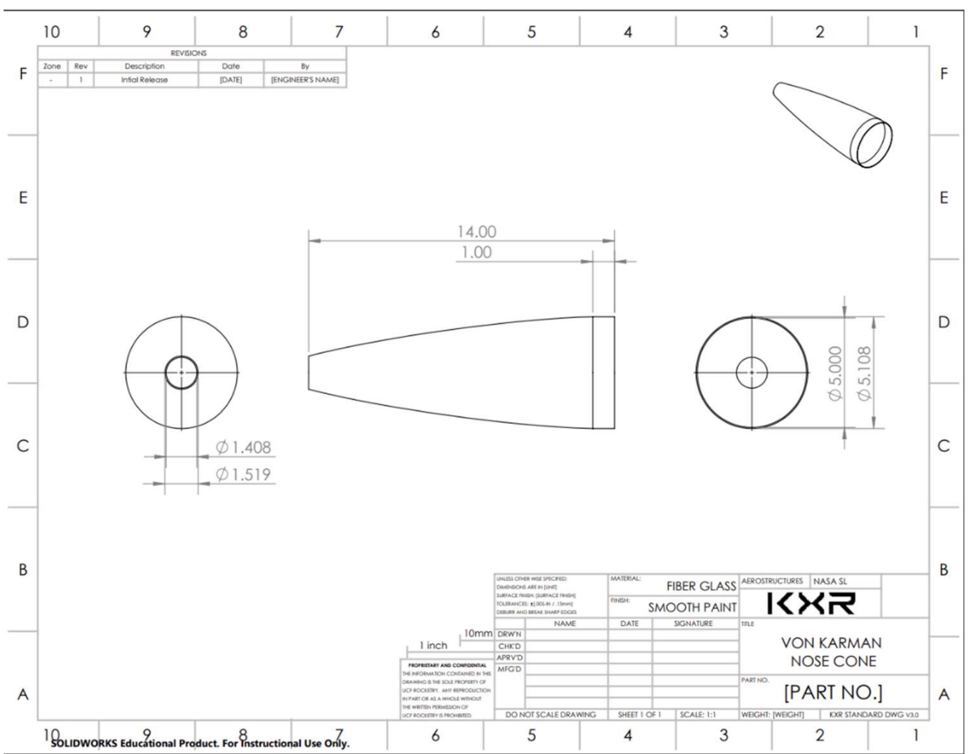
The Upper Body Tube houses our P.I.L.L and Main parachute.

3.1.3.4 Nose Cone and Components





The Nosecone Tip is screwed into a thread rod going straight through the nosecone. It is machined from 6061 Aluminum and will be done at the UCF machine shop.



The Nosecone houses our telemetry module, ATTSAB and will be made from Fiberglass.

3.1.4 Locations of Separation Points and Energetic Material

We will have a dual deployment for our recovery. Separation will occur below the nose cone and above the upper body tube, and below the coupler and above the lower body tube. The drogue parachute will eject out of the lower body tube, and the main parachute and PILL will eject out of the upper body tube. Separation will occur from black powder charges. These will active at apogee for the drogue and at an altitude of 550ft for the main. We will have redundant black powder charges that each will contain 3.9g of black powder for the main deployment and 1.5g of black powder for the drogue deployment. This will be retained by 4 shear pins on either charge well.

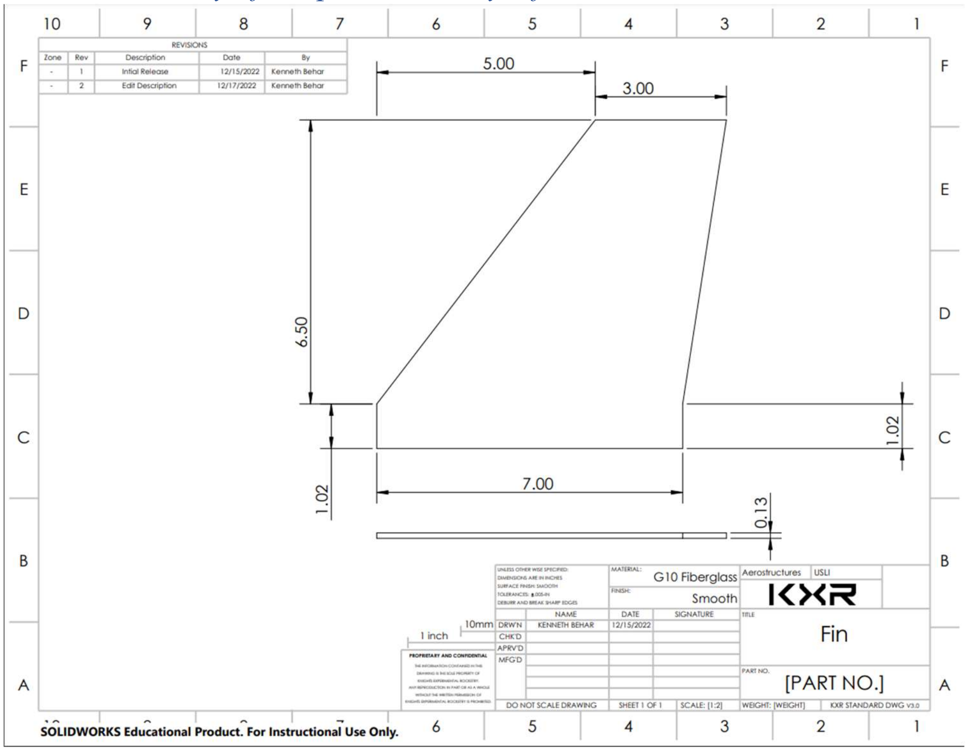
3.1.5 Manufacturing Readiness

Currently, the only component recorded to be purchased is the MDF Plywood Boards. The manufacturing team will be working in an outdoor shop located on campus, associated with Siemens Energy. At the same facility, the main body tube of the rocket will be constructed from carbon fiber pre-preg material with the use of an autoclave oven located at a lab at this facility. The rocket's fins will be outsourced and manufactured from G10 fiberglass through the use of a CNC mill machine. A 4-axis CNC machine will also be utilized in manufacturing for the nose cone tip, which will be made from aluminum. Regarding the rest of the nose cone, we'll be utilizing a female split mold fabricated from MDF boards. We plan to wetlay fiberglass in it to each half of the mold our nose cone and vacuum bag the mold to cure. The motor retainer will be print from , cut from a laser wood machine within the TI Lab on-campus. The tailcone will be manufactured through 3D printing and will be using PETG filament.

Prior to the actual manufacturing process, the team constructed fixed manufacturing process plans in order to ensure proper use and safety methods during the length of the manufacturing period. Specific parts within the rocket have undergone design changes due to manufacturing concerns, specifically due to the direct price, scale, and fragility of parts, however, each system feels as though the decisions completed for final design fit best.

3.1.6 Design Integrity

3.1.6.1 Suitability of Shape and Fin Style for Mission

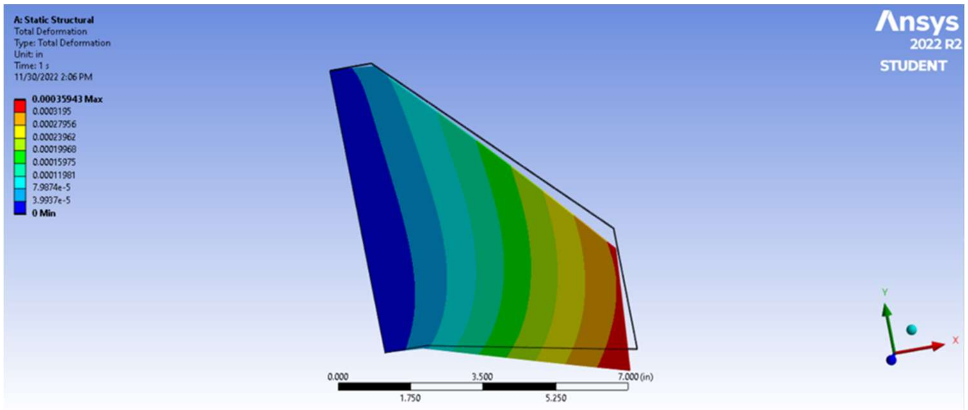


We stayed with a swept back trapezoidal fin due to the low amount of induced drag, and the high correcting lift. Within manufacturing of the fins, the choice of this shape is ideal due to the ease of creating them on a CNC machine, in comparison to other fin shapes that arose. There will be 4 fins in total, weighing 1.19 lbs, for the entire component.

3.1.6.2 Proper Use of Materials

3.1.6.2.1 Fins

When doing the FEA on the fins we used a force of 400 Newtons when the max forces that the fin should be experiencing is about 140 Newtons. Doing so gives a factor of safety worked into our calculations to make sure the fins can withstand such a force. The max deformation we were able to calculate was about 9.129522e-6 meters. This measurement is how far the tip is deformed from the original state based off the 400 Newton force. This is one of the reasons we decided to go with fiberglass for the fins instead of let’s say plywood. The fiberglass gives better material properties and less deformation under stress which would make the fins more structurally sound.



3.1.6.3 Motor Mounting and Retention

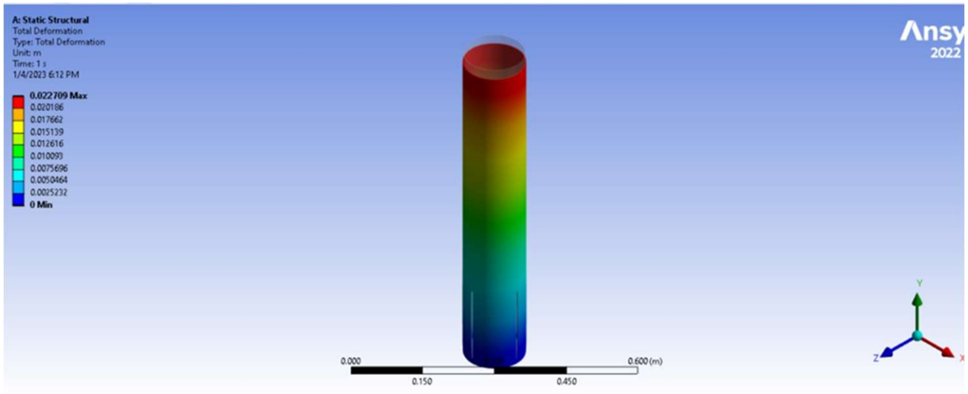
The motor will be attached mainly by being threaded to the bulkhead sitting at the top of it. It will also be held in place by the motor retainer that will be screwed into the tail cone to make sure the motor stays stable. The motor retainer and tail cone will be 3D printed from PETG because it will not be taking much of the force, so it is cheaper and more effective to print. Now when it comes to the centering rings for the motor, we decided to use plywood because again it is cheaper, and they will not be taking much of a force so there is no need to use fiberglass which is more expensive and not cost effective.

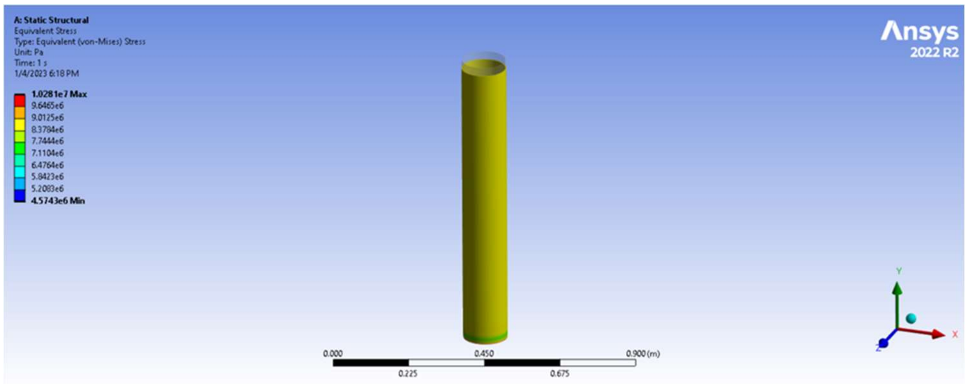
3.1.6.4 Airframe

3.1.6.4.1 Lower Airframe

The material used for the lower body tube is pre-peg carbon fiber with a tensile strength of approximately 4.9 GPa and modulus of 0.29 GPa. Conducting FEA on the body tube, it was shown that the body tube would be able to withstand 2000 lbf placed on it despite its slender frame. The maximum deformation would be a total of 0.0227 meters where the load is placed. The maximum stress that it will experience will be 11 MPa which is well under its tensile strength. The other following properties were used for the material of the body tube for the FEA:

3	Density	1.8	kg m^-3
4	Isotropic Elasticity		
5	De Density	Young's Modulus and P...	
6	Young's Modulus	294	MPa
7	Poisson's Ratio	0.26	
8	Bulk Modulus	2.0417E+08	Pa
9	Shear Modulus	1.1667E+08	Pa
10	Tensile Ultimate Strength	4.902	GPa

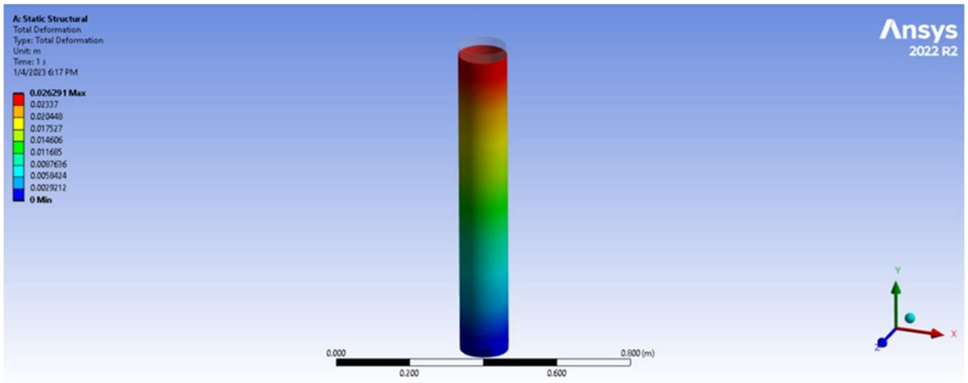


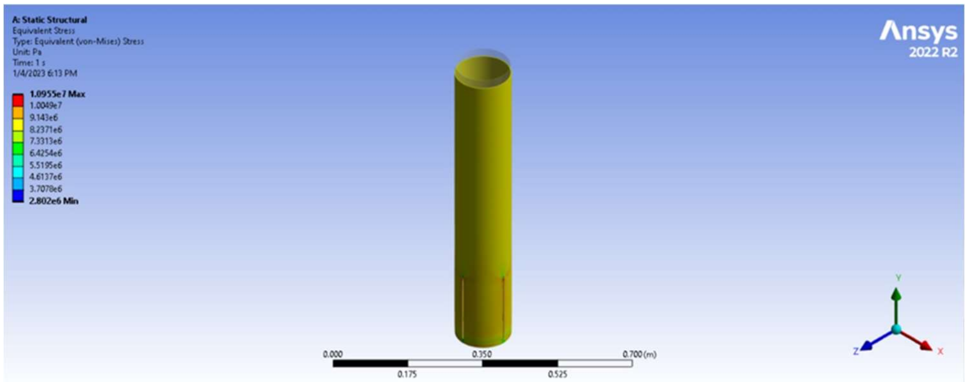


3.1.6.4.2 Upper Airframe

The material used for the upper body tube is pre-peg carbon fiber with a tensile strength of approximately 4.9 GPa and modulus of 0.29 GPa. Conducting FEA on the body tube, it was shown that the body tube would be able to withstand 2000 lbf placed on it despite its slender frame. The maximum deformation would be a total of 0.0226 meters where the load is placed. The maximum stress that it will experience will be 11 MPa which is well under its tensile strength. The other following properties were used for the material of the body tube for the FEA:

3	Density	1.8	kg m^-3
4	Isotropic Elasticity		
5	De Density	Young's Modulus and P...	
6	Young's Modulus	294	MPa
7	Poisson's Ratio	0.26	
8	Bulk Modulus	2.0417E+08	Pa
9	Shear Modulus	1.1667E+08	Pa
10	Tensile Ultimate Strength	4.902	GPa





3.1.6.5 Final Mass of Vehicle and Subsystem

Full Vehicle Weight	22.558 lbs
Nose Cone Subsystem Weight	2.471 lbs
Upper Tube Subsystem Weight	7.238 lbs
Coupler Subsystem Weight	3.814 lbs
Lower Tube Subsystem Weight	4.197 lbs

3.2 Subscale Flight Results

3.2.1 Scaling Factors

3.2.1.1 Constant Factors

A majority of our rocket subscale rocket was designed with a constant 3/5 scaling ratio, in order to ensure that the design is as similar to our full-scale rocket as possible. This is a crucial factor in validating our design in order to continue to the manufacturing of our rocket.

- Body tubes were scaled from 5" inner diameter to 3" inner diameter and total length from 67" to 40"
- Nosecone was scaled from 16" to 9.6" long and 5.1" diameter to 3.1" diameter
- Tailcone was scaled from 5.1" diameter to 3.1" diameter and 4" length to 2.4" length
- Fins were scaled from 7" length to 4.2" length and 5.5" height to 3.3" height

3.2.1.2 Variable Factors

While we attempted to keep as much of the subscale rocket accurate to the full-scale rocket as possible, some features needed to be scaled using different factors due to changes in materials and what products are commercially available.

- Nosecone and tailcone were scaled from 0.5” thickness to 0.1” thickness
- Motor mount was scaled from 3” (75mm) to 1.5” (38mm)
- Body tube and coupler thickness remained at 0.05”

3.2.2 Design and Construction

3.2.2.1 Nosecone

The nosecone was designed by scaling down our full-scale nosecone’s CAD model, which then had the thickness updated to 0.1 inches and was split into two pieces for ease of 3D printing. The two individual pieces were printed out of PETG and bonded together using JB PlasticWeld and sanded to create a uniform, aerodynamic surface. The nosecone also houses an experimental avionics payload, which sits on a removable shelf-like section underneath the coupler.

3.2.2.2 Upper Body

The upper body tube of the rocket is cut from a cardboard mailing tube measured to 21 inches long. The cardboard has an outer diameter of 3.1 inches and inner diameter of 3 inches. There is a bulkhead placed 12 inches from the bottom of the tube which has a U-bolt used to connect the shock cord to the upper body tube. The top of the tube has four holes for M4 bolts that will secure the nosecone to the tube and a ½ inch hole for the camera. The bottom of the tube has two holes for 2-56 shear pins that connect the coupler to the tube. A vent hole was also drilled about 8 inches up from the coupler.

3.2.2.3 Avionics Bay

The avionics bay is made up of a 7.2” coupler with stepped bulkheads consisting of two 1/8-inch plywood on each side with two ¼-20 threaded rods running through it. Inside the coupler, there is a sled made of a laser cut piece of 1/8-inch plywood, which houses the limit switch for our arming mechanism, our Missileworks RRC3 flight computer, a Featherweight GPS tracker, and a RunCam Nano4 camera which is integrated onto the bulkhead to record the parachute’s deployment. There is also a 1.2” switch band placed on the center of the coupler which has one ½ inch vent hole as well as two 1/8-inch holes for the arming pin.

3.2.2.4 Recovery

For our recovery system, our rocket consists of a custom-made drogue and main parachute, designed to fit the needs of our rocket. The drogue parachute is a 16” ellipsoidal parachute with a 6” spill hole to improve the stability while it is descending. This parachute is housed in the lower body tube of the rocket and gets deployed at apogee, slowing the rocket to roughly 60 ft/sec. The main parachute is a 42” ellipsoidal parachute with an 8” spill hole. The main parachute is housed within the upper body tube of the rocket and gets deployed at 700ft, slowing the rocket to roughly 20 ft/sec.

3.2.2.5 Booster

The booster includes the lower body tube, fin cage, and tailcone. The lower body tube is cut from a cardboard mailing tube measured to 18 inches. The cardboard has an outer diameter of 3.1 inches and inner diameter of 3 inches. The bottom of the tube has four holes for M3 bolts that will secure the tailcone to the tube. The top of the tube has two holes for 2-56 shear pins that connect the coupler to the tube. A vent hole was drilled about 8 inches from the coupler. There are four 4.7-inch slits in the lower body tube that allow the fin cage to slide into the body tube.

There is a total of three 1/8-inch birch plywood centering rings within the lower body tube, all of which connect the lower body tube to the fin cage. The fin cage contains the fins, centering rings, and motor tube. The motor tube is made from a paper towel roll tube trimmed to an outer diameter of 1.55 inches and inner diameter of 1.5 inches. There is a centering ring 1.125 inches away from the top end of the motor tube that holds a U-bolt used to connect the lower body tube to the shock chord. The lower two centering rings are spaced 4.2 inches apart, to allow the fins to slot in. The lower ring is 0.5 inches away from the bottom of the tube. The fins are a swept back trapezoidal design. It has a height of 3.3 inches, a tip chord of 1.8 inches, a root chord of 4.2 inches that matches the length of the 0.61-inch fin tabs, and a sweep length of 3 inches. The fins were made from 1/8-inch birch plywood.

The tailcone is a 3D printed PETG conical shape 0.15 inches thick. It is 2.4 inches long with a base diameter of 3.1 inches and an aft diameter of 2.25 inches. It also had four holes that coincide with the four on the lower body tube, allowing it to be bolted into place. This locks the motor into place during flight.

To connect everything together, the fin cage was placed into the lower body tube in line with the slits cut into the tube. This was secured with a fillet of epoxy. The tailcone can be bolted or unbolted as needed with an allen key.

Figure 1 Fully integrated subscale rocket on the launch pad

3.2.3 Launch Day Conditions

Our subscale rocket was launched on December 17th, with the Spaceport Rocketry Association in Palm Bay, Florida. The flight occurred at 2:16pm, with sunny weather and 10mph winds from the NNE. The pressure which was used to calibrate our Avionics Payload was 30in and the temperature was 58° F.

3.2.4 Flight Analysis

3.2.4.1 Flight Profile

Our flight was simulated using the conditions at the launch site in order to have the most accurate simulation possible. The rocket would launch on a CTI H152 Blue Streak motor, reaching a maximum velocity of 296 ft/s and an apogee of 1355 feet. At that point, a 0.5-gram black powder charge will separate the lower body tube from the coupler, releasing a 16-inch drogue parachute to slow the rocket to 64 ft/s. It will then descend until it reaches an altitude of

700ft, where a 0.75-gram black powder charge will separate the upper body tube and deploy a 42-inch main parachute to slow the rocket to 19.7 ft/s for a safe landing.

The rocket also contains two redundant black powder charges to help ensure that the segments separate, and the parachutes deploy. The first backup charge is the deployment charge included with the CTI H152, which has a 10 second delay. This charge will take place two seconds after apogee, giving the Missileworks RRC3 flight computer the first opportunity to fire its charge. The second backup charge is a 1-gram charge which gets activated by the flight computer which will separate the upper body and deploy the main parachute at roughly 600ft.

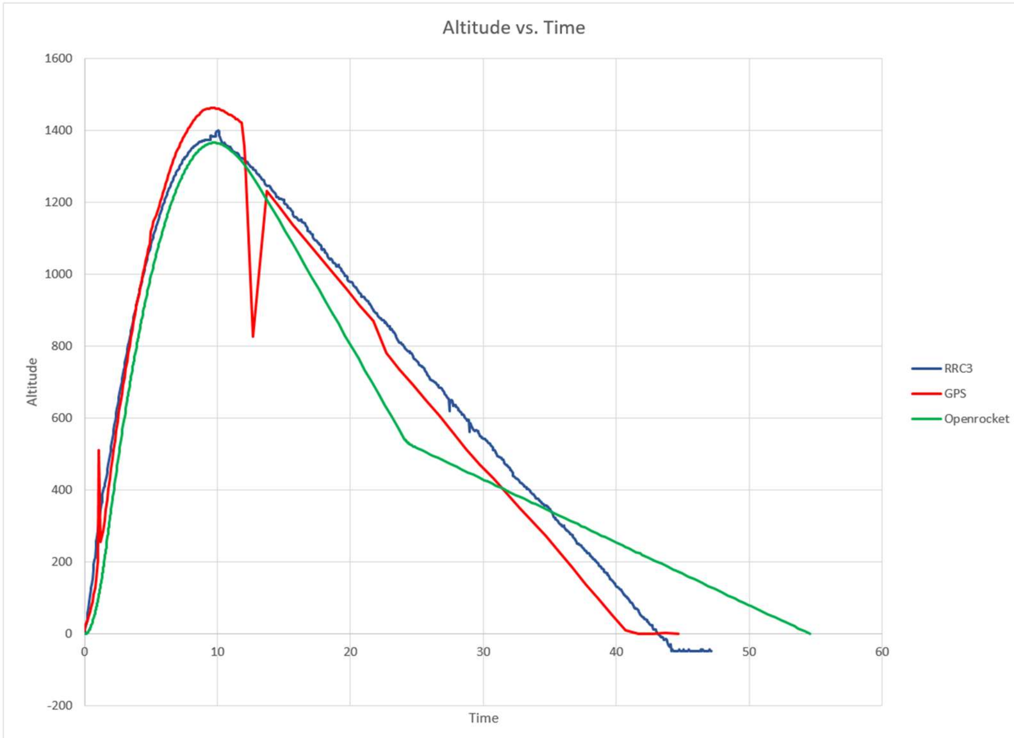
3.2.4.2 Predicted vs. Recorded Flight Data

Our subscale rocket ended up performing very similarly to what the simulations predicted, with a few key differences due to a failure in the recovery system.

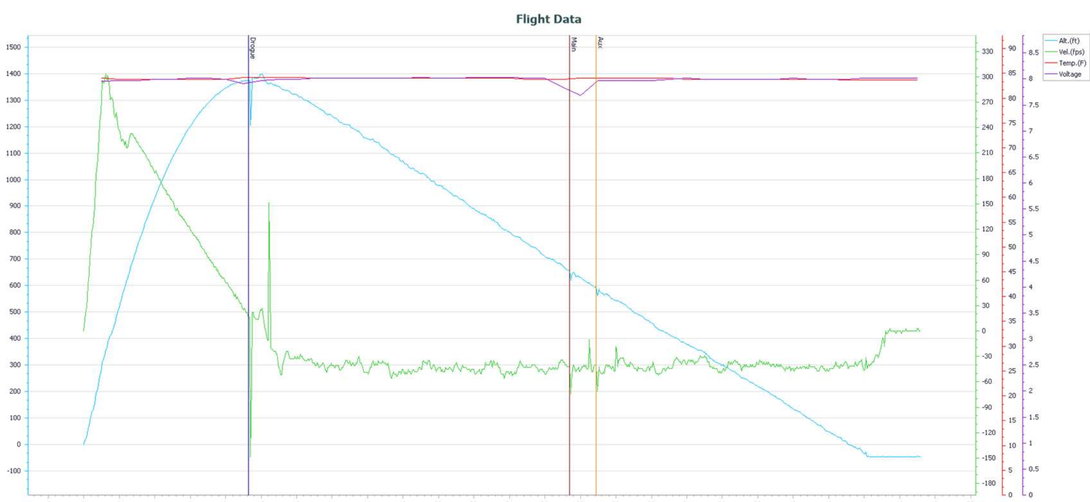
	Simulation	Recorded
Apogee (ft)	1355	1374
Maximum Velocity (ft/s)	298	303
Drogue Descent Rate (ft/s)	64.3	40
Main Descent Rate (ft/s)	19.7	40
Drift Distance (ft)	315	175

Simulated vs. Recorded Flight Data

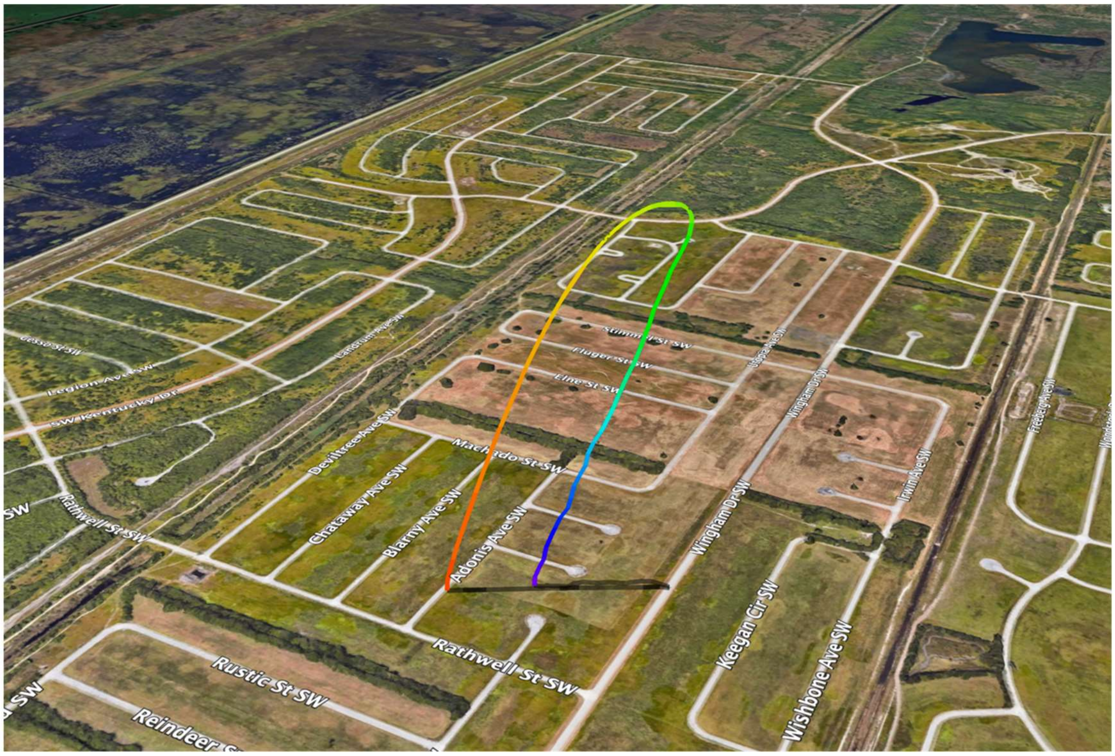
The drogue descent rate was recorded to be 24.3 ft/s slower than the simulation, likely because as the rocket descends, it tends to fall with the body horizontal to the ground which causes an increase in the drag, and therefore a decrease in the descent rate. The main descent rate is notably the same as the drogue descent rate, indicating that the main parachute failed to deploy, which will be discussed in section 3.2.4.3. This increased descent rate likely prevented the rocket from drifting closer to the launchpad due to having less time drifting in the wind.



Simulated vs. Recorded Flight Data Graph



Recorded Flight Data (RRC3)



Featherweight GPS Data

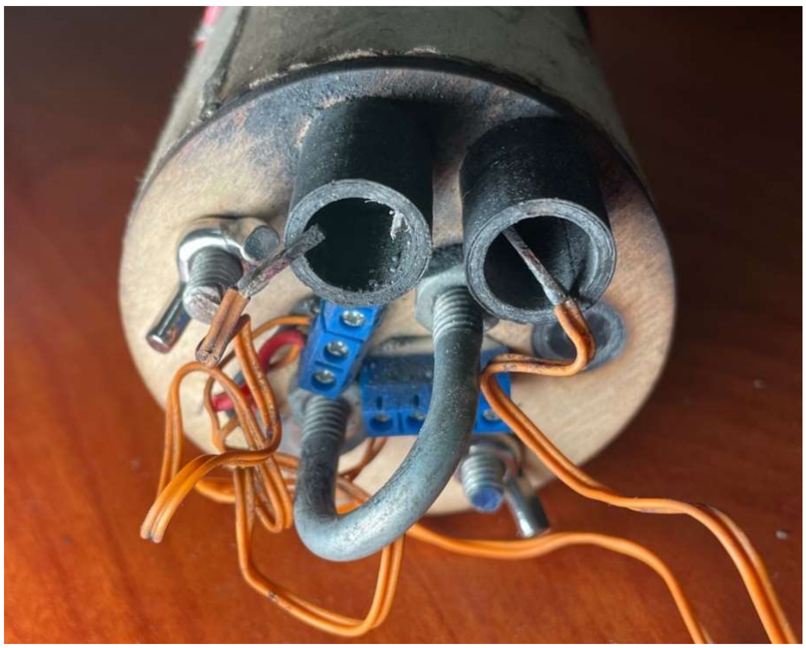
Subscale rocket in flight

3.2.4.3 Recovery System Failure

During the flight of our subscale rocket, the recovery system suffered from a failure which prevented the main parachute from deploying and decelerating the rocket for a safe landing.

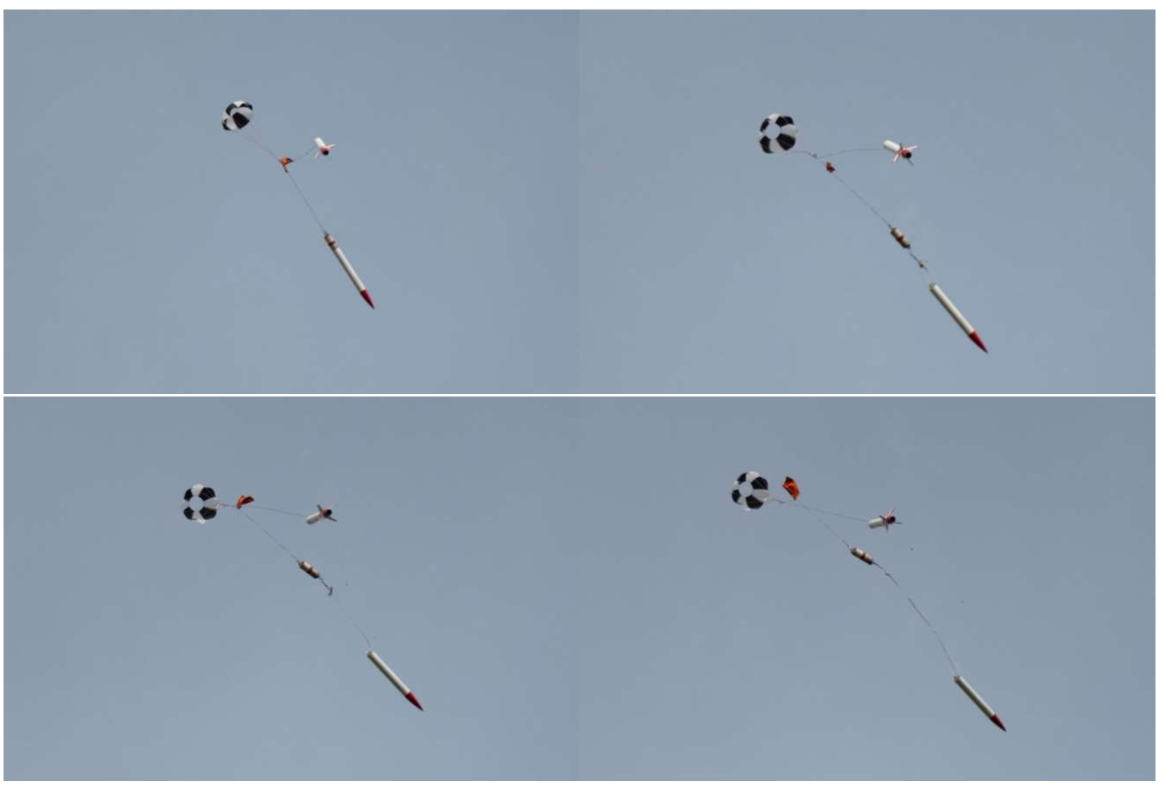
After reviewing the images and flight data, we have concluded that the main parachute became jammed within the upper body tube due to inefficient and unorganized packing methods of the parachute and shock cords.

Even though the parachute did not leave the body tube, the rocket's flight computer did still operate as expected and fired the primary and backup charges at the correct time, though the separation force was not great enough to pull the parachute out of the rocket. The descent rate of the rocket was roughly 40 ft/s for the entire descent as the primary source of drag was the 16-inch drogue parachute. Due to the higher-than-expected landing velocity, one of the rocket's fins snapped entirely, with the two adjacent fins sustaining a small crack along the length of the fin.



Primary and secondary charges fired

Damaged fins



Separation sequence

3.2.5 Subscale Flight Results

Despite the partial failure of our subscale rocket's recovery system, we have determined that the design of our rocket is still viable at the full scale, and we will continue to the manufacturing of our rocket, Asclepius. Moving forward, we plan to make repairs to the subscale rocket's fins, and re-fly it in January 2023 to validate updates made to our parachute and shock cord packing methods, as well as to give our team a dress rehearsal for our full-scale launches.

3.3 Recovery System

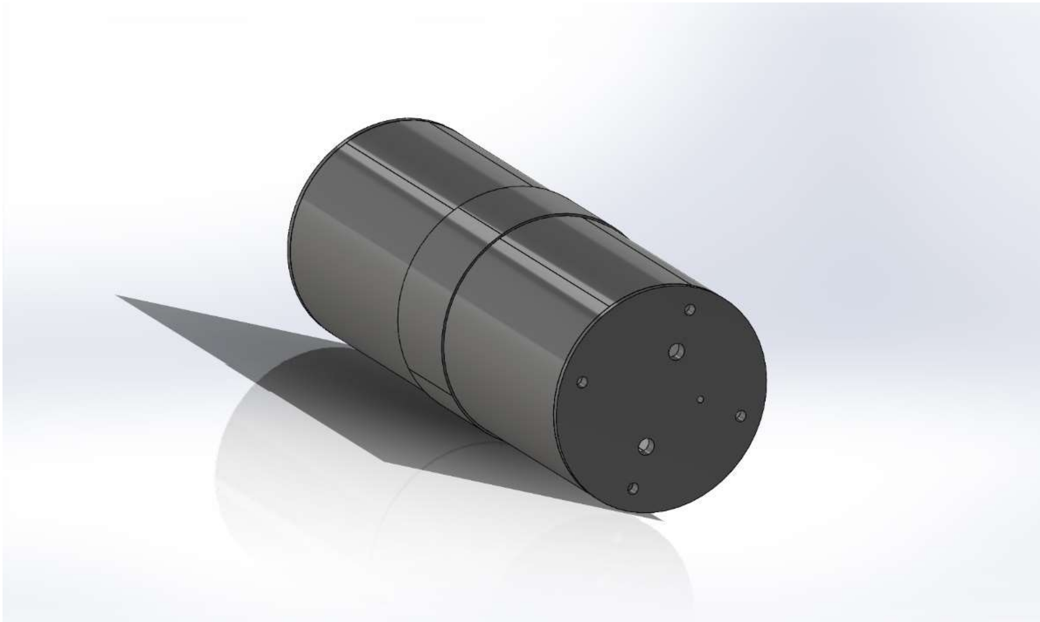
3.3.1 Recovery CDR Design and Justification

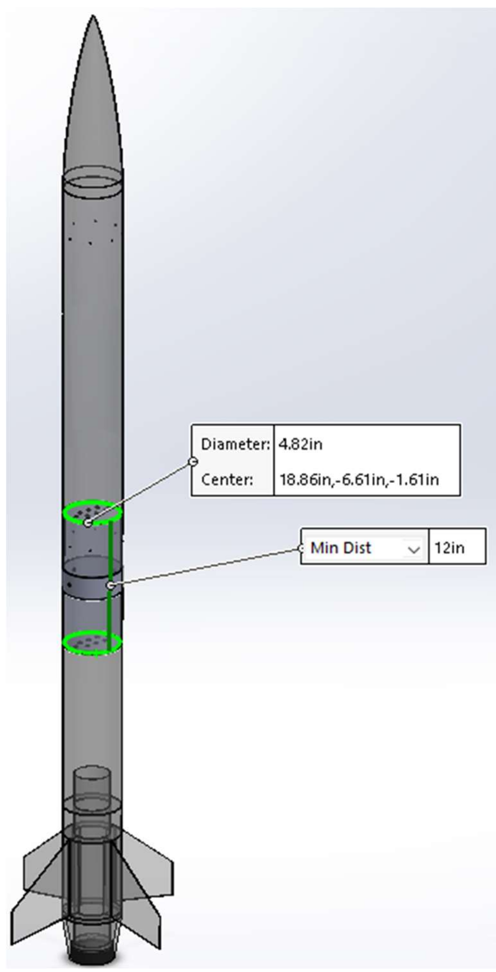
The team chose this current recovery design for the Asclepius Electronics Bay (AEB) because it was cost-effective to utilize the existing space created by the centering plates. Each face of the electronics plate offers 16.34 square inches of area to use, which equates roughly to a total area of 65.36 square inches of area to use for the altimeters and batteries. The other iteration of AEB uses a sled design that provides a total area of roughly 45 square inches. This iteration would have also needed centering rings to prevent any torsion created during flight.

Another reason the team chose this design was for simplicity. All components are divided into sections of the AEB. The Stratologger Altimeter section is in the upper portion of the AEB, the Arming Pin Module occupies the middle section, and the RRC3 Sport Altimeter sits in the lower section. Using two altimeters and two limit switches provides redundancy for the system which will reduce the risk of any errors in the system.

3.3.1.1 Coupler

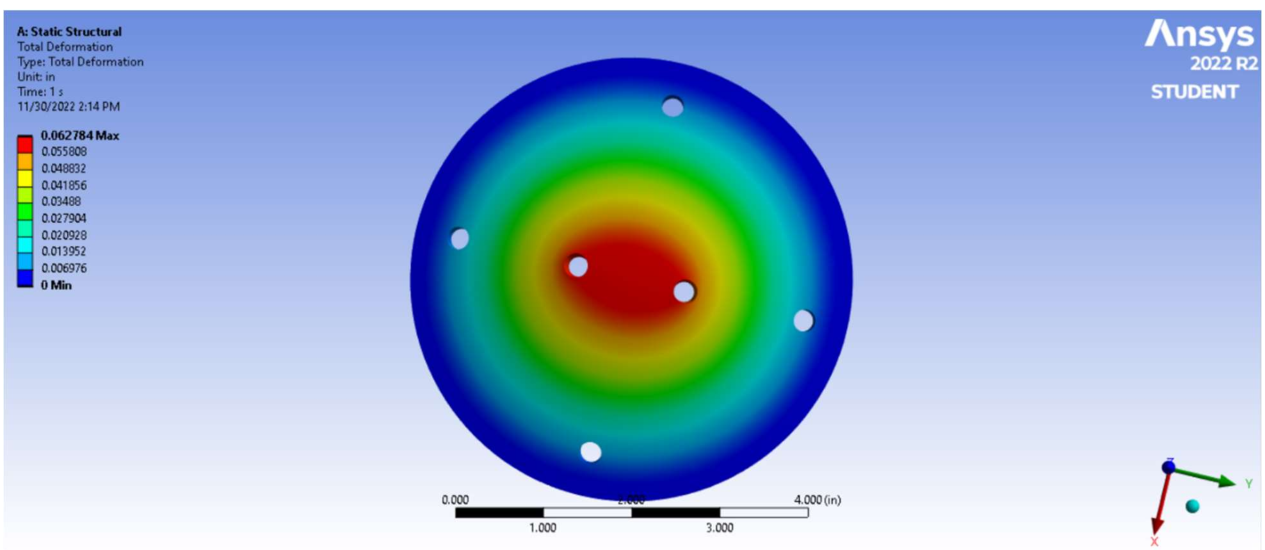
The coupler will be manufactured out of fiberglass and have a length of 12 inches. The outer diameter of the coupler will be 5 inches, while the inner diameter is 4.815 inches. Choosing fiberglass as our material for the coupler reduces our concern for manufacturing safety. Since we have fiberglass readily available, it also decreases our spending for the project so we can use the funds elsewhere. Fiberglass will be more than enough to withstand impact forces and keep rigidity in the system.




Diameter: 4.82in
Center: 18.86in,-6.61in,-1.61in
Min Dist 12in

3.3.1.2 Bulkheads

Because of the availability of fiberglass within our inventory, we decided to use fiberglass for the bulkheads of the coupler. This will be cheaper than buying another material such as carbon fiber or plywood. Also, fiberglass is expected to have an ultimate tensile strength of approximately 3000 MPa compared to its counterpart carbon fiber and plywood with ultimate tensile strengths of approximately 3500 MPa and 35 MPa, respectively. Although fiberglass has less tensile strength than carbon fiber, we thought that the decrease in costs is better than the increase in unnecessary tensile strength. The bulkhead will have a diameter of 5 inches and 4.815 inches for its shoulder along with a thickness of .125 inches for both. Since the body tubes' inner diameter is 5 inches and we chose to have 0% tolerance, we made the bulkheads diameter to be 5 inches. The diameter of 5 inches for the bulkhead is also optimal because it is large enough to fit components within the coupler and it is also small enough to prevent the spread of stress points. Based on the structural analysis from Ansys, the stress from the snatch force will be concentrated in the middle and to reduce this we decided to use a U-bolt instead of an I-bolt to divide the stress into two points. This resulted in an elliptical shape for the stress areas rather than circular.



3.3.1.3 Hardware

Before deciding on what hardware to use in the recovery system, we first had to consider what forces we'd be under. The main one in this case being snatch force. We used a table made in open rocket as well as hand calculations to find our possible snatch forces. The table includes different velocities due to extraneous variables such as tumbling, as well as different possible velocities depending on drogue size. As an addendum, it is worth noting that OpenRocket does not account for tumbling, so the estimated snatch force is likely an overestimate.

Air Density: 1.188 $\frac{kg}{m^3}$ at 1000 ft above sea level (Huntsville Alabama sits at 640 ft)
Speed during decent: $30.5\ \frac{m}{s} - 34.45\ \frac{m}{s}$ ($34.45\ \frac{m}{s}$ OpenRocket prediction with 1' drogue)
Main Drag coefficient: 0.97
Area: $4.67\ m^2$

Calculation example: (using max possible speed)

$$F_D = \frac{1}{2}(r)(V_d^{\,2})(C_d)(A_m)$$

$$F_D\ = \frac{1}{2}\left(1.188\ \frac{kg}{m^3}\right)\left(30.48\ \frac{m}{s}\right)^2 (.97)(4.67\ m^2)$$

$$F_D = \frac{1}{2}(1103.6881)(4.5299) = 2499.7983\ Kg\ \cdot \frac{m}{s^2}$$

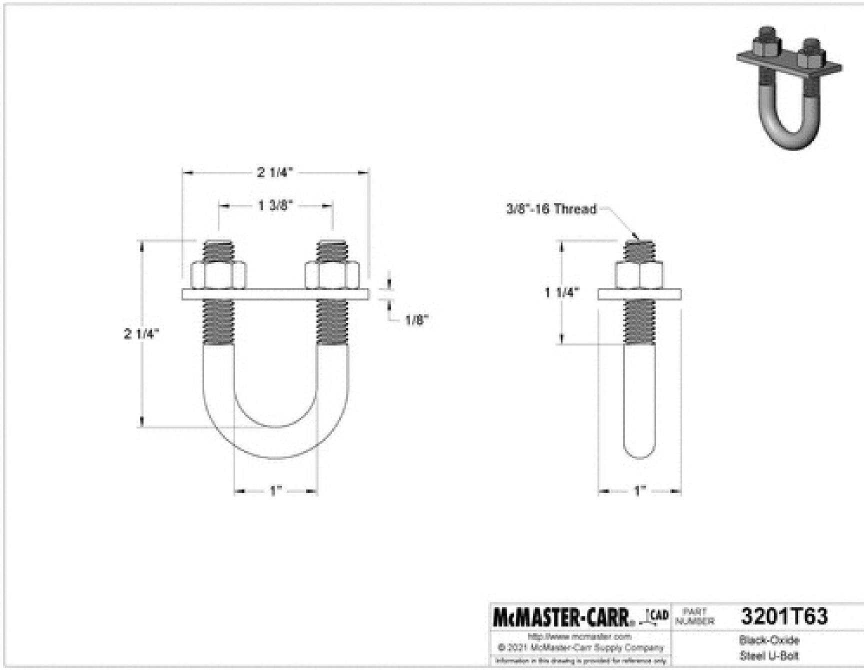
$$F_D = \frac{3193.4012\ N}{4.448} = 562.0050\ lbf$$

Descent speed ft/s	Descent speed m/s	Snatch force (N)	Snatch force (lbf)
55	16.764	756.1890149	169.9980963
60	18.288	899.9274227	202.311784
65	19.812	1056.164823	237.4353576
70	21.336	1224.901214	275.3688171
75	22.860	1406.136598	316.1121625

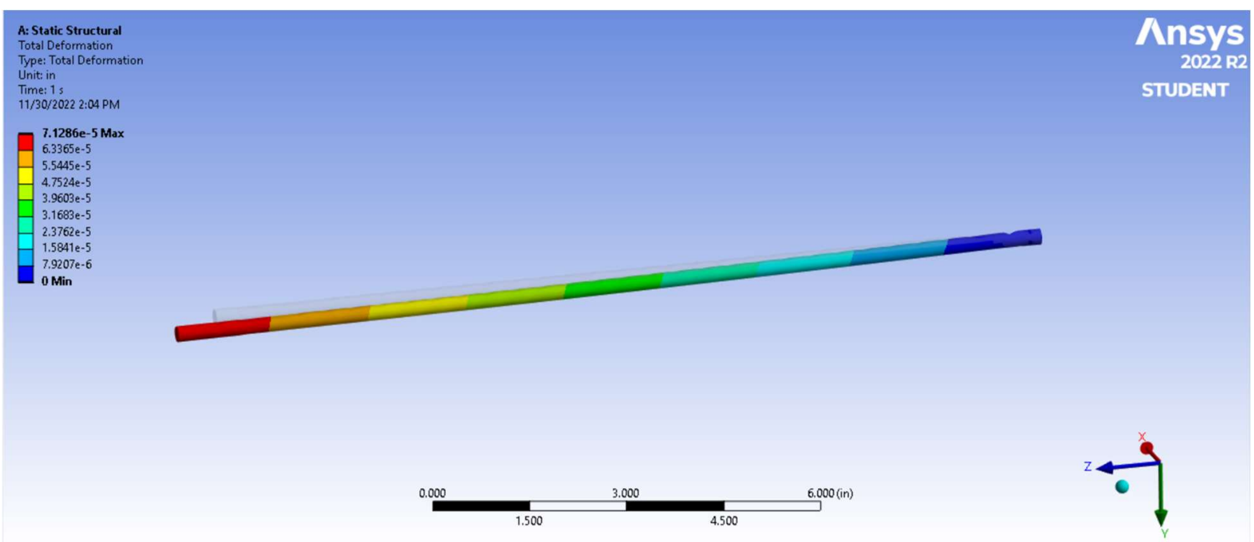
85	25.908	1806.104341	406.0285109
90	27.432	2024.836701	455.201514
95	28.956	2256.068053	507.1844029
100	30.480	2499.798397	561.9771777
105	32.004	2756.027732	619.5798384
110	33.528	3024.75606	679.992385

The main parachute has been calculated to produce a snatch force ranging between 169.99 lbf and 679.99 of force – depending on velocity and thus drogue size. For this force, we are attaching the shock cord to a Black-Oxide Steel U-Bolt, ⅜'-16 Thread Size, 1" ID. Said U-bolt has a capacity is of 1075 lbf. The ⅜" U bolt was chosen over the ¼" of the same material because of it can withstand more force than its counterpart. When also accounting for cost, assembly, and size, using a decision matrix it can still be seen that the ⅜" is the best choice.

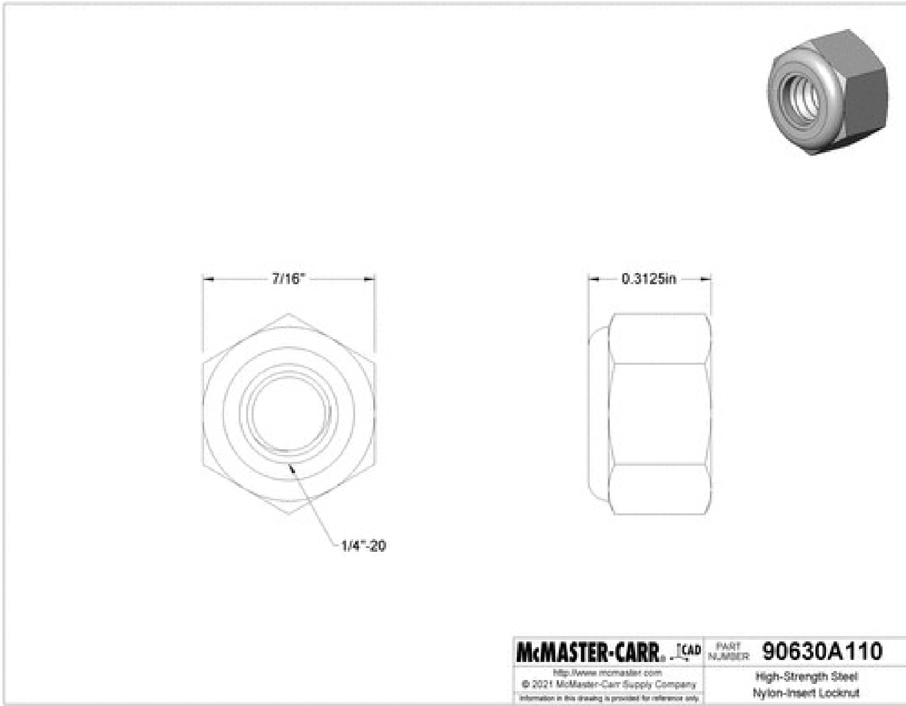
		RATINGS	
Criterion	**Weight**	**3/8" U-Bolt**	**1/4" U-Bolt**
Strength	4	4	3
Cost	3	3	3
Safe	5	5	1
Stability	3	5	3
Reliability	5	4	2
Total		**85**	**45**



For the rods we are using 0.25" Aluminum Round Bar 6061-T6511- Extruded because aluminum is flexible so it will resist breaking under torsion force. It has a weight of 0.06 pounds per foot, tensile strength of 42 KSI, yield strength of 40 KSI, and shear strength 25 KSI. Although rather thin, the price point is unmatched, and supplementing this with the use of four rods in lieu of just two means we do not need to worry about the strength of the rods.



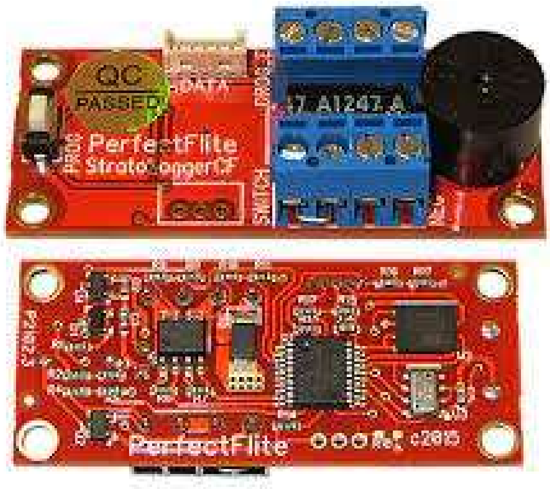
As for the locknuts, we are using high-strength steel nylon-inserted locknuts. 7/16" width and 5/16" height, with a ¼" ID to add more strength into the system.

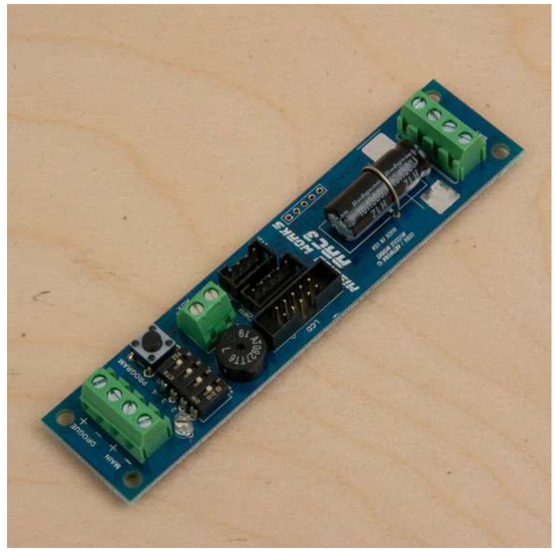


3.3.1.4 Primary and Redundant Altimeters

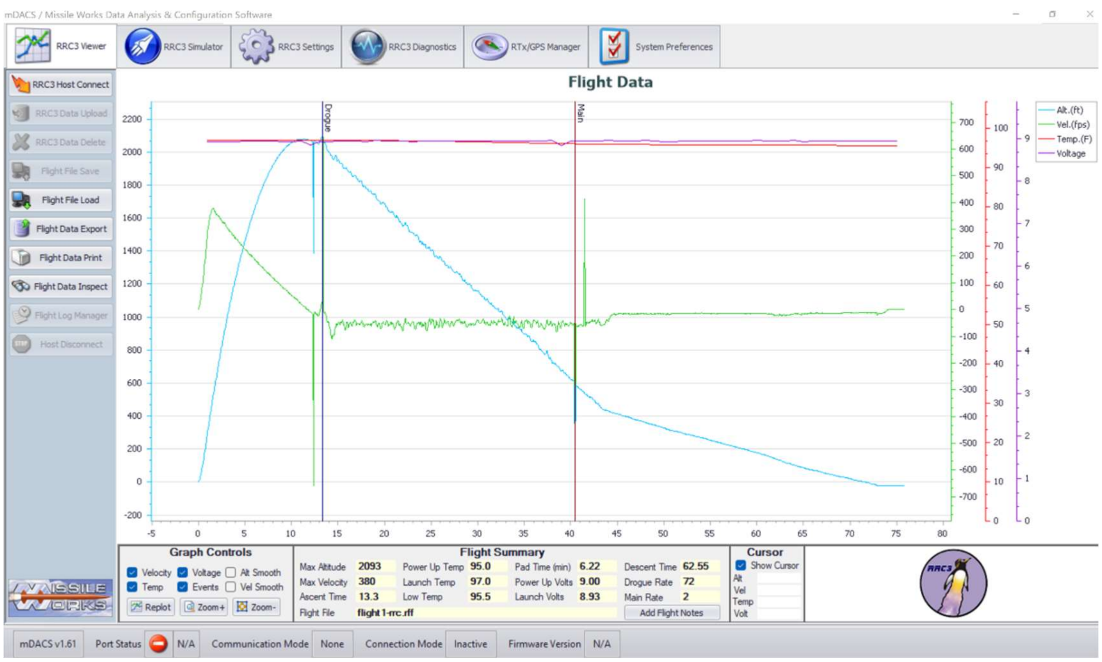
The recovery system will utilize an RRC3 Sport as the primary altimeter as well as a StratoLoggerCF as the redundant altimeter. The RRC3 has a length of 3.92 inches with a width of 0.925 inches and weighs 0.60 ounces. The RRC3 was chosen for its flexibility. The RRC3 is optimized for 9-volt batteries, voltage can range from 3.6 – 10v; This altimeter is also designed to function with Microsoft Windows Operating System: this allows for the collection of detailed flight data and graphs. However, the RRC3 Sport - when armed - has a max power draw of 35ma, thus, a factor of safety must be met to ensure the rocket can remain two hours on the launch pad before being armed. On the other hand, the StratoLoggerCF was chosen as our redundant altimeter as it has a very low power draw of 1.5ma, and is capable of providing in depth flight data: altitude, temperature, battery voltage (at a rate of 20 samples per second), and more which can be corroborated against the telemetry system's custom flight computer. The StratoLoggerCF also has a small form factor coming in at two inches in length, 0.84 inches in width, and 0.5 inches in height with a weight of 0.38 ounces.

StratoLoggerCF RRC3 Sport





Example of Flight Data from an RRC3
Note: Data is not related to NSL rocket



3.3.1.5 Batteries

In order to meet requirement 2.6. of the handbook, we have opted for the use of Lipo batteries to ensure longevity on the launch pad; each altimeter will have its own dedicated battery to achieve a certain level of redundancy. As for the specific battery choice, we've opted for a 7.4v 300 mAh Rhino 50C LiPo Battery. The difference in form factor between a typical 9v Alkaline battery is negligible, however our specific Lipo battery comes in at about 2.2in*1.2in*0.38in, weighing in at 1.06 ounces. Ultimately, we opted to use the Lipo as Alkaline batteries are not rechargeable, have high internal resistance, and relatively high-power draws, however, it is worth noting the risks of using a Lipo as special conditions must be taken to assure the quality of the battery: 50-70% charge, storage, and draining battery for disposal. The last alternative was NiMh batteries. NiMh batteries are far worse than Lipos in every fashion, however, they do offer better longevity, meaning it may be better suited to meet section 2.6. of the handbook. That being said, the other drawbacks of NiMh batteries, and the fact that our team is extremely unfamiliar with the use of said batteries lead to us avoiding usage of the battery. Regardless of battery choice, each battery would have a dedicated section on the sleds with slots for zipties to hold them in place.

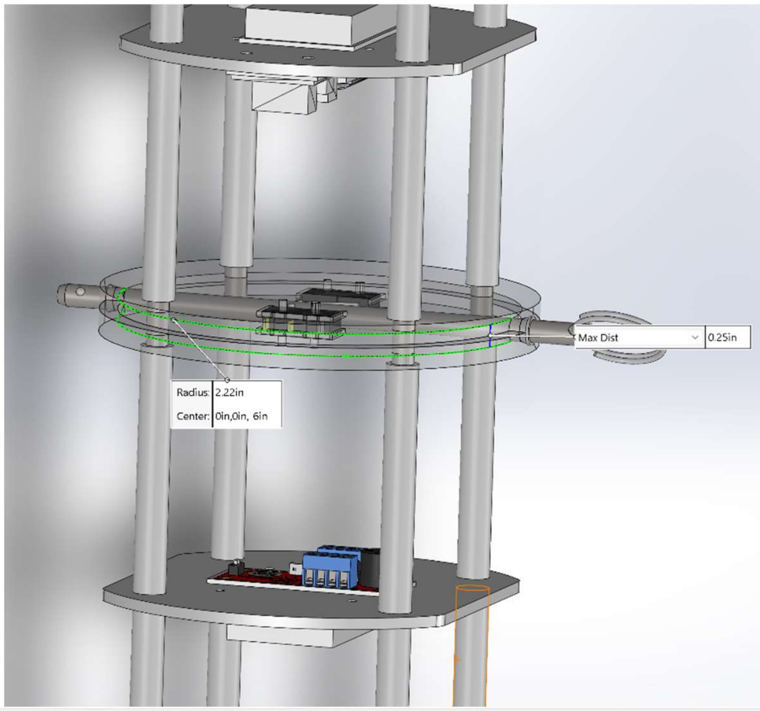
		RATINGS		
Criterion	Weight	Li-Po 300mAH	9-volt Alkaline	NiMH 2700 mAH
Weight	2	5	3	2
Life Span	8	5	2	4
Temperature Range	5	5	5	3
Rechargeability	6	5	1	5
Cost	2	2	5	2
Failure Potential	6	1	5	2
Total		115	92	97

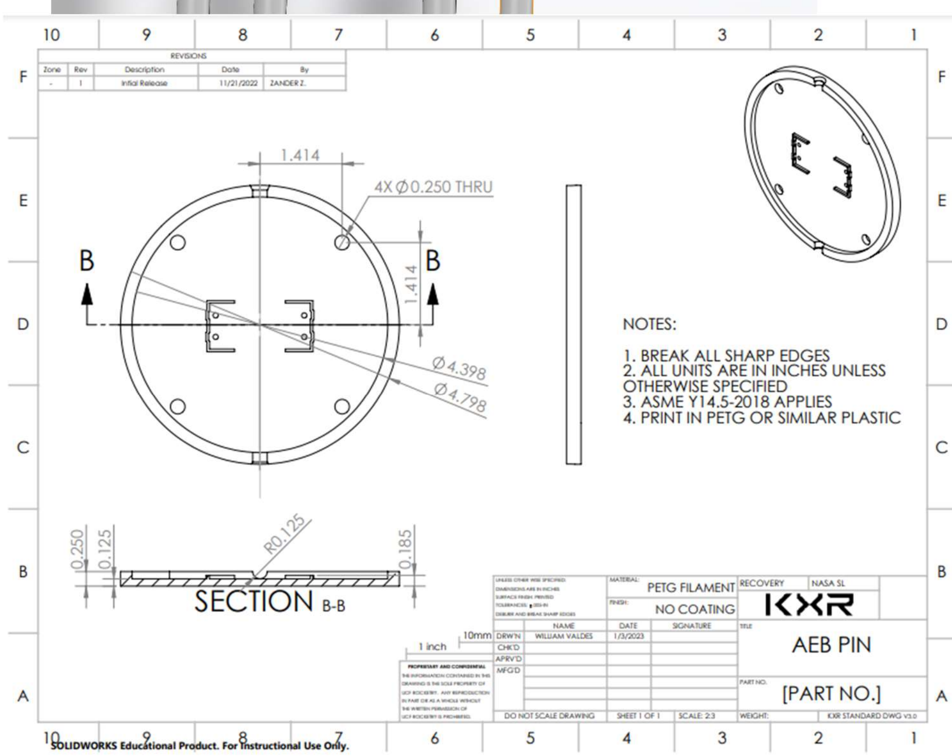
Rhino 300mAh 2S 50C LiPo Battery

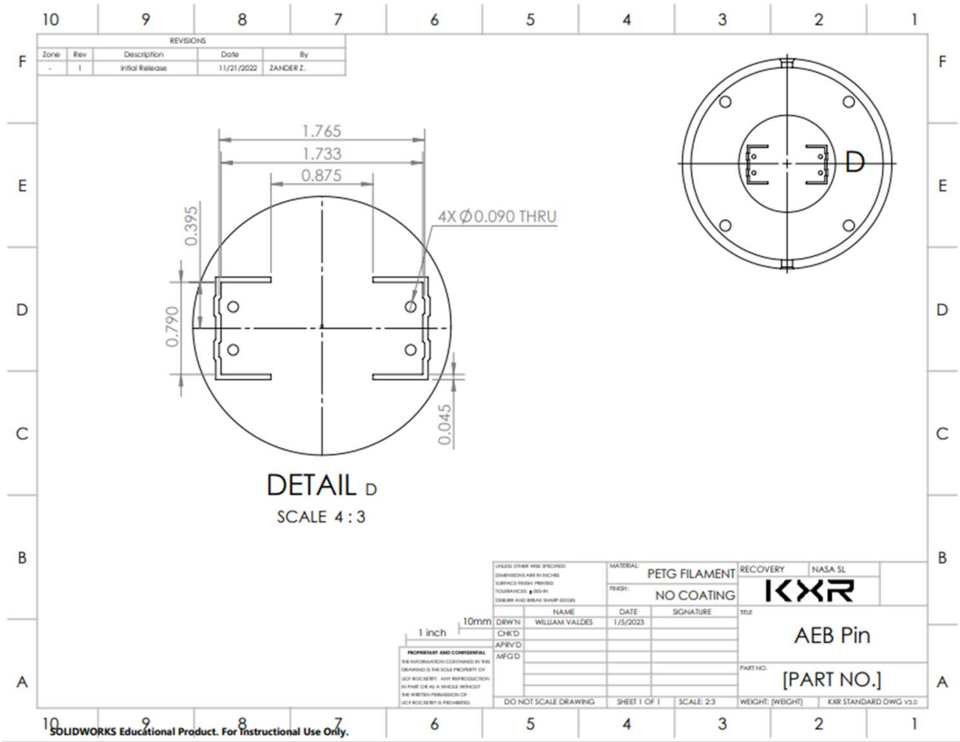
3.3.1.6 Arming Mechanism

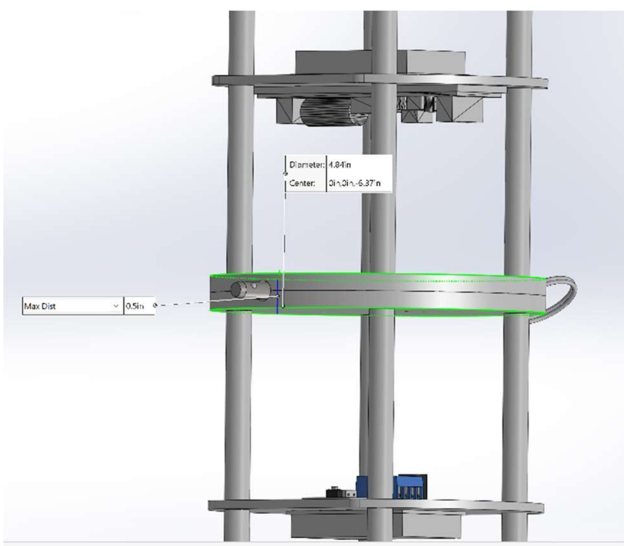
The electronics bay will house two limit switches for each altimeter in the pin module. The pin module consists of two adjacent plates with a gap of 0.25 inches. The limit switches will be "sandwiched" between the two with a removable pin holding them down. When the pin is released, the switches activate and send a signal to arm the altimeters. This arming mechanism is designed to meet the requirements for section 3.6. of the handbook, force exerted on the pin by the switch also ensures that removing the pin would require clear intention and prevent any safety concerns. As for the specific limit switches, we will be using the SS-5GL2. These will have a unit weight of 0.056 ounces and dimensions of 0.78in*0.4in*0.25in.

Pin Module (Dimensions Shown)









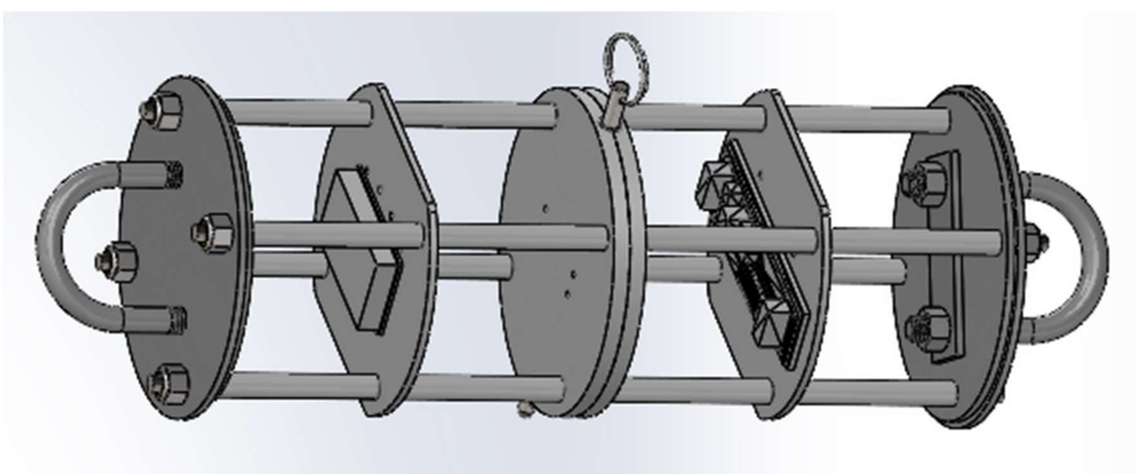
3.3.1.7 Ejection Charges

Charge wells are hollow cylinders filled with black powder that are mounted to both the head or rear of the coupler bulk plates to help the drogue and main chutes deploy out of the body, for the subscale we used a total of four charge wells which included two on the head and two on the rear of the coupler. Charge wells were used on the subscale due to our team's familiarity with them. For the full-scale we will be using floating point charges because they are more effective, reduce weight, and easier to manufacture. Floating charges are black powder filled pouches that can be placed away from the coupler – in the case of high-power rocketry, this usually means the tip of an index finger of a glove with an e-match in it and tied off. For example, they can be placed in the nose cone of the rocket so that, when they go off blast will be directed towards the parachute and coupler helping the parachute out, while the blast from the charge wells is only directed at the coupler and will not help the parachute out.

		RATINGS	
Criterion	**Weight**	**Floating Point**	**Chargewell**
Cost	1	5	5
Weight	1	5	5
Efficiency	5	5	5
Ease of Use	3	5	2
Total		**50**	**41**

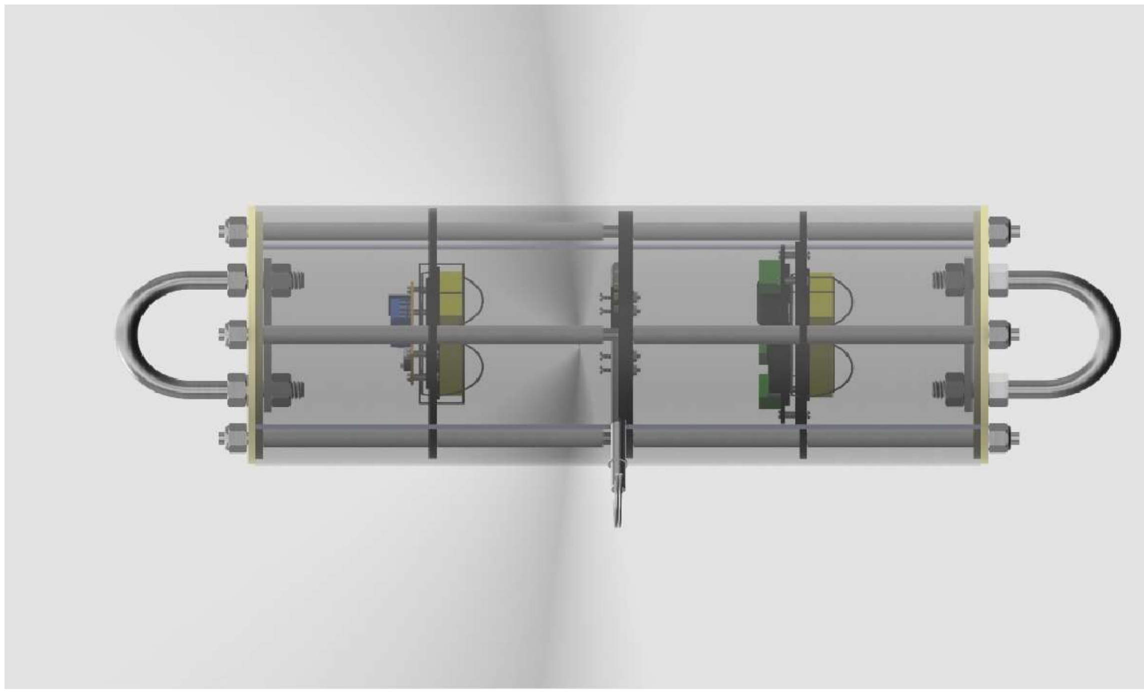
3.3.1.8 Shaft Guards

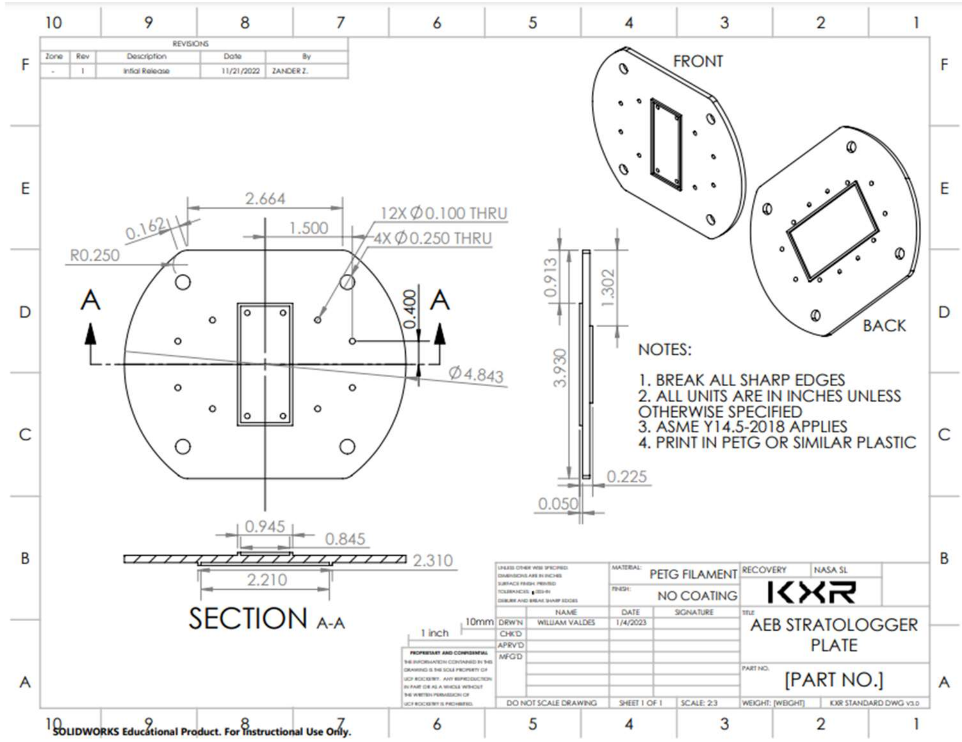
For the shaft guards, the material we will be using is PVC (Polyvinyl Chloride) piping. The PVC pipe will be used to cover the aluminum rods acting as "guards." The guards will allow us to evenly space each plate while also supplying a faster means of assembly as compared to threaded rods; faster assembly and thus disassembly would also make it easier to do maintenance on in case of any mishaps at the launch site. The dimensions of each PVC shaft guard will be 2.75 inches long with an inner diameter of 0.25 inches and an outer diameter of 0.375. Four of these will be placed between a bulkhead and plate or a pin module. There will be 16 guards total in our design.

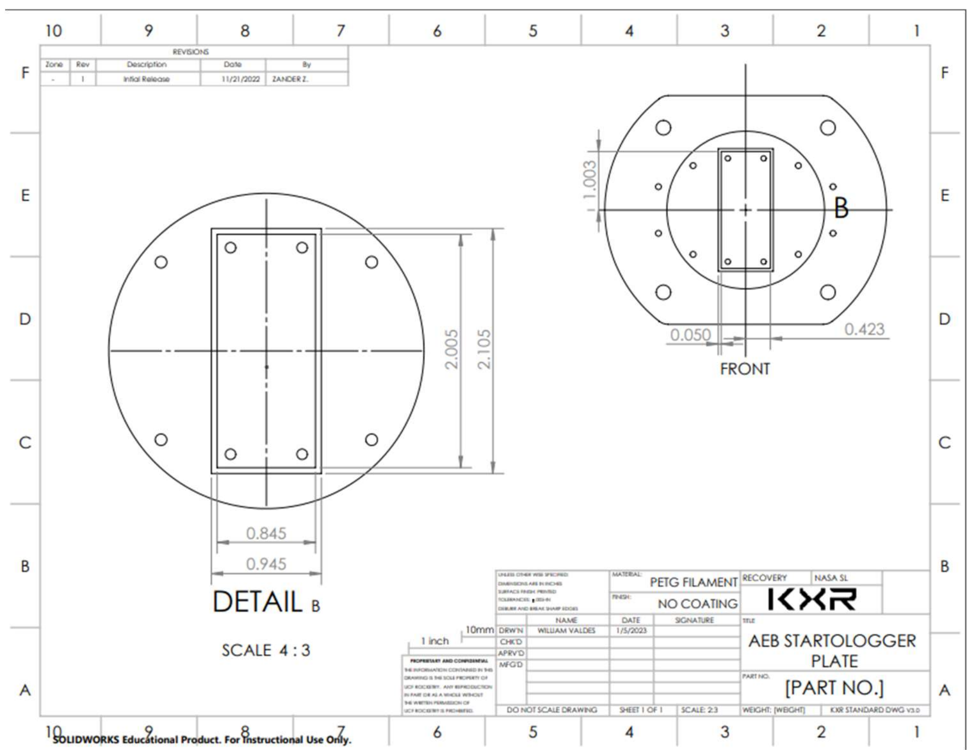


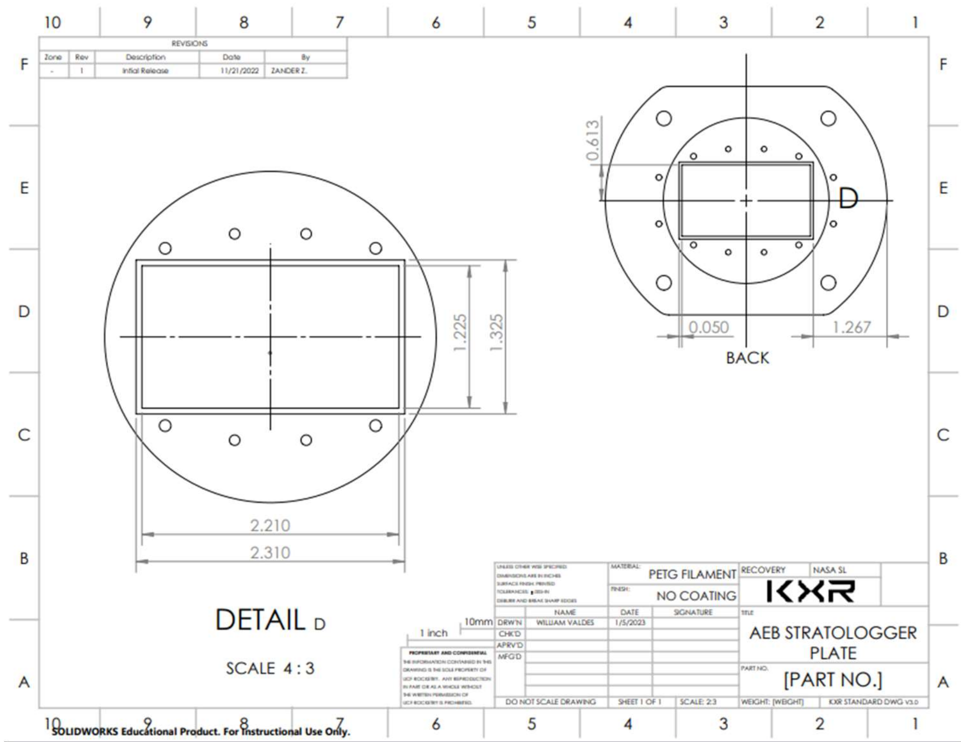
3.3.1.9 Electronics and Intermediate Plates

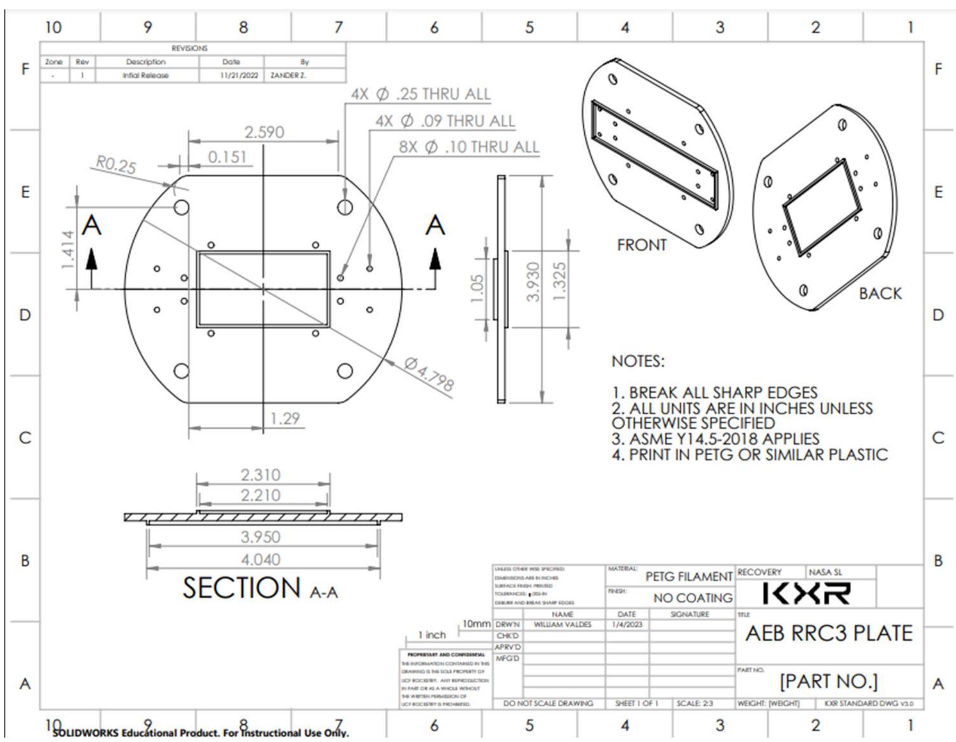
We chose not to use sleds for the recovery design because we thought that it would be unnecessary to use both the sled and plates. We can utilize the same space by using only the plates. It was also discussed that due to the length of the coupler, the bending forces will be greater within the coupler and the sled will be more prone to these bending forces compared to just using the plates which will have exponentially fewer bending forces acting on it. We want the forces to be distributed along the rods within the coupler and not the sleds or the plate, thus its removal. Also, it was discussed that different altimeters must be in a certain orientation to give the most accurate data. However, the RRC3 and Stratologger do not require any specific orientation unlike the RRC2 and other contemporary altimeters.

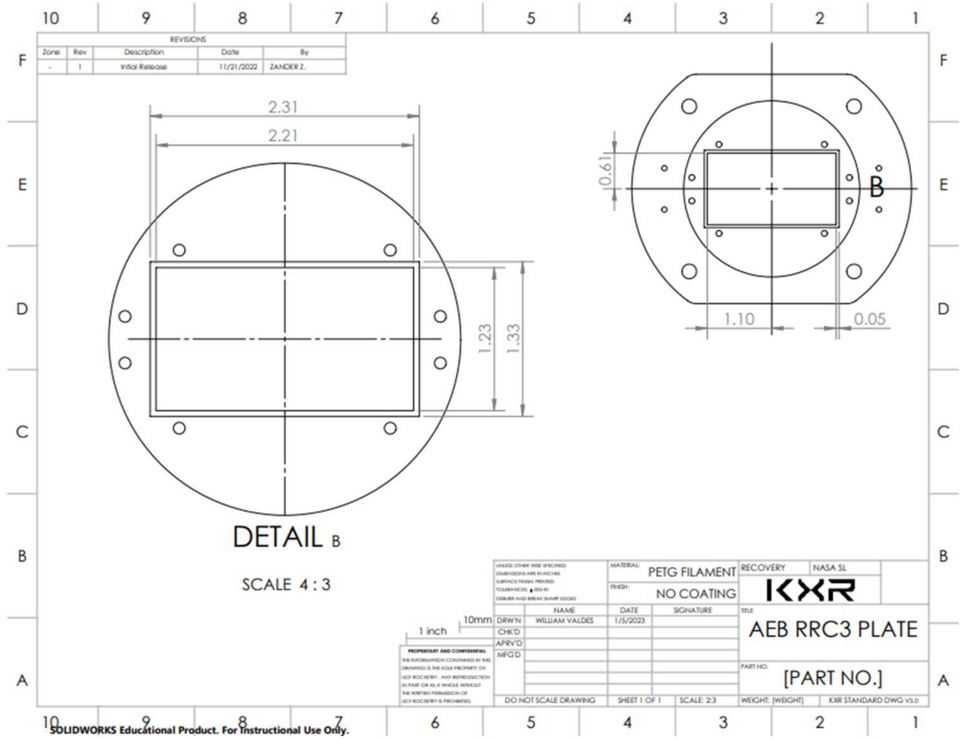


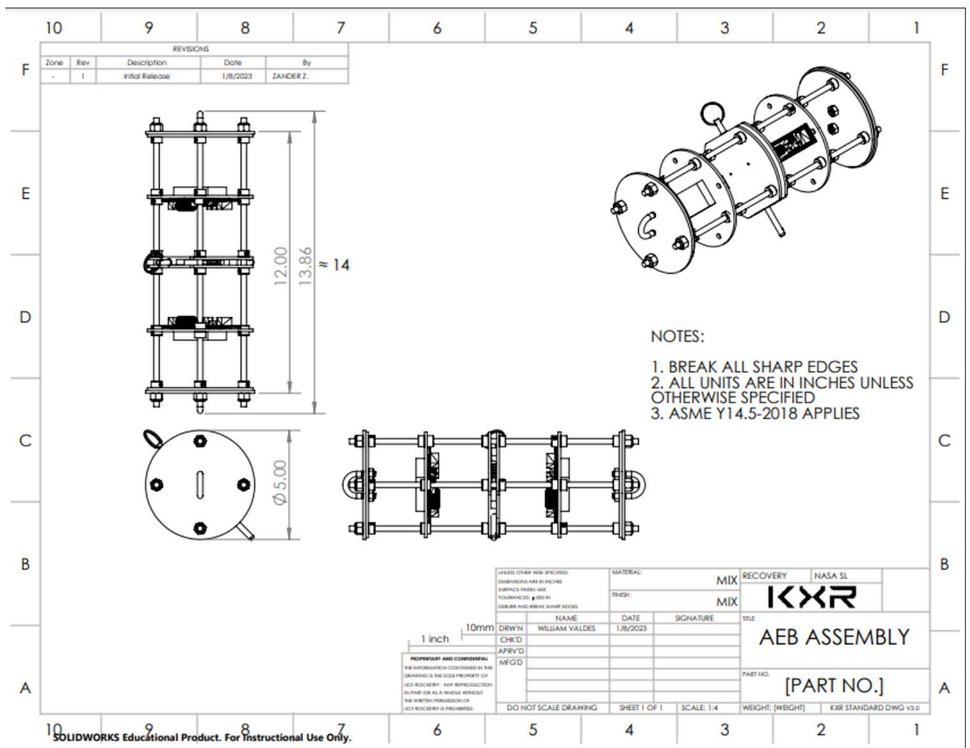

FRONT
BACK
12X Ø0.100 THRU
4X Ø0.250 THRU
NOTES:
1. BREAK ALL SHARP EDGES
2. ALL UNITS ARE IN INCHES UNLESS OTHERWISE SPECIFIED
3. ASME Y14.5-2018 APPLIES
4. PRINT IN PETG OR SIMILAR PLASTIC
SECTION A-A
PETG FILAMENT
NO COATING
RECOVERY
NASA SL
WILLIAM VALDES
1/4/2023
AEB STRATOLOGGER PLATE
[PART NO.]
DO NOT SCALE DRAWING
SHEET 1 OF 1
SCALE: 2:3
SOLIDWORKS Educational Product. For Instructional Use Only.


FRONT
DETAIL B
SCALE 4 : 3
PETG FILAMENT
NO COATING
RECOVERY
NASA SL
WILLIAM VALDES
1/5/2023
AEB STARTOLOGGER PLATE
[PART NO.]
DO NOT SCALE DRAWING
SHEET 1 OF 1
SCALE: 2:3
SOLIDWORKS Educational Product. For Instructional Use Only.


DETAIL D
SCALE 4 : 3
BACK
AEB STRATOLOGGER PLATE
PETG FILAMENT
NO COATING
WILLIAM VALDES
1/5/2023
[PART NO.]
SOLIDWORKS Educational Product. For Instructional Use Only.


4X Ø .25 THRU ALL
4X Ø .09 THRU ALL
8X Ø .10 THRU ALL
FRONT
BACK
SECTION A-A
NOTES:
1. BREAK ALL SHARP EDGES
2. ALL UNITS ARE IN INCHES UNLESS OTHERWISE SPECIFIED
3. ASME Y14.5-2018 APPLIES
4. PRINT IN PETG OR SIMILAR PLASTIC
AEB RRC3 PLATE
PETG FILAMENT
NO COATING
WILLIAM VALDES
1/4/2023
[PART NO.]
SOLIDWORKS Educational Product. For Instructional Use Only.


REVISIONS
Initial Release
11/21/2022
ZANDER Z.
2.31
2.21
0.61
1.10
0.05
1.23
1.33
DETAIL B
SCALE 4 : 3
PETG FILAMENT
NO COATING
RECOVERY
NASA SL
KXR
WILLIAM VALDES
1/5/2023
AEB RRC3 PLATE
[PART NO.]
DO NOT SCALE DRAWING
SHEET 1 OF 1
SCALE: 2:3
SOLIDWORKS Educational Product. For Instructional Use Only.


REVISIONS
Initial Release
1/8/2023
ZANDER Z.
12.00
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Ø5.00
NOTES:
1. BREAK ALL SHARP EDGES
2. ALL UNITS ARE IN INCHES UNLESS OTHERWISE SPECIFIED
3. ASME Y14.5-2018 APPLIES
MIX
MIX
RECOVERY
NASA SL
KXR
WILLIAM VALDES
1/8/2023
AEB ASSEMBLY
[PART NO.]
DO NOT SCALE DRAWING
SHEET 1 OF 1
SCALE: 1:4
SOLIDWORKS Educational Product. For Instructional Use Only.

		RATINGS	
Criterion	Weight	Vertical	Horizontal
Orientation	5	5	4
Weight	4	3	5
Efficiency	3	5	5
Ease of Use	3	2	4
Total		58	67

3.3.2 Parachutes and Attachment Hardware

3.3.2.1 Parachute Choices

By doing multiple iterations in OpenRocket, we found that 7 ft. diameter Rocketman's Parabolic Nylon Parachute was the best main parachute to use because it provided the most desirable ground hit velocity speed of approximately 21.3 ft/s. Also, we chose an 1 ft. diameter Rocketman's Parabolic Nylon Parachute for the drogue parachute because it provided enough drag for the rocket to slow it down for a safe main parachute deployment. However, based on the simulations, the velocity at main parachute deployment was 143 ft/s which would lead to parachute deployment. Unfortunately, OpenRocket does not take the tumbling of the rocket into account when making these approximations so realistically, the velocity at deployment should be much lower than shown in the simulations. With these two parachutes, we were able to achieve an approximate descent time of 72.38 seconds which is almost ideal for our rocket. It will not drift that far but it will also come down on the ground with an appropriate, safe speed.

3.3.2.2 Attachment Hardware and Heat Shielding

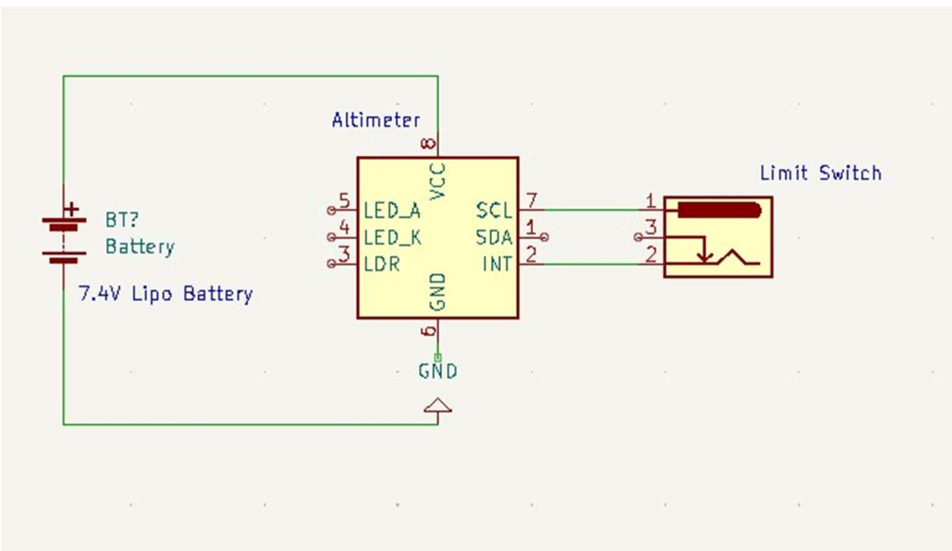
The parachute will have a quick link attached to the end of it and this will be used to attach the shock cord to the bulkhead. The bulkhead will have a U-bolt so that the forces can be divided between the two bases of the U-bolt instead of an I-bolt where the force will be concentrated in one area. A fire-retardant blanket, specifically named Nomex Blanket, will be attached on the shock cord a few feet away from the parachute to avoid any possible tangling and also to protect the parachute from burning due to the black powder charges.

3.3.3 Electrical System and Schematics

3.3.3.1 Electrical Components and Redundancy

For redundancy, our electrical system for recovery has two systems that consist of a 7.4 V LiPo battery, an altimeter, and a limit switch. This way, our recovery system will have an increased chance of arming and deploying at the right time. For redundancy, we have also used both RRC3 and Stratologger altimeters to also increase our redundancy in arming the system.

3.3.3.2 Wiring Diagram (Schematics)



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3.3.4 Ejection Charge Sizing and Airframe Pressurization

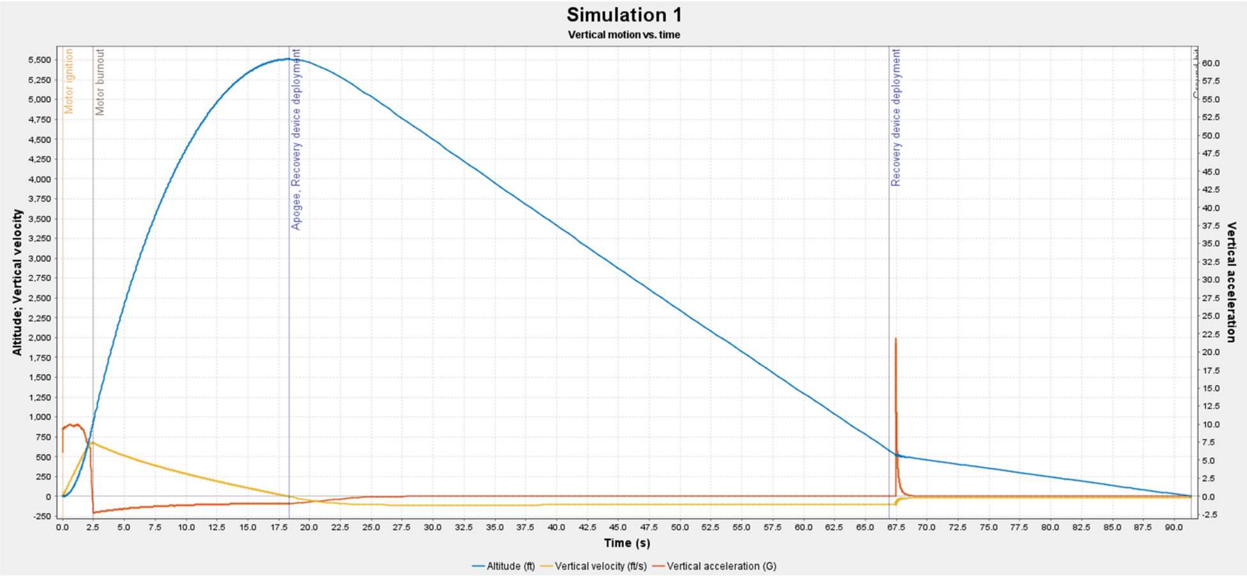
$$Grams(BP) = \frac{454\ g}{1\ lbf} \cdot \frac{Pr\,e\ ssure(psi\ ) \cdot Volume(inches^3)}{206\ \frac{inches \cdot lbf}{lbm} \cdot 3307\ °R}$$

In the avionics bay there will be two charge wells per parachute a primary and a backup, we calculated these wells to hold 3.9 grams for the main parachute and 1.5 grams for the Droge chute for the primary charge, as well as the redundant charges to be 5.1 grams and 2.1 grams. We found our redundant charge mass by increasing the shear force by 50%. After some testing we found that the main charges of 3.9 and 1.5 were not sufficient so we upped both to be the redundant mass and kept the redundant charges for the failure of the e match as compared to just not being enough force. Black Powder was chosen because it is light weight, reliable, inexpensive, and easy to get. FFFFg powder was the specific black powder that was chosen due to its fast burn rate which causes our charge wells to obtain a higher pressure.

3.4 Mission Performance Predictions

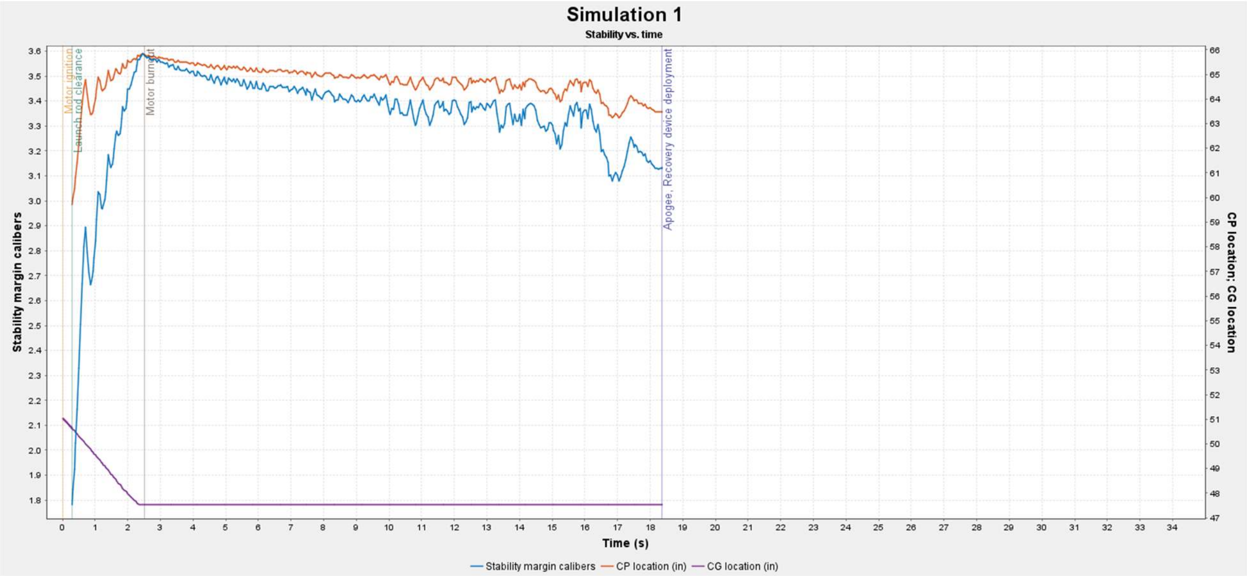
3.4.1 Trajectory Analysis

3.4.1.1 OpenRocket Simulations



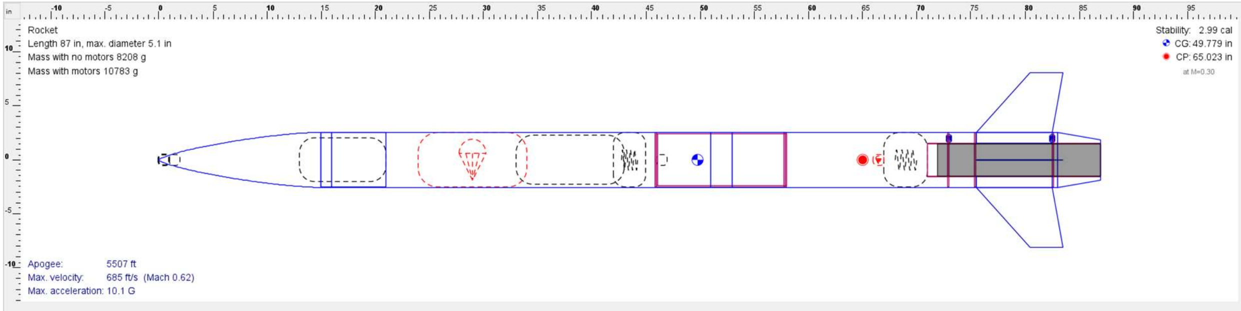
3.4.2 Vehicle Characteristics

3.4.2.1 Stability vs Time



OpenRocket Stability vs Time Simulation of Ideal Case

3.4.2.1.1 OpenRocket

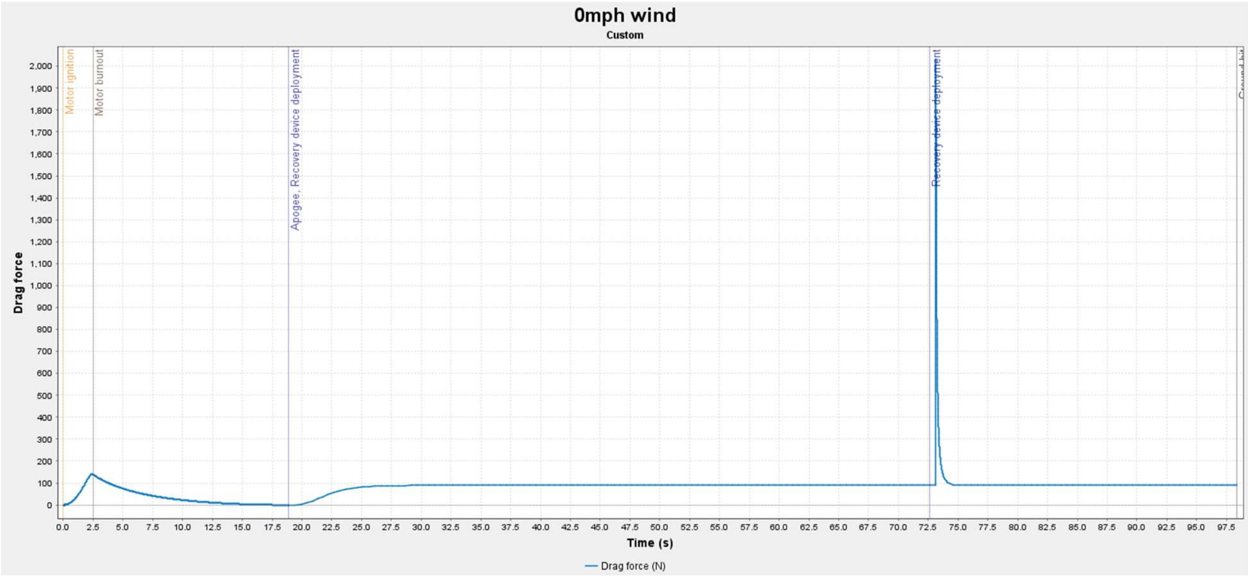


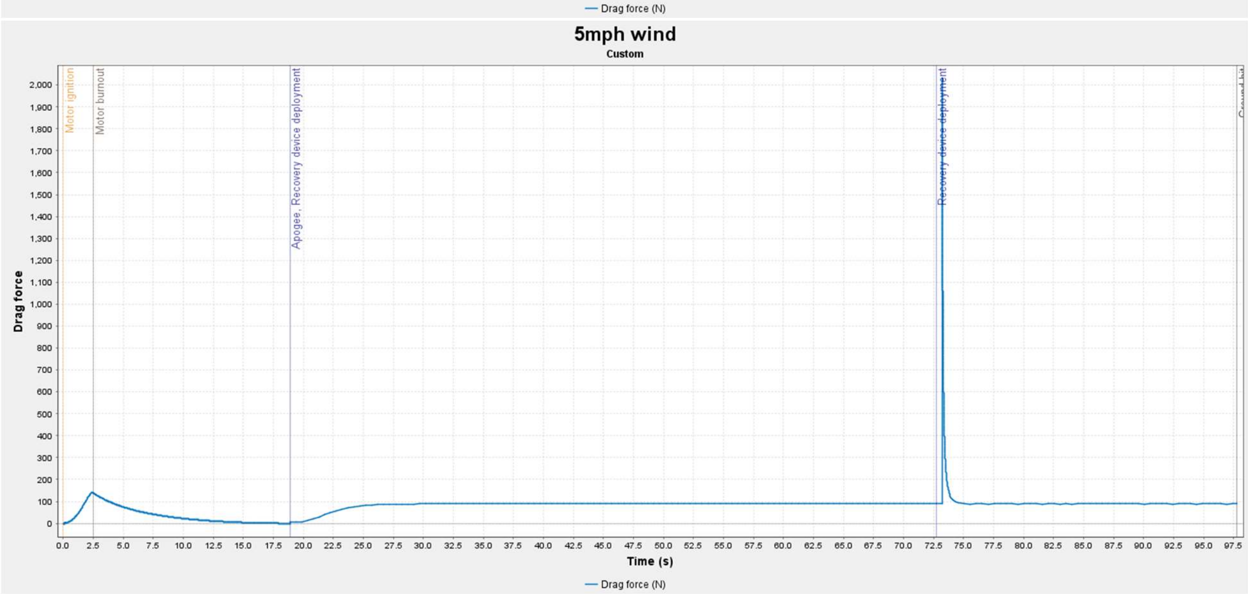
OpenRocket full vehicle design by parts

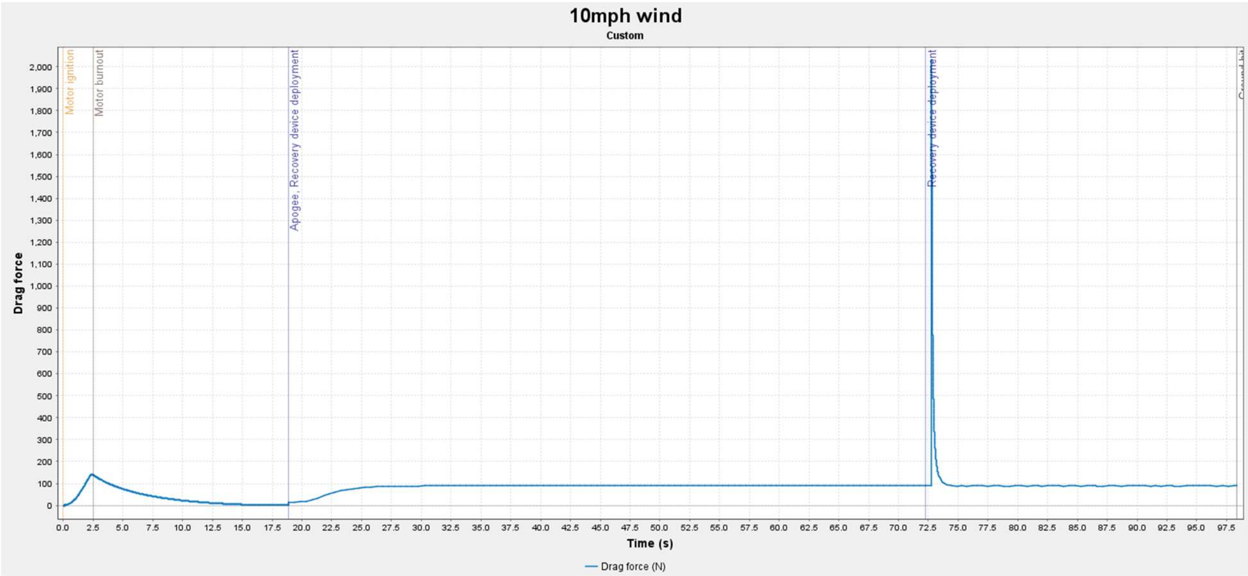
The OpenRocket simulations regarding stability and time at Huntsville, Alabama describe that the rocket will start with an expected stability margin of 2 cals off the launch rail, which measures 144”, also maintaining the requirement of two calibers. When running the simulation regarding the Stability vs. Time of an ideal case within OpenRocket, the stability of the rocket increases significantly within the first few seconds of launch because there is less mass near the aft end. Both drag and gravity cause the rocket to begin once it hits apogee, and thus, the stability of the rocket begins to decrease exponentially as well. However, throughout the entirety of the rocket’s ascent and descent, it remains over 2 Cals.

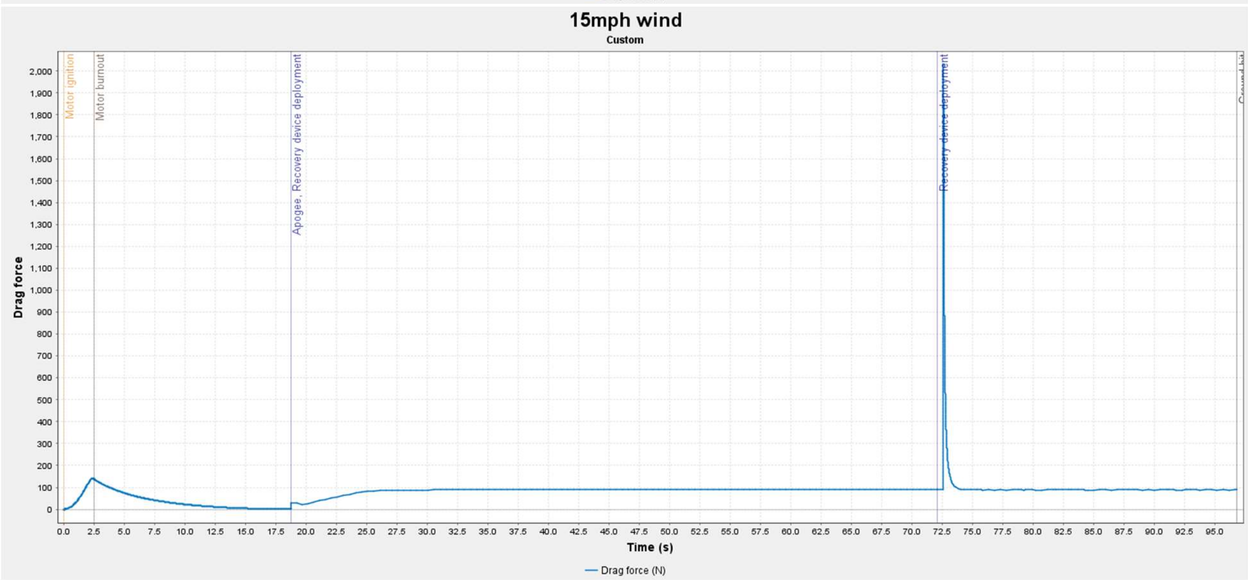
In regard to both the center of gravity (CG) and the center of pressure (CP), within the entirety of the simulation, they remain secure. The center of gravity (CG) is the point at which the entire weight of the system may be concentrated.

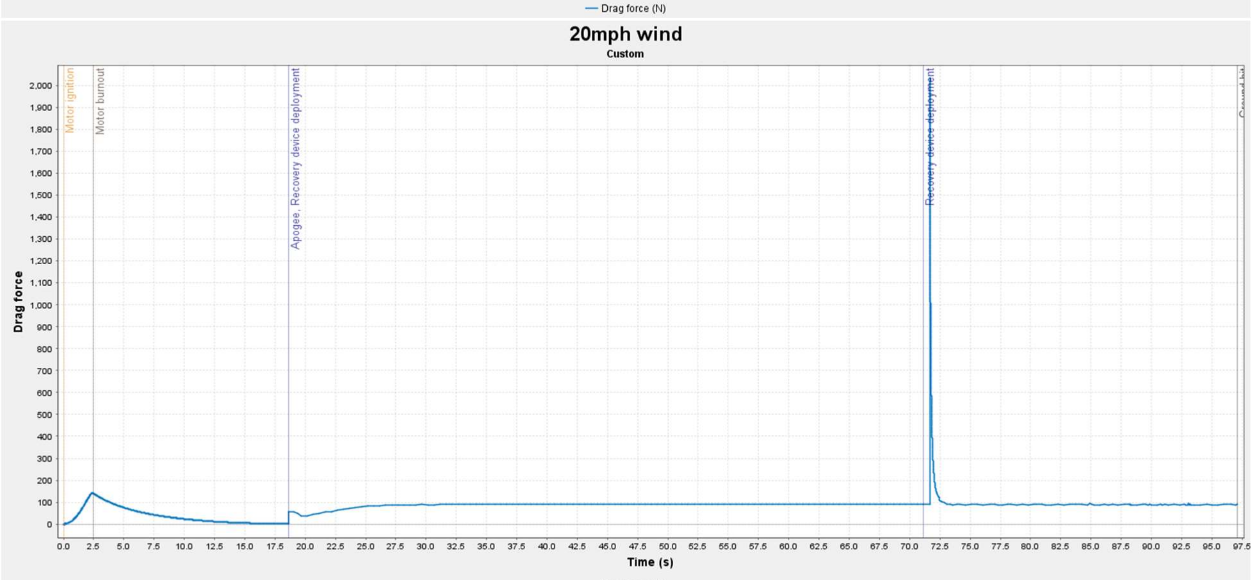
3.4.2.2 Drag vs Time






10mph wind
Custom
Motor ignition
Motor burnout
Apogee, Recovery device deployment
Recovery device deployment
Drag force
Time (s)
Drag force (N)

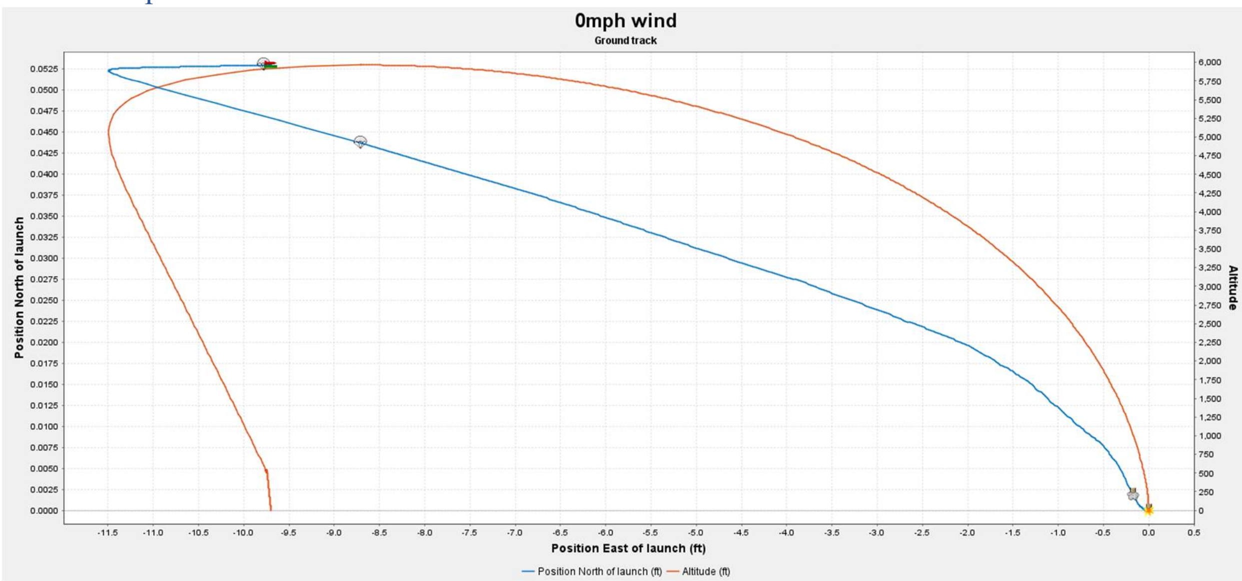

15mph wind
Custom
Motor ignition
Motor burnout
Apogee, Recovery device deployment
Recovery device deployment
Drag force
Time (s)
Drag force (N)

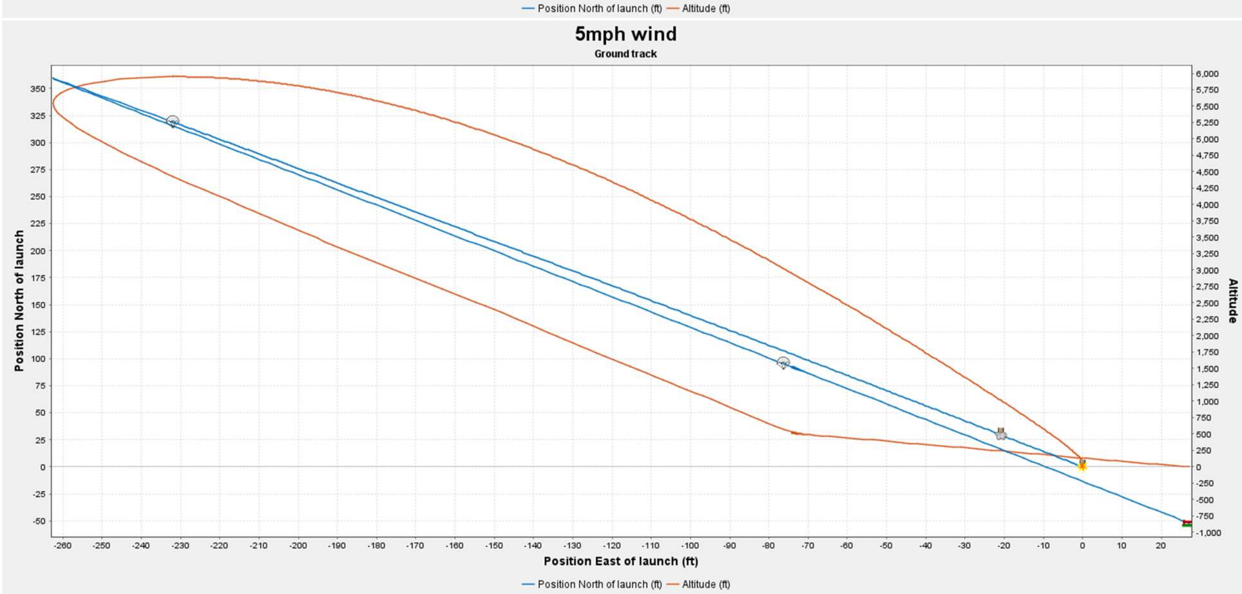

20mph wind
Custom
Motor ignition
Motor burnout
Apogee, Recovery device deployment
Recovery device deployment
Drag force
Time (s)
Drag force (N)

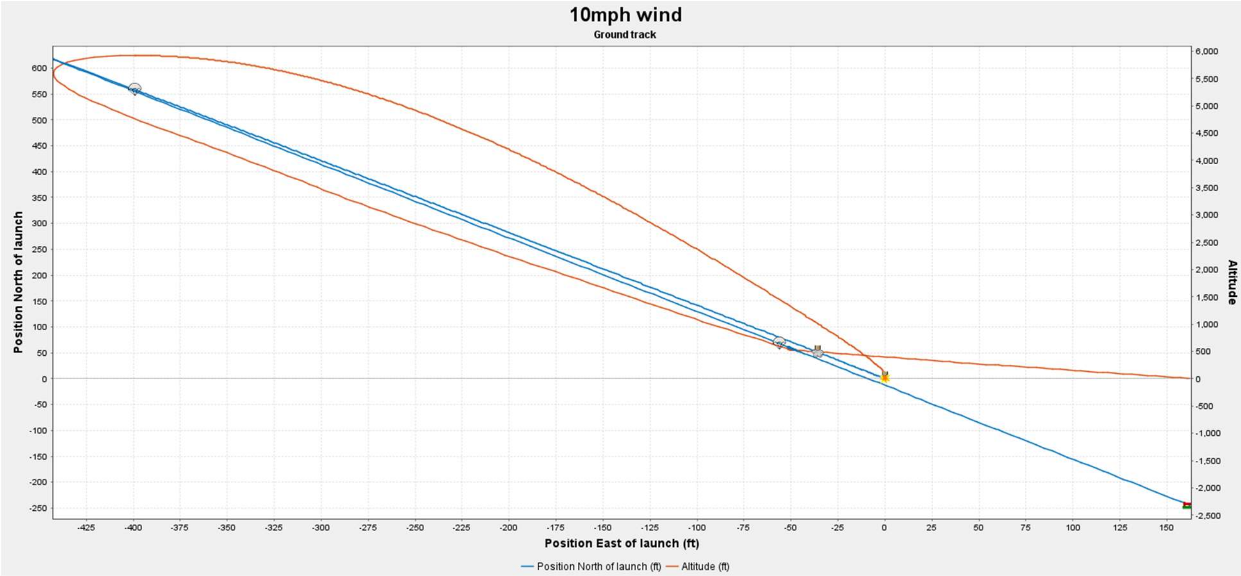
As you can see above In all five cases the drag force on the rocket stays about 140 N no matter what the wind speed is at. This is because the max speed of the rocket is much higher than the max speed of the wind so there is little effect on the drag force.

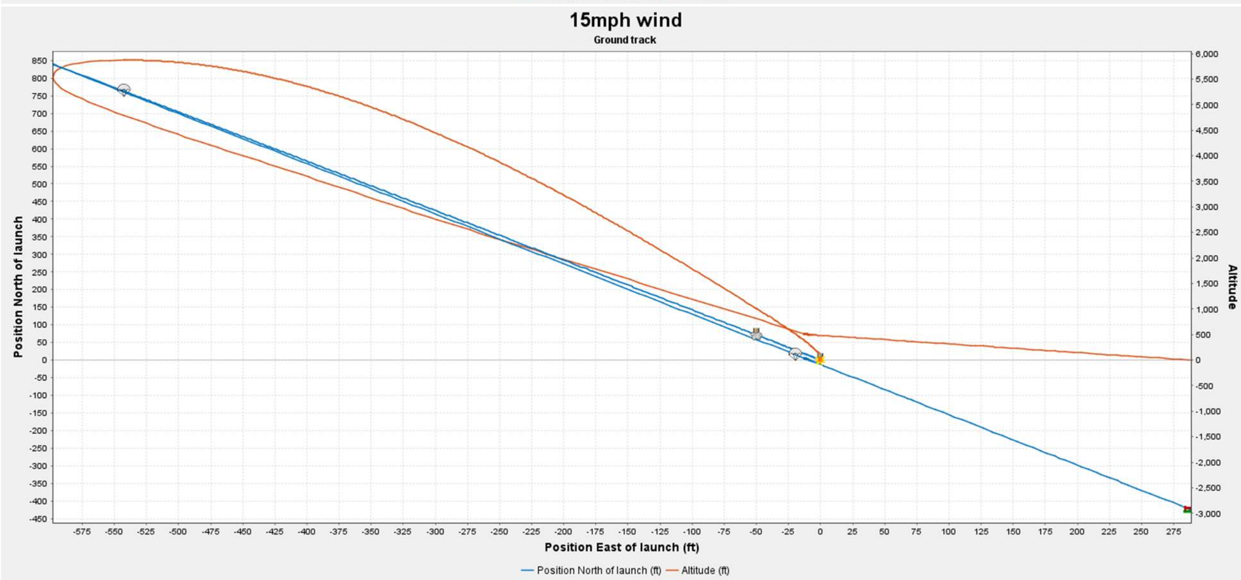
3.4.2.3 Drift Distance Estimations and Hand Calculations

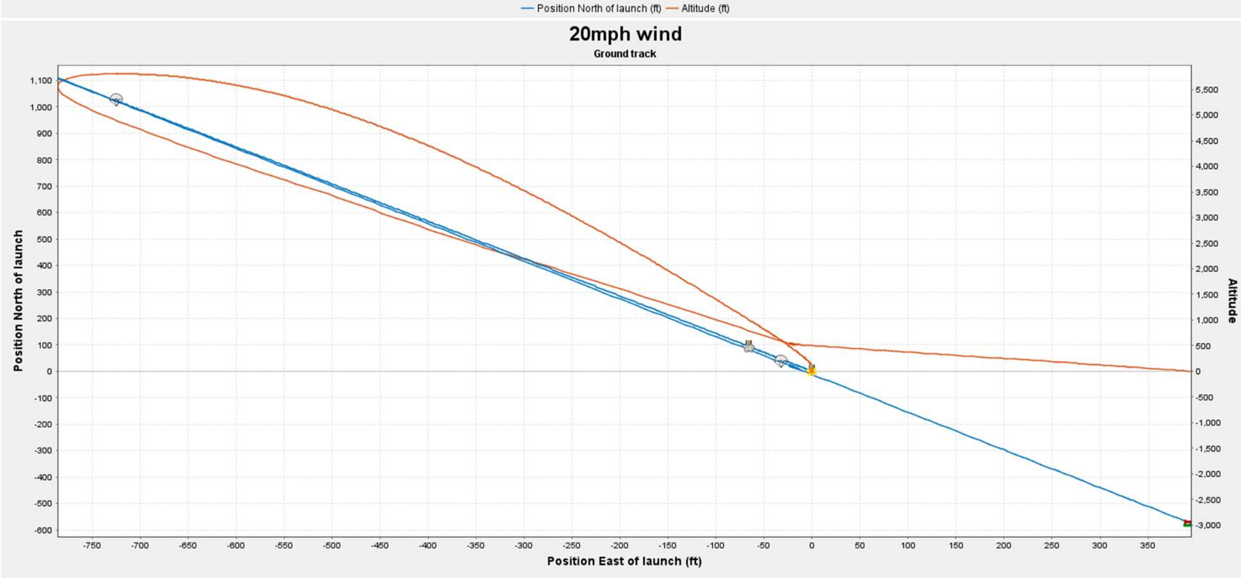
3.4.2.3.1 OpenRocket Drift Calculations






10mph wind
Ground track
Position North of launch
Position East of launch (ft)
Altitude
Position North of launch (ft)
Altitude (ft)


15mph wind
Ground track
Position North of launch
Position East of launch (ft)
Altitude
Position North of launch (ft)
Altitude (ft)


20mph wind
Ground track
Position North of launch
Position East of launch (ft)
Altitude
Position North of launch (ft)
Altitude (ft)

As you can see above these are our different drift calculations based on different wind speeds with a launch angle set at 0 degrees. With no wind we would only drift by about ten feet from the launch pad. The worst case would be at 20mph which the max drift would be about 400 feet east of the launch pad and about 575 feet south of the launch pad.

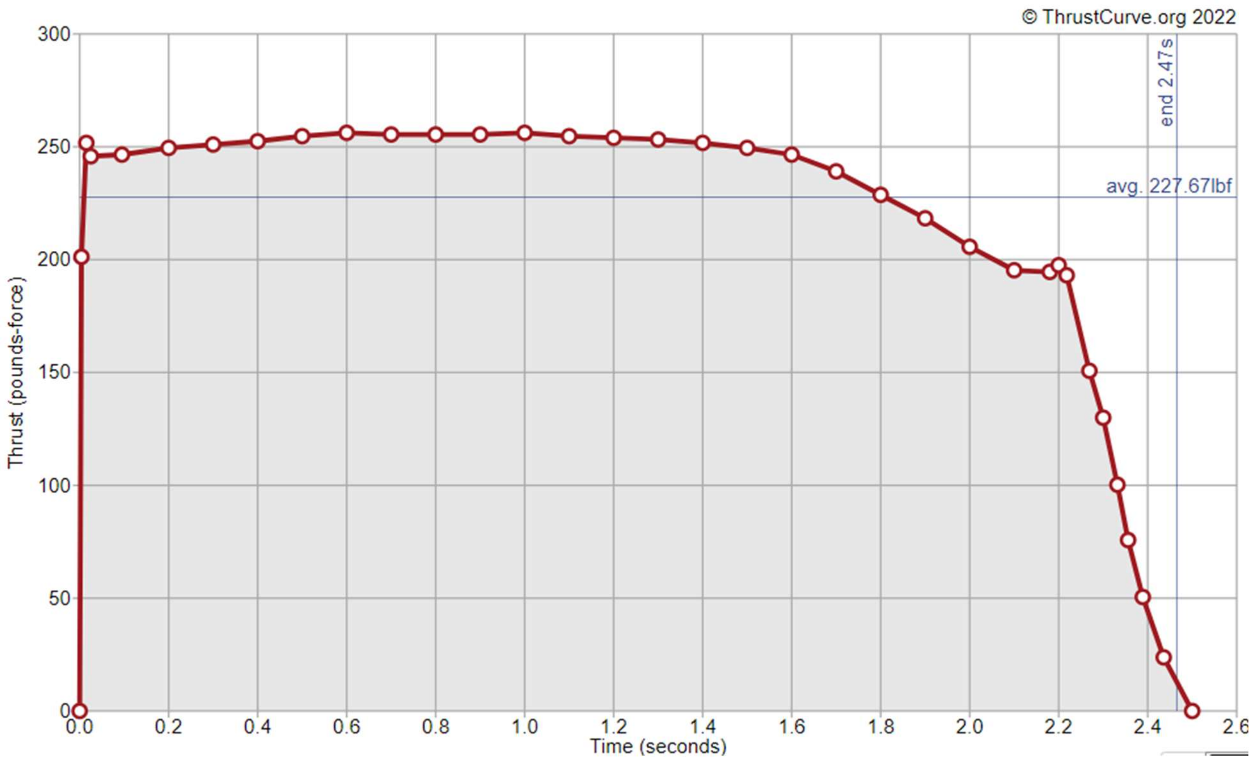
3.4.2.3.2 Hand-Calculations

To calculate the drift we used the formula $D = t * V * \sin(\theta)$. In the equation, D represents drift distance, t represents descent time, V represents windspeed and $\sin(\theta)$ represents the horizontal component of the windspeed referencing the launch angle θ. Using a descent time of 79.49 seconds and windspeed of 29.33 ft/s with a launch angle of 90 degrees we get a drift of 2331.44 feet. The max drift is within our requirement of 2500 feet.

3.4.3 Motor Characteristics

The motor we have chosen for this years project is the Aerotech K1000T. We decided to go with the K1000T due to the fact that it is a high thrust motor. We needed to go with a high thrust motor because we wanted to make sure our velocity off the rail was high enough to ensure a safe and stable flight.

Aerotech K1000T	
Total Impulse	2511.5 Ns
Burn Time	2.4 s
Max Thrust	376.33 lbf
Propellant	Blue Thunder



3.4.3.1 Thrust-to-Weight Verification

The expected max weight of our rocket is 22.558 lbs. When the rocket leaves the launch rail, the motor will have a thrust of 249.36 lbf. The minimum thrust to weight we must have is 5:1, with a weight of lbs and a thrust of 249.36 lbf our thrust to weight ratio is 11:1. We are well above the requirement of a minimum of 5:1 thrust to weight ratio.

3.4.4 Kinetic Landing Energy

Kinetic Energy Under Drogue			
Section 1: 620.122 ft-lbf		Section 2: 2672.31 ft-lbf	
Kinetic Energy Upon Landing			
Section 1: 25.58 ft-lbf	Section 2: 40.85 ft-lbf	Section 3: 24.59 ft-lbf	Section 4: 15.84 ft-lbf

As you can see above the heaviest section, which is section 2 stays under the maximum requirement of 75 ft-lbf.

3.5 Subscale Ground Test

3.5.1 Purpose

The purpose of the ground testing procedure for the subscale rocket is to ensure that all recovery components are functioning well and to determine the amount of black powder needed for appropriate body tube separation.

3.5.2 Safety Precautions

To ensure a safe procedure, a detonator as well as cover was used when activating the e-match to deploy both the drogue and main. The individual detonating the black powder was instructed to be at least 2 yards away from the rocket behind cover. Another individual was on standby with a fire extinguisher 4 yards away from the rocket in case of emergency. If there was a misfire, the team was instructed to wait 5 minutes before approaching the rocket with proper safety equipment to assess the situation. The test was supervised by team leads and managers to ensure safety standards were being followed.

3.5.3 Analysis

3.5.3.1 Drogue Analysis

During the tests for the drogue deployment, 0.5 grams of black powder was used for separation. After 2 misfires, the third test proved successful. Misfires were due to the e-match not being set up correctly. After deployment, the team agreed to 0.55 grams of black powder to ensure deployment.

3.5.3.1 Main Analysis

During the tests for the main deployment, 0.5 grams of black powder was used for separation. The first test proved successful. After deployment, the team agreed to 0.55 grams of black powder to ensure deployment.

4 Payload

4.1 Design and Verification

4.1.1 System Overview

The payload system has three main responsibilities. First, is the actual Experiments, in our case, the Payload Integrated Launch Log (PILL), made to meet the Experiments requirements in the NASA SL handbook. Secondly, is Telemetry, which controls promotional video and live video feed in tandem with the ground station sub-system. Lastly, the Payloads system is also to provide aid regarding the COTS altimeters used by the Vehicle Design's Recovery sub-system.

4.1.2 Sub-System Overview

4.1.2.1 Experiments Sub-System

The experiments sub-system is dedicated to fulfilling NASA's Payload Experiment requirements. Our experiment payload, dubbed the P.I.L.L. (Payload Integrated Launch Log), is a self-contained autonomous camera system capable of receiving RF commands from NASA and recording images upon landing. The experiments sub-system contains an outer casing, electronics sled, batteries, microcontroller, camera, radio module, antenna, real-time clock module, and a linear elevator mechanism. The secondary payload – the run cam split – remains out of the scope of the experiments sub-system as it is purely dedicated to meeting the experimental requirements dedicated in the Student Launch handbook and is independent of extraneous goals set by our USLI team.

4.1.2.2 Telemetry Sub-System

The goal of the Telemetry Sub-Systems is to develop proper procedures and techniques that can be utilized in future KXR Nasa SL applications. Our Telemetry Bay, dubbed the ATTSAB (Asclepius Triangular Triple Sled Avionics Bay) serves the purpose of gathering live data throughout flight and analyzing the current stage of flight. Following this, live transmission of this gathered data will be transmitted to the ground station using RF transmitters and LoRa satellites. This data will then be analyzed by an operator to ensure nominal flight. This will be achieved by integrating multiple components including a microcontroller, IMU, Barometer, RF Transceiver, GPS module, SD card, and LiPo batteries all housed on a custom PCB.

4.1.2.3 Ground Station Sub-System

The goal of the ground station-subsystem is to create a live controllable interface for the flight computer onboard the Asclepius. Communication will occur between two independent interfaces. The components utilized in the sub-system interfaces are the LoRa modules, antennas, the ESP-32 microcontrollers, and a laptop as live display for the ground station. As data is sent through the LoRa transmissions the controller can interpret and monitor the data live.

4.1.3 Manufacturing Plan

4.1.3.1 Experiments Manufacturing Plan

The experimental payload (PILL) consists of an outer casing, an electronics sled, a linear elevator mechanism, and electronic components. The outer casing will consist of three sections. Each section will be created by a fused filament fabrication (FFF) 3D printer using polycarbonate filament. 3D printers will be provided by the UCF Innovation Lab. After printing, the surface of the outer casing will be coated with impact-resistant epoxy. The three sections of the outer casing will overlap to form gaps for rows of 5mm steel balls, making a bearing interface. These balls will be inserted through a hole in the outer casing wall, which will subsequently be closed off with a grub screw. The outer casing will feature endcaps held in place by screws and interlocking tabs. One endcap will be removable, while the other will be glued in place and have a U-bolt mounted to it. This U-bolt will be used to attach the payload to the shock cord.

The internals of the PILL will be fastened to an electronics sled inserted via the removable endcap. This sled will be 3D printed using PETG filament. The electronics sled will feature mounting holes for all electrical components, which will be secured with machine screws and rubber standoffs to reduce vibrations. All electronic components will be Commercial Off-The-Shelf (COTS) products, including a Raspberry Pi, a Pi camera and lens, a servo motor, a real-time clock module, a battery hat, a radio dongle, and an antenna. The linear elevator mechanism will also be attached to the electronics sled. The center section of the PILL will feature a hatch that will be held in place by a rubber seal until it is pushed open by the linear elevator. Code for the electronic components will be written entirely in Python due to its syntax and ease of use. OpenCV (Open Computer Vision) will be utilized for vision processing. An initial functional prototype of the experimental payload is expected to be completed in early 2023. This prototype will be subjected to various testing, including drop tests, longevity tests, and functionality tests.

As for the epoxy coating which adorns the PILL, we recognized the PILL's atypical shape would make it difficult for the resin to bond to it. Thus, we decided to outsource the manufacturing of the Resin to the Research I Pavilion at the University of Central Florida. The facility houses a vacuum-forming machine that not only would create an exact mold of our payload, but it would allow our team to fasten the epoxy around every corner of the body. Utilizing this method mitigates any weak points the body might acquire from not having the epoxy completely cover the payload.

4.1.3.2 Telemetry Manufacturing Plan

The telemetry manufacturing plan involves effectively testing and assembling all components for the flight computer. This involves troubleshooting and testing each component's efficiency. Therefore, leading us to finalize the components used. During the manufacturing period, a PCB will be developed for the final flight computer. All final components will be integrated and assembled for a final assembly. Assembly for this will require soldering. Before doing any soldering, safety will be emphasized for any participating member through reference to the soldering procedures. The timeline of the overall manufacturing plan involves starting testing once components are shipped in November and having the finalized flight computer ready to go by March. This leaves us with enough time to prepare for the competition in April.

4.1.3.2.1 Component Testing

It is necessary that each individual sensor that is used within the telemetry system provides consistent and accurate data. To achieve this goal, we tested each sensor in an environment that is easily set to a constant value that can be verified by an external resource, or by testing multiple sensors of equal quality in the same environment. Specifically, the accuracy of the BMP 280 Barometer was ensured by setting the local pressure at sea level, gathered at the location of the launch site from the national weather service, this allows for altitude offset due to a difference in pressure and ensures accurate altitude measurements. The BNO085 is an electromechanical sensor so calibration is only needed in the case of large magnetic fields surrounding the sensor, which does not apply. We ensure that the accelerometer reads the force of gravity in each direction at .98G and manually ensure that the gyroscope accurately measures degrees using a protractor. The transceivers are tested by sending test codes through the desired frequency and ensuring that it is received on the other end

4.1.3.2.2 Final Assembly Procedure

In order to efficiently connect all components, a wire diagram was created. The components used in the final assembly of the subscale perfboard were the ESP-32 microcontroller, BMP280 barometer, BNO 085, and the Micro SD card. Prior to soldering any components, safety was emphasized. All participating members were ensured to have a full understanding of soldering safety such as not touching the iron and keeping a fan on. All components had header pins soldered into their ports to be soldered onto the the perfboard, with the proper connections to each of the components. Per each soldered component, a multimeter was utilized to ensure all connections had continuity. Upon completing all connections, the flight computer was tested in its finalized form.

4.1.3.3.3 Telemetry Manufacturing Plan

Finalizing Subscale Flight Computer	*January 18, 2023*
Developing PCB draft	*January 18, 2023*
Second Subscale Flight	*January 19, 2023*
Ordering last components and ground station equipment	*February 1, 2023*
Ordering PCB	*February 5, 2023*
Testing all Ground Station Equipment	*February 15, 2023*
Testing all final Flight Computer Components	*February 20, 2023*
FInalizing Flight Computer	*March 12, 2023*
Integrating Ground Station	*March 12, 2023*

4.1.3.3 Ground Station Manufacturing Plan

4.2 Science Value

4.2.1 Science Payload Objective

The Payload System has three main objectives. The primary payload consists of an outer casing, electronics sled, linear elevator, and a 3:2:1 gear ratio camera-motor system. The science payload's objective is to be able to receive RAFCO commands that will be sent out by the NASA SL ground station, then upon landing perform said commands. The execution consists of maneuvering the camera system 360 degrees about the z-axis, changing filters, and saving time stamped images to be later presented in the PLAR. Finally, the science payload must be recoverable and able to re-launch without issues. The secondary objective includes collection of data and tracking of flight milestones. Within the avionics bay there is a custom flight computer consisting of an accelerometer, gyroscope, and barometer. The avionics bay will record and store flight data as well as video; similarly, a COTS GPS would be used to locate the rocket after flight. Lastly, the Payload system's last objective is the recovery of the rocket. A dual-deployment system would serve to deploy a drogue parachute, deploy the main parachute, and help the PILL escape the upper tube – although listed under aerostructures, the actual COTS altimeters will be wired and set up by the payloads system.

A separate objective exists for the sake of promotional material. Although all STEM engagement requirements will be fulfilled by the launch date, we saw it fit to continue with our USLI team's social media objective. The secondary payload – a Run Cam Split – will be used to record said promotional material which will fall under the care of the Telemetry system. If deemed possible, as well as supported by public interest, we will also attempt to record live video of the launch – however, as we'd need to register another transmitter, this remains only a possibility and is currently keep as a static recording system.

4.2.2 Payload Success Criteria

In order to consider our Payload successful, we must meet the requirements outlined in the NASA Student Launch Handbook. Our payload must land safely upon impact with the ground and self-orient itself parallel to the horizon; promptly, the camera must be able to rotate about the z-axis.

Our Payload system will achieve this using a polycarbonate rolling cage that is split into two larger sections and one smaller section that are lined with ball bearings in between each section. The camera will spin using a 3:2:1 geared Servo system and will be pushed out of the polycarbonate outer casing rolling cage through a linear elevator. Certain specifics regarding hardware must be met: FOV, accepting RAFCO, etc.

Additional self-imposed requirements must also be met to consider the payload system successful. This includes live telemetry, flight renders, video recording, and more.

Sub-System	Requirement ID	Success Criteria	Status
Experiments	4.2.11.	Camera capable of rotating about the z-axis	Incomplete
Experiments	4.2.1.2.	Camera has a FOV within 100 to 180 degrees	Incomplete

Experiments	4.2.1.3.	All images taken shall have visible time stamps	Incomplete
Telemetry	4.2.1.4.	Camera must execute commands with a maximum of 30 seconds between commands	Incomplete
Telemetry	4.2.2.	Potential commands are able to be conducted in any and all orders	Incomplete
Telemetry	4.2.3.3.	Payload system shall not initiate RAFCO commands before launch	Incomplete
Experiments	4.2.4.	Payload is not jettisoned	Incomplete
Telemetry	4.2.5.	Sequence of time-stamped photos is presented in correct order Post-Launch Assessment	Incomplete
All	4.3.2.	All FAR and NAA rules and regulations are followed	Incomplete
Telemetry	Self-imposed	Flight Video Recorded	Incomplete
Telemetry/GS	Self-imposed	Live Telemetry	Incomplete

This list is not tentative, but only indicative of the goals we deemed most important as a measure of our own success. A more tentative general list can be found in section 6 Project Plan.

4.2.3 Experimental Logic, Approach, and Method of Investigation

According to the requirements, we were to design an experiment that takes a picture parallel to the horizon and saves it to a SD card. The method of control would be utilizing received radio frequencies to manipulate the image and/or camera. Our approach, which will be referred to as the "PILL", utilizes a gravity-based orientation mechanism to allow for the camera's complete alignment with the horizon. In the design, we will be utilizing a lead screw mechanism to maintain complete, stable control of the camera in all cases. Experimentally, we modelled multiple iterations of the PILL to find the best compromise between clarity and stability. In the first iteration we had the entire electromechanical system on the interior of a 4" polycarbonate tube. This design had an inherent height issue which forced us to redesign the entire PILL leading to the lead screw mechanism to raise the camera mount to any desired height. The most recent design has a captured polycarbonate tube that is suspended using bearings to allow for independent rotation on the ground.

4.2.3.1 Experiments Deliverables

Our experiments system is focused on creating a payload that can operate autonomously once landing, that can take and edit photos from an onboard camera based on RAFCO radio commands – requirement 4.1 and 4.2. Because it's a main part of the mission, we decided to name this part of the payload the "PILL." Although the PILL will not be flown in the vehicle demonstration flight, extensive ground testing shall be conducted to ensure payload effectiveness; however, a weighted simulant will be flown in the location of the PILL as described by section 2.19.1.3.1. To fulfill the RAFCO requirements, the interior of the PILL will contain our radio antenna that will forward the radio signals to our Raspberry Pi 4b, and initialize our mechanism to raise the camera outside of the casing and to rotate it 360 degrees. The Raspberry Pi will receive signals from NASA, rotate the servo, and capture images. In addition, the Pi will also be able to apply filters to the image, change the camera color mode, add time stamps, and rotate the image. Finally, the sequence of photos the camera takes will be stored on a microSD card until the PLAR and presented in the order of radio commands received.

4.2.3.2 Telemetry Deliverables

The telemetry sub-system is aimed at developing a flight computer that can collect data throughout the course of the flight. This data will include GPS, velocity, altitude, acceleration, and pressure. This data will be logged onto two independent storage cards and reported back to students on the ground. From this we can then interpret the data and create models of the flight profile in programs like MATLAB. The end goal upon testing and refining the final flight computer is for the development of aerobrakes for the 2023/2024 NASA student launch team.

4.2.3.3 Ground Station Deliverables

The function of the ground station is to act as a live controllable interface for the onboard flight computer and a real-time data interpreting interface. The ground station will be able to send commands to the flight computer to initiate the pre-flight launch mode where GPS will lock onto satellites, and the IMU data feed will initiate and begin to monitor for launch. The commands will be monitored through a display interface that will visually inform operators of the current launch status. The ground station will also feed the live data into storage, however, due to possible data loss from RF interference this live data feed will only be used supplementary in scenarios where onboard data recovery is not viable, or there is a system malfunction.

4.2.4 Testing and Calibration Measurements

4.2.4.1 AEB Testing and Calibration

We have performed both practical and theoretical tests on the recovery system and it has performed consistently well in both categories.

As for theoretical tests, the AEB has been fully modeled in SolidWorks with the proper hardware dimensions to confirm that internal components will fit properly in the assembly. The full model has also been put into the CAD for the Full-scale rocket to confirm the fit within the coupler. Secondly, we have performed finite element analysis on the rods and plates that make up the structure of the AEB. The rods sufficiently resist torsion forces and do not deform significantly. The plates with the U-bolts which are used to tie in the shock cord also perform well in FEA. Finally, hand calculations were performed to determine the shock force during deployment for both drogue and main, and the U-bolts have been chosen accordingly.

For practical tests, we have performed both a ground test and a flight test in our subscale rocket. For the ground tests, we simply connected electrical matches to our black powder charge wells, then connected the matches via wires to a battery. This was done in order to check our calculations of the proper amount of black powder for complete separation of both sections. The first test of the drogue charge was unsuccessful, so the black powder was increased from 0.3 grams to 0.5 grams. The second test for drogue separation was successful. After testing the main, black powder charges were increased proportionally for the same reason. On December 17th we launched the subscale model of the rocket which contained the previously tested black powder charges, this time wired to the recovery avionics chosen for the AEB and programmed to ignite at the proper altitudes.

4.2.4.2 ATTSAB and Avionic Testing and Calibration

The ATTSAB has also been put through testing both theoretical and practical tests, though less extensive than the AEB.

For theoretical testing, ATTSAB hardware has been properly dimensioned in SolidWorks and tested for fitment on the sleds. The fitment of the bay within the nosecone has also been confirmed through numerous redesigns and slight dimensional Adjustments to produce a well fitted bay. The RunCam split has been included in this assembly and will also fit in the nosecone. Since the ATTSAB is under much less force than the AEB or the PILL (since it will not be ejected from the main body), we have not performed FEA on the design, but will be using sufficiently strong materials to guarantee the structural stability of the ATTSAB.

Practical testing of the Avionics used in the ATTSAB has been done both separately and during flight. The flight computer was originally tested on a breadboard, then constructed fully on a PCB and tested with pre-programmed libraries. We then assembled the avionics in the shoulder of the Subscale nosecone and did a preflight test. The test was performed by having different individuals run around while holding the nosecone and see if data being recorded reflected direction and movement. After a successful preflight check, the flight computer was used to record the data of our subscale flight.

After the assembly of the full ATTSAB, we will test battery run time, radio relay of data to the ground station, and successful relay and recording during flight.

4.2.4.3 PILL Testing and Calibration

Testing has been performed on the pill design within the constraints of a design that has yet to be constructed. We have performed finite element analysis on the body of the pill for the different method of attachments to the shock chord and have settled on the use of a U-bolt to minimize stress on the external structure. The calculated stress on the polycarbonate body will lead to minimal deformation during ejection. The outer casing of epoxy has been determined as sufficient protection for the body against impact force (calculated based on decent velocity and mass of the pill). The internals will be under much less stress, which will be well handled by the PETG.

Other than FEA, we have used SolidWorks to confirm that all internal components of the pill will fit properly in their designed space, and that the PILL itself will fit well inside the payload bay of the rocket.

For physical testing, some prototyping was done as a proof of design in the early stages of the PILL, and further testing will be performed after the final prototype is manufactured (early 2023). Independent tests will be performed on each part of the PILL, including the ball bearing rotational assembly of the outer casing, the linear elevator mechanism for the camera and its ability to rotate a full 360 degrees, and the hatch. Electronic systems will be tested before being assembled on the sled to make sure that everything is running properly, and battery runtime with the full load of all PILL related electronics will also be checked. Finally, we will fully assemble the prototype and conduct drop tests with a parachute attached to the U-bolt. All these tests will be performed on the final construction of the PILL before flight.

4.2.5 Precision and Accuracy of Instrumentation

Component	What is being Measured/Purpose	Precision/Accuracy
Adafruit ESP32 Feather V2	PCB	N/A
Adafruit 9-DOF Absolute orientation IMU	Motion Sensor	High accuracy, multitudes of different measurements such as Orientation, velocity, acceleration, magnetometer, temperature, etc.
Adafruit BMP 280	Barometric Sensor	±1 hPa
Adafruit Ultimate GPS	Position tracker	**Position Accuracy:** 3.0m **Velocity Accuracy:** 0.1m/s

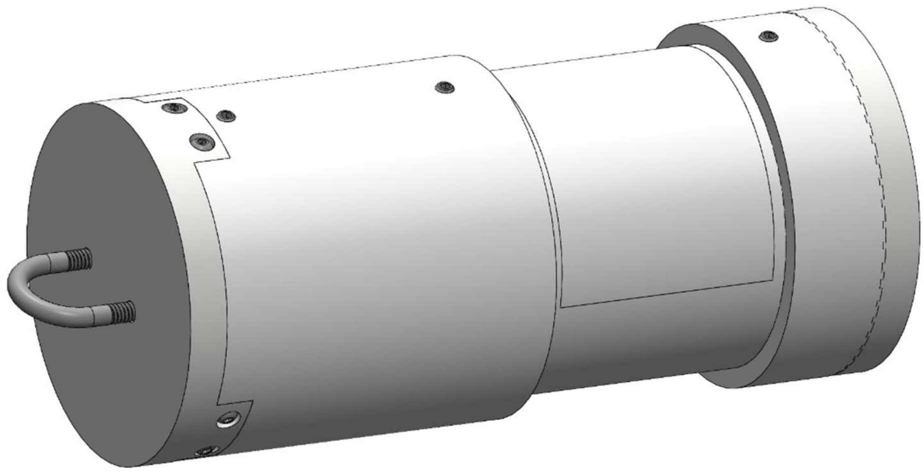
		Timing Accuracy: ±20ns RMS within 100ms in one pulse
Omni Directional Antenna	For communication with ground station	N/A
Adafruit RFM 95W LoRa Radio transceiver	Same as above	N/A

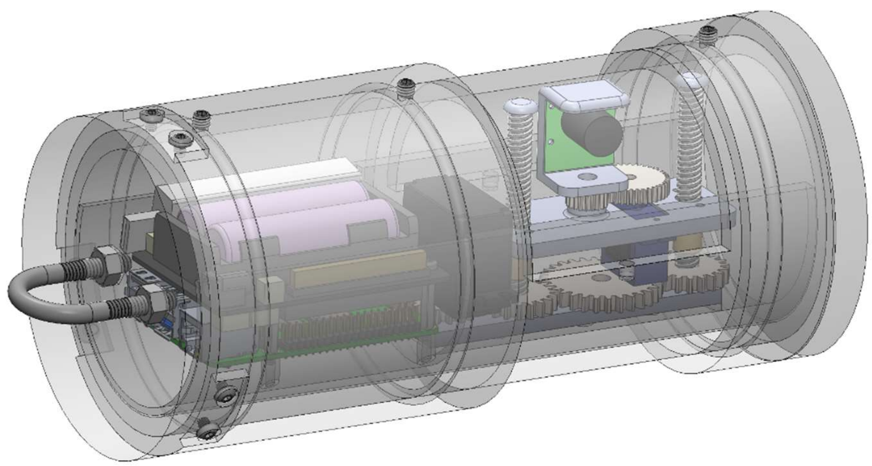
4.2.6 Expected Data and Analysis

Telemetry will largely be in charge of flight data. We will be collecting live telemetry including but not limited to, atmospheric pressure, atmospheric pressure, acceleration, velocity, time, orientation, and location. Said data will be collected through the custom-made flight computer located in the nose cone; additionally, data will be loaded onto an SD card. A public library by "Electronic Cats" will also allow us to make a 3d render of the rockets flight using orientation and acceleration values collected by the accelerometer/gyroscope. Furthermore, the COTS altimeters located in the coupler were chosen specifically for their flight data capabilities. Reading from the COTS altimeters will be used not only to model the rockets flight, but as well as to show the efficacy of our custom flight computer for the purpose of standardizing equipment in later years. An independent run cam split will also be collecting imagery and may be repurposed for live video if deemed possible; however, video remains a promotional item from STEM engagement and not a priority.

The PILL itself be time stamping images which will be used to fulfill the handbook requirements, but as well as demonstrate a detailed timeline of the PILLS imagery mechanism. The timeline will be compiled in the PLAR to show how responsive the PILL is to RAFCO commands sent out by the NASA ground station.

4.3 Experiments Sub-System





4.3.1 PDR Design Flaws

Our original PILL design that was presented for the PDR posed more flaws than we first recognized. The student launch board had brought these flaws to our attention – were we not aware of them. Our team evaluated these flaws as we continued the design phase for our payload. During the Q&A session for PDR some concerns such as distortion, eyebolt location, and height were all brought up as concerns that we have taken into consideration upon redesigning the primary payload.

4.3.1.1 Distortion

One of the original design flaws was the distortion caused by polycarbonate tubing used for the outer casing. In the original design, the camera did not extrude outside of the polycarbonate tubing.

Non-polarized polycarbonate sheets, on average, have a refraction index of 1.59. This means the distortion caused by the material alone would already be fairly large; however, this is only exemplified by the shape of the housing (being that of a cylinder) with the camera offset so far in one direction. To mitigate this flaw, our team had agreed to extruding the camera outside of the rolling cage by using a linear elevator that will use a screw and 2:1 gear motor to push the camera through a rubber seal before performing the RAFCO commands. By using this method, distortion is no longer a problem, and we are given the freedom of being able to use any RF-transparent material for the PILL body.

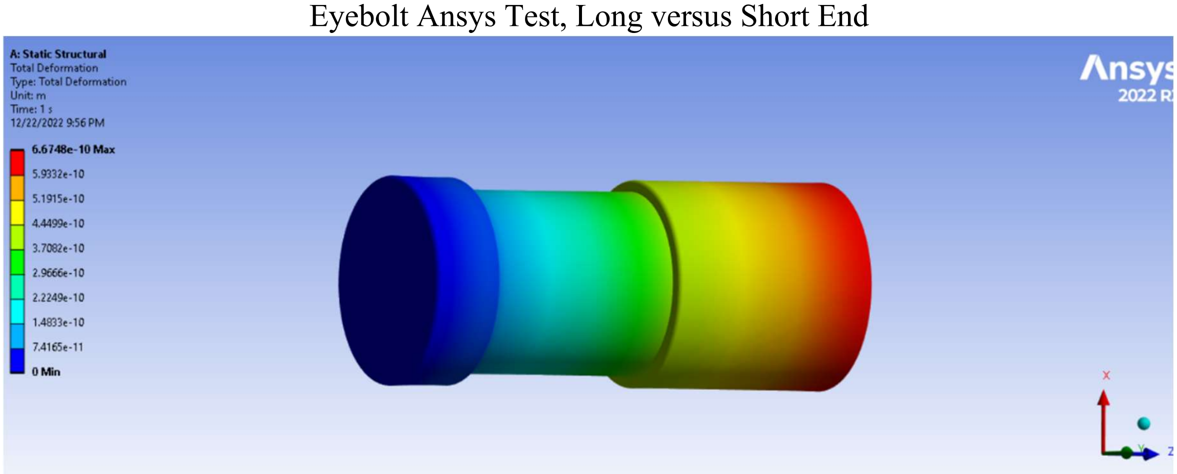
4.3.1.2 Eye/U Bolt Location

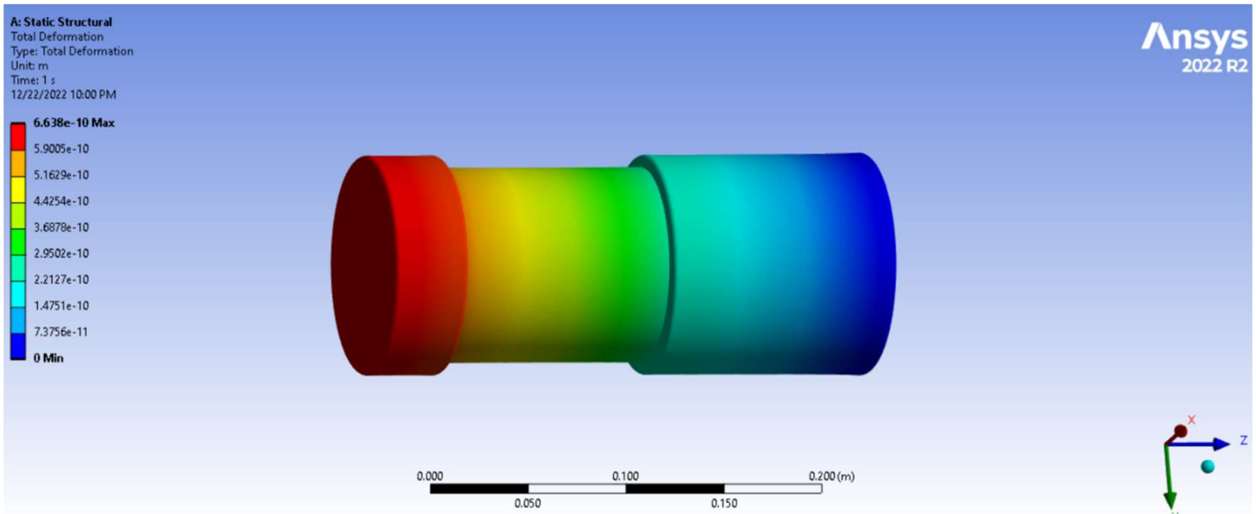
The location of the Eye/U bolts has been a debated issue during the redesign process due to the spacing issue within the rocket. Due to previous OD of the PILL (4”) centering rings would only allow for a clearance of 0.5” within the rocket as it has a 5” OD; furthermore, the new PILL design assumes an OD of 4.5” meaning we’d have a 0.25” clearance.

To address the issue of spacing inside the rocket, our team has decided to keep the eyebolt location on the end cap of the payload. Additionally, if the Eye/U bolts were on the top of the PILL, since the camera is now exiting the PILL, this could create another obstruction.

The PILL will be connected by a cut-off piece of the Kevlar shock chord, reducing the snatch force the PILL would experience. Thus, we only needed a single end cap to have the bolt, so we included both attachment points in Ansys, as well as eyebolts versus U-bolts.

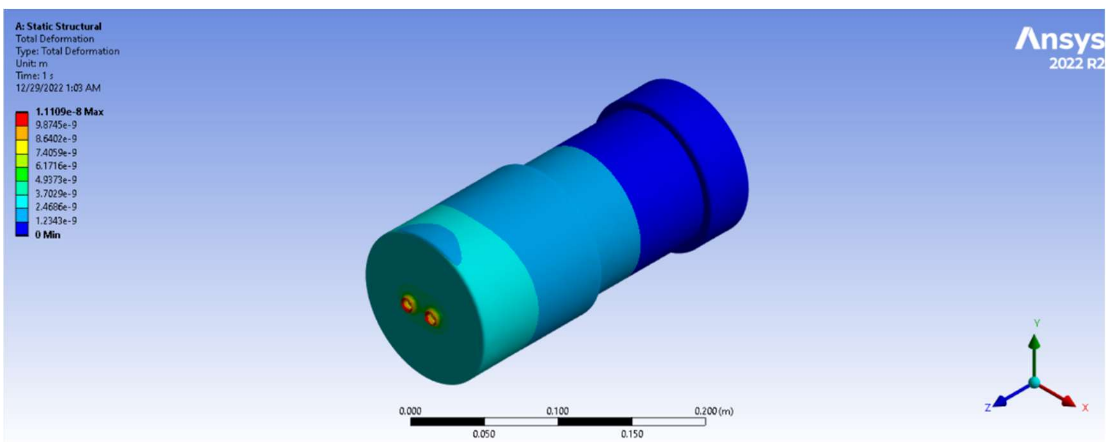
Eyebolt Ansys Test, Long versus Short End





Thus, it is obvious that the bolt should be attached to the longer end to avoid destruction of the PILL along electronics sled.

U-bolt Location Ansys FEA test



Despite knowing which end cap we'd opt to use, we figured the smaller form factor and extra attachment point of a U-bolt would be more optimal. We conducted the same FEA test in Ansys and found this to be true, so alongside the location of the bolt, we also decided to use a U-bolt.

4.3.1.3 Height

A concern that was discussed during the Q&A section of the PDR was the height of the camera when faced with obstacles such as tall grass and rocks. During the redesign process, the team had decided to redesign the camera's motor system entirely so the camera can spin 360 degrees about the z-axis but can also be raised outside of the polycarbonate outer casing – this remains true for every new design.

4.3.1.4 Polycarbonate Heat Resistance

While polycarbonate is an impact-resistant material, it softens when met with temperatures above 132°C; our black powder charges would create gases around this temperature, which could potentially damage the body. As this problem is present in most plastics, we needed to find a solution in lieu of switching materials. To circumvent this, we decided to create our own heat-resistant epoxy to coat the PILL alongside the UCF Research Pavilion.

4.3.2 Design Process and Alternatives

Our design process emphasized rapid iteration to increase the expected reliability of the PILL. When a design was proposed, we would present our idea to the team and defend each member's own idea. After each idea was presented, the team would discuss the pros and cons of each design. Once the discussion was had on the various aspects of each design, the team would vote on which idea would be best suited to the mission. Once the idea was decided upon, the pictures and data discussed would be implemented into a CAD model to further increase the understanding of the ideas voted on. Subsequent ideas would be compounded through multiple iterations to correct slight errors in the model, and then the model would be presented at weekly integration meetings for open discussion with the entire NASA Student Launch team.

As an addendum, it is worth noting that we had decided through the use of a decision matrix, that all subsequent iterations must have the camera leave the PILL, as this solves the issue of both height and distortion – a trend you will see in each subsequent design.

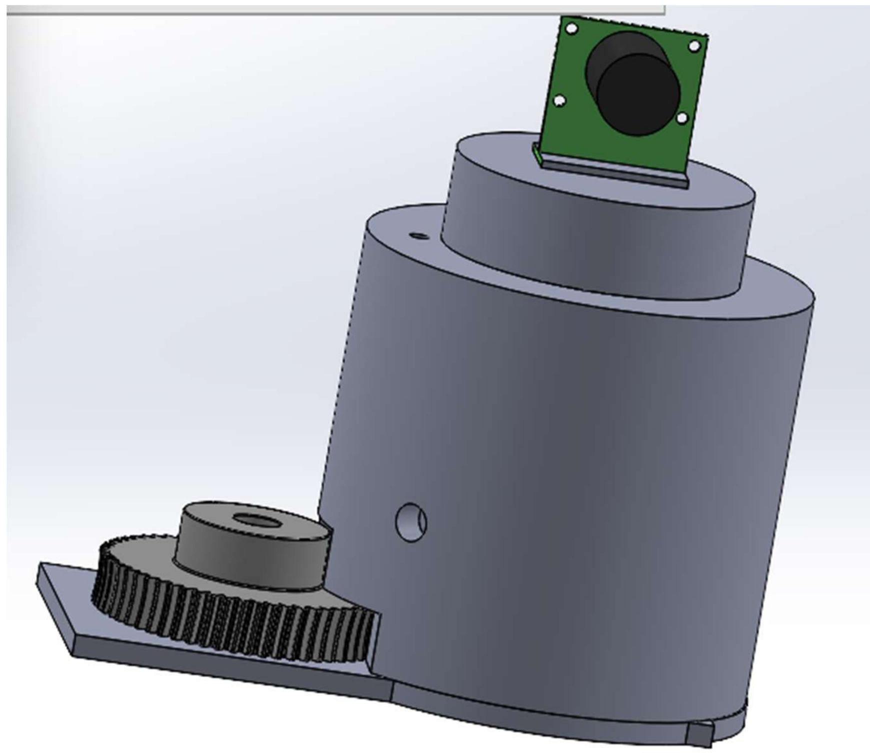
		RATINGS	
Criterion	**Weight**	**Camera Extrustion**	**No Extrusion**
Distortion	5	5	2
Height	5	5	2
Spacing	5	1	5
Total		**55**	**45**

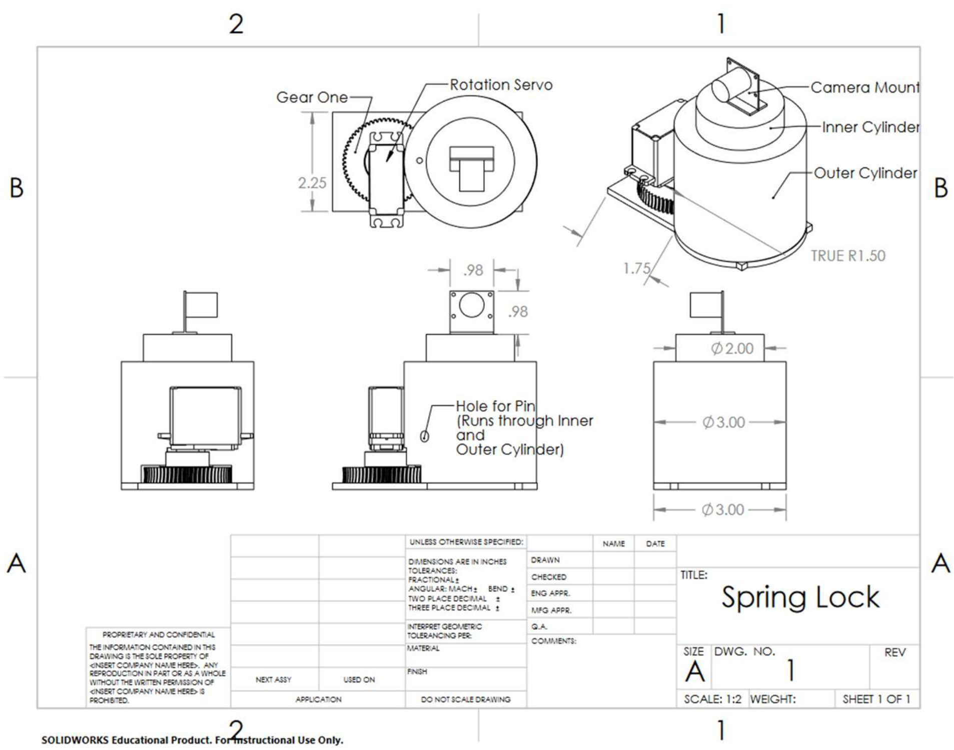
4.3.2.1 Linear Actuator

Our team had originally decided on using a COTS linear actuator to raise the camera outside the outer casing, however many problems were presented when doing further research into linear actuators. One of the immediate problems that we faced was space limitation; Linear actuators are rarely seen in sizes of 4 inches or less and require a large battery to perform. Another concern was that if the team were to use a 4-inch linear actuator, there would be barely any added height relative to the volume occupied by the actuator, which would make implementing the system nearly impossible.

4.3.2.2 Spring Lock

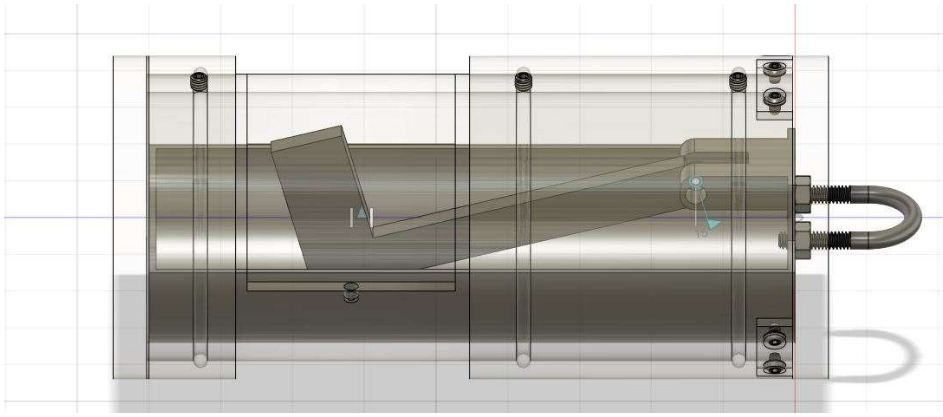
The spring lock design utilizes a pin that is stuck between two cylinders to lock them in place. Once the motor pulls the pin out, the spring will extend and push the inner cylinder up and out the outer cylinder. Subsequently the same motor that pulled the pin out will spin two gears that are attached to the now extended inner cylinder using a cylinder with a hexagon cut-out to rotate the camera. While simpler than other designs, the spring lock was deemed too unpredictable compared to more controlled alternatives.

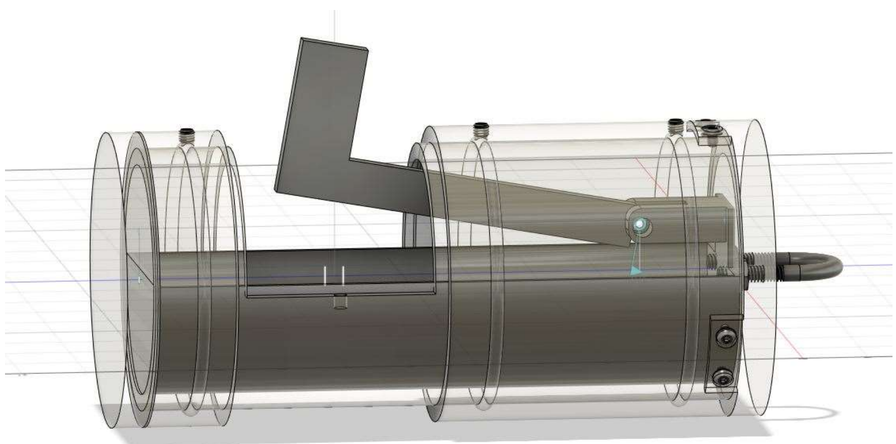




4.3.2.4 Boom Arm

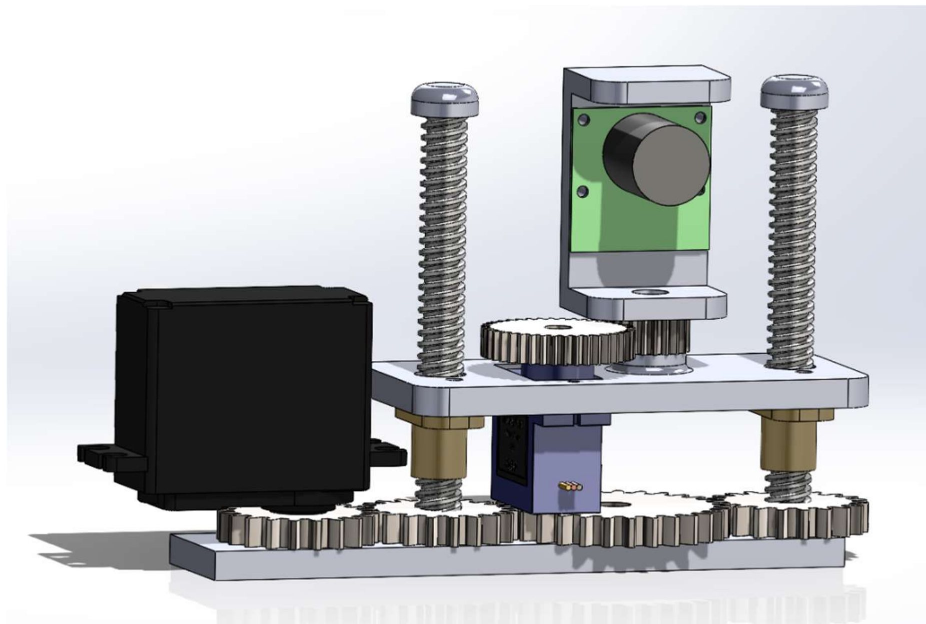
The boom arm design was inspired by the fire department's ladder truck. It allows the vertical height to be stored in a horizontal position, for deployment and its compact nature. Instead of using a vertically stored system, i.e., a lead screw, we would have a much larger height at deployment than a restricted system. For an example, a lead screw can only lift the camera to 2x the height of the lead screw, while the boom arm can be the total length of the payload bay allowing for a much larger height. Whilst efficient, the boom arm would be very hard to manufacture and implementing the rotation of the camera about the z-axis would be limited.

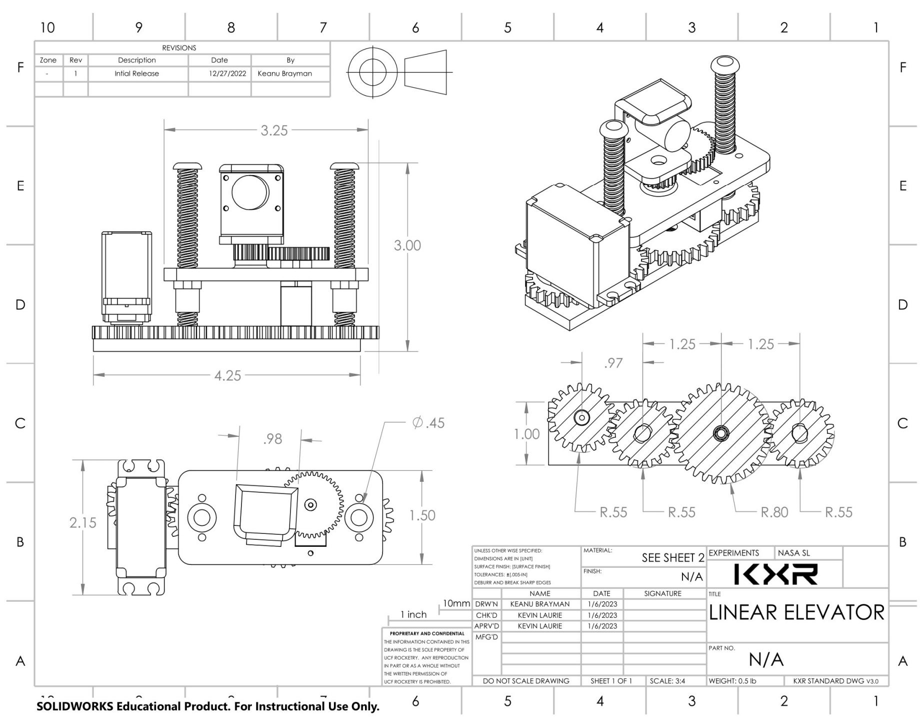


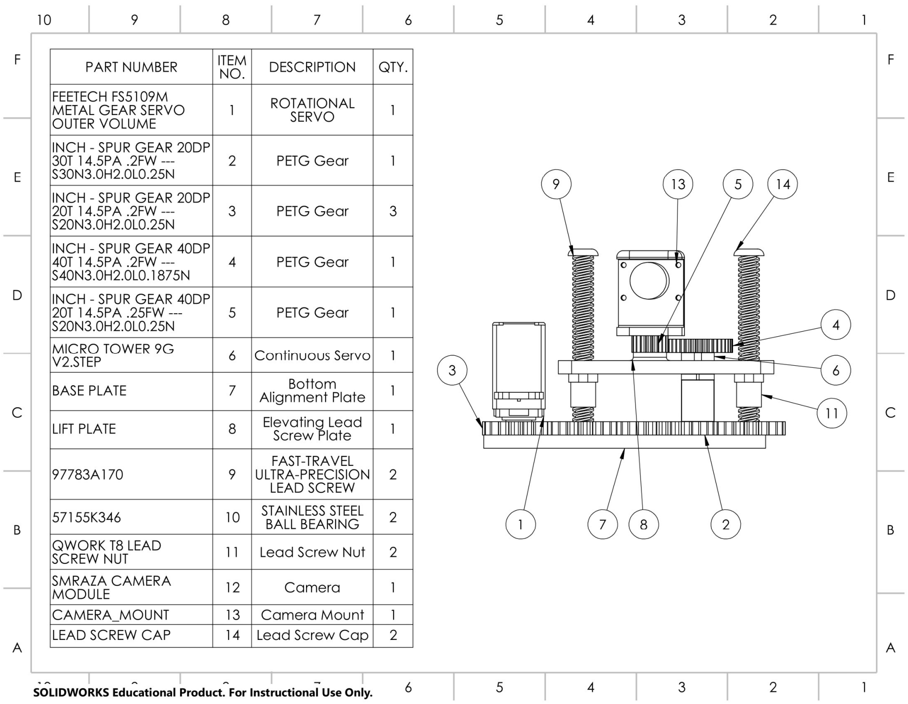


4.3.2.3 Linear Elevator (Current Design)

This iteration of the payloads uses a lead screw mechanism to elevate the camera outside the PILL through a hatch. The camera is mounted on a small platform, with a lead screw and a support rail running vertically on either side. The lead screw is geared to a continuous servo, moving the entire platform up or down. A limit switch will be placed beneath the platform to detect when it is in the bottom position. The advantages of this design are precise control and increased camera height. The latest version of the lead screw design has been improved to use 2 lead screws for added stability. Furthermore, our custom linear elevator design is far more space efficient than a COTS linear actuator, making it better suited for fitting within the PILL. It is worth noting that this design limits orientation about the y-axis as the PILL loses the self-orienting sled, however, the terrain and small form factor means it is unlikely the PILL will not be parallel to the y-axis whilst still maintaining the ability to orient about the x-axis and z-axis.







PART NUMBER	ITEM NO.	DESCRIPTION	QTY.
FEETECH FS5109M METAL GEAR SERVO OUTER VOLUME	1	ROTATIONAL SERVO	1
INCH - SPUR GEAR 20DP 30T 14.5PA .2FW --- S30N3.0H2.0L0.25N	2	PETG Gear	1
INCH - SPUR GEAR 20DP 20T 14.5PA .2FW --- S20N3.0H2.0L0.25N	3	PETG Gear	3
INCH - SPUR GEAR 40DP 40T 14.5PA .2FW --- S40N3.0H2.0L0.1875N	4	PETG Gear	1
INCH - SPUR GEAR 40DP 20T 14.5PA .25FW --- S20N3.0H2.0L0.25N	5	PETG Gear	1
MICRO TOWER 9G V2.STEP	6	Continuous Servo	1
BASE PLATE	7	Bottom Alignment Plate	1
LIFT PLATE	8	Elevating Lead Screw Plate	1
97783A170	9	FAST-TRAVEL ULTRA-PRECISION LEAD SCREW	2
57155K346	10	STAINLESS STEEL BALL BEARING	2
QWORK T8 LEAD SCREW NUT	11	Lead Screw Nut	2
SMRAZA CAMERA MODULE	12	Camera	1
CAMERA_MOUNT	13	Camera Mount	1
LEAD SCREW CAP	14	Lead Screw Cap	2

4.3.3 Decision Matrix

		RATINGS			
Criterion	**Weight**	**COTS Linear Actuator**	**Spring Lock**	**Boom Arm**	**Linear Elevator**
Y-axis Orientation	2	1	1	5	1
Reliability	5	5	1	5	5
Spacing	7	1	5	1	3
Distortion	7	5	5	5	5
Height	7	3	5	4	4
Manufacturability	3	5	2	4	4
Total		**105**	**118**	**117**	**123**

4.3.4 Outer Casing

4.3.4.1 Materials

The chosen material to encapsulate our payload electronics will be polycarbonate. Considered one of the strongest plastics, polycarbonate holds an average tensile strength of 11,000 psi; notching an impact strength of around 80 kilojoules per meter squared. Given we are launching our payload from an average of 5,000 feet, these measurements were crucial to determining what material we would utilize for the outer casing of our payload.

Additionally, the effect of black powder charges was of concern. Our outer casting not only needed to be strong but heat resistant. Capable of sustaining temperatures up to 132 degrees Celsius, polycarbonate will suffice in our use case – but deformation remains a possible concern.

Furthermore, Thermoplastics, such as Acetal were considered for the outer casting, however, while it held a high heat resistance of 184°C; its tensile properties were significantly weaker than the polycarbonate, making brittleness a concern. After omitting Acetal, our group investigated fiberglass. Since it would be a part of our heat-resistant coating, it was assumed to be utilized as a strong outer casting. However, similar to Acetal the notched impact strength and overall tensile strength were less than 9,000 psi.

Our final cause for concern, overall, was clarity. Our material needed to have enough transparency in which we are able to capture an adequate image. Although the camera is leaving the PILL and thus it no longer needs be clear, as a redundancy, we chose polycarbonate for its clear, almost glass-like properties. Thermoplastics and fiberglass were taken out of the picture as their thread patterns would make the payload virtually clear.

		RATINGS		
Criterion	**Weight**	**Polycarbonate**	**Thermoplastic**	**Fiberglass**
Weight	1	5	5	5
Impact Resistance	5	3	5	1
Heat Resistance	5	3	3	3
Transparency	3	5	2	2
Cost	5	5	3	5
Tensile Strength	5	5	3	5
RF Transparent	10	5	5	5
Total		**150**	**135**	**109**

4.3.4.2 Epoxy Heat-Resistant Coating

Coming to a decision to encase our electronics within a polycarbonate body, we needed to examine the capabilities behind the payload's integrity. We understood that polycarbonate is an impact-resistant material, but it softens when met with temperatures above 132°C; our black powder charges could potentially damage the body. In collaboration with the Nanotechnology Research Facility at the University of Central Florida, we will be creating our own heat-resistant epoxy to mitigate such a situation.

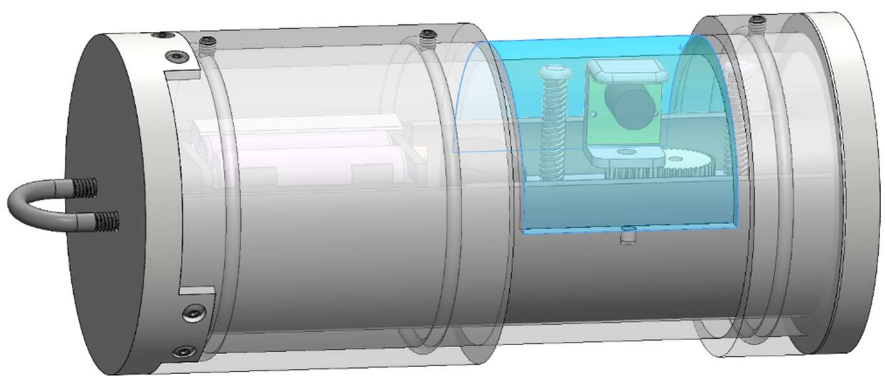
Continuing with the polycarbonate trend, we will be utilizing a liquid platinum clear epoxy resin and hardener mixed with off-white impact-resistant polycarbonate pellets and ¼’’ fiberglass strains to create an epoxy strong enough to encapsulate our payload electronics and defend against the blast of our charges. Additionally, we will investigate the use of ½’’ to ¼’’ viscose rayon fibers as they hold similar if not more substantial properties than fiberglass.

The procedures being established at the moment will explore a ratio-to-ratio experiment where the epoxy resin and harder will be mixed with either polycarbonate or viscose rayon to produce a resilient epoxy. In terms of testing, the new epoxy will be examined for its impact and heat resistance, elasticity, and transparency. These examinations will be conducted within the

Nanotechnology facility as previously mentioned through the use of vacuum-chambered machinery where the environment can be altered to examine the epoxies' endurance.

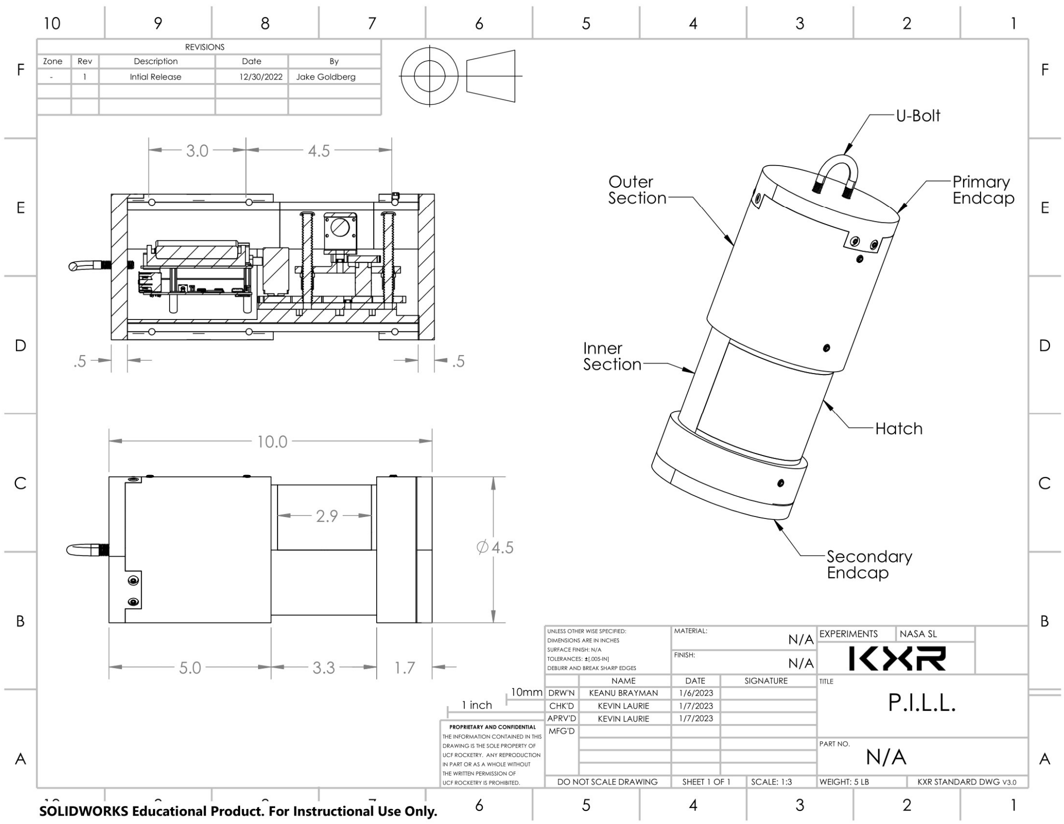
4.3.4.3 Camera Slot

We will include a hatch cutout on the inner tube to allow for the camera lens to be protected from the elements during landing. Without a hatch to extrude the camera from the PILL body, we would most likely have obstructions in the camera view due to debris generated from launch and landing as well as distortion due to the shape of the PILL and the nature of light refracting in a cylinder. The hatch also allows the camera to pierce the safety of the outer casing, allowing for a clear view of the surrounding area. Current, the hatch will consist of a rubber seal that by nature of the ball bearings in this design, will always be aligned with the z-axis



4.3.4.4 Dimensions and Spacing

The dimensions of the PILL will be 10" x 4.5" OD. This OD was chosen to allow for adequate spacing of the shock cord and centering rings or packing material to increase the likely hood of a successful extraction. The inside tube will be 8"x 3.47" OD to allow for enough material on the outer casing to absorb impact. The inner tube will be spaced about .5" from either end of the PILL. The .03" difference accounts for the ball bearing races that were integrated into the PILL to allow for independent rotation of the tubes.



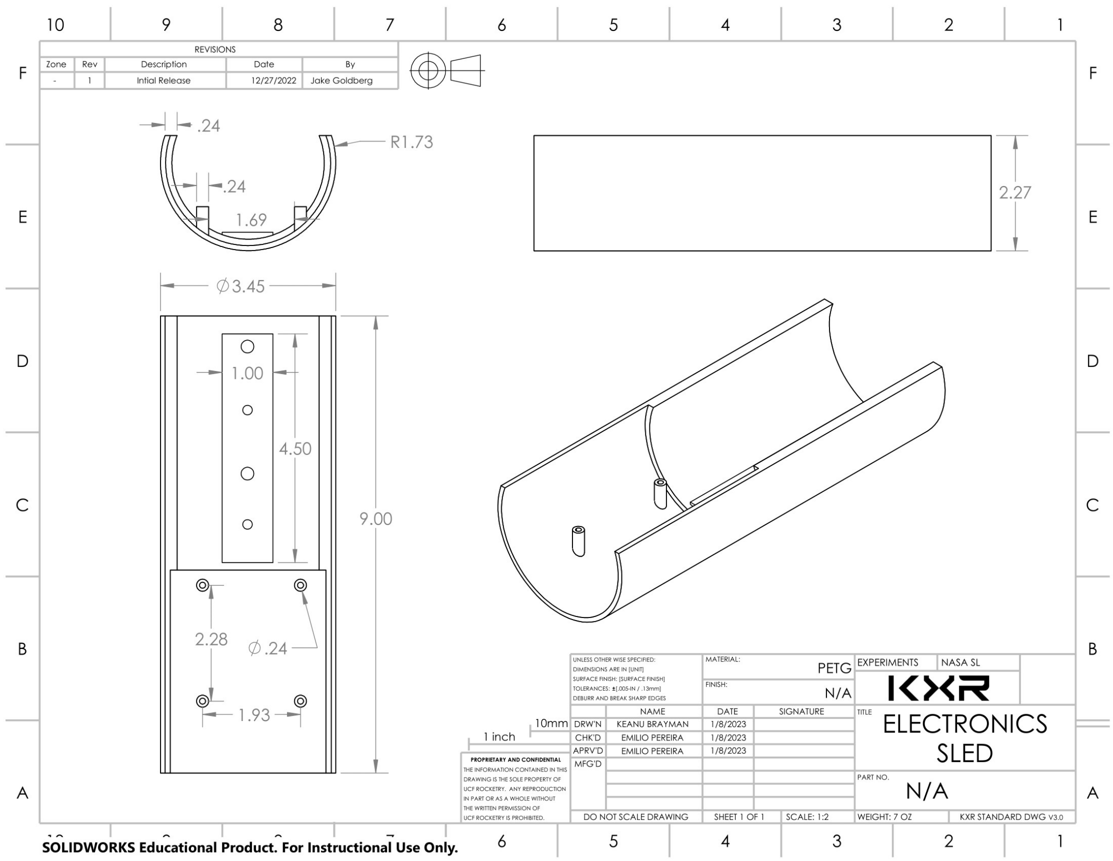
4.3.5 Inner Sled

The inner 'electronics' sled is composed of all the electronics that are used to aid in the execution of the payload requirements. The electronics sled has three main sections as shown in the image below, these sections are used to divide the screw actuator, battery, and electrical components and provide space for all electronics. The electronics consist of a Raspberry Pi 4, Adafruit Real Time Clock module for Raspberry Pi 4, Smraza Raspberry Pi 4 Camera, IMU/adafruit BNO, antenna and radio SDR dongle.

4.3.5.1 Materials

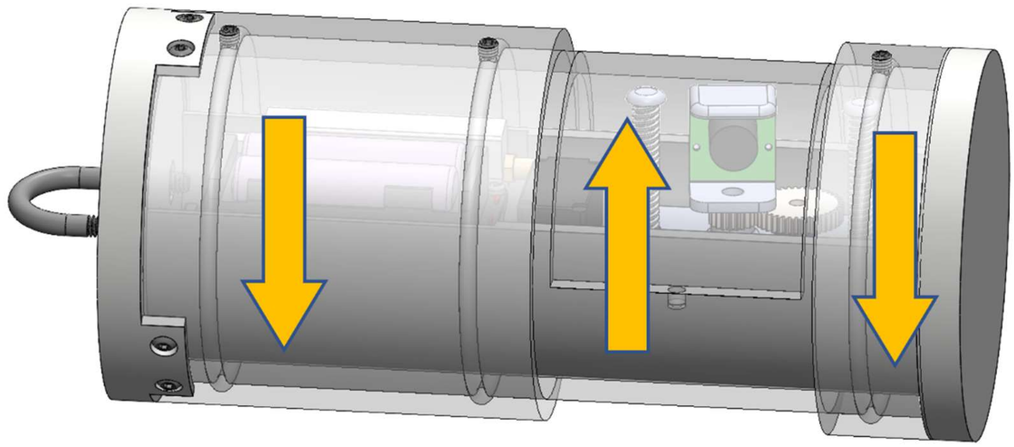
During the manufacturing process, our team will make custom-made designs such as the electronic sled, outer casing, and supports for the linear elevator. The inner electronic sled casing is made of a PETG filament. This choice of materials has remained consistent across multiple iterations throughout the design phase due to certain properties that make the material desirable such as the strength of and RF transparency of PETG filament.

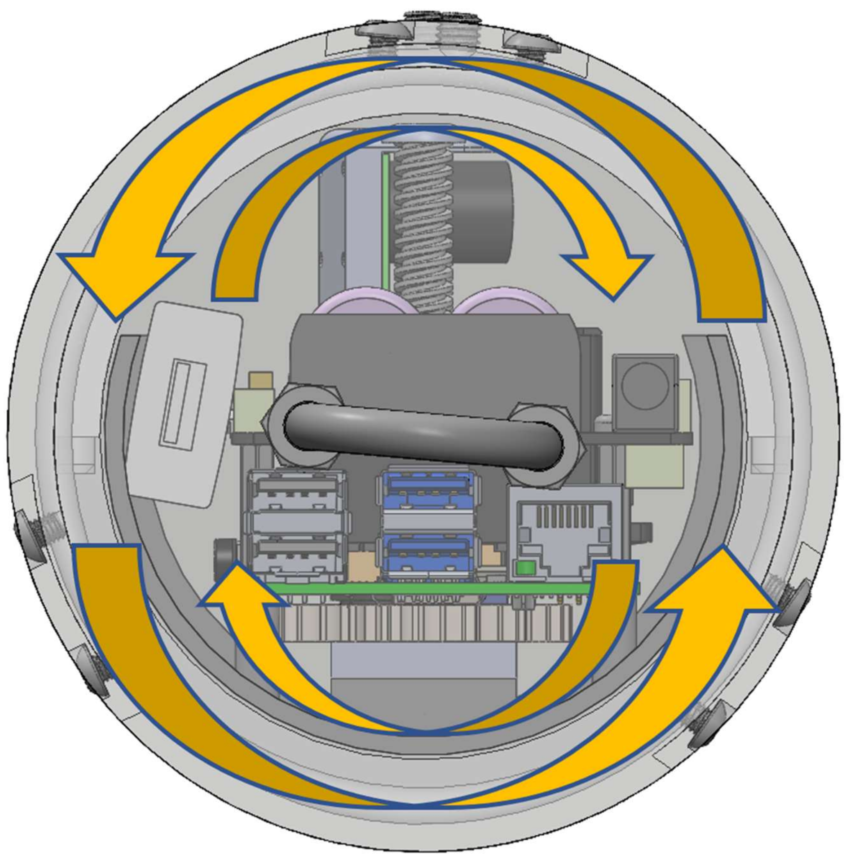
4.3.5.2 Dimensions and Spacing



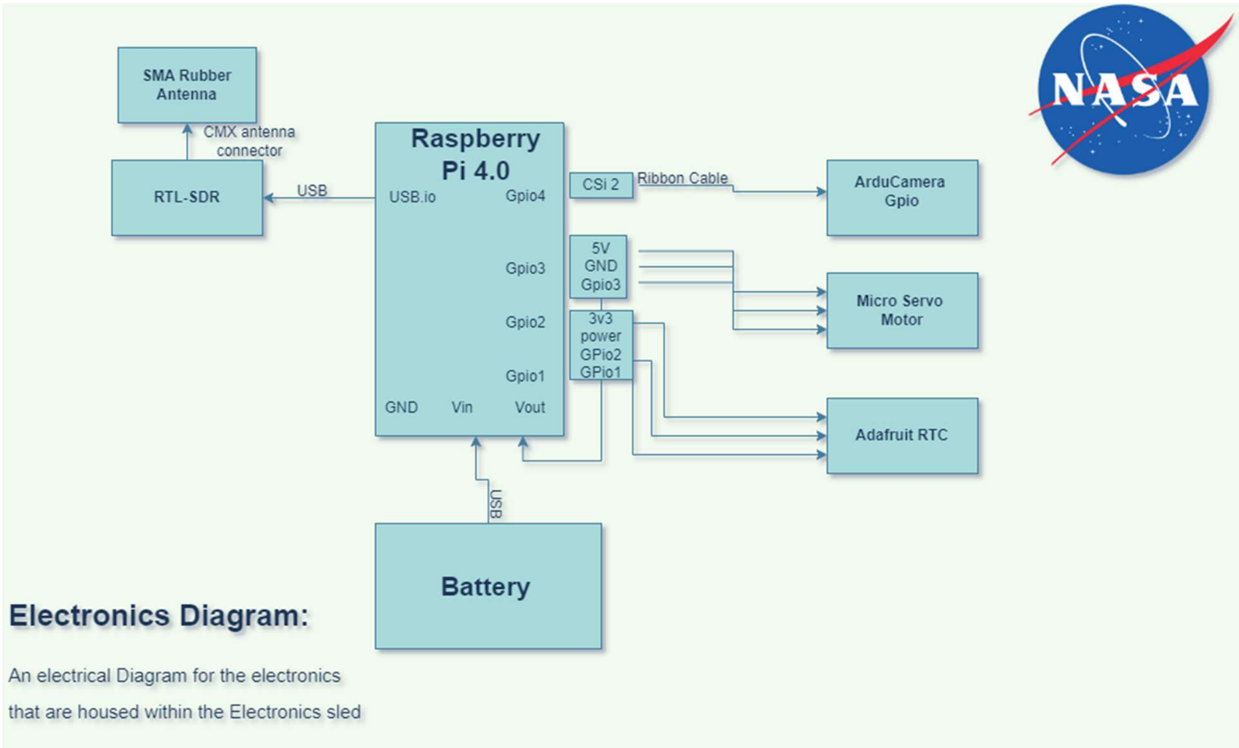
4.3.5.3 Self-Orientation

The PILL payload is designed to keep the camera parallel to the horizon regardless of its landing orientation. This is achieved by stabilizing the camera using gravity. The ball bearings that are lined along the connecting pieces of the two larger parts of the outer casing allow the experimental payload to roll independently from the inner section upon landing. Furthermore, we had designed the payload to have the electronics to be on the bottom half of the cylinder to make the payload more bottom-heavy. By using the weight of the electronics, battery, and the linear elevator combined with the low center of mass, the camera system is able to remain upright. This concept ensures that the camera is aligned orthogonal to the z-axis and can execute the commands sent out by NASA. An additional note, the payload now has the limitation of being unable to move about the y-axis. Our team believes that due to the terrain being provided for competition and the small length about the y-axis, this will not be a problem. This limitation is necessary as it allows us to eliminate the problems of height and distortion.





4.3.6 Electronics



(Some updates have been made since the creation of this diagram.)

4.3.6.1 Microcontroller

For our microcontroller, we decided to use a Raspberry Pi 4b 4gb due to it being one of the most powerful computers in the Raspberry Pi lineup and its extensive memory capacity making it ideal for video recording. Compared to an Arduino, the Pi is more apt at giving inputs to the servo and camera based on radio signals as well as compatibility with OpenCV. Compared to an Asus Tinker 4, although being similarity in the memory department, better compatibility with Python libraries makes the PI an optimal choice that is far easier to work with; additionally, due to the Tinker board being newer, it has less refinement behind the software running it, making the Pi the better option overall. Thus, we decided opted for the use of Raspberry Pi as our microcontroller.

		RATINGS		
Criterion	**Weight**	**Raspberry Pi 4b**	**Arduino**	**Asus Tinker**
Ram	6	5	1	3
Image Editing	7	5	1	5
Time Stamp	5	5	5	5
Camera Control	7	5	5	5
Low Power Draw	3	2	5	3
Multiple Process Capability	5	5	1	5
Cost	3	1	5	2
Total		159	98	153

4.3.6.2 Camera

In PDR, our choice of camera was a Raspberry Pi HQ camera coupled with a lens modification to achieve NASA's 100–180-degree FOV requirement as described by section 4.2.1.2. However, issues arose with the length of our lens being too wide which may cause complications with our camera deployment system. As such, we have decided to move forward with a different camera instead: the Smraza Raspberry Pi 4 Camera.

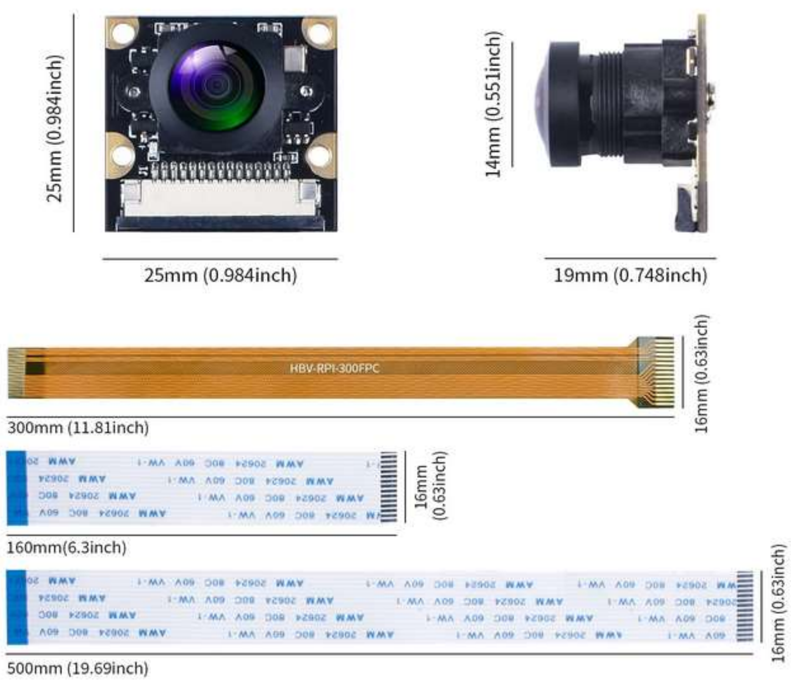
The major reason we decided to use this camera instead is due to the length of the lens attached to it, which is 19mm (0.748 inches). Compared to the original 28x30 mm size, this would be much smaller. Although it would be preferred if we didn't have to use any lens, many of the camera modules that are compatible with Pi either do not meet the FOV requirement or do not have good image quality, thus, a lens add-on is necessary.

Below is a table comparing the specifications of the two cameras:

Specification	Raspberry Pi HQ Camera (Old)	Smraza RPi 4 Camera (New)
FOV	120 (With attached lens)	160
Video Resolution	12.3 MP	5 MP
Sensor	IMX477R	OV5647
Comes with Lens?	No	Yes

Although the resolution is a lot less than the original, the Smraza contains a 5MP sensor chip equipped with a 1080p zoom lens, which is more than sufficient for our purposes. The 160-degree FOV also satisfies the FOV requirement. Ultimately, since both were satisfactory in regards to the NASA requirements, the deciding factor was size as it would be easier to work with, leading to the final choice of the Smarza RPI 4.

		RATINGS	
Criterion	**Weight**	**Raspberry Pi HQ**	**Smarza Pi 4**
Size	3	1	3
Resolution	1	1	1
FOV	2	2	2
Total		**8**	**14**



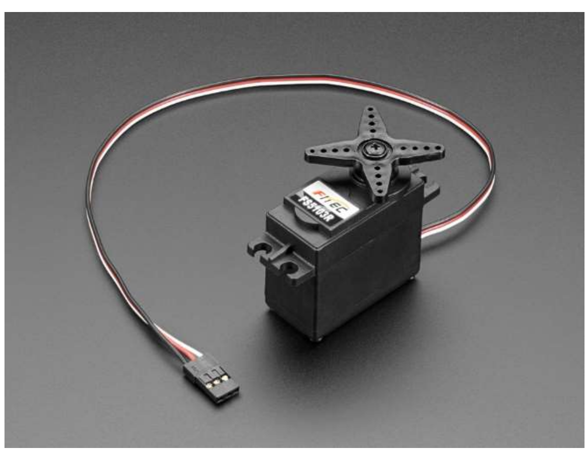
4.3.6.3 Motors

4.3.6.3.1 Camera Rotation Motor

For our rotation motor, we decided to pick the SMRAZA SG90 servo. Compared to other options we found, it had the best average quantity and quality for the 20$ price range and is made of higher quality materials than similarly priced options. The amazon listing for it is also the most detailed, letting us know exactly what we are buying, what the inside looks like, and having high reviews as well. Even though it has a 180-degree rotation angle, we can gear it up to move 360 degrees for our rotation of the camera.

4.3.6.3.2 Linear Elevator Motor

For our linear elevator motor, we decided on the FeeTech FS5103R Continuous Rotation Servo. This servo can rotate continuously in any direction rather than turning to a certain angle, making it perfect for spinning the lead screws. This motor is extremely affordable at $12 while meeting all design needs and space requirements.



4.3.6.4 RF

4.3.6.4.1 Radio Module

The RTL-SDR Blog Software Defined Radio will be used to receive commands from NASA. The radio can accept up to 1.7 GHz which satisfies NASA's frequency requirement and will be plugged into the Raspberry Pi in order to pass the given commands into the Python code.

Our radio has the following specifications:

Specification	RTL-SDR Blog V3 Radio
Tuner Technology	ADS-B, DAB, Digital
Tuner	R820T2 (500 kHz to 1.7 GHz with up to 3.2 MHz of bandwidth)
Chip	RTL2832 ADS
Oscillator	1PPM TCXO
Connector	SMA F

4.3.6.4.2 Radio Antenna

The antenna we chose is the Mini Short Walkie Talkie Antenna. The reason we chose this antenna is because of its frequency as well as being compatible with our radio.

Specifications	Mini Short Walkie Talkie Antenna
Antenna Type	Radio
Impedance	50 Ohm
Model	ABBREE AR-805S
Connector	SMA F
Band	Dual Band VHF/UHF
Max Power	10 Watts
Antenna Length	5 cm/1.96"

Frequency	144/430 MHz
Gain(MAX)	2.15 dBi/3.0 dBi

4.3.6.5 Real-time Clock Module

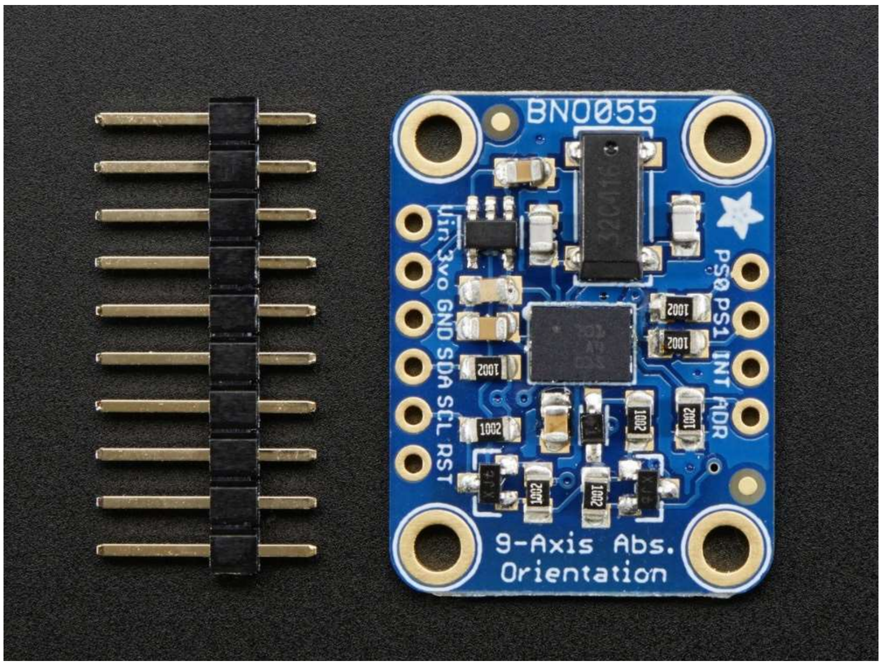
In order for the timers on the Pi to work without internet or adjustments, we decided to add a Real-Time Clock Module. The Adafruit PiRTC DS3231 is perfect for our situation as it will be able to keep track of time even if powered off or through temperature changes. This will make our timestamped images more accurate.

We considered the cheaper PiRTC PCF8523, but not only does it get affected by changes in temperature, it can gain or lose up to 2 seconds per day. The DS3231 uses a temperature sensor situated next to the integrated crystal used to keep track of time. This layout helps the sensor accommodate frequency changes so that the timekeeping remains accurate. Overall, despite being more expensive, the DS3231 is the best choice for our purposes.

		RATINGS	
Criterion	**Weight**	**PiRTC DS3231**	**PiRTC PCF8523**
Accuracy	3	5	1
Price	2	3	5
Total		**21**	**13**

4.3.6.6 Inertial Measurement Unit

We will utilize the BNO055 9-DOF Absolute Orientation IMU to provide orientation and acceleration data to the PILL. The BNO055 will detect when the PILL is launched by measuring the sudden acceleration of the liftoff. During flight the BNO055 will continue to track acceleration, until it detects that it is no longer moving. This will inform the PILL that it has landed. The BNO055 will monitor the self-orienting system to determine when the camera hatch is upright. Once the correct orientation is achieved, the camera deployment sequence will be initiated. Should the PILL bounce or roll upon landing, the BNO055 will detect these motions and prevent the camera from deploying until conditions are safe.



4.3.6.7 Image Processing

For processing our images, we will use the OpenCV library. It is typically used for computer vision and machine learning, but it can be a powerful image processor as well. We will also be writing the code in Python due to its compatibility with the Raspberry Pi; additionally, since our USLI team is largely composed of first- and second-year students, many have taken UCF's introductory coding course which focuses solely on Python, meaning Python is more accessible for our members.

Within our code, OpenCV will read in the image sent from the camera, apply any effects if necessary, and save imagery in an SD card. An accurate timestamp will be overlaid on the image as well and the code will also handle conducting certain commands. It is worth noting that whilst C/C++ runs much faster than python, there are limited libraries for the use of Raspberry Pi, so it is far less compatible. Overall, it became evident that Python would be the obvious choice for our purposes.

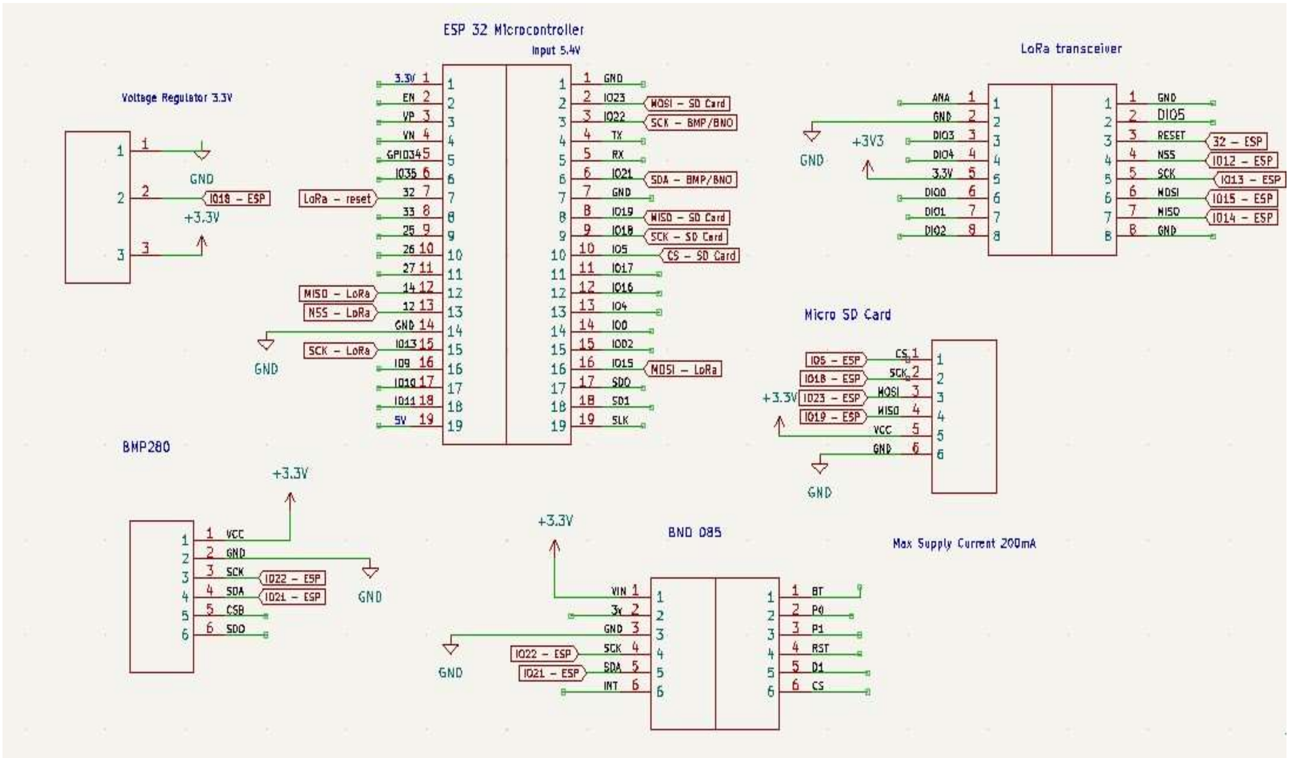
		RATINGS	
Criterion	Weight	Python	C/C++
Ease of Access	3	5	3
Performance	5	3	5
Compatibility	5	5	3
Total		55	49

4.4 Telemetry Sub-System

The Telemetry Sub-System aims to create a compact flight computer that can gather and interpret accurate data concerning position, orientation, and speed. Through development and testing, we will maximize the accuracy of the chosen sensors and the efficiency of central processing to create precision outputs. This will allow for the later development of an Aerobrake system for the 23/24 SL team. The aerobrake will improve the accuracy of the desired altitude, therefore, increasing the team's final apogee score. Additionally, we aim to masss produce the PCBs we design for the NSL team, and allow it to be reused for our host club Knights Experimental Rocketry's (KXR) other projects.

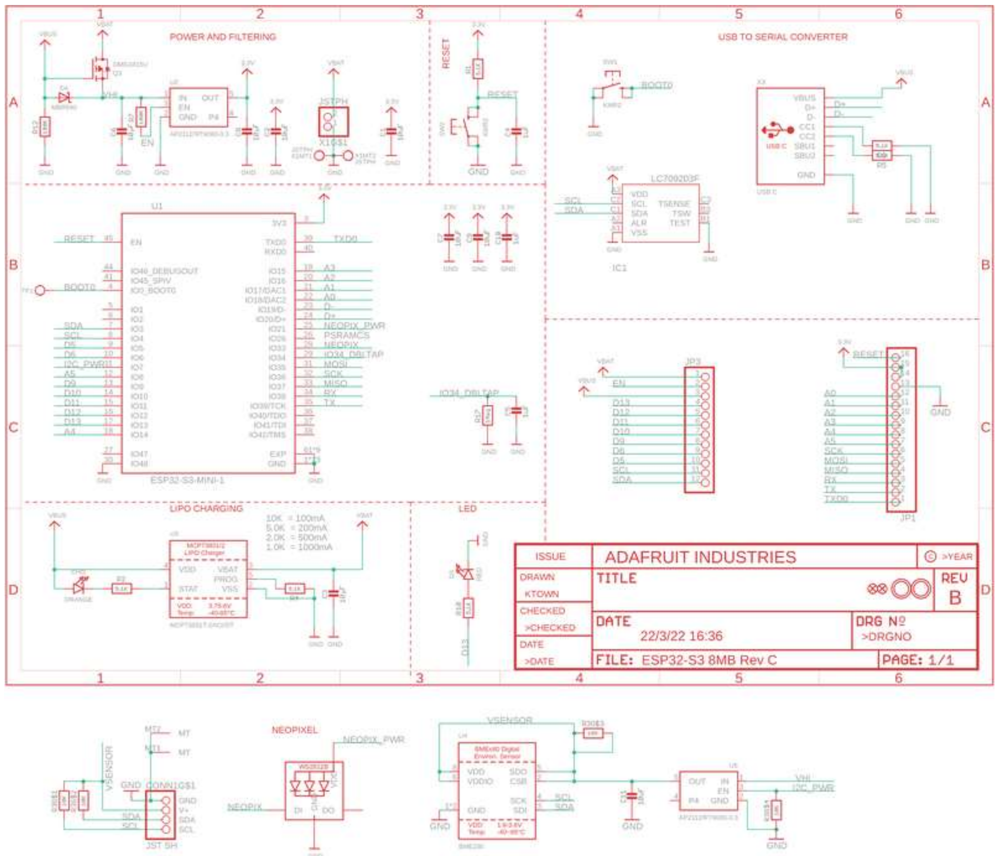
4.4.1 Flight Computer

Two 18650 Lithium-Ion batteries were selected to power the telemetry system. The large capacity, rechargeability, reliability, and accessibility made this battery the nominal choice with a base voltage of 3.6V and 2600mAH. The utilization of a 5v Buck converter was necessary to convert the 18650 LiPo battery's variable 7.4V DC to a constant 5V DC that is utilized by the main components of the flight computer. One concern relieved from using a Buck converter is possible voltage spikes or drops in which we could lose power or damage components as the LiPo battery discharges through use. These two components provide reliable redundant power to all the components of the flight computer including the ESP-32 Microcontroller, BNO085 IMU, BMP280 Barometer, LoRa Module, Adafruit GPS, and the Run Cam Split.



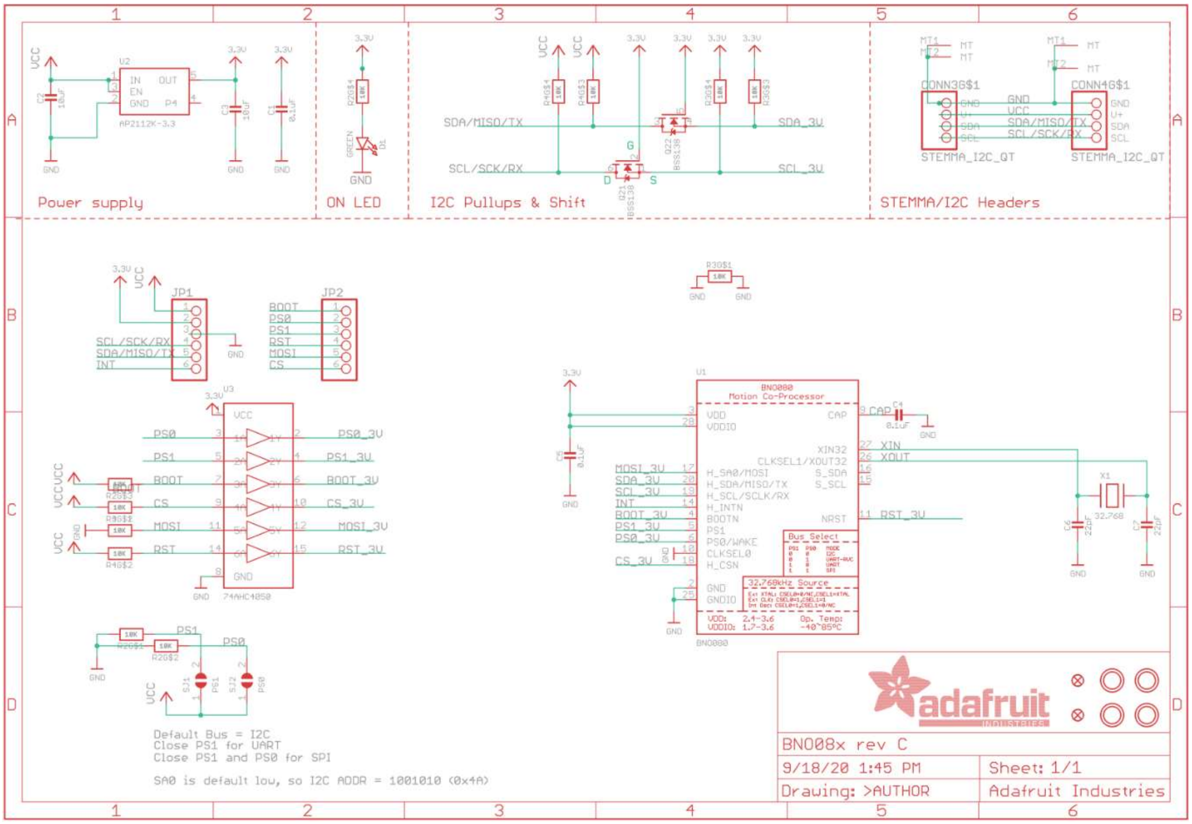
4.4.1.1 Microcontroller

The ESP-32 was chosen as our microcontroller due to its extensive capabilities and relatively low cost. The 32-bit architecture of the ESP-32 offers us more memory and peripheral support along with processing speed. It is capable of 3.3V and 5V inputs and outputs, allowing ease of use with all the chosen sensors. Some other features of this microcontroller are built-in RF, Bluetooth, and Wi-Fi capabilities. These features will be utilized to monitor the status of the Flight computer on the launchpad and confirm all sensors are functioning nominally leading up to launch. The ESP32 will handle all the data interpretation and logic control following the stages of our flight plan and will document all this data to flash storage and a removable SD card. The ESP-32 includes communication pins for each of the following protocols, I2C port (SDA, SCL), hardware UART (RX, TX), and SPI (SCK, MOSI, MISO). All these features are included in a form factor of about 2”x1”, this allows us to interpret all the gathered data on board, without having to transmit to a ground station for analysis. The excess processing power of this microcontroller allows for the development of future applications to assist and improve upon the telemetry and recovery sub systems.



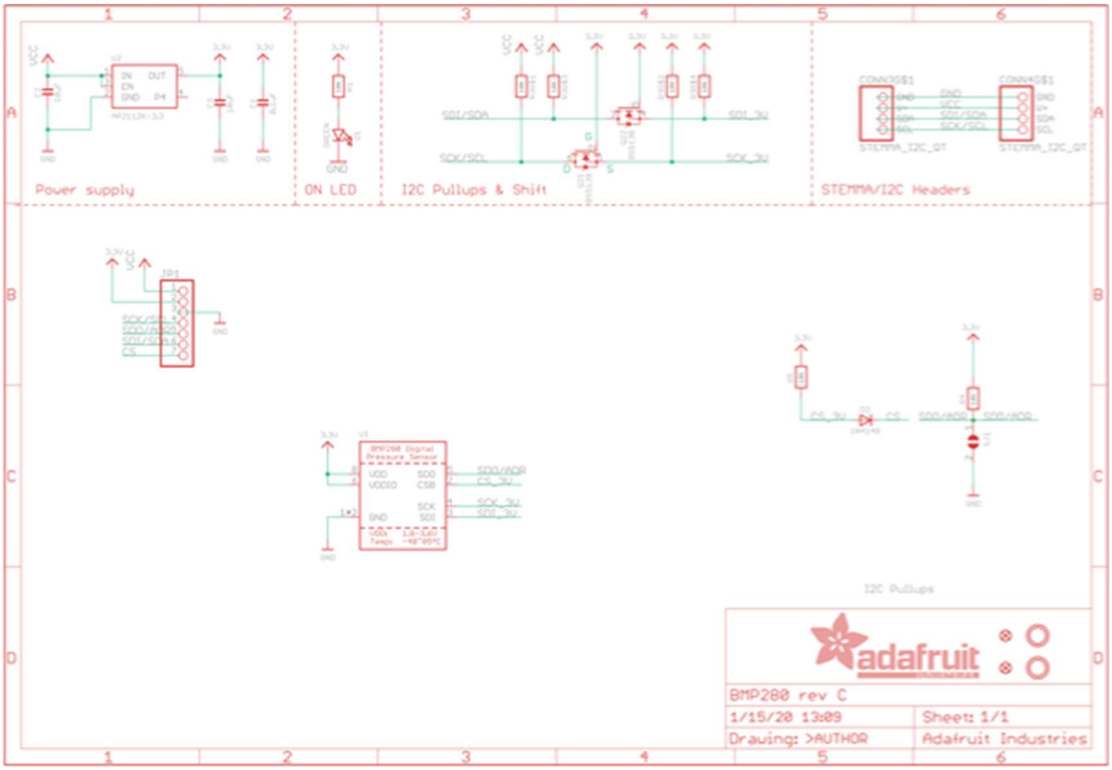
4.4.1.2 Gyroscope and Accelerometer

The chosen IMU is the BNO085. The data it will transmit includes absolute orientation, angular velocity, 3-axis acceleration, 3-axis magnetic field strength, 3-axis gravitational acceleration, and linear acceleration. Although not aircraft grade, the built-in algorithms and use of sensor fusion export accurate data that can be utilized in a real-time system. The Ground Station (4.5) will use the data to simulate the real time orientation throughout all stages of the launch. BNO085 communicates over the I2C protocol to be easily interfaced by our chosen microcontroller.



4.4.1.3 Barometer

The chosen Barometer is the BMP280 due to the combined accuracy, reliability, and low power consumption it offers. This sensor will primarily be used as an altimeter as it converts barometric pressure to altitude with an accuracy of ±1m. The measurement abilities of the BMP280 include a pressure range from 300hPa to 1100hPa with a pressure resolution of 0.16Pa and an advantage over the BMP 180 1Pa measurement ability. Another benefit of utilizing the BMP280 was the low power consumption of 2.7µA compared to the earlier models' 12µA power draw. Although currently unutilized, the built-in temperature sensor offers ±1C of accuracy which may be later utilized to increase accuracy across onboard radio transmitting systems.We tested this sensor on our subscale rockets flight computer to gather experimental data that proved this sensor's accuracy.



4.4.1.4 GPS

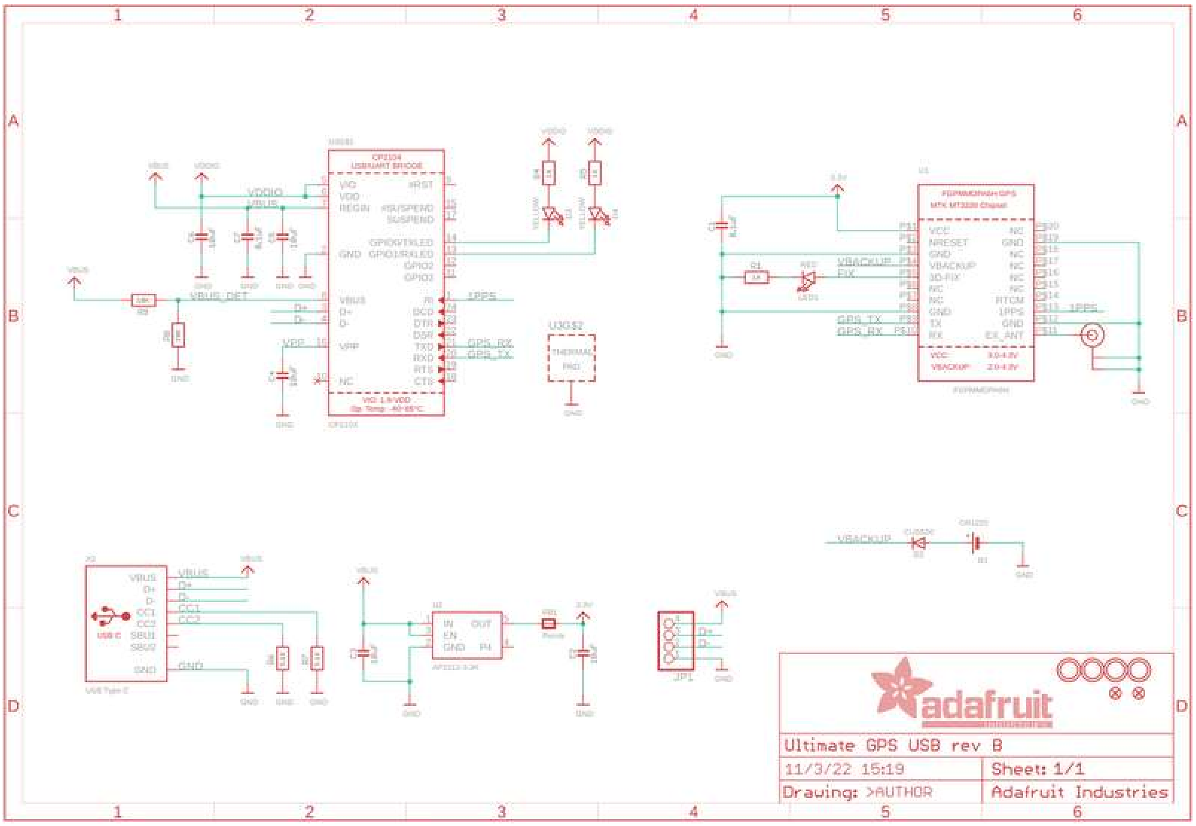
The GPS system will allow us to easily determine our landing site. This system consists of two independent GPS modules functioning on 2 independent frequencies to provide increased accuracy and redundancy.

4.4.1.4.1 Main GPS

The main GPS of this system is the Featherweight system. Functioning on the 933MHz band, this GPS functions independently from the flight computer providing independent accurate GPS data within a small form factor and minimal power consumption. The Featherweight will be powered directly from the power distribution board's (4.4.1.7) 5V supply to prevent potential outages or overvoltage from connecting directly to the chosen power source (4.4.1.6). The included software will allow us to monitor the GPS location through a phone or the Ground station which will be described more in-depth in 4.5.

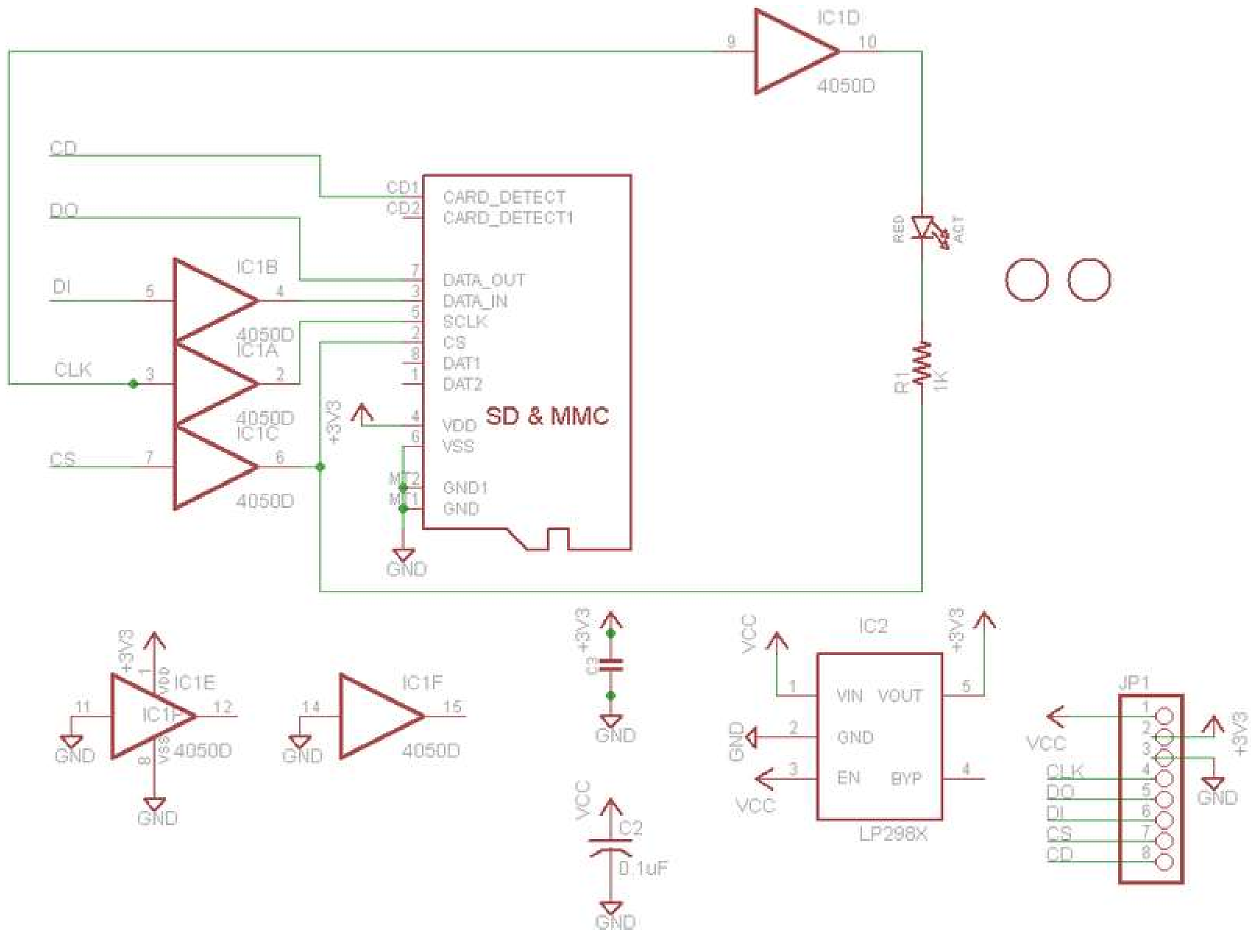
4.4.1.4.2 Redundant GPS

The secondary redundant GPS is an Adafruit Ultimate GPS Breakout board. This GPS, similar to Featherweight offers low power consumption and a small form factor. However, the Adafruit functions on the 433MHz band and is integrated into the flight computer, allowing us to interpret the GPS data through the ESP-32 and transmit data to the ground station for live feed. This allows us to easily plot and analyze the drift in real-. The communication protocol utilized is UART. While UART is not as quick at data transfer compared to SPI or I2C, it offers efficient and reliable data transfer for our GPS signal.

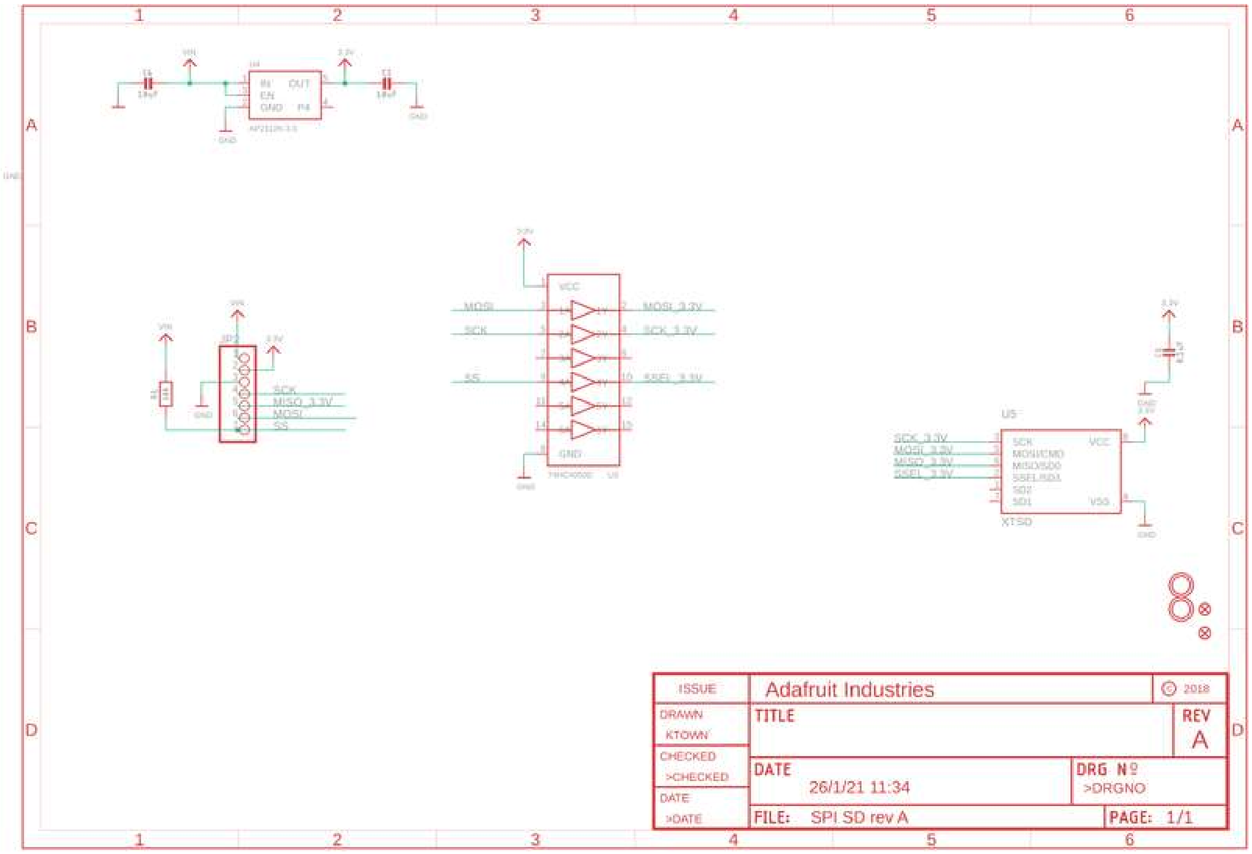


4.4.1.5 Flash SD Card and SD Card Reader

Along with transmitting the data gathered to the ground station, to compensate for signal interference we will be logging all the data read from our sensors. This data will be interpreted through the ESP-32 and stored in two independent locations. The first is a micro-SD card, which offers easy access to data upon recovery of the system. However, due to the mechanical system within the micro-SD card breakout board, possible intense vibrations throughout flight may create inconsistency in data, and possibly corruption. So, we will also be using an external 512mb flash memory board that will be directly connected to the ESP-32 for our most reliable data storage. Both breakout boards utilize the SPI protocol to store data. SPI has the advantage of high speed and low power data transfers when compared to I2C which many of the other peripheral sensors utilize.



Micro SD Breakout Schematic



512MB Flash Storage Schematic

4.4.1.6 Battery Selection

The chosen power source for our flight computer is 2 18650 Lithium-Ion batteries connected in series for a total output of 7.4V and 2600mAh of capacity. This choice offers superior reliability and capacity compared to other choices; this is highlighted in the decision matrix below. The total 2600mAh of capacity offers an estimated 100 to 180 minutes of runtime. This calculation was done with the assumption that each component is utilizing its maximum current draw constantly. By utilizing these values, we have accounted for any idle duration that the flight computer will sit through on the launch pad. This excess of power allows for an increased recovery timeslot, where if the drift is greater than calculated, we will not have to deal with a Loss of signal from the telemetry system. The jst xh connector will be utilized to connect our batteries to the PCB to ensure a secure connection while still maintaining a removable battery

4.4.2 RF

4.4.2.1 Frequency

Two independent frequencies were chosen to transmit telemetry data: the 70cm band at 433.2 MHz and the 33cm band at 917.4 MHz. The higher frequency 33cm band will be utilized by the featherweight GPS system to solely transmit our primary GPS data. The lower frequency 70cm band will transmit all other telemetry data including altitude, temperature, orientation, acceleration, velocity, redundant GPS, and flight profile status. To transmit on this band a LoRa Radio transceiver will be utilized and interfaced through the ESP-32. LoRa Radio offers long transmitting distances at low data speeds of approximately 22kbps. Due to this, all data will be consistently formatted in a simple comma-separated text.

4.4.2.2 Antenna

To transmit data from the payload on the 433 MHz band, a custom-made antenna will be manufactured. The antenna will be a vertically polarized ¼ wave antenna made from solid copper wire. The antenna will be supported through a 3D printed mount. The base of the antenna will be soldered directly to the LoRa Transmitter Module, and the PCB will act as the ground plane. The antenna will be tuned to the transmitting frequency using an external network analyzer.

4.4.2.3 Radio Frequency Workshop

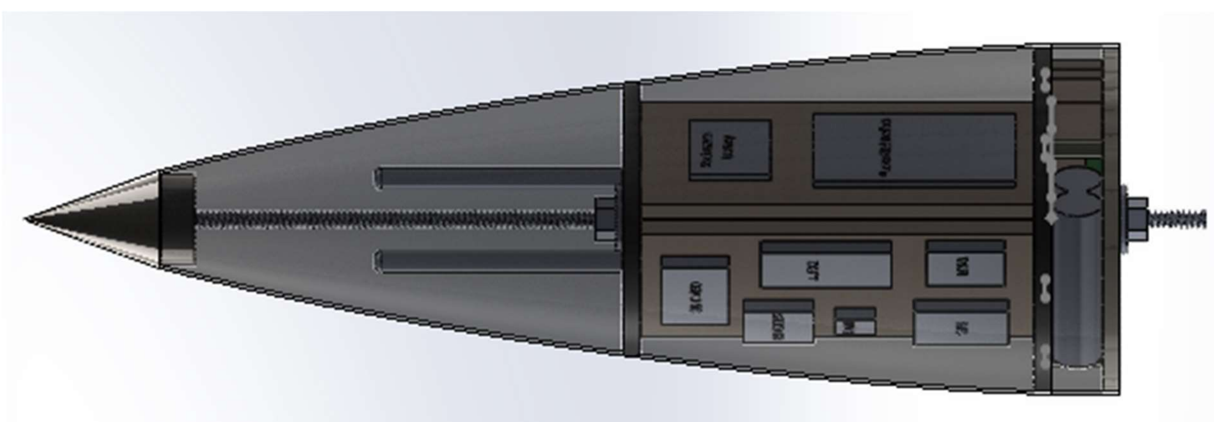
Member enrichment remains the focus of our USLI team, we strongly believe NSL should not only be a platform to show off the skills you already have, but a medium to develop new ones. Currently all transmitters will operate under the callsign KQ4FDO, however, in order to aid in manufacturing our own antennas, as well as programming components for RAFCO commands, our USLI team will be hosting an "RF Workshop" where we will prep members for their Technician's Exam, as well as give them the more valuable knowledge found in General class workshops. In combination with free testing with GLAARG for UCF students, it is also feasible that the workshop will become a means of STEM engagement to help others be more involved in similar projects.

4.4.3 Avionics Sled

4.4.3.1 Design

The Asclepius Triangular Triple Sled Avionics Bay or ATTSAB for short, is the name given to our avionics bay. There were many factors that led to the creation of the ATTSAB, but the first one that inspired the idea was the desire to communicate with the flight computer via radio signal. The body of the rocket is made out carbon fiber, which blocks radio signal. In order to avoid this, we chose to move the avionics bay into the nose cone, which is made of fiberglass. This created the need for the ATTSAB design.

There were a few predetermined factors within the design of the nosecone that we knew we would have to work around when designing this bay. The dimensions of the nosecone itself being the obvious ones, and another one being the threaded rod which was used to apply tension onto the nosecone via the metal tip. We decided to incorporate this rod into the structure of the bay instead of merely working around it. We use lock nuts to hold the bay together, allowing a simplistic friction fit design for the triple sled set up. Moving forward, we chose the triple sled design for 2 main reasons. Firstly, to maximize the space for electronics and wiring within the limited space. Secondly, the combined sleds now inherently resist torsion forces without requiring extra supports. With batteries below and electronics on the outside, the internal space created by the three sleds made for an easy wiring solution. Additionally, it made it easy to include space for a camera which will be used to record the rocket's flight, for promotional purposes.



Other designs that were considered were the Tripod and Twin sled design. The tripod design was the precursor to the ATTSAB, it consisted of the same triple sled design, but instead of centering rings it used a tripod stabilizer system as an idea to make the internals of the nosecone more impact resistant. We quickly moved forward from this design after closer inspection due to its inefficient space usage and propensity to shake during flight. The twin sled design came from the need of our telemetry lead to have easy access to the electronics. The idea was to have two sleds attached together via rods that would slide up and out of the nose cone via tracks, essentially functioning like a removable drawer of electronics. We ended up discarding this idea, since this design brought up other problems such as organization, wiring, etc. Out of the three, the simplest and most efficient design was clearly the ATTSAB.

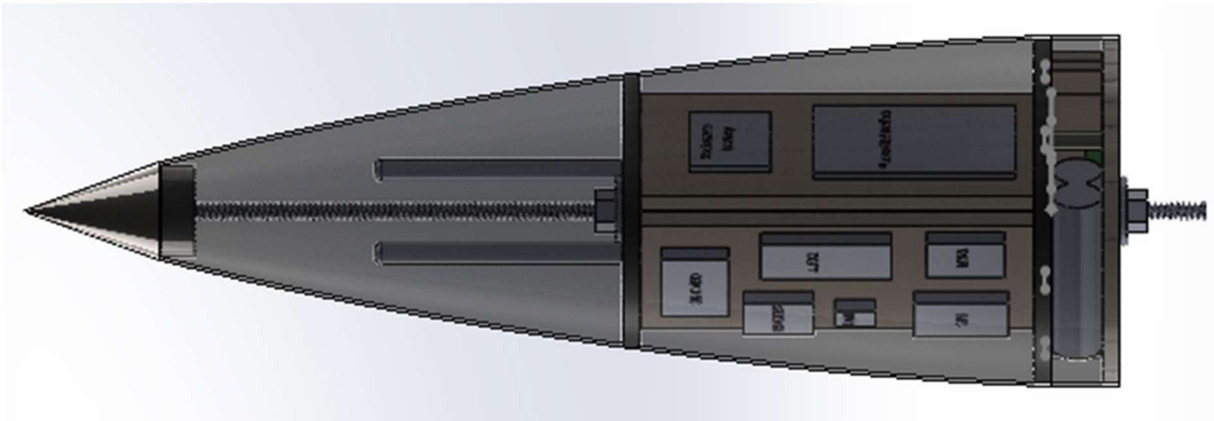
		RATINGS		
Criterion	**Weight**	**Triple Sled**	**Single Sled**	**Tripod**
Space Efficiency	6	5	3	2
Manufacturability	3	3	5	1
Structural Stability	5	3	2	5
Organization of Avionics	2	5	3	5
Total		**64**	**49**	**50**

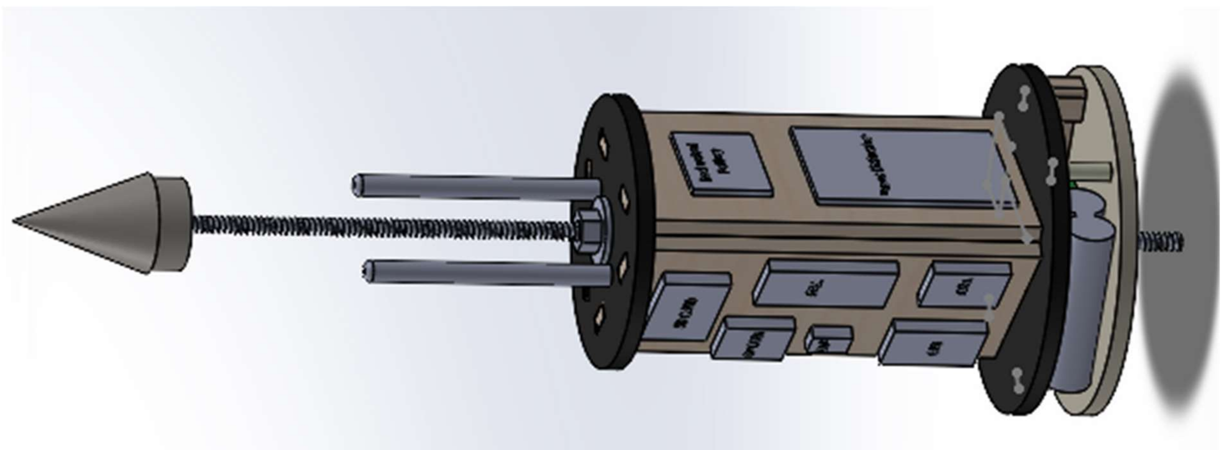
4.4.3.2 Materials

For the top and bottom centering plates we will be 3d printing using PETG as we have excess filament from other components in which it is necessary The niche shape also means 3D printing would make manufacturing much easier. Furthermore, we want a material that will be able to take the pressure from the lock nuts well without deforming, and we can include threaded inserts easily during the printing process. The threaded inserts are able to be placed into the hot plastic and will dry inside the plates, allowing them to be secured to the rod.

The sleds will be made of plywood as they are a simple shape to laser cut and would benefit from being able to flex lightly. The dowels underneath the lower plate will also be wood as they will not need to withstand high amounts of force and cutting wooden dowels to size is an easy process. The camera mount in the lower section will be 3d printed as it is a very specific shape and will be simplest to manufacture that way. It will also be experiencing little to no force so there are not many concerns regarding the possible loads the nose cone will experience.

4.4.4 Nose Cone Integration





4.4.5 Software

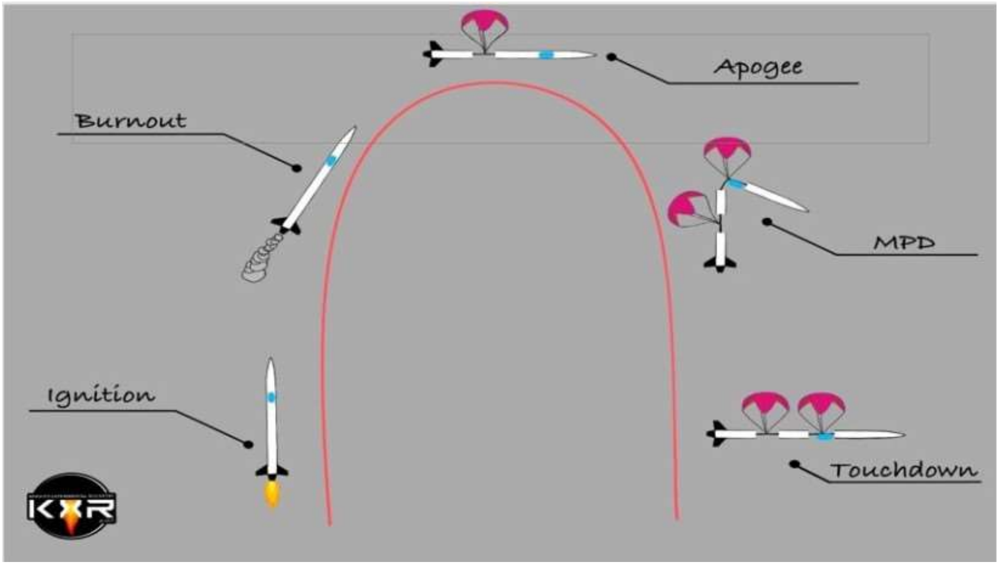
The software used for the ground station will be the TestFlight app. Therefore, communication can be tracked utilizing a cell phone via Bluetooth connection. The app installs BTAP, the blue tooth application software) and the LoRa radio or GPS application software. For optimal connection with the ground station the antenna should be laid horizontally instead of towards the actual rocket.

4.4.5.1 Software Design

The software that the ESP-32-based flight computer will be utilized by be written in the Arduino IDE. The advantages offered by this IDE are easy interfacing with the microcontroller, automatic functional prototypes, and easily understood. This IDE is based on C and C++ programming languages that are extremely powerful and allow for a large extent of manipulation.

4.4.5.2 Flight Path

The software that will run the Flight Computer will be based on 5 stages of flight that are defined in the following sections -



(MPD - Main Parachute Deployment)

4.4.3.2.1 Idle State

The Idle state will be the standard state that the Flight computer sits in. This state will be manually activated by the operator on an HTML website hosted using the ESP-32's built-in 2.4GHz Wi-Fi. Following this initialization, the 2.4GHz local wifi network will be shut down to conserve power. This allows for easy transportation of the entire system to the launchpad without accidental initialization of the launch state. Instructions can be found in the pre-flight launch checklist. The Idle state will actively monitor the accelerometer outputs from the BNO085. The transition from the Idle State into the Launch State will be highlighted in the following section.

4.4.3.2.2 Launch State

The Launch State will be initiated once the acceleration of the rocket monitored by the IMU reaches 14 m/s. This will indicate the ignition of the H-class rocket motor. This state once activated will begin the data logging sequence, which will interpret the raw values given from all sensors onboard, but mainly the barometer and the IMU. All data will be logged onto the onboard SD card, and flash storage. The barometer data will be converted into altitude in feet to be sent through the LoRa transmitter. All other IMU, GPS, and battery status data will also be sent through the LoRa transmitter to the ground station for live interpretation and monitoring. Throughout this state, the barometer pressure value will be monitored after it has been processed through a Kalman filter to smooth extraneous data points. This is done to monitor the velocity precisely to trigger the following profile where velocity is equal to zero.

4.4.3.2.3 Apogee

The rocket hits its apogee once it's reached its highest point in flight, where velocity equals zero. This will be determined through the development of a Kalman filter for the BMP280 barometer. The Kalman filter can be used to better estimate system parameters when collecting data on pressure. This will create greater accuracy with our estimations in real-time. This will reduce the noise that could come from sensor data. Within this state data logging and LoRa transmissions remain normal.

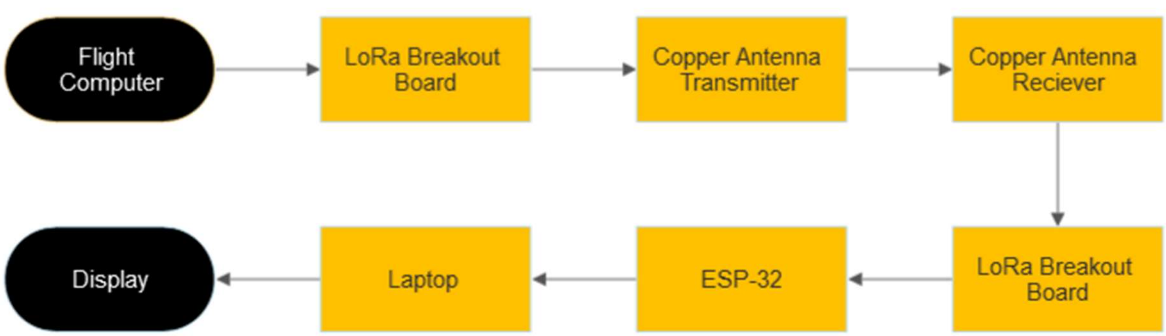
4.4.3.2.4 Main Chute

The change in velocity that will determine the initialization of this stage of flight will be determined through data gathered from the vehicle demonstration flight. Although an estimate of this change in speed can be acquired through simulations, it is not accurate due to drag induced by tumbling not being accounted for. Within this state data logging and transmissions remain normal, however, the operator will begin to focus on both the main and redundant GPS data sent to the ground station to ensure accurate tracking of the landing location. This state will also begin to monitor linear velocity and altitude to initiate the following state.

4.4.3.2.5 Touchdown

The touchdown state is initiated when the rocket has landed on the ground. This will be determined once the accelerometer data gathered from the IMU reads 0, and the altitude given from the barometer holds constant for > 10 seconds. This will conclude the flight of Asclepius.

4.5 Ground Station Sub-System



4.5.1 Purpose

The ground station sub-system aims to gather flight data throughout the launch. This will be communicated on two independent frequencies highlighted in. The ground station, while not required, will help to build relevant skills for the telemetry sub-system as well as serve as a learning experience for our members. In order to effectively operate the ground station equipment, at least one member must be HAM Radio Certified (all transmitters will operate under the call sign KQ4FDO)

4.5.2 Components

4.5.2.1 70cm Band Antenna

The same custom antenna used in section 4.4.2.2 will be repurposed for receiving on the Ground Station's LoRa breakout. The antenna will also be composed of a copper wire tuned to the frequency of 443.2 MHz, a frequency found on the restricted 70cm band.

4.5.2.2 LoRa Breakout

The Adafruit RFM96W is a LoRa radio transceiver which will allow us to send and accept data assuming it is encrypted with the same CTCSS tone as well tuned to the transceiver's respective frequency. A duplicate transceiver will be attached to the custom flight computer which will allow us to receive live data during flight.

This specific breakout uses SPI communication to communicate with the ESP32 found on the flight computer. The breakout has a SX1276 LoRa modem attached to it. The LoRa digital communication method has an estimated accurate range of 6,561.68ft, which is more than satisfactory for NASA Student Launch's range. It is worth noting that LoRa modules can far exceed such limits, however, this is the maximum which we can safely assume accuracy.

Several libraries exist made specifically for the RFM96W breakout. Said libraries are geared towards usage for Arduino IDE which will be ran on an ESP32.

4.5.2.3 Computer

A laptop with Arduino IDE will be used to interpret the transmitted data being interfaced by the receiving ESP32. The laptop will be running the LoRa module's preset libraries and will serve as a display for the resulting data. The purpose of this display is expounded on in section 4.5.3

4.5.3 Interfacing

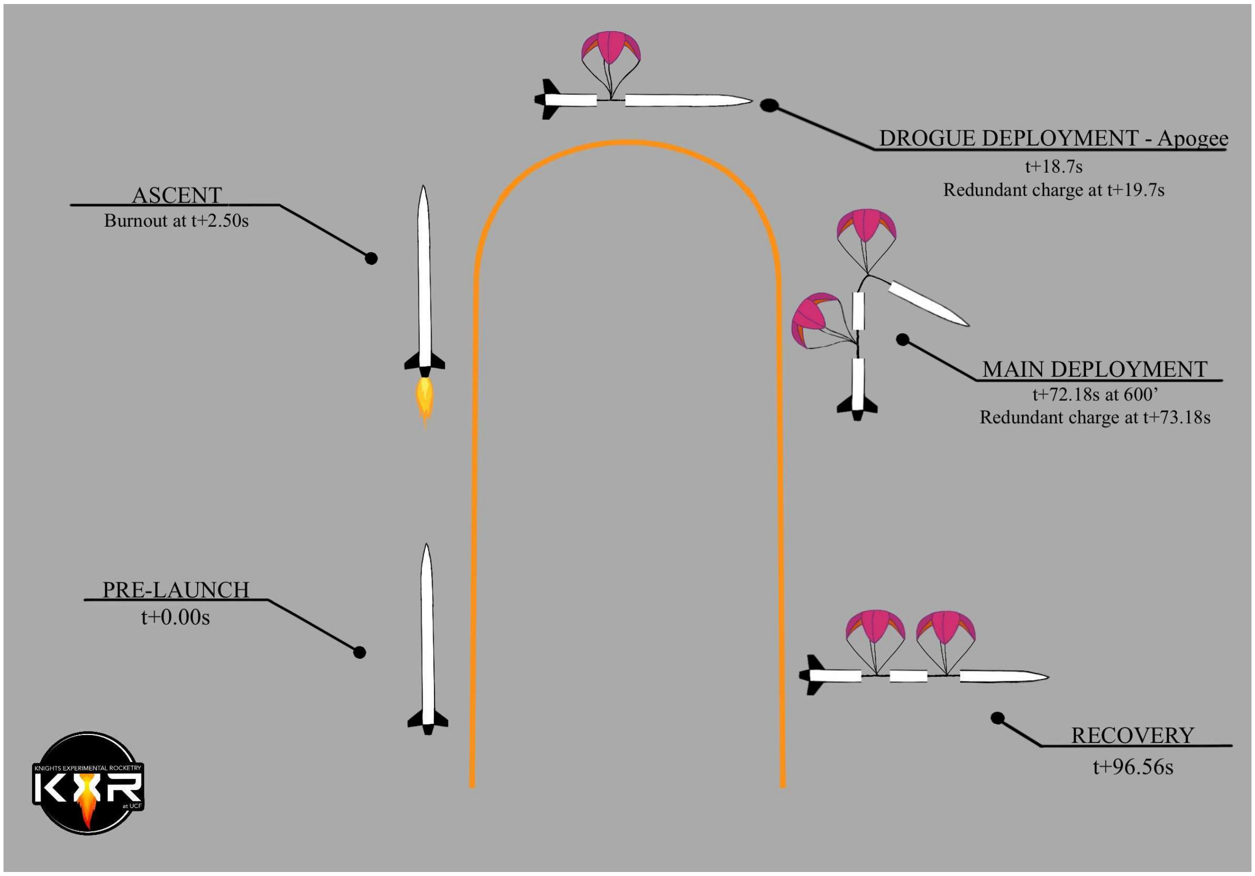
4.5.3.1 Software

The software that will be utilized to interface the ground station with a user operator will be an esp-32 connected to a windows laptop. The laptop will serve as the graphical interface, described in the following section. The software that will be used to manipulate and display this data graphically will be written in Excel VBA. This will allow us to create macros that will take the data that is exported from the ESP-32 and display it graphically for a user to interpret.

4.5.3.2 Graphical Interfacing

To be able to monitor the live flight status throughout the duration of the flight, a graphical interface is necessary to allow an operator to easily monitor all aspects of the flight. To gather all the necessary information that is transmitted live through the LoRa transceiver, a windows laptop will be interfaced with the ground station. Graphs displaying data from the IMU, Barometer, and GPS will be displayed along with the current flight path status.

4.6 Payload Deployment



Our flight path is depicted in the diagram above. It starts with ignition and continues until ground hit. After the burnout stage is finished the rocket reaches apogee and the drogue parachute deploys. After the drogue, the main parachute deploys, the PILL will exit the rocket alongside the parachute; the PILL will be attached by a 48" piece of Kevlar shock cord tied to the main shcok cord. After this, the rocket will slow down and have a ground hit of roughly 20m/s. Upon ground hit, the PILL will deploy its camera and begin enacting the RAFCO commands.

4.7 Sub-Scale Flight Computer

4.7.1 Purpose

The purpose of the sub-scale flight computer was to test the sensors during flight. This could therefore be used for data analysis on its capabilities. Through this, we could determine the accuracy of the current design, as well as compute offset values. Further presenting the performance of the software under flight conditions and leading to the detection of any possible errors or weak points. Overall, the flight aims to test the overall integration of each component. If any errors arise, we then know how to fix them before eventually completing the final flight at the competition in April.

4.7.2 Components

4.7.2.1 Microcontroller

We chose to utilize the ESP-32 for both Full and Subscale flight computers. This microcontroller has an extreme excess of processing power for the data interpretation and logging that occurred on the subscale flight. However, keeping this part consistent allowed us to become familiar with the abilities of this microcontroller.

4.7.2.2 Barometer

The choice to use the BMP280 came down to its precision sensing capabilities combined with the sensors low cost. The sensor's use in the flight computer is to take barometric pressure and convert the readings to Altitude measurements. The measurement abilities of the BMP280 include a pressure range from 300hPa to 1100hPa with a pressure resolution of 0.16Pa and advantage over the BMP 180 1Pa measurement ability. Another choice to use the BMP280 was the lower power consumption of 2.7µA compared to the earlier models 12µA power draw. The increased sensor accuracy, lower power draw, and sensor size were the deciding factors for the Telemetry team to use the BMP280.

4.7.2.3 IMU/Accelerometer

The chosen accelerometer for the Subscale flight was the MPU 6050. This sensor only offers 6 DOF compared to the 9 DOF offered by the BNO085. Due to this, we lacked the more advanced algorithms and the magnetometer offered by the BNO085. However, we still utilized the accelerometer and gyroscope given on the MPU 6050, setting the accelerometer sensitivity to ±8G, nearing the estimated 7.14G's that the subscale would experience. The MPU 6050 follows the same I2C protocol that the BNO085 utilizes allowing for easy communication to the microcontroller.

4.7.2.4 SD Card

The subscale utilizes the same micro-SD card breakout board that the Full scale utilizes. All data from the subscale will be stored within the card. This will include data on altitude, temperature, velocity, etc.

4.7.2.5 LED

A standard 3.3V LED was utilized to communicate the status of the flight controller up until arming for launch. The Status lights use a series of consecutive blinks that are documented within the arming procedures to inform the user that each sensor and arming procedure is nominal.

4.7.2.6 Testing

Launching a test flight computer with the critical sensors, IMU and Barometer, allowed us to gather initial data and determine how these sensors function throughout the stages of launch. Some concerns such as the Barometer getting accurate atmospheric pressure were considered and remediated by drilling vent holes in the side of the upper body tube.

4.7.2.7 Software

The software that runs the subscale flight computer is script written in the Arduino IDE that mainly focuses on data logging. Contrary to the Full-Scale flight computer, which has 5 stages of flight that are cycled through based off live data interpretation, all data is logged to the SD card. This is done by gathering each piece of raw data that can be gathered from the sensors included on flight. Following flight, all this data can be examined and applied to improving the final software.

Multiple Libraries were used by other third parties. Said third parties include Adafruit, and Electronic Cats.

```
#include "stdio.h"
#include "I2Cdev.h"
```

```
#include "MPU6050.h"
#include "Adafruit_BMP280.h"
#include "SPI.h"
#include "SD.h"
#include "FS.h"
#include "Wire.h"

// Object Declarations
MPU6050 accelgyro;
Adafruit_BMP280 bmp;

// MPU6050
int16_t ax, ay, az;
int16_t gx, gy, gz;
// aa = adjusted acceleration/gyro
float aax, aay, aaz;
float agx, agy, agz;
//BMP280
sensors_event_t temp_event, pressure_event;
float temp, pressure, altitude;
float local_altitude;
// File IO
String dataMessage;
char file_name[] = "/data01.txt";
//Flight Profile
const long interval = 50;
long startTime = 0;
unsigned long elapsedTime = 0;
unsigned long currentMillis = 0;
unsigned long previousMillis = 0;
double printable_time = 0;
int launch = 0;
int land = 0;
float initial_alt;


// Output data will not be absurdly fast
#define OUTPUT_READABLE_ACCELGYRO
// Led declaration
#define LED_PIN 32
bool blinkState = false;
// Takes an integer nob(number of blinks) and makes the led blink however many seconds are
thrown to period
void error_blinks(int nob, double period)
{
```

```
  int i;
  // converting the seconds that are given into milliseconds
  period = period * 1000;
  delay(1500);

  for (i = 0; i < nob; i++)
  {
    digitalWrite(LED_PIN, HIGH);
    delay(period);
    digitalWrite(LED_PIN, LOW);
    delay(period);
  }
  delay(1500);
}

void writeFile(fs::FS &fs, const char * path, const char * message)
{
  File file = fs.open(path, FILE_WRITE);
  if(!file){
    Serial.println("Failed to open file for writing");
    return;
  }
  if(file.print(message)){
    Serial.println("File written");
  } else {
    Serial.println("Write failed");
  }
  file.close();
}

// Function to write the data to a file!
void appendFile(fs::FS &fs, const char * path, const char * message)
{
  File file = fs.open(path, FILE_APPEND);
  if(!file){
    Serial.println("Failed to open file for appending");
    return;
  }
  file.print(message);
  file.close();
}

// Write the sensor readings on the SD card
void logSDCard(void)
{
```

```
  dataMessage = String(printable_time) + "," + String(aax) + "," + String(aay) + "," + String(aaz)
+ "," + String(agz) + "," + String(agy) + "," + String(agz) + "," + String(temp) + "," +
String(pressure) + "," + String(altitude) +  "\r\n";
              // String(temperature) + "\r\n";
  appendFile(SD, file_name, dataMessage.c_str());
}

// Turn the MPU on and change the sensitivity of the Accel to 8g and Gyro to 1000deg/s
void initilize_MPU(void)
{
  // Initlizing the MPU
  Serial.println("Initializing I2C devices...\n");
  accelgyro.initialize();
  // Configure Accelerometer Sensitivity
  Wire.beginTransmission(0x68);
  Wire.write(0x1C);                  //Talk to the ACCEL_CONFIG register (1C hex)
  Wire.write(0x10);                  //Set the register bits as 00010000 (+/- 8g full scale range)
  Wire.endTransmission(true);
  // Configure Gyro Sensitivity
  Wire.beginTransmission(0x68);
  Wire.write(0x1B);                   // Talk to the GYRO_CONFIG register (1B hex)
  Wire.write(0x10);                   // Set the register bits as 00010000 (1000deg/s full scale)
  Wire.endTransmission(true);
}

// Transform raw data into G's
void adjust_mpu_value(void)
{
  // Transform accel data into G's - for 8g sensitivity divide by 4096
  aax = (float)ax / 4096.0;
  aay = (float)ay / 4096.0;
  aaz = (float)az / 4096.0;

  //Transform Gyro data into Radians - for +/-1000deg/s divide by 32.8
  agx = (float)gx / 32.8;
  agy = (float)gy / 32.8;
  agz = (float)gz / 32.8;
}

//Goodluck little subscale, xoxo - andy
float get_local_altitude(void)
{
  local_altitude = 1016.25;
  return local_altitude;
}
```

```
// Confirming devices are initilized
void test_connections(void)
{
  delay(4000);
  Serial.println("Testing device connections...\n");
  if (accelgyro.testConnection())
  {
    Serial.println("MPU6050 connection successful\n");
    error_blinks(2, 1);
  }
  else
  {
    Serial.println("MPU6050 connection failed\n");
    error_blinks(6, 0.3);
  }

  delay(8000);

  //initilizing the bmp here
  if (bmp.begin())
  {
    Serial.println("BMP280 connection successful\n");
    error_blinks(2, 1);
  }
  else
  {
    Serial.println("BMP280 connection failed\n");
    error_blinks(6, 0.3);
  }
  delay(8000);
}

// Checking if an SD card is inserted into the reader
void SD_Inserted(void)
{
  while(!SD.begin())
  {
    Serial.println("Card Mount Failed");
    error_blinks(6, 0.3);
  }
  uint8_t cardType = SD.cardType();
  if(cardType == CARD_NONE)
  {
    Serial.println("No SD card attached");
```

```
    error_blinks(6, 0.3);
    return;
  }
  error_blinks(2, 1);
}

// Creating a file on the SD Card (Need to fix this to change the file name everytime it is powered on, by incrememnting 1 in the file name)
void create_file(void)
{
  File file = SD.open(file_name);
  Serial.println("Creating file...");
  writeFile(SD, file_name, "Time, aX, aY, aZ, gX, gY, gZ, temp, pressure, altitude \r\n");
  file.close();
}

void setup()
{
  Serial.begin(38400);
  Wire.begin();

  // Setup green LED :)
  pinMode(LED_PIN, OUTPUT);

  initilize_MPU();

  test_connections();

  SD_Inserted();

  create_file();

  delay(120000);

}

void loop()
{
  // Read values from mpu, Transform values into g's
  accelgyro.getMotion6(&ax, &ay, &az, &gx, &gy, &gz);
  adjust_mpu_value();

  // Read values from BMP
  temp = bmp.readTemperature();
  pressure = bmp.readPressure();
```

```
 altitude = bmp.readAltitude(get_local_altitude()); //  Write a function that takes the local
altitude from a .txt file in the SD card, encode blinks into LED to tell issues for flight computer

 // Checking if the acceleration in G's is greater than 14m/s^2 (1.4G)
 if (aaz >= 1.4 && launch == 0)
 {
  // Begin the clock, Initiate launch, turn LED on
  startTime = millis();
  initial_alt = altitude;
  launch = 1;
  digitalWrite(LED_PIN, HIGH);
 }

 //elapsedTime = millis() - startTime; - this may be unneccesary
 currentMillis = millis();

 // If it has been 'inteval' of whatever interval is set to and we have launch start logging data
 if (currentMillis - previousMillis >= interval && launch == 1)
 {
  previousMillis = currentMillis;
  // Write values
  logSDCard();
  printable_time += 0.05;

  //*UNNECCESARY - Printing values to the serial monitor for testing
  Serial.print(printable_time); Serial.print(", ");
  Serial.print(aax); Serial.print(", ");
  Serial.print(aay); Serial.print(", ");
  Serial.print(aaz); Serial.print(", ");
  Serial.print(temp); Serial.print(", ");
  Serial.print(pressure); Serial.print(", ");
  Serial.print(altitude); Serial.print("\n");//*/
 }

 // If its been 2 minutes and the current altitude is less than or equal to the starting launch
altitude +or- 3 meters(10ft) and we have launched, wait 30 seconds and then go into an infinite
loop to stop logging data.
 if (currentMillis > (startTime + 120000) && altitude <= (initial_alt + 3) && launch == 1)
 {
  land = 1;
  delay(30000);
  while(1)
  {

  }
```

```
}
```

4.7.2.8 Battery Selection

The battery choice for the Subscale flight computer is a single alkaline 9v battery. The ease of use and high voltage allowed for simple integration of all the components used in the subscale flight computer. Since there are no requirements for our subscale flight (in reference to duration on the launch pad) the low price point of a typical 9v battery made it the optimal choice consider our needs.

5 Safety

In any project, risk is inevitable. It is our job to be able to recognize those risks and treat them accordingly. In order to avoid undesirable results, especially physical injury, it is crucial to have clear procedures in place. This section provides methods that will limit risks at assembly and launch, as well as specific descriptions of possible hazards and their prescribed solutions.

5.1 Draft of Assembly and Launch Procedures

5.1.1 Setup

- Inspections for damage from travel
    - According to each subsystem, checks for damage and/or missing parts will be conducted prior to checks and assembly.
        - Each team lead shall inspect for presence of all parts, according to the engineering drawings of their final designs.
        - While unlikely with our main manufacturing materials, inspections for dents or chips in the epoxy coatings, 3D printed structures, and all other components shall be conducted.
        - Ensure all electronics are undamaged
            - Check for disconnections, tangled wires, and dents or chips in hardware.
- Checks for environment:
    - Ensure wind speeds are below 25 mph.
        - If above 5 mph, alter the direction of the launch rail.
    - Ensure clouds or obscuring phenomena of more than five-tenths coverage are not present.
    - Check humidity and terrain for excessively dry conditions.
        - If so, a fire blanket must be placed below the launch pad.
        - Remove any dry brush that could act as tinder in case of a fire from the area.
    - Ensure no high voltage electrical lines or major highways are present at the launch site.
    - Ensure no buildings or structures are within 1500 feet of the launch site.

- Briefing to team members by Safety or Systems Team Lead:
  - Timeline of events prior to, during, and after launch
  - Launch field etiquette
  - Assurance of NAR minimum safe distances, per our motor's impluse
    - Minimum diameter of cleared area: 125 ft
    - Minimum personnel distance: 2000 ft
  - Overview of troubleshooting measures
    - Designate members to observe trajectory for ballistic collision
  - Identification of fire suppression and first aid equipment
    - Designate member(s) to administer fire suppression and first aid in case of emergency

5.1.2 Aerostructures

5.1.2.1 Recovery Pre-Flight Check

- Drogue
  - Attach drogue shock cord and parachute
    - Using quick links, attach the end labeled "bottom" to lower airframe.
    - Using quick links, attach the end labeled "upper" to the U-Bolt on the coupler.
    - Using a quick link, attach the parachute on the third loop near the upper end of the drogue shock cord.
    - Ensure quick links are fully tightened.
  - Fold and insert parachute
    - Attach the smaller nomex blanket to the drogue shock cord
    - Z-fold drogue parachute
      - Lay out the parachute then gather the lines and organize the parachute flat.
      - Fold each side repeatedly toward the center.
      - Organize it so the diameter is 15% of the diameter of the parachute size.
      - Fold the parachute from top down in three sections so it appears to make a "Z" shape.
      - Pull the fabric from the underside of the parachute around the side and over the top.
      - Make a crease in the center of the fold.
      - Bring the line up 1/3 of the crease then wrap the lines around the parachute smoothly.
    - Burrito wrap into nomex blanket.
    - Insert into lower airframe
    - Z-fold the shock cord into 4 equal section, and wrap varying amounts of painters or masking tape around each section.
- Main
  - Attach main shock cord and parachute

- Using quick links, attach the end labeled “bottom” to the coupler airframe.
- Using quick links, attach the end labeled “upper” to the U-Bolt on the nose cone shoulder.
- Using a quick link, attach the main parachute onto the main shock cord through the loop near the upper end
  - Ensure quick links are fully tightened.
- Fold and insert main parachute
  - Attach the smaller nomex blanket to the main shock cord
  - Z-fold main parachute
    - Lay out the parachute then gather the lines and organize the parachute flat.
    - Fold each side repeatedly toward the center.
    - Organize it so the diameter is 15% of the diameter of the parachute size.
    - Fold the parachute from top down in three sections so it appears to make a "Z" shape.
    - Pull the fabric from the underside of the parachute around the side and over the top.
    - Make a crease in the center of the fold.
    - Bring the line up 1/3 of the crease then wrap the lines around the parachute smoothly.
  - Burrito wrap into nomex blanket.
  - Insert into upper airframe.
  - Z-fold the shock cord into 4 equal sections and wrap varying amounts of painters or masking tape around each section.
- Black Powder Prep
  - The student mentor will be performing the black powder preparation and installation.
- Assemble
  - With the black powder chargers installed, slide the coupler into the lower airframe section
  - Install the 4-40 shear pins through the coupler and the lower airframe section
  - Slide the coupler into the upper airframe and attach the upper airframe section to the coupler using metal screws.
  - Slide the nose cone onto the upper airframe and install 4-40 shear pins.

5.1.3 Payloads

5.1.3.1 Telemetry Pre-Flight Check

- Software Initialization
  - Load Arduino IDE
  - Initial configuration procedure
    - Open preferences

        - Within the additional boards manager URL text box, copy the following line : http://arduino.esp8266.com/stable/package_esp8266com_index.json,https://dl.espressif.com/dl/package_esp32_index.json
        - Close preferences
      - Open the Library manager
        - Search the following : bmp280
        - Install "Adafruit BMP280 Library by Adafruit"
          - Install all excess libraries when prompted.
        - Search the following : MPU 6050
        - Install "MPU6050 by Electronic cats"
    - Compiling and uploading code to the ESP-32
      - Connect Micro USB
        - Select Port
        - Select the board "NodeMCU-32S"
        - Hit Upload
          - You will now be prompted with "Connecting…..Connecting….."
        - Press and hold the "IOO" button on the esp-32.
  - Physical Setup
    - Physical inspections of the following – examining for damage from travel
      - PCB Board
      - Batteries
      - Wires
      - Connectors
      - Antennas
    - Initialize batteries
      - Plug in JST XH connector
      - Ensure all components power on properly by visually inspecting power LED's
    - Install assembly into Nose Cone
      - Ensure threaded rod is securly fastened into the nosecone tip
    - Install Nosecone into Body tube
  - Final Inspection
    - Connect the ground station laptop to the ESP-32 2.4GHz Wi-Fi and ensure the HTML website is properly configured
    - Ensure LoRa module connected to the ground station laptop is receiving live information.

5.1.3.2 Experiments Pre-Flight Check

- Perform a visual inspection of the PILL.
  - Inspect the exterior of the PILL for any dirt, debris, damage, or other concerns.

    - This may include but is not limited to: dust or dirt buildup, cracks in the casing, or plastic deformation.
  - Inspect and verify all PILL internals.
    - Remove the primary endcap (the one with a U-bolt) from the PILL by loosening the six screws on the outer rim.
    - Slide the Electronics Sled carefully out of the PILL through the endcap opening.
    - Confirm all electronics and linear elevator components are present, free of dust or debris, and undamaged.
  - The following electronics must be accounted for:
    - Raspberry Pi
    - Battery Hat
    - Real-Time Clock Module
    - BNO055 Inertial Measurement Unit
    - Radio SDR Dongle
    - Radio Antenna
    - Camera
    - Continuous Servo
    - Rotational Servo
    - Limit Switch
- Replace the two AA batteries in the Battery Hat.
  - Ensure both batteries are fully charged before installing.
- Power on the PILL.
  - Provide power to the Raspberry Pi by shortly pressing, then depressing the power button found on the Battery Hat.
  - Ensure the startup procedure executes properly by watching for the following indicators.
    - Flashing lights on the Raspberry Pi
    - Continuous servo motor moving the linear elevator up, then down.
    - Camera rotation servo rotating the camera 360 degrees.
  - Should any of the previously mentioned startup indicators fail to execute, perform the following troubleshooting steps.
    - Ensure all cables are undamaged and not twisted or caught on any mechanisms.
    - Disconnect all power connectors, ensure they are undamaged and free of debris, then reconnect them.
    - Ensure the two AA batteries in the Battery Hat are fully charged. A low charge may be indicated by the LEDs present on the Battery Hat.
    - With all the above steps performed, attempt to power on the Raspberry Pi again.
- Ensure the linear elevator and camera rotation servo are fully functional.
  - Upon correctly powering on, the continuous servo and rotational servo will attempt to spin. Verify that their movement is smooth and unrestricted.

    - If any issues with rotation are observed, perform the following troubleshooting steps:
        - Find and remove any blockages from the gears and motors.
        - Ensure all gears and motors appear undamaged.
        - Test the air for the smell of burning and look for smoke.
        - If smoke is detected or either servo motor continues not to spin, a motor replacement may be necessary.
- Connect to the Pi via ethernet and verify output log data.
    - Plug one end of an ethernet cable into the RJ45 port on the Raspberry Pi. Plug the other end into a laptop, either directly into an RJ45 port or through an adapter.
    - Open a command prompt window on the laptop and SSH into the Raspberry Pi. Details of this process will be documented once the Raspberry Pi has been received and programmed.
    - Once connected to the Raspberry Pi, read the output logs to ensure the PILL is functioning correctly.
        - The following log statements should appear in some form:
            - PILL powerup sequence initiated.
            - Raspberry Pi is online
            - PILL script executing
            - Power input adequate
            - Real-Time Clock reporting
            - BNO055 readings within bounds
            - Radio is operational
            - Camera is operational
    - Should the Raspberry Pi SSH connection fail, perform the troubleshooting steps found in the "Power on the PILL" section.
    - Should any of the log statements fail to appear or return an error, perform the following troubleshooting steps:
        - Confirm that the correct software has been loaded onto the Raspberry Pi.
        - Follow any troubleshooting steps proposed in the error statements.
- Return the Electronics Sled and seal the PILL.
    - Slide the Electronics Sled carefully back into the PILL.
    - Place the primary endcap (the one with a U-bolt) on the PILL and tighten the 6 screws as shown Ensure that both endcaps of the PILL are tightly secured and not at risk of coming loose.
        - If either endcap is loose, tighten the bolts as far as possible without using excess force.
- Verify the Hatch and Bearing Mechanism are operating smoothly.
    - Exercise the Hatch by moving it from fully closed to fully open.
    - Rotate all sections of the PILL independently by hand to ensure that they are spinning freely.

    - If the hatch or bearing mechanism is not moving freely, perform the following troubleshooting steps:
        - Find and remove any debris or blockages from the hatch and bearing mechanism.
        - Apply lubricant to the hatch or bearings if necessary.
        - Place the PILL on a flat surface and ensure that it naturally aligns such that the camera and electronics face directly upward.
    - Should the PILL not naturally align correctly, perform the following troubleshooting steps:
        - Remove any foreign objects from within the PILL.
        - Perform the troubleshooting steps found in the previous section.
- Seal the Hatch
    - Move the hatch into the closed position such that it is held in place by the rubber seal.
    - Ensure the hatch does not open if the PILL is held upside-down or at an angle.
- Attach and test the U-Bolt
    - Ensure the U-bolt is securely fastened to the primary endcap of the PILL.
    - Coordinate with aerostuctures to attach shock cord.
        - Tug on the shock cord while holding the PILL to ensure it does not come loose.
- Final Inspection
    - The team lead will ensure that all steps listed above have been followed.
    - A final visual inspection will be conducted
        - Confirm that the lights on the Raspberry Pi are on and blinking
        - Ensure that all elements remain in prime condition, free from debris or damage.

5.1.5 Prior to launch

- Go/No Go poll
    - The systems manager will conduct a poll for each system, where "Go" means that their components are prepared for launch, and "No Go" means that any component is not ready for launch. Leads representing each subsystem will include:
        - Payloads
            - Recovery
            - Telemetry
            - Experiments
        - Aerostructures
            - Design and Analysis
        - Integration
    - If any are "No go", all operations halt and the corresponding subsystem will solve the issue. Repeat the previous step until all systems are "Go".
    - If all systems are "Go", operations may proceed.

- Once all components are prepared and each section is integrated, the rocket will be transported to the launch pad.
    - A team of essential launch personnel will be determined. Only this team may accompany the rocket to the launch pad.
    - Two participants will carry the rocket from either end.
        - Before installing the vehicle onto the launch rail, check:
            - The launch controller is disarmed
            - The launch rail is the minimum distance of 2000 feet from spectators
            - Conditions remain favorable as per the Environment Checklist
            - The launch pad is stable and sufficiently sized
        - Installation
            - Point launch rail to predetermined degrees.
                - If wind speeds are above 5 mph, alter the direction accordingly.
            - Slide the vehicle onto the launch rail along rail buttons
                - If resistance is encountered, remove the vehicle and ensure proper alignment of rail buttons and, if necessary, apply lubricant.
    - Motor installation
        - Only the student mentor may perform this step, with proper PPE, which may include gloves and safety glasses, to his discretion.
            - Insert motor tube into lower airframe, ensuring centering rings hold securely.
            - Install tailcone, ensuring bolts are securely fastened.
            - Screw motor retainer into tailcone.
    - Ignitor Installation
        - Only the student mentor may perform this step, wearing proper PPE, which includes safety glasses and gloves.
            - Ensure alligator clips are clean and undamaged.
            - Ground alligator clips to remove excess static charge.
            - Install the ignitor through the nozzle of the motor and push the ignitor all the way up the core of the motor.
    - Vehicle Launch
        - A 5 second countdown will ensure at adequate volume for all participants to hear.
        - The launch controller officer will push the button to ignite.

5.1.6 Post Flight

- At the scene of collision
    - After a full 60 seconds have passed since collision, and no other rockets are set to launch in the vicinity, designated members of recovery, as well as one member from each subsystem, will go investigate the scene of the collision.
        - Initially upon recovery, no members shall come into physical contact with the rocket.

        - Photo documentation of the scene of collision will be collected. Members from each subsystem will ensure no evidence is left undocumented.
        - It shall be determined that all sections are present, and any damage will be taken note of.
        - Once leads have agreed it is safe to proceed, each section of the rocket will be carefully lifted off the ground and consolidated into the hands of two members. It will then be carried back to the ground station.
- Once returned to ground station
    - Telemetry Data Retrieval
        - SD-Card
            - Separate Nosecone from the Bodytube
            - Remove the ATTSAB asslembly from the Nosecone
            - Remove the SD-Card from the flight computer PCB
            - Insert the SD-Card into the ground station computer
            - Run the Excel VBA script to interpret the written data in visual graphs for an operator to examine
        - Flash storage
            - Insert a micro-usb cable into the ESP-32 located on the ATTSAB and the ground station computer
            - Run the Arduino IDE script to remove the data off the flash storage.
            - Run the Excel VBA script to interpret the written data in visual graphs for an operator to examine
        - Disassembly
            - Remove JST XH connectors to the two LiPo batteries
            - Inspect for visual damage
    - Deconstruction
        - Motor
            - Remove motor retainer and tailcone
                - Inspect for physical damage on interior
        - Avionics Bay
            - Remove the nose cone
                - Inspect for physical damage on sled
                - Turn off all electronics

5.1.7 Troubleshooting

- Misfire
    - The launcher's battery will be removed to ensure it is disarmed. The avionics will be disabled as well.
    - After a minimum of 60 seconds, designated leads will approach the launch pad. If necessary, the failed igniter and motor will be removed.
    - Determine if another launch is feasible.
- Unintended ballistic trajectory

- Members will be tasked with observing trajectory. If signs of parachute deployment are not detected at 4 seconds past apogee, the following must be executed by any members within a 500 foot radius of the anticipated collision:
  - The members first referenced will announce “Scatter”
  - Upon hearing this, all spectators must run in the opposite direction of the apparent trajectory for a minimum of 10 seconds.
- Missing Section(s)
  - The most likely location of the missing section will be determined on a map using launch trajectory and winds data.
  - Present members will search for components that could indicate point of separation.
  - Reference the Vehicle Failure Modes and Effects sheet for guidance on associated dangers, if the failure mode can be determined.
  - Using the most likely location determined in the first step, assemble a team and head to that location.
    - Spread out team members, spacing approximately 20 feet from adjacent members in a 20-foot radius. Each member will face away from the group's center and slowly begin walking, scanning the ground ahead of them. If necessary, also scan the vertical surroundings.
    - If any evidence, such as marks in the dirt, is found, the team will reconvene and repeat the previous step from the location of the evidence.
  - Repeat these steps until the missing section is found.

5.2 Hazard Analysis Method

By assigning a letter and number to each event that corresponds to their respective likelihood and severity, we can more efficiently describe each event, and treat them accordingly.

5.2.1 Likelihood of Event

Description	**Percent Chance**
Frequent - 5	100% - 80%
Likely - 4	80% - 60%
Occasional - 3	60% - 40%
Rarely - 2	40% - 20%

Improbable –1	20% - 0%

5.2.2 Severity of Event

Description	**Level of Risk**
Fatal - A	Extremely High Risk
Critical - B	High Risk
Moderate - C	Medium Risk
Minimal - D	Low Risk

5.2.3 Risk Analysis

	Fatal - A	**Critical - B**	**Moderate - C**	**Minimal - D**
Frequent - 5	5A	5B	5C	5D
Likely - 4	4A	4B	4C	4D
Occasional - 3	3A	3B	3C	3D
Rarely - 2	2A	2B	2C	2D
Improbable - 1	1A	1B	1C	1D

5.3 Personnel Hazard

Hazard	**Description**	**Risk Rating**	**Mitigations**	**Verification**
Mishandling of black powder	If the black powder explodes while transferring	1B	We will prevent this by securely storing black	All black powder will be handled by our NAR

	it to the charges, then injuries such as burns may occur		powder away from anything that could cause a spark or fire. The safety officer will have to check off the area before any black powder is moved	(National Association of Rocketry) certified mentor
Skin contact with epoxy	Epoxy has direct contact with a team member's skin while working on the construction of the rocket, which could result in chronic contact dermatitis, a rash that is not life threatening or contagious, but is extremely uncomfortable	3D	All team members using epoxy will be required to wear disposable latex gloves, long sleeve shirts, pants, and will be required to complete a safety quiz	Team members will have to check with the Safety Officer that they are wearing the correct safety equipment before using epoxy
Inhalation of epoxy fumes	When epoxy fumes are inhaled due to working with the epoxy, it can cause irritation in your nose, throat, and lungs. Continuous exposure to these fumes can end in asthma and sensitization	2C	To prevent team members from inhaling epoxy fumes, all members who use epoxy will wear a mask while using it in a well-ventilated setting	Before using epoxy, team members will have to show the Safety Officer that they are wearing masks
Skin contact with Super glue (CA)	If super glue gets onto a team member's skin due to working with super glue, it	5D	If gloves, protective eyewear, and long clothes are worn, then the risk of	Team members will have to show that they are wearing proper safety equipment

	could cause irritation. It could also cause skin to be removed with glue if not removed properly		super glue getting on skin is extremely low. If this does occur, the person with the super glue on their skin will immediately wash that part of their skin thoroughly with hot water and soap	before they start working with super glue.
Inhalation of motor fumes	Exposure to motor fumes while working with the motor can cause headaches, dizziness, nausea, and fatigue. Exposure to these toxic fumes over an extended period could lead to death	3C	We will prevent inhaling toxic motor fumes by only working with the motor outside in a well-ventilated space	The Safety Officer will check the wind direction and advise attendees where to spectate from
Inhalation of paint fumes	While painting the rocket, team members may inhale the fumes from the paint. This can cause short term issues like headaches, dizziness, runny nose, and itchy eyes. Some more serious problems that could stem from this could be nervous system and organ damage	4C	This can be mostly prevented by painting outside so fumes are not trapped. This can also be prevented by wearing a mask.	All team members that are painting will have to show the Safety Officer that they are wearing masks

Projectile materials during manufacturing	Material thrown from drill press due to being caught on the drill bit may cause severe injury through impalement, laceration, or otherwise high-speed impact of penetration with/of the skin. This will cause potentially severe loss of blood.	2C	We will prevent this by requiring any team member that is using the drill press to watch safety markings and to keep hands and loose articles of clothing or hair out of the drill area. Material being drilled will be clamped securely using vises and clamps, and members will be required to wear safety glasses.	Team members will be required to always wear safety glasses and secure the material being drilled. Using the correct type of drill bit and drilling speed for the material and size of hole.
CNC machines dust gets in operator's or spectator's eyes, nose, or mouth	Dust coming out of the machine could get in someone's eyes and cause irritation. A launched broken bit could impale a bystander and cause blood loss.	1D	This will be prevented by having a plexiglass cover in between the opening of the machine and the team members. Protective eyewear, and restrained clothing will be worn, and hair and loose articles will be secured to minimize the chance of a problematic incident. A dust collector will also be in place.	The Safety Officer or authorized mentor will be present whenever the CNC machine is being used. They will make sure that everyone is following the right procedures.

While using the electric drill a team member is pinched by the drill, or is impaled by the drill	A team member is pinched or impaled by the electric drill while constructing the rocket. This could cause a range of injuries including slight irritation to blood loss	2C	This will be prevented by using caution and making sure the item being drilled is secured in place to prevent movement which could lead to injury. This can also be prevented by using the appropriate but for the material.	All team members who are using electric drills will have to confirm with the Safety Officer or trained mentor that the item being drilled is being done so with the appropriate bit and that it is properly secured
A team member is impaled by a driver	A team member impales themself or others while using a driver. This may result in blood loss.	2C	Team members will ensure that the item is properly secured using clamps or vices whenever using a driver	Before working with drivers team members will have to show the Safety Officer that the item is properly secured
Contact with debris from ballistic collision (due to Catastrophic Rocket Engine Failure)	Destruction of the rocket resulting from Catastrophic engine failure, caused by malfunction of the rocket during flight, would result in falling debris, potentially burning, cutting or otherwise injuring participants.	1B	This can be prevented by having everyone stand as far away from the rocket as possible during the launch.	If this occurs the Safety Officer will make sure that the while team follows all safety procedures
Contact with debris from ballistic collision (due to parachute deployment failure)	Failure of the parachute to deploy during the launch could result in the destruction of the rocket, which	2B	To prevent this, we will make sure that the parachute is inserted properly, and the cord is in a position where it	Everyone on the team will be properly instructed by our experienced high-powered rocketry mentor on how to properly

	would create the risk of projectile debris which, if it hits participants, could cause burns, cuts, and other injuries.		will not get caught on anything. In case this happens, everyone in the immediate area will move as far as they can to lower the risk of obtaining injuries from the impact of the rocket	pack a parachute and the Safety Officer will double-check the process on all launch occasions
Fiberglass fumes are inhaled by a team member	A team member inhales toxic fumes produced while cutting or sanding fiberglass, causing slight lung irritation.	2C	This can be easily prevented by wearing a mask	The Safety Officer will make sure that all team members that are working with fiberglass are wearing masks
Fiberglass shards cut skin	A team member is cut by a shard produced when cutting or sanding this fiberglass. This could result in blood loss.	1D	We will require all members working with fiberglass to always wear gloves	Team members who are working with fiberglass will have to check in with the Safety Officer to make sure that they are wearing gloves
Carbon Fiber fumes are inhaled by a team member	A team member inhales toxic fumes produced while cutting or sanding carbon fiber. These fumes can cause slight irritation in your lungs	2C	All team members using carbon fiber will be required to wear masks.	The Safety Officer will make sure that all team members that are working with carbon fiber are wearing masks
Carbon Fiber shards cut skin	A team member is cut by a shard produced when cutting or sanding	1D	We will require all members working with carbon fiber to	Team members who are working with carbon fiber will have to check

	carbon fiber. This could result in blood loss and carcinogenic effects.		always wear gloves	in with the Safety Officer to make sure that they are wearing gloves
Burns from gas oven	In manufacturing, a team member is burned by the gas oven.	2C	Proper training for use of the gas oven and necessary PPE will be required from team members who wish to use it.	Training on use of the gas oven will be distributed to team members, and the safety officer will ensure proper PPE is in use.
Burns from soldering	Molten metal gets on skin when manufacturing electrical components, resulting in burns.	3D	Proper procedure regarding soldering will be followed.	A procedure for soldering will be written and followed, and only trained members may use hot tools.
Particulate matter from explosion impacting participant members	Projectiles resulting from the explosion at launch could harm participants.	1B	All members present at the launchpad will be wearing proper PPE, and everyone will be 25 feet away from the launchpad at launch.	Safety officer will ensure proper equipment is worn and proper distance is kept before allowing
Hearing Damage	Proximity to loud noises, such as those present at launch and from tools and machines during manufacturing, can cause long term hearing loss or tinnitus.	3D	Seek alternative machines and methods if possible. Noise cancelling equipment, such as earplugs, shall be worn.	Team leads will see that all possible hazards have been reduced in the design process, and that proper PPE is worn during all operations.

Tripping Hazards	Any objects, especially cords along the ground or from above, in the path of a participant pose a tripping threat. Injuries from tripping include bruising, but can be a catalyst for worse injuries if one falls into a secondary hazard.	3C	An organized, controlled environment shall be prioritized at all times. Participants shall be expected to clean up after themselves per every task, and not leave things such as tools laying around.	Participants shall hold each other accountable to keeping an organized environment, with team leads responsible for the state of the environment.
Cryogenic burns	Skin contact with dry ice is known to result in cryogenic burns.	2B	Designated thick gloves and tools such as a shovel or other scoop must be used to handle dry ice.	Materials Safety guidelines must be implemented by present leads whenever hazardous materials are in use.
Lead exposure	During soldering, lead exposure may occur. Chronic health problems are known to result from lead exposure.	2C	Only solder in well ventilated areas. Masks shall be worn when excessive fumes are present.	Monitoring of conditions and behavior in labs shall be carried out by present leads.
Octane Poisoning	Frekote Mold Release acts as a serious irritant upon ingestion, inhalation, or contact with skin or eyes.	2A	Frekote Mold Release will only be used in well-ventilated spaces, with gloves, safety glasses, and proper clothing. Masks will be available if	Implementation of safety measures proposed by the safety data sheet for this material will be done by both Safety and Manufacturing leads.

			deemed necessary.	

5.4 Vehicle Failure Modes and Effects Analysis

Hazards	**Description**	**Risk Rating**	**Mitigations**	**Verifications**
Airframe Failure	Buckling or shear of the rocket ripping it apart and causing debris. Could cause loss of vehicle.	1A	Ensure all measurements, manufacturing methods and material simulations are accurate and done in a proper fashion.	Manufacturing leads are to inspect every simulation and CAD design, as well as monitor all manufacturing and materials.
Ignition Failure	Issues with the continuity on the launch pad.	2D	Make sure to check the continuity before loading the pad.	Ensure this is listed on the flight day checklist.
Instability	Occurs when the stability margin is <1.00. The rocket and have a dangerous flight path creating a hazard. This would lead to possible loss of vehicle.	2A	All the models and simulations must be updated when changes are made, every single material must be accounted for when manufacturing.	The center of gravity must be determined and physically marked right after completion of the rocket.

Altimeter Failure	Connection loss or programming issues, flight path can become dangerous, this would lead to possible loss of vehicle.	3A	Testing of altimeter and its settings before launch	Ensure this is listed on the flight day checklist
Bulkheads Tear	Cavity or tearing of the bulkhead exposing delicate components of rocket, leading to the charges damaging the components.	2A	Proper manufacturing and use of measurements.	Reassuring all measurements are correct prior to any manufacturing and checking the integrity before flight day.
Motor Retention	Forces exerted by the motor cause it to break off weak and poorly made retainers, causing damage and possible complete loss of the vehicle.	3B	Proper design and manufacturing methods used to prevent any weak points.	During manufacturing the leads must inspect and determine if it is usable before launch day
Charge damage	Excess charges used to cause physical damage to bulkheads, couplers, parachutes, payloads, and avionics. This could lead to a total loss of the vehicle	3A	Proper calculations of charges needed to not use any excess and cause damage within the rocket.	Measurement of the charges must be made precisely before loading on launch day and when charging careful handling must be made.

Inaccurate Calculations	Forces calculated improperly could lead to the production of too thin tubes. This could lead to weak spots for failure.	3A	Make sure the correct measurements are utilized to ensure the tubes result in the proper thickness	Reassuring all measurements are correct prior to any manufacturing.
Nose cone failure	Nose cone halves are not properly bounded which leads to the failure of the nose cone	2B	Proper technique is carried out when integrating the nose cone with the rest of the rocket	Ensure that during the manufacturing process, that the nose cone is properly attached
Fin failure	Fins are not properly bonded to the rocket which could lead to the failure of the flight.	3A	Proper technique is carried out when bonding the fins with the rest of the rocket	Ensure that during the manufacturing process, that the nose cone is properly attached
Failure to retrieve flight data	Connection loss or programming issues could lead to the team not being able to retrieve the flight data	3C	Testing of the system used to retrieve flight data prior to launch	Make sure that it is on the flight day checklist.
Parachute Disconnection	The parachute detaching from the rest of the system after deployment due to an inability to	1A	Ensuring factor of safety of at least 1.5 when comparing the maximum exerted snatch	Collection of this data and proper analysis must be done before manufacturing.

	withstand the snatch force would result in a ballistic collision.		force and the maximum force the U-Bolt can sustain.	
Failure of Parachute Deployment	The parachute failing to release from the body tube would result in a ballistic collision.	3A	Ensuring that both the main and drogue parachutes are able to move freely in and out of the body tube.	The Recovery lead shall witness that the folding of the parachutes are optimal and ensure their mobility.
Unstable flight	If unstable flight occurs due to the fin material being too thin, or the center of gravity being below the center of pressure, this can cause the rocket to wobble in the air, and can affect the rocket's flight path making it unpredictable and dangerous	2D	This can be prevented by putting the center of gravity above the center of pressure. This stabilizes the rocket and prevents any wobbling from changing the course of the rocket.	During the design and construction of the rocket the Safety Officer will have to double check the center of gravity and the center of pressure.

5.5 Environmental Concerns Analysis

Hazards	**Description**	**Risk Ratings**	**Mitigations**	**Verifications**

Landscape	If there are power lines, trees, brush, forests, or any obstructions that may affect the success of the rocket is a hazard to the vehicle, and it may result in total loss	2A	The angle of launch will be away from all obstructions and try to aim for the landing to be away from those obsturctions as well.	When putting the vehicle on the pad we must ensure the angle and the direction are verified by the safety officer.
Humidity	The weather may influence the electrical components of the rocket, even if the rocket isn't directly exposed to rain, it may still have an effect. Could result in loss of the rocket, if components are destroyed.	2A	All handling of the rocket must be in adequate weather conditions, even during launch day the rocket should only be pulled out of the transport vehicle if the conditions are correct.	The team will verify the weather to be sure of the conditions.
Winds	High wind may cause the rocket to veer of course and head towards obstructions and people.	4B	The windspeed will be determined the day of the launch.	Verification of the speeds must occur right before the rocket is scheduled to be on the pad.
Fire	The combustion from the rocket may cause a fire in the area depending on if there is vegetation under the pad.	3C	The vegetation near the launch pad should be laid down, if possible, it's important to get it out of the way.	The area must be cleared by the safety officer to make sure there is no risk of fire.

Wildlife	Any interaction with wildlife could be detrimental to the rocket and the deadly animal that encounters it.	2B	Limiting the presence of local wildlife at location.	Researching local wildlife and ensuring they are not within the path of the expected trajectory at time of launch
Pollution at launch	Fumes and debris from the rocket left behind could be harmful to the environment, especially local flora and fauna.	4B	Leaving every site cleaner than we found it.	Using fuels and materials that are less likely to pollute, and the Safety Officer will implement “Leave it as you found it” behaviors on launch day.
Pollution during construction	Chemicals used during manufacturing being improperly disposed of can cause devastating environmental effects.	4C	Follow guidelines for disposal given by safety data sheets for hazardous materials	Manufacturing and safety leads will ensure procedures set by materials’ safety data sheets are implemented.

5.6 Sub-scale Safety Documents

5.6.1 Sub-Scale Telemetry Arming Procedure

- Set local barometric pressure
  - Go to https://www.weather.gov/
  - Enter the location of the launch site
  - Note the barometer pressure
  - Within the Arduino IDE, open “SubscaleFlightController_Final”
    - Locate the function “float get_local_altitude(void)”
    - Change “local_altitude” to noted reading in hPa.
- Initialization and upload
  - Load Arduino IDE
  - Initial configuration procedure
    - Open preferences
      - Within the additional boards manager URL text box, copy the following line : http://arduino.esp8266.com/stable/package_esp82

66com_index.json,https://dl.espressif.com/dl/package_esp32_index.json

            - Close preferences
        - Open the Library manager
            - Search the following : bmp280
            - Install "Adafruit BMP280 Library by Adafruit"
                - Install all excess libraries when prompted.
            - Search the following : MPU 6050
            - Install "MPU6050 by Electronic cats"
    - Compiling and uploading code to the ESP-32
        - Connect Micro USB
            - Select Port
            - Select the board "NodeMCU-32S"
            - Hit Upload
                - You will now be prompted with "Connecting…..Connecting….."
            - Press and hold the "IOO" button on the esp-32.
- Connect 9V battery
    - Upon supplying power, the flight computer will begin to initialize through a series of LED blinks
        - all NOMINAL blinks are spaced 1 second apart
        - Error startup on any sensor will cause 6 rapid blinks (.3 second interval)
- Allow Design and Analysis lead to setup run cam
- Secure nosecone to upper body tube.
- Following the initial startup checks, there is a built in 2-minute delay where the flight computer will sit in an idle state.
    - After 2 minutes, any motion in the Z-axis greater than 14m/s^2(including the force of gravity) will trigger data log
    - That motion will initiate launch
- Recovery Procedure
    - Break ESP32 infinite loop
        - Remove the micro-SD card
        - Disconnect power and remove micro-SD card
            - This device will RE-WRITE over ALL OF THE DATA if the launch procedure is performed after recovery, to reiterate – this device lacks the ability to realize it already did its job, it will do it again and destroy all of our valuable data if there is a power cycle.

5.6.2 Sub-scale Post-Flight Analysis

5.6.2.1 Event

On December 17th, 2022, NSL launched a sub-scale rocket at Palm Bay's launch ground. The rocket successfully launched, deployed a drogue chute, but failed to deploy its main chute, resulting in damages to the rocket when landing.

5.6.2.2 Flight Profile Report

1. At 0 seconds, CTI H-152 motor ignites

2. At 9 seconds apogee of 1,374 feet reached – a deviation of +34 feet from Open Rocket estimate of 1340 feet.

3. First charge goes off at 9 seconds. Lower body tube separates from coupler, deploying the drogue parachute and slowing the rocket to 40ft/s

4. Redundant motor ejection charge goes off at 11 seconds.

5. Second charge goes off at 27.5 seconds, at a height of 700 feet. Lower body tube separates from coupler, however main parachute fails to deploy.

6. Redundant charge for the main parachute goes off at 29.5 seconds.

7. Ground hit velocity of 40ft/s at 44.5 seconds.

8. Upon recovery, one fin has partially snapped, two adjacent fins have hair line cracks along base.

5.6.2.3 Potential Causes for Failure

ID	Failure Event	Root Cause	Likely (1-5)	Reasoning
A1	Snapped Fin	Main Deployment Failure	5	Although the lower body tube separated, the main seemingly snagged and failed to deploy, resulting on an impact velocity of 40 meters per second
A2	Hairline Cracks on Fins			
A3	Missing Readings	BMP280 Failure	3	Level Shifter for 3.3V BMP280 to 5V output likely failed during flight
A4	Video Loss	SD Card Storage Full	5	SD Card was found to be filled during testing, so 8gb SD was fully taken up

5.6.2.4 Mitigating Failures

ID	Mitigation
A1	Either smaller main parachute as a 48-inch parachute is unnecessary for our current sub-scale weight, or a larger inner diameter for the body tube to ensure the parachute does not 'snag'
A2	
A3	Extensive testing on level shifter design or buying a 5v Adafruit BMP280. New BMP280 would likely be cheaper and easier
A4	Clearing SD card before flight, or using an alternate 32gb SD versus the original 8gb SD

5.7.2.5 Takeaways

Overall, more in depth testing must be conducted. All failures were results of oversights on our behalf. Noting this, repeated recovery tests should be conducted as well as more strenuous telemetry tests. It is favorable that such oversights have occurred on sub-scale, however, said mistakes cannot happen twice. In regard to telemetry, cheap parts end up being more expensive, cheaper parts from companies such as HiLetGo have potential to be hard to work with, as well as are more prone to being DOA. As for recovery, the 48-inch parachute increases the odds that snatch force tears a bulkhead as well as snags as we observed in our sub-scale flight. Whilst a general safety factor two is ideal for most situations, going well above that could be costly as well as lead to extraneous failures.

6 Project Plan

6.1 Mission Success Requirements

Requirement	Payloads	Vehicle	Recovery	Systems	Verification Plan	Verification Action
1.1				X	Only we will do all the work	The executive board of the club will ensure all aspects of design, manufacturing, and analysis are overseen
1.2				X	We will keep track of our project plan in an excel spreadsheet	The Systems Lead Manager will be responsible for meeting with Project System Leads to update necessary items
1.3				X	We will submit everyone that is attending Launch week activities by CDR	The Systems Lead Manager will be responsible for ensuring that the roster list for attending students is complete by CDR
1.5				X	We will be posting constant updates on our Instagram	The Knights Experimental Rocketry Executive board oversees all social media and will communicate with the Systems Lead Manager
1.6				X	We will email all documents by the deadline	The Systems Lead Manager will be responsible for collecting all documents necessary from each subsystem and emailing them to the appropriate location
1.7				X	We will complete all satisfactorily requirements on time	The Systems Lead Manager will be responsible for establishing hard deadlines for subsystems to follow in order to satisfy requirements
1.8				X	We will have all documents in PDF format	The Systems Lead Manager will communicate that all documentation must be in PDF format
1.9				X	We will have a table of contents and subsections	The Systems Lead Manager will format the PDF such that we have a table of contents
1.10				X	We will have page numbers on every page	The Systems Lead Manager will format the PDR such that we label every page
1.11				X	We will use a computer for video teleconferences	The Systems Lead Manager will be responsible for ensuring that there is a computer available for video teleconference

1.12	X	X	X	X	We will only use launch pads provided by Student Launch's launch services provider	NASA Ground crew will communicate to us which pad to use and where to go on launch day
1.13					We will have a mentor	
1.14				X	We will use an excel spreadsheet to document how long we have worked on each section	The Systems Lead Manager will be responsible for communicating to the other subsystem leads ensuring that they are recording there hours
2.1	X				We will deliver the payload to an apogee of 5000 feet	The Vehicle Design Manager wll ensure that payload reaches 5000 feet
2.2	X			X	We will declare our finial altitude goal by PDR	The Systems Lead Manager will ensure that the Vehicle Design lead has verified the apogee recorded through Openrocket
2.3	X	X	X	X	We will build a recoverable and reusable rocket	The Vehicle Design, Payload, and Systems Manager will establish procedure to test and validate that the rocke tis recoverable and reusable
2.4	X				We will only have a maximum of four independent sections. We will also have 2 airframe diameters in length on each coupler/airframe shoulders	The Vehicle Design Manager will work with the subsystem throughout
2.5	X	X	X	X	We will be able to prepare the rocket for launch within 2 hours	The Systems Lead Manager will organize the other 2 subsystems to work effectively and efficiently on launch day
2.6	X	X	X	X	We will be able to remain in launch-ready configuration on the pad for a minimum of 2 hours	The Systems Lead Manager will organize the other 2 subsystems to work effectively and efficiently on launch day
2.7		X			We will be able to launch the vehicle using a 12-volt direct	The Vehicle Design team will validate and test through static fires that the rocket can launch with the given ignition system

2.8	X	X			We will not use any external circuitry or ground support equipment	The Payloads Manager will verify that all electronics can work independently of ground support systems
2.9		X			We will use only commercially available ematches or igniters	The Vehicle Design manager will ensure that the only igniter mechanism purchased is ematches. This will be communicated to the Systems Lead Manager
2.10		X			We will only use a commercial motor	The Vehicle Design manager is responsible for selecting and focusing design iniatives on a commerical off the shelf motor
2.11		X			We will only use a single motor	The Vehicle Design manager is responsible for ensuring all guidelines are met as given by NASA
2.12		X			We will use a maximum of L-class motor	The Vehicle Design manager will be observant of the NASA guidelines and also the motor selected such that it falls within required rules
2.13		X			We will not be using a pressure vessels	The Vehicle Design manager will ensure that no pressure vessels are considered or purchased throughout the design and manufacturing process
2.14		X			We will have a minimum static stability margin of 2 at point of rail exit	The Vehicle Design team will validate and justify with Open Rocket that the stability has a minimum of 2 at point of rail exit
2.15		X			We will have a minimum thrust to weight ratio of 5:1	The Vehicle Design team will determine and validate with Open Rocket that the thrust to weight ratio is 5:1
2.16					We will not be using any external structural protuberance	The Vehicle Design Manager is responsible for ensuring that there is no structural protuberance from the airframe of the rocket
2.17					We will have at least 52 fps at rail exit	The Vehicle Design team will verify and validate with Open

						Rocket that the exit rail velocity is 52 feet per second
2.18	X	X	X	X	We will launch a subscale model prior to CDR. The subscale will resemble and perform similarly to the full-scale model. We will have an altimeter that will record the model's apogee altitude. We will have altimeter graphs or high-quality video and pictures of the as landed configuration	The Systems Lead Manager will be responsible for coordinating with the other leads and subsystems the manufacturing process, timeline, and procedures for subscale launch
2.19					We will launch a full-scale rocket launch in the same configuration we would be launching in as if it was actually launch day for competition	The Systems Lead Manager will be responsible for coodinating with the other leads and subsystems the updated manufacuturing process, timeline, and procudres for full-scale launch
2.20					We will complete an FRR Addendum if required to re-fly or completing a payload demonstration flight	The Systems Lead Manager will be responsible for communicating with the other subsystems to obtain specific infomration in order to complete the FRR
2.21					We will have our team name and launch day contact information in or on the rocket airframe in a place of easy of access	The Systems Lead Manager will communicate effectively with NASA all of our information and with the Vehicle Design Manager to have the information on the Airframe
2.22	X		X		We will mark and protect all lithium polymer batteries	The Payloads Manager will require that all batteries be protected and marked

2.23		X			We will not utilize forward firing motor, motors that expel titanium sponges, a hybrid motor, cluster motor, friction fitting for motors, exceed Mach 1 at any point during flight, 10% of the total unballasted weight of the rocket as it would sit on the pad, transmissions will not exceed 250mW of power, transmissions will not create excessive interference, and no metal	The Vehicle Design Manager will ensure that all motor designs fall within specifications outlined by NASA
3.1			X		We will use a dual deployment recovery system	Recovery team will ensure use of a dual deployment recovery system.
3.2			X		We will perform a successful ground ejection test for all electronically initiated recovery events prior to the initial flights of the subscale and full-scale vehicles	Recovery lead will ensure proper recovery events prior to launches with successful ground ejection tests.
3.3		X			We will have a maximum kinetic energy of 75 ft-lbf at landing	Vehicle Design team will ensure vehicle design will be exerting a maximum kinetic energy of 75 ft-lbf at landing.
3.4			X		We will use redundant commercially barometric altimeters	Payloads team will ensure use of redudant barometric altimeters.
3.5			X		Each altimeter will have a dedicated power supply	Payloads team will ensure all altimeters will be battery-powered individually.
3.6			X		Each altimeter will be armed by a dedicated mechanical arming switch	Payloads team will ensure altimeters are armed manually.

3.7			X		Each arming switch will be capable of being locked in the ON position	Payloads team will ensure arming switch will be turned on and locked in.
3.8			X		All recovery systems will be separate from payload electrical circuits	The Recovery Subsystem Lead will ensure that all electronics will be independent of experiements and telemetry electronics
3.9		X			We will be using removable shear pins	Vehicle Design team will ensure use of removable shear bolts during stage separation.
3.10		X			We will land with in a 2,500 feet radius of the launch pads	Vehicle Design team will ensure the launch radius is 2500 feet.
3.11	X		X		We will have a descent time of less than 90 seconds	We will ensure that descent time will be in accordance of our simulations from Open Rocket
3.12	X				We will have a GPS in all sections of the rocket that won't be tethered together	The Payloads Recovery team will ensure GPS will be in all nontethered portions of the rocket.
3.13	X				The recovery system electronics will not be adversely affected by any other on-board electronic devices	The Recovery subsystem lead will work with Experiements and Telemetry to ensure no advserse affects to on board electronics.
4.1	X				We will design a payload that upon landing autonomously receives RF commands and performing a series of tasks with an on-board camera system	The Payloads Experiments subsystem will be in charge of our Payload Integrated Launch Log (PILL).
4.2	X				We will have camera system capable of swiveling 360 degree to take images of the entire surrounding area of the launch vehicle. We will be able to accept RF	The Experiments Subsytem will have a telemetry capable payload containing a camera capable of 360 degree motion.

					sequence and perform a set of actions in order.	
4.3			X		We will only use black powder for in-flight recovery.	The Systems Lead Manager will be responsible for ensuring that the the use of black powder will be used for recovery systems.
5.1				X	We will use a launch and safety checklist	The Systems Lead Manager will be responsible for ensuring use of a launch and safety checklist.
5.2		X			We will identity a student safety officer	We will host an interview process to select a saftey officer that is qualified and will ensure that our team reamins safe durin manufacturing
5.3	X	X	X	X	The student safety officer will be responsible for design of vehicle and payload, construction of vehicle and payload components, assembly of vehicle and payload, ground testing of vehicle and payload, subscale launch test, full-scale launch test, competition launch, recovery activities, STEM Engagement Activities	Our safety officer will outline procedures and ensure all actions of design and manufacturing will be in accordance with safety standards.
5.4	X	X	X	X	We will abide by the rules and guidance of the local rocketry club's RSO	We will follow all rules and regulations set by Knights Experimental Rocketry.
5.5	X	X	X	X	We will abide by all rules set forth by the FAA	We will make sure everything is done in accordance with all set rules.
6.1				X	We will not show up to NASA Launch Complex without permission. We will complete and pass	We will ensure we have permission for launch and have all prequities completed before launch.

					and LRR conducted during Launch Week.	
6.2	X	X	X	X	We will launch at a NAR or TRA sanctioned and insured club launch if we do not end up launching at the NASA Launch Complex	Launch team will drive to our HPR L1 workshop launch site in Palm Bay if we are unable to travel to Huntsville.
6.3	X				The PILL will be a clear strucutre capable of landing normal to the ground	Payoads team will design exterior of the PILL with a clear polycarbonate capable of centering with respect to the ground..
6.3.1	X				The PILL will enclose a microcontroller, motor, batteries, and camera that are able to withstand impacts from landing and aerodynamic forces	Experiments subsystem will ensure PILL is capable of withstanding descent and impact conditions.
6.3.2	X	X			The PILL will be able to recieve long range radio command from NASA to instruct the devices on board	Experiments subsytem will ensure Pill is capable of telemetry and Vehicle Design team will ensure upper body tube is radiotransparant.
6.3.3	X				The PILL will be able to survive a landing impact velocity of 21 feet per second	Payloads subsystem will ensure PILL is capable of impact of 21 feet per second without failure.
6.3.4	X				The PILL structural design will be justified and validated through decision matrix methodology and iterative design	The Experiements subsystem will utilize decision matrix methodology and comparison and contrast methods to determine structural design choices

6.2 Business

6.2.1 Budget

6.2.1.1 General Budget

Recieved	Purchased?	Item Label	Component Description	Details	Quantity	Category	Price Each	Total Cost	Vendor
no	no	First Aid kit	First Aid Only 178 Piece Contractor's First Aid Kit (9302-25M) , White		2	Safety	$26.83	$53.66	Amazon
no	no	Sharpies	Sharpies 4 count silver		2	Organization	$5.32	$10.64	Amazon
no	no	Sharpies	Sharpies 12 count Black		1	Organization	$8.48	$8.48	Amazon
no	no	Duct Tape	1.89 in. x 120 yd. 300 Heavy-Duty Duct Tape in Silver (2-Pack)		1		$ 11.98	$11.98	Home Depot
no	no	Masking Tape	Scotch 1.88 in. x 60.1 yds. Contractor Grade Masking Tape (6-Pack)		2		$ 22.58	$45.16	Home Depot
no	no	Storage	Plastic 27 Gallon Container		3		$ 15.98	$47.94	Home Depot
no	no	Outlet Extender	6 outlet power strip heavy duty three pronged		2		6.99	$13.98	Amazon
no	no	Extention Cable	50 ft three pronged Extention Cable		2		16.58	$33.16	Home Depot

6.2.1.2 Vehicle Design Budget

Status	Account	Subsystem	Safety Index	Received	Purchased?	Item Label	Components Description	QTY	Price Each	Total Cost	Vendor
Incomplete		Recovery	low	no	yes	Nylon 8 ft Chute Main	8' Nylon Chute Main (20% discount)	1	$70.50	$70.50	Rocketman
Incomplete		Recovery	low	no	yes	Kelvar	1,200lb Kelvar Shock Cord 30'	1	$35.50	$35.50	Rocketman
Incomplete		Recovery	low	no	yes	Kelvar	1,200lb Kelvar Shock COrd 25'	1	$28.50	$28.50	Rocketman
Incomplete		Recovery	low	no	yes	Drogue Chutes	1' Standard Parachute with 20% discount	1	$23.50	$23.50	Rocketman
Incomplete		Recovery	low	no	yes	PILL Shock Cord	5ft 5/8" 3,200lb Tubular Nylon Shock Cords	1	$15.00	$15.00	Rocketman
Incomplete		Recovery	low	no	yes	Chute Protectors	18" x 18" Chute Protector	1	$26.50	$26.50	Rocketman
Incomplete		Recovery	low	no	yes	Chute Protectors	6" x 6" Chute Protector	1	$11.50	$11.50	Rocketman
Incomplete		Recovery	low	no	yes	Nylon 4-40 Shear Bolts	Nylon Pan Head Screws Phillips, 4-40 Thread, 5/16" Long pack of 100	1	$8.48	$8.48	McMaster
Incomplete		Recovery	low	no	yes	U-Bolt	Black-Oxide Steel U-Bolt with Mounting Plate, 3/8"-16 Thread Size, 1-3/4" ID	5	$2.66	$13.30	McMaster
Incomplete		Recovery	low	no	yes	U-Bolt Nuts (25 ct.)	Extra-Wide Thin Nylon-Insert Locknut Zinc-Plated Low-Strength Steel, 1/2"-13 Thread Size	1	$13.46	$13.46	McMaster
Incomplete		Recovery	low	no	yes	Quick Links	Oval-Shaped Threaded Connecting Link ype 316 Stainless Steel, 3/8" Thickness, 1/2" Opening, Not for Lifting	10	$7.77	$77.70	McMaster
Incomplete		Recovery	low	no	yes	U-bolt Washer (25 ct.)	316 Stainless Steel Washer for 1/2" Screw Size, 0.531" ID, 1.25"	1	$12.09	$12.09	McMaster
Incomplete		Manufacturing	high	no	yes	Fillet Epoxy	Thixo Fast Cure 2:1 Epoxy Adhesive - One 185 ml Cartridge & 2 Mixing Tips Code: TBTotalXyla	1	$27.92	$27.92	TotalBoat
Incomplete		Manufacturing	low	no	yes	Popsicle Sticks	100 pack of popsicle sticks Jumbo	1	$6.95	$6.95	Amazon
Complete		Manufacturing	low	yes	yes	Plywood	1/4"x4'x8' Hardwood PureBond Plywood	1	$44.68	$44.68	Home Depot
Incomplete		Manufacturing	low	no	yes	Sandpaper	120-3000 grit sandpaper for sanding composite	2	$7.99	$15.98	Amazon
Incomplete		Manufacturing	low	no	yes	Microfiber Cloth	14x14 Micorfiber Cloth blue 24 pack	1	$14.99	$14.99	Amazon
Incomplete		Manufacturing	high	no	no	Frekote Mold Release	Frekote 700-NC Mold Release	2	$30.67	$61.34	Composite Envisions
Incomplete		Manufacturing	low	no	yes	Paper Towel	Shop Towels 6 pack	1	$11.98	$11.98	Home Depot
Incomplete		Manufacturing	low	no	yes	Nose Cone Tip	T6511 2.000" ALUMINUM 6061 ROUND BAR 5" long	1	$30.94	$30.94	Metal Supermarkets
Incomplete		Manufacturing	high	no	no	Dry Ice	Publix Dry Ice	40	$1.89	$75.60	Publix
Incomplete		Manufacturing	low	no	yes	Orbital Sander	5in. Orbital Sander w/ Dust Bag	0	$26.88	$0.00	Walmart
Complete		Manufacturing	low	yes	yes	Orbital Sand Paper	Gator 5-inch 8-Hole Red Resin Aluminum Oxide Multi-Surface Hook and Loop Sanding Discs, 60-Grit, 5-Pack, 3725-30	2	$4.69	$9.38	Walmart
Complete		Manufacturing	low	yes	yes	Red Cups	Solo Disposable Plastic Cups, Red, 18oz, 50 count	2	$4.29	$8.58	Walmart
Complete		Manufacturing	low	yes	yes	MDF Boards	1/4 in. x 2 ft. x 4 ft. Medium Density Fiberboard	4	$12.49	$49.96	Home Depot
Complete		Manufacturing	low	yes	yes	Threaded Rod	1/4 by 36in	3	$8.47	$25.41	Home Depot
Incomplete		Manufacturing	low	no	yes	Aluminum Mandrel Extrude	5.000 x 0.125 ALUMINUM 6061 ROUND TUBE 40" long	1	$110.65	$110.65	Metal Supermarkets
Incomplete		Manufacturing	high	no	no	Uni Directional CFF Pre pre	711 KSI HIGH TENSILE STRENGTH FIBER ■ 36 MSI STANDARD MODULUS CARBON FIBER ■ 250F EPOXY RESIN ■ 0.006" THICK	21	$41.39	$869.19	Rockwest Composites
Incomplete		Manufacturing	low	no	no	Release Film	rtech A4000 High Performance Fluoropolymer Release Film – Viol	0	$13.90	$0.00	Composite Envisions
Incomplete		Manufacturing	high	no	yes	Fiberglass Sheets	E-Glass - Style 7500, 9.4 Oz (319 GSM) Total Weight - 50" Wide X 0.012" Thick	3	$38.79	$116.37	Rockwest Composites
Incomplete		Manufacturing	low	no	no	Packing Tape	IDL Packaging Concord Packing Tape - 2" x 1.6 mil x 110 Yards, Clear (Pack of 6)	1	$31.54	$31.54	Amazon
Incomplete		Manufacturing	low	no	no	Shoulder Coupler	5" G12 Coupler (10")	1	$47.41	$47.41	Wildman Rocketry
Incomplete		Manufacturing	low	no	no	Coupler	5" G12 Coupler (12")	1	$56.89	$56.89	Wildman Rocketry
Incomplete		Manufacturing	low	no	no	Fiberglass Plates	G-10 FR4 .125" x 12"' x 24"	5	$33.69	$168.45	ePlastics
Incomplete		Manufacturing	low	no	no	Yelllow Sealant Tape	Yellow Sealant Tape	10	$9.95	$99.50	Fiberglast
Incomplete		Intergation	low	no	no	Rail buttons	LARGE RAIL BUTTON (FITS 1.5" RAIL - 1515)	2	$5.70	$11.40	Apogee Components
Incomplete		Intergation	low	no	no	Motor Mount 75mm	1ft G12-3.0	1	$22.56	$22.56	Wildman Rocketry
Incomplete		Manufacturing	low	no	no	Mixing Tips	Thixo Cartridge Mixing Tips (12)	1	$11.99	$11.99	TotalBoat
						Shipping	Shipping	1	$34.84	$ 34.84	Wildman Rocketry

6.2.1.3 Payloads Budget

Status	Accou	Subsysten	Safety Index	Recieved	Purchas	Item Label	Component Description	QTY	Price Eac	Total	Vendor
Complete	SGA	Telemetry	low	yes	yes	ESP32	Adafruit ESP32 Microcontroller 2mb memory	1	$19.95	$ 19.95	Adafruit
Incomplete		Telemetry	low	no	no	LoRa radio transciever	Adafruit LoRa Radio Transciever	2	$19.95	$ 39.90	Adafruit
Incomplete		Telemetry	low	no	no	Flash Memory SD	Adafruit SPI Flash SD 512 MB	1	$9.50	$ 9.50	Adafruit
Incomplete		Telemetry	low	no	no	Adafruit GPS	Adafruit Ultimate GPS	1	$29.95	$ 29.95	Adafruit
Incomplete		Telemetry	low	no	no	BNO085	BNO085 Absolute Orientation IMU	1	$24.95	$ 24.95	Adafruit
Incomplete		Experiments	low	no	no	RTC Module	Adafruit PiRTC - Precise DS3231 Real Time Clock for Raspberry Pi	1	$14.95	$ 14.95	Adafruit
Incomplete		Experiments	low	no	no	Continuous Servo	Continuous Rotation Servo - FeeTech FS5103R	2	$11.95	$ 23.90	Adafruit
Incomplete		Telemetry	low	no	no	3.3v Voltage regulator	3.3V Buck Voltage regulator 5 pack	1	$12.49	$ 12.49	Amazon
Incomplete		Telemetry	low	no	no	5v Voltage regulator	5V Buck Voltage regulator 5 pack	1	$12.49	$ 12.49	Amazon
Incomplete		Telemetry	low	no	no	Male Female Bullet Connectors	yueton 30Pairs 3.5mm Male Female Banana Plug Bullet Connector Replacements	1	$7.99	$ 7.99	Amazon
Incomplete		Telemetry	low	no	no	BMP 280	Barometric pressure sensor	1	$6.99	$ 6.99	Amazon
Incomplete		Telemetry	low	no	no	SD Card	proprietary non-volatile flash memory card	1	$9.28	$ 9.28	Amazon
Incomplete		Telemetry	low	no	no	Camera Module	Run Cam Split	1	$79.99	$ 79.99	Amazon
Incomplete	SGA	Recovery	low	no	yes	Zipties	200 Zipties	1	$5.99	$ 5.99	Amazon
Incomplete	SGA	Recovery	med	no	yes	Heated Threaded Inserts	Threaded Heat Embedment Nut for Printing 3D Prin	1	$7.99	$ 7.99	Amazon
Incomplete	SGA	Recovery	med	no	yes	Rhino 300mah LIPO	Rhino 300mAh 2S 50C LiPo Battery Pack w/XT30	2	$10.87	$ 21.74	Amazon
Incomplete	SGA	Recovery	low	no	yes	Wires	Silicone red/black wires. 10 ft	2	$6.48	$ 12.96	Amazon
Incomplete	SGA	Recovery	low	no	yes	SS-5GL2 Limit Switch	ss-5GLT-HX Limit Switches 4 pack	1	$7.99	$ 7.99	Amazon
Complete	SGA	Experiments	high	yes	yes	Chopped Fiberglass Strands	4 Inch Chopped Fiberglass Strands - 100% E-Glass Fibe	2	$17.99	$ 35.98	Amazon
Complete	SGA	Experiments	low	yes	yes	Raspberry Pi 4B	GeeekPi Raspberry Pi 4 4GB Starter Kit - 32GB Edition	1	$229.99	$ 229.99	Amazon
Complete	SGA	Experiments	high	yes	yes	Clear Epoxy Resin Kit	Non Toxic Clear Epoxy Resin 1 Gallon Kit	1	$64.95	$ 64.95	Amazon
Incomplete		Experiments	med	no	no	Batteries	4X Energizer E92 Batteries	1	$5.99	$ 5.99	Amazon
Incomplete		Experiments	low	no	no	120 degree lens	Arducam 120 degree ultra wide angle lens	1	$34.99	$ 34.99	Amazon
Incomplete		Experiments	low	no	no	Ribbon cable extension	Arducam for Raspberry Pi Camera Ribbon Flex Extension Cable Set	1	$9.99	$ 9.99	Amazon
Incomplete		Experiments	low	no	no	IMU/Adafruit BNO 055	BNO55 Absolute Orientation IMU	1	$35.40	$ 35.40	Amazon
Incomplete		Experiments	low	no	no	Battery Pack	MakerHawk Raspberry Pi UPS Power Supply Uninterruptible UPS HAT	1	$30.99	$ 30.99	Amazon
Incomplete		Experiments	low	no	no	Dupont Wires	Male to Female Dupont Wire	1	$6.98	$ 6.98	Amazon
Incomplete		Experiments	low	no	no	Antenna	Mini Short Walkie Talkie Antenna AR-805S SMA-Female Dual Band High Gain Long Range Antenna	1	$7.99	$ 7.99	Amazon
Incomplete		Experiments	low	no	no	TPU filament	oll Soft 3D Printer Filament, 1kg Spool (2.2 lbs),	2	$21.99	$ 43.98	Amazon
Incomplete		Experiments	low	no	no	Camera Module	Smraza Raspberry Pi 4 Camera Module 5 Megapixels 1080p OV5647 Sensor	1	$16.99	$ 16.99	Amazon
Incomplete		Experiments	low	no	no	Radio SDR Dongle	RTL-SDR Blog R820T2 RTL2832U 1PPM TCXO SMA Software Defined Radio	1	$32.39	$ 32.39	Amazon
Incomplete		Experiments	low	no	no	Servo	Smraza 4 Pcs SG90 9G Micro Servo Metal Geared Motor Kit	1	$9.99	$ 9.99	Amazon
Incomplete		Experiments	low	no	no	Usb extender	URWOOW 2 Pack SuperSpeed USB 3.0 Angle Male to Female Extension Cable	1	$6.80	$ 6.80	Amazon
Incomplete		Experiments	med	no	no	Polycarbonate 3D Filament	Polymaker PC Filament 1.75mm, Clear Polycarbonate Filament 1.75mm 1kg Cardboard Spool - PolyLite PC Filament Transparent, Strong & Tough & Heat Resistant 3D Printer Polycarbonate Filament 1.75	2	$29.99	$ 59.98	Amazon
Incomplete		Experiments	low	no	no	Lead Screw	2pcs 400mm Tr8X8 Lead Screw with T8 Brass Nut for 3D PrinterRight Hand, 1/4"-20 Thread Size, 18" Long	1	$14.99	$ 14.99	Amazon
Incomplete		Experiments	low	no	no	Lead Screw Nuts	QWORK T8 Nut Trapezoidal Screw, 4Pcs Brass 3D Printer Upgrade	1	$7.47	$ 7.47	Amazon
Incomplete		All	low	no	yes	PETG Filament	eSUN 3D 1.75mm Solid Silver PETG 3D Printer Filament 1KG	2	$22.99	$ 45.98	Amazon
Incomplete		All	low	no	yes	Standoffs and M3 Bolts	M3, M3.5 Bolts with Brass Standoffs	1	$12.88	$ 12.88	Amazon
Incomplete	SGA	Telemetry	low	no	yes	Featherweight GPS	Full System Featherweight GPS + Ground Station + Battery	1	$365.00	$ 365.00	FeatherWeight Altimeters
Incomplete	SGA	Recovery	low	no	yes	1/4 inch x 5 ft White PEX- Pipe	5ft 1/4in PVC Pipe	1	$2.48	$ 2.48	Home Depot
Incomplete		Telemetry	low	no	no	PCB	Printed Circuit Board	1	$8.00	$ 8.00	JLCPCB
Complete	SGA	Experiments	med	yes	yes	Polycarbonate Resin Pellets	Impact Resistant Polycarbonate Pellets	1	$124.89	$ 124.89	McMaster-Carr
Incomplete		Experiments	low	no	no	Ball Bearings	Stainless Steel Ball Bearing Open, Trade Number R144	12	$5.30	$ 63.60	McMaster-Carr
Incomplete		Experiments	low	no	no	U-Bolt	Black-Oxide Steel U-Bolt 1/4"-20 Thread Size, 1" ID	1	$3.68	$ 3.68	McMaster-Carr
Incomplete		Experiments	low	no	no	M3 Screws 6mm (100 pack)	Alloy Steel Socket Head Screw Black-Oxide, M3 x 0.5 mm Thread, 6 mm Long	1	$10.91	$ 10.91	McMaster-Carr
Incomplete		Experiments	low	Enter Safety	no	Grub Screws (25 pack)	Alloy Steel Thread-Locking Cup-Point Set Screw Black-Oxide, M6 x 1 mm Thread, 6 mm Long	1	$17.63	$ 17.63	McMaster-Carr
Incomplete		Experiments	low	no	no	5mm Steel Balls (50 pack)	Hardened Bearing-Quality 440C Stainless Steel Ball 5 mm Diameter	2	$10.73	$ 21.46	McMaster-Carr
Complete	SGA	Recovery	low	yes	yes	RRC3 "SPORT"	RRC3 Sport Dual Deployment Altimeter	1	$79.95	$ 79.95	Missle Works
Complete	SGA	Recovery	low	yes	yes	1/4" Aluminum 6061 Rods	24 inch Aluminum 6061- T6511 Rods	7	$3.00	$ 21.00	OnlineMetals.com
Complete	KXR	Recovery	low	yes	yes	StratoLoggerCF Altimeter	StratoLoggerCF Altimeter	1	$69.95	$ 69.95	Perfectflite

6.2.1.4 Propulsion Budget

Status	Account	Subsystem	Safety Index	Received	Purchased?	Item Label	Components Description	QTY	Price Each	Total Cost	Vendor
Incomplete		Recovery	low	no	no	K1000T	Motor Reloads	4	$182.69	$ 781.91	Wildman
Incomplete		Recovery	low	no	no	752560M	Motor Casing	1	$392.00	$ 419.44	Wildman

6.2.1.5 Travel Budget

Team	Recieved	Purchased?	Item Label	Component Description	Details	Quantity	Price Each	Total Cost
ALL	no	no	Hotel	Hotel Costs		1	$5,661.92	$5,661.92
ALL	no	no	Gas	1500 miles at 4 dollars per gallon with a 20 mpg car		7	$300.00	$2,100.00
ALL	no	no	Rental Vehicle	Avis Rental Cars		0	$326.23	$0.00

6.2.2 Funding Plan

Funding Source	
FSGC / KXR	$ 3,000.00
SG FAO Bill	$ 3,000.00
SG CRT Bill	$ 3,000.00
Student Travel Fees	$ 5,100.00
Total	$ 14,100.00

6.2.2.1 Student Government

UCF's student government has granted our team a $3000 bill, exclusive to this project. Purchases are filed through the ASF office's accountant and have covered all fees for vehicle design and a significant portion of the payloads budget. Said money does not have to be returned, however, we must demonstrate a $3000 matching contribution which will be provide by FSGC and KXR – the hose of UCF's USLI team.

6.2.2.2 Florida Space Grant Consortium

The Florida Space Grant Consortium will hopefully be providing $3000 to meet our matching contribution, however, due to unforeseen circumstances, FSGC has not gotten back to us and we will proceed under the assumption that said money will not be available to us – although we will continue to attempt to acquire said funds.

6.2.2.3 KXR Funding

Knight's Experimental Rocketry is the host club for UCF's USLI team. Sponsorships from Blue Origin, Daytona 500, and Lockheed Martin have allowed us alternate means to meet our matching grant, as well as afford additional expenses for the project.

6.2.2.4 Travel Funds

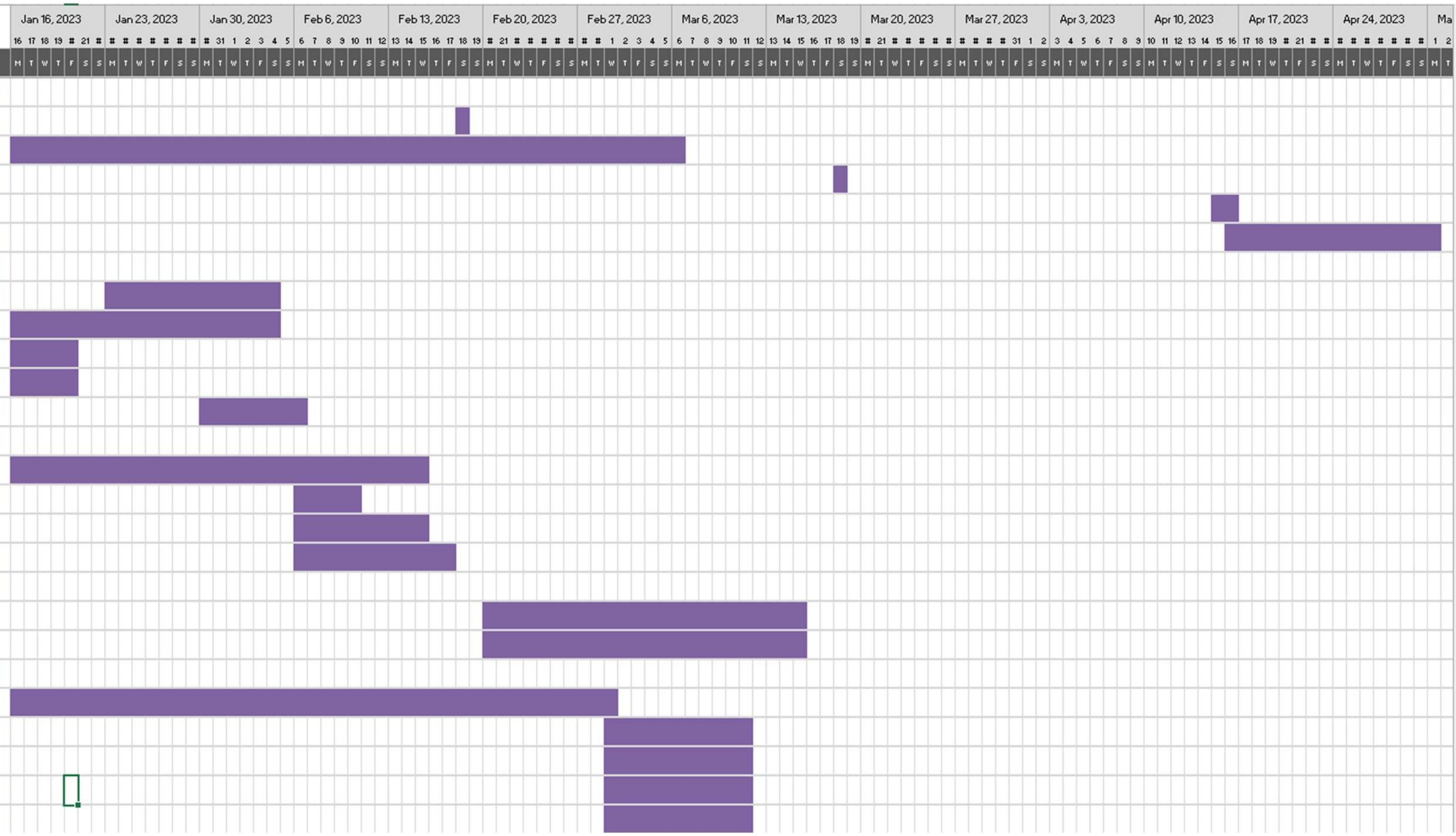
Our team will be making the ten-hour drive from UCF to Huntsville. Seven drivers will volunteer their vehicles. Under the assumption that gas will be $4.00 per gallon, with each vehicle at 20 miles per gallon, we have estimated a $2100 cost for gas. This is not fundable by Student Government, so funds will be collected from the 30 attendees.

As for lodging, Student Government, has agreed to provide half the lodging costs with a similar matching contribution in the event we decided to use hotels, however, even without the funds from Student Government, AirBnBs may be cheaper and closer to the Braggs farm location regardless. In either situation, rough estimates are approximately $3000 including tax which will also be accrued via member funds.

6.3 Timeline

Display Week: 1

TASK	ASSIGNED TO	PROGRESS	START	END
Important Dates				
Vehicle Demonstartion Flight	Nathan	0%	2/18/23	2/18/23
Flight Readiness Review	Nathan	0%	1/9/23	3/6/23
Payload Demonstration Flight	Nathan/Emilio	0%	3/18/23	3/18/23
Launch Day	Nathan/Emilio	0%	4/15/23	4/16/23
PLAR	Nathan/Emilio	0%	4/16/23	5/1/23
Manufacturing				
Airframe	Brad	0%	1/23/23	2/4/23
Nose cone	Brad	0%	1/16/23	2/4/23
Fins	Brad	0%	1/16/23	1/20/23
Tailcone	Brad	0%	1/16/23	1/20/23
Assemble	Brad	0%	1/30/23	2/6/23
Recovery				
Altimeter Test	Daniel/Zander	0%	1/16/23	2/15/23
Packing Test	Daniel/Zander	0%	2/6/23	2/10/23
Ground Test	Daniel/Zander	0%	2/6/23	2/15/23
GPS Test	Daniel/Zander	0%	2/6/23	2/17/23
Telemetry				
Ground Station/Telemetry Test	Andrew/Olivia	0%	2/20/23	3/15/23
Live Video Test	Andrew/Olivia	0%	2/20/23	3/15/23
Experiments				
Depolyment Test	K		1/16/23	3/1/23
Depolyment Test	K		3/1/23	3/11/23
Impact Test	K		3/1/23	3/11/23
RAFCO Test	K		3/1/23	3/11/23
Orientation/Camera Test	K		3/1/23	3/11/23



6.4 STEM Engagement

6.4.1 Fall Plans

Event Date	Name of Group	In-Person or Virtual	Preschool –4	5–9	10–12	Undergrad Educators Adult (noneducators)
10/08/2022	University of Central Florida Engineering tabling event	In-person	X	X	X	~ 400
10/29/22-10/30/22	SmallSats Education Conference 2022	In-person	~10	~150	~20	~60
10/30/22-111/02/22	OpenMotor workshop	In-person	X	X	X	~40
11/04/22-111/18/22	OpenRocket Workshop	In-person	X	X	X	~30
11/14/22-111/18/22	Python/Raspberry Pi Workshop	In-person	X	X	X	~30

6.4.2 Spring Plans

Event Date	Name of Group	In-Person or Virtual	Preschool –4	5–9	10–12	Estimated Undergrad Educators Adult (noneducators)
01/13/23	1007C Presentation	In-Person	X	X	X	~800

Mid-January	STEM Seminar I Outreach	In-Person	X	X	X	~200
Mid-January	STEM Seminar II Outreach	In-Person	X	X	X	~200
Mid-January	National Society of Black Engineers (NSBE)	In-Person	~80		X	X
End of January	Arduino Workshop	In-Person	X	X	X	~40
Beginning of February	HAM Radio Workshops	In-Person	X	X	X	~40
Beginning of February	Composites Workshops	In-Person	X	X	X	~40
Beginning of February	Hardward/manufacturing Workshops	In-Person	X	X	X	~40
Mid-February	STEM Day	In-Person	X	~60	X	X

6.4.3 Member Enrichment

6.4.3.1 Workshops

USLI enriches students' curiosity, engagement, and experience by holding workshops. Our workshops have a wide variety of educational materials such as learning new software to teaching hardware and manufacturing. The main goal of the workshops hosted at USLI can vary from gaining certifications in software, learning software to have proficiency, or developing skills to aid in manufacturing during the duration of all projects. The workshops that are hosted by the organization are created and hosted by students, meaning all curricula designed by the students are executed by students.

The workshops are provided for students who are involved in various projects in USLI and want to learn a specific skill or gain more experience to contribute their knowledge and skill to their project/team. USLI has broadened the horizon for various projects to emerge in the club that is hosted by our respected leads. Workshops such as Python/OpenCV, Arduino, and HAM Radio workshops were introduced to the organization and have shown extremely positive feedback.

6.4.3.2 National Society of Black Engineers

To further STEM engagement USLI is collaborating with the National Society of Black Engineers (NSBE) in Downtown Orlando to host around 80 third to fifth-graders for an after-school event. The students will engage in various rocketry activities such as building their own bottle rocket and learning about circuit boards as well as an overview of the benefits aerospace brings to enrich our communities.

6.4.3.3 Intro to Engineering

Our USLI team will be presenting to UCF's introductory engineering course, which includes four classes of 200 students each. We will be going over current designs as well as the process of manufacturing said components. This is not only a means of recruiting new members but exposing students to NASA's Artemis Challenge. In addition to the presentation, we will be showing previous award-winning rockets our members have worked on in competitions such as Friends of Amateur Rocketry, as well as hosting a Q&A.

6.4.3.4 Stem Seminar I&II

UCF's Excel/Compass course is a program geared towards STEM undergraduates of all ages. The Seminar hosts 200 students participating in all forms of STEM degrees. Compared to the intro to engineering section, we will have a much larger time slot which will allow us to show the internals of our previous rockets, as well as cover the same content found in the intro to engineering presentations. A similar subsequent Q&A will be hosted at the end of the presentation.

6.4.3.5 STEM Day

Our USLI team will be hosting a STEM Day at the University of Central Flordia where around 60 fifth graders are invited to engage where they will learn how to create their own bottled rocket, understand the mechanics behind rocketry, and how gravity affects our bodies in space.