Project Heimdall

Critical Design Review

Cedar Falls High School

1015 Division Street, Cedar Falls, IA 50613

January 3, 2022

1. Summary of CDR Report

1.1 Team Summary

- Team name and mailing address
    - Cedar Falls High School Rocket Club - 1015 S Division St. Cedar Falls, Iowa
- Name of mentor, NAR/TRA number and certification level, and contact information
    - Tyler Sorensen, [redacted]
- Anticipated primary and backup final launch location and date
    - 4-23-22 at the NASA SLI Launch site a Huntsville, Alabama (back up on 4-24)
- Document the number of hours spent working on the CDR milestone.
    - The team spent approximately 232 total man hours in the design process and creation of CDR deliverables.

1.2 Launch Vehicle Summary

- Target altitude (ft.) - 3,750 Feet AGL
- Final motor choice - Cesaroni K-1440
- Size and mass of individual sections (on the pad)
    - Booster Section: 14.346 lbs, 39 inches long
    - Recovery Section: 8.495 lbs, 26 inches long (excluding 6 inch coupler)
    - Payload Section: 8.959 lbs, 33.5 inches long (excluding 6 inch coupler)
- Recovery system
    - Standard dual deploy recovery system using two separate and independent deployment systems (each running off of a strattologgerCF altimeter)
    - 24” Elliptical Drogue deploys at apogee (backup at apogee+1).
    - 72” Iris Ultra Standard that deploys at 600 ft. AGL (backup at 500 ft. AGL).
    - Descent time is 66.43 seconds with drift in 20 mph wind of 1,948 feet.
- Rail size - 12 foot x 1515

1.3 Payload Summary

- Payload title - Reusable Virtual Flight Display (RVFD)
- Summarize payload experiment
    - The payload consists of two components. First, a camera array to record 360 degree video footage to make a virtual reality experience. Second, a circuit board that collects orientation, accelerometer, and altitude data to be used as an information display in the virtual reality flight.

2. Changes Made Since PDR

2.1 Changes Made to Vehicle Criteria

Upon receiving actual fiberglass components, the team found that the components were heavier than initially expected. This shifted the center of mass of the vehicle and increased the overall weight by a great amount. To counter this change, the team redesigned the payload retention system and recovery electronics bay retention system to cut weight. In the process of cutting weight and achieving a better stability margin, the booster section was shortened from 42 inches to 39 inches. This was influenced by the impact that a large stability margin demonstrated on the subscale flight.

Minor changes were also made to the fin assembly. When the components were delivered, the body tube slots had been cut too long and the fin tabs were also a full 14 inches opposed to the ordered 7. As a result, the fin assembly was redesigned to accommodate this manufacturer error. Details about these new designs are included in Figures 3.1.2 and 3.1.3. The external shape of the fins did not change.

In the recovery system, the team changed the planned GPS tracker from the AIM Xtra to the Featherweight GPS because it is lighter and designed more for tracking, opposed to the AIM which was also designed to serve as a recovery system altimeter. The team also decided to use firewire igniters for the ejection charges after one of the originally planned Quest Q2G2 igniters failed in the subscale launch.

2.2 Changes Made to Payload Criteria

As mentioned in section 2.1, the fiberglass components being heavier than expected required the need to cut weight. As a result, the payload retention system was redesigned, butting the original weight estimate from over 4 pound to 2.86 pounds.

The team will now only be using the BNO-055 sensor. The BNO-085 was removed because its limitations of 8G and non-determinate “higher accuracy” made it less of an asset to the team. With the removal of the BNO-085, the PCB was redesigned to remove excess surface area and therefore cut cost.

2.3 Changes Made to Project Plan

The team updated the budget based on vehicle and payload changes and added testing and launch dates to the schedule to ensure all requirements are verified. A chart of requirement verification was also added. Team derived requirements were updated according to design.

3. Vehicle Criteria

3.1 Design and Verification of Launch Vehicle

- Include unique mission statement and mission success criteria

Project Hiemdall aims to bring rocket flight closer to the general population. To achieve this, the Heimdall vehicle will carry 3 cameras and a flight computer that will record video data as well as 3D orientation, temperature, and altitude vs. time. Mission success would be a safe and successful vehicle flight and recovery that allows for all video footage to be recorded at 4K and 30 FPS and all data to be recorded at 20hz unobstructed for the duration of the flight. With mission success, a virtual flight experience can be produced for public distribution.

- Identify which of the design alternatives from PDR were chosen as the final components for the launch vehicle. Describe why those alternatives are the best choices.

Component	Selection	Justification
Nose Cone	5:1 G12 Fiberglass Ogive	Despite being heavier, the 5:1 nose cone offers superior aerodynamics that help the vehicle reach greater atitudes. Fiberglass was chosen as the material because it offers superior strength and resistance to corrosion than plastic nose cones, but is much cheaper than carbon fiber.
Body Tube	6.17” (OD) 6.00” (ID) G12 Fiberglass	The body tube for the vehicle was chosen to be a 6 inch diameter in order to fit the camera array for the payload. A 5 inch tube did not allow for enough space for 3 high quality cameras and, while a 5.5 inch tube would be sufficient, due to supply shortages the team had to settle with a 6 inch diameter. Fiberglass was again chosen as the material because it offers superior strength and resistance to corrosion than cardboard, but is much cheaper than carbon fiber.
Couplers	5.998” (OD) 5.820” (ID) G12 Fiberglass	This size of coupler was of course chosen because it matches the size of the body tube. To ensure consistent strength throughout the vehicle, fiberglass was also chosen as the material for the same reasons of strength and cost. The total coupler length ensures that 6 inches of coupler connect each body tube component at points where separation will occur (this can be seen in the design drawings below).
Fins	3 - Trapezoidal G10 Fiberglass 0.1875” Thick Tapered Ends	The team decided to use 3 trapezoidal fins made of 0.1875” fiberglass. 3 fins are being used, opposed to four, because each fin weighs 1.05 pounds and given the already very large vehicle, weight and drag need to be minimized. The

		trapezoidal shape was chosen because it offers less drag than clipped delta but is easier to manufacture (and modify, if need be) than an elliptical shape. Fiberglass was chosen, again for the superior physical and chemical strength compared to plywood, but cheaper price compared to carbon fiber. The 0.1875” thickness was chosen because it allows the fins to remain rigid enough under high speeds to avoid flutter and fracture. The end of the fins are tapered in thickness (front and aft) to allow for superior aerodynamics.
Motor Mount	2.376” (OD) 2.126” (ID) 24” Long G12 Fiberglass	This size of motor mount tube was selected due to the use of the CT-K1440 motor. This motor is a 54 mm motor and is 22.5” long. The 2.126” (54 mm) inner diameter (ID) and 24 inch length allow for the perfect size to house the motor. The extra length on the tube provides a small buffer area so that wadding and other recovery materials don’t rest directly on top of the motor. Fiberglass was chosen in this area particularly for its chemical strength. Fiberglass is more resistant to chemical corrosion than cardboard and will not combust under temperatures present during the burn of the motor. This makes fiberglass a reasonable choice because it can withstand the stresses near the motor but is not nearly as expensive as carbon fiber.
Centering Rings	0.13” G10 Fiberglass	Both the centering rings and bulk plates were chosen to be fiberglass due to the same strength and cost principle
Bulk Plates	0.2” G10 Fiberglass	explained above. This thickness of fiberglass is rigid enough to retain the motor assembly and serve as bulkheads in the electronics bay and payload while adding minimal weight to the vehicle.
Motor Retainment	AeroPack 54mm retainer (Model #: RA54L)	This motor retainer was chosen for the final design because the size matches the CT-K1440 motor. The team is also very familiar with AeroPack retainers and have used them for TARC, NASA SLI (including this year's sub-scale flight), as well as personal projects. The team has never once experienced product failure.

- Using the final designs, create dimensional and computer-aided design (CAD) drawings to illustrate the final launch vehicle, its subsystems, and its components.

Figure 3.1.1 below shows the overall vehicle length, subsection length, coupler lengths, and switch band lengths. The subsequent figures show more detailed dimensions of each subsection that the vehicle will separate into during the recovery process.

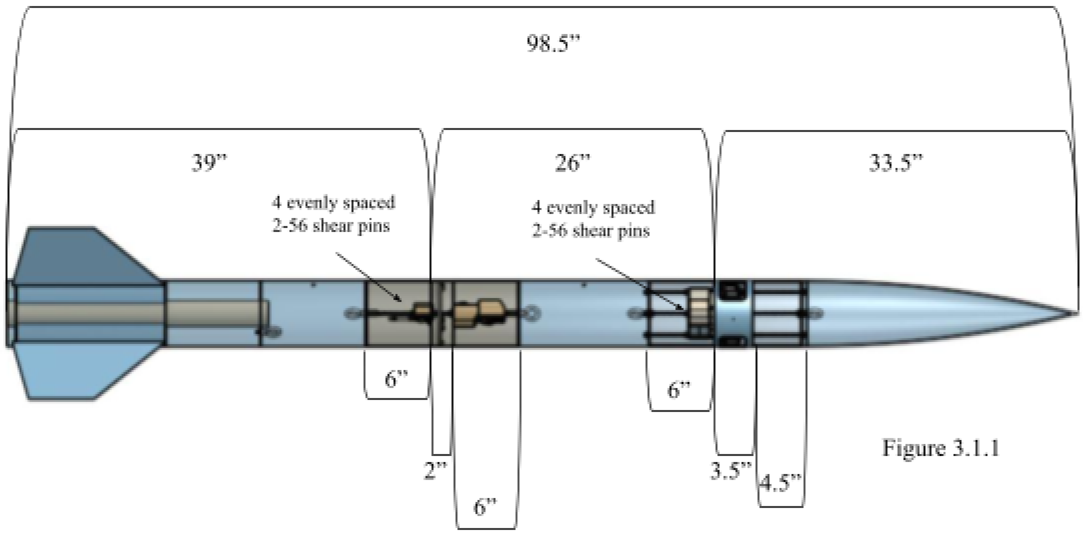


Figure 3.1.1

The body tube has an outer diameter of 6.17 inches.

Booster Section:

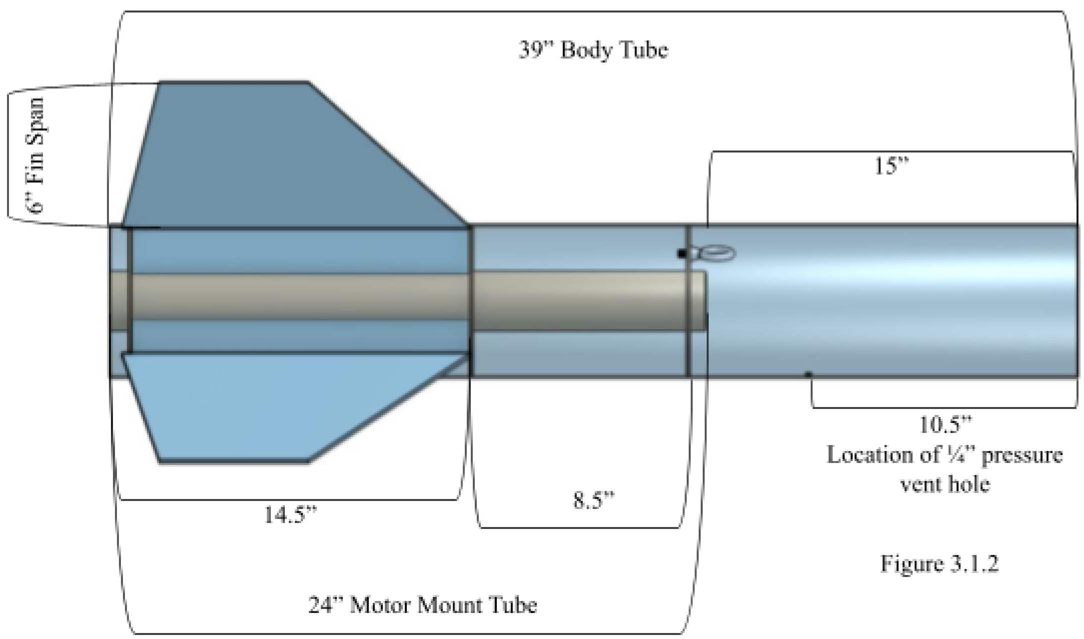


Figure 3.1.2

Dimensions not labeled in drawing above: The bottom centering ring is placed 0.75 inches from the bottom of the booster body tube. The Motor mount tube extends one inch above the top centering ring. The rail buttons are placed 13.875 inches from the bottom of the booster and the other will be 12 inches above that at 25.875 inches (the center of pressure), centered between two of the fins and inline with each other.

More detailed dimensions of the fins and centering rings are included below:

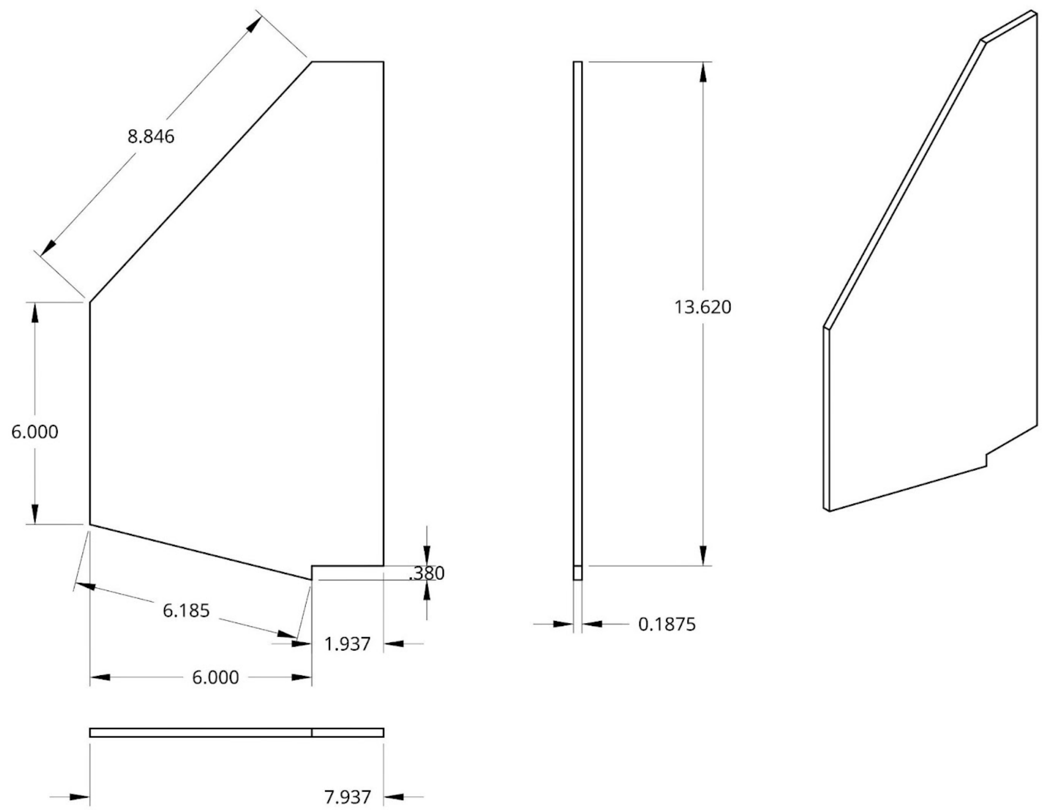


Figure 3.1.3

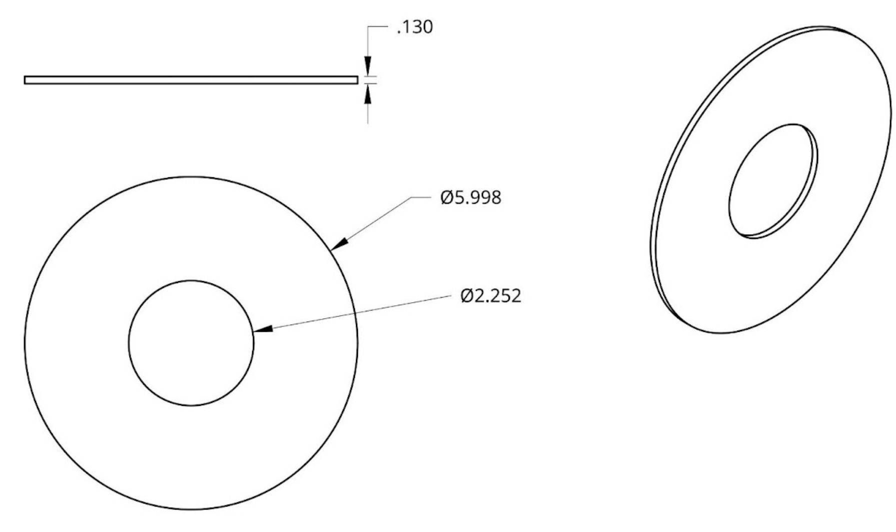


Figure 3.1.4

Payload Section:

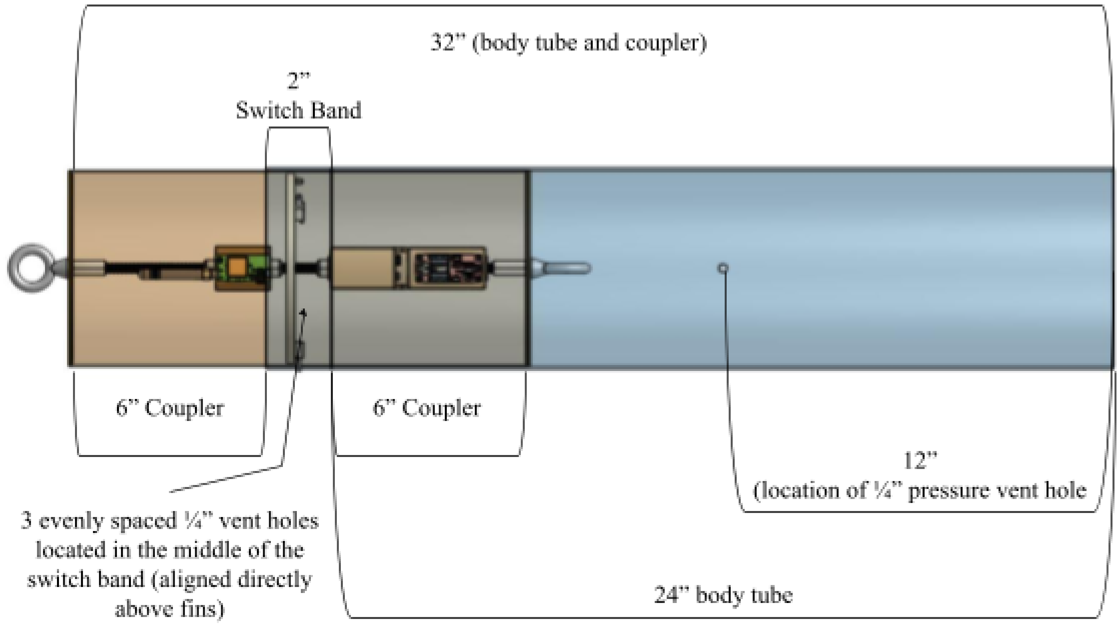


Figure 3.1.5

The 24" Body tube is secured to the coupler using 4 evenly spaced plastic rivets, 3 inches from the end of the tube.

Recovery Electronics Bay:
Note: This component stays attached to the recovery section at all times during flight, but is separated in this analysis so more detail can be provided.

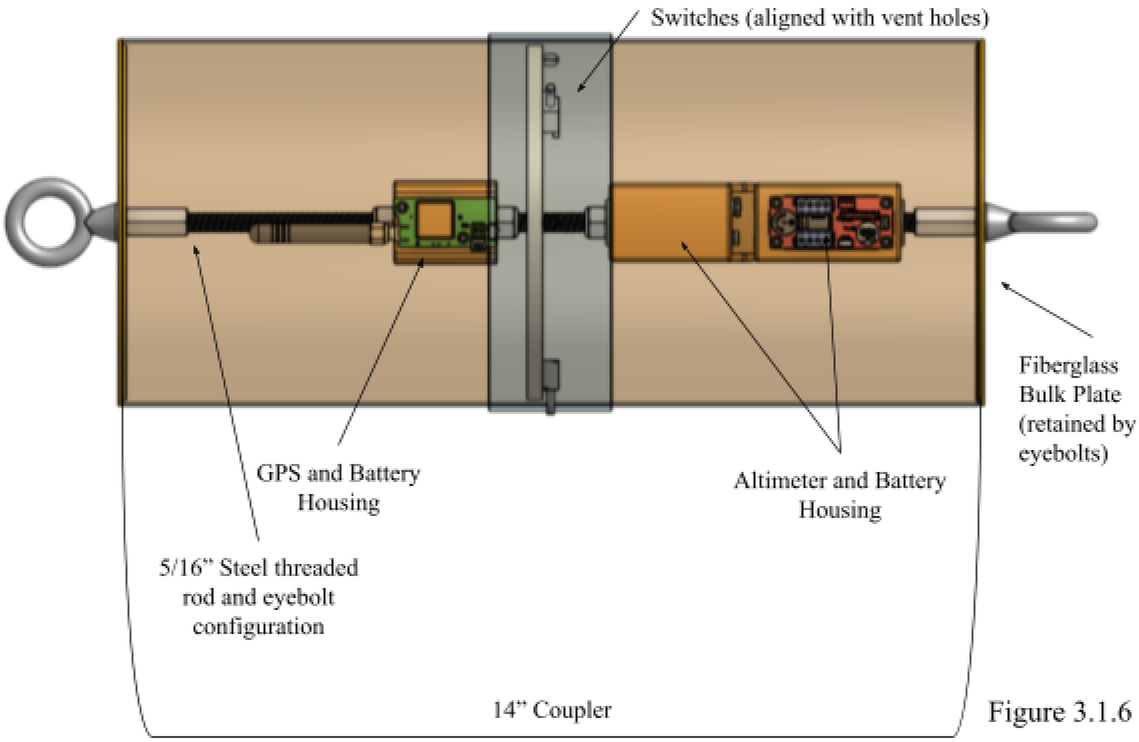


Figure 3.1.6

More detailed dimensions of the housing for the electronics, as well as the bulkheads, are included below.

Altimeter Housing:

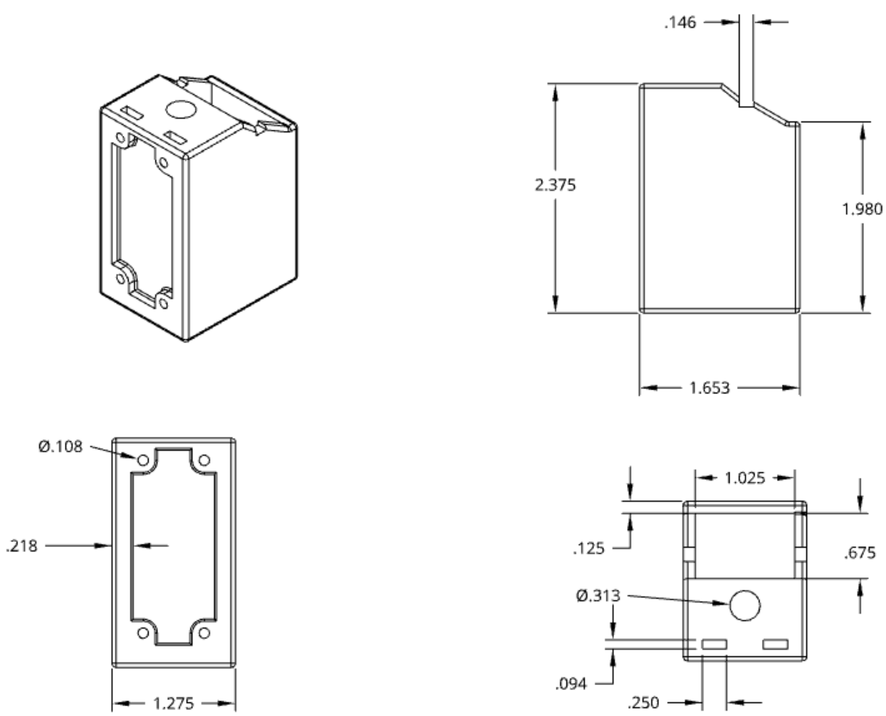


Figure 3.1.7

GPS Housing:

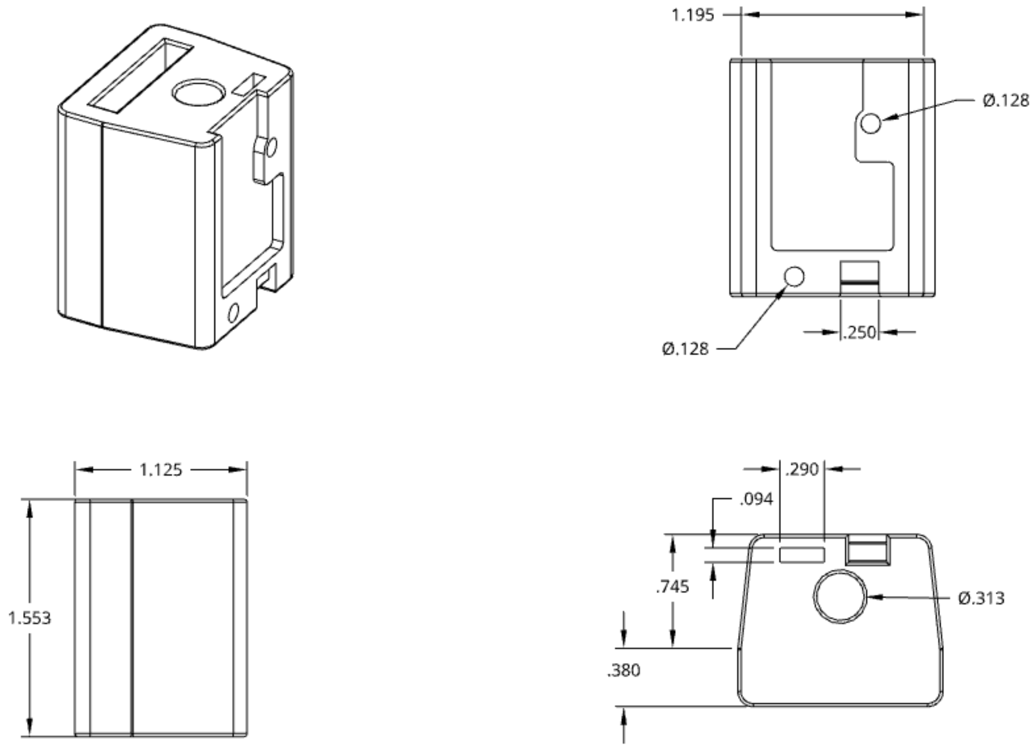


Figure 3.1.8

Bulkheads:

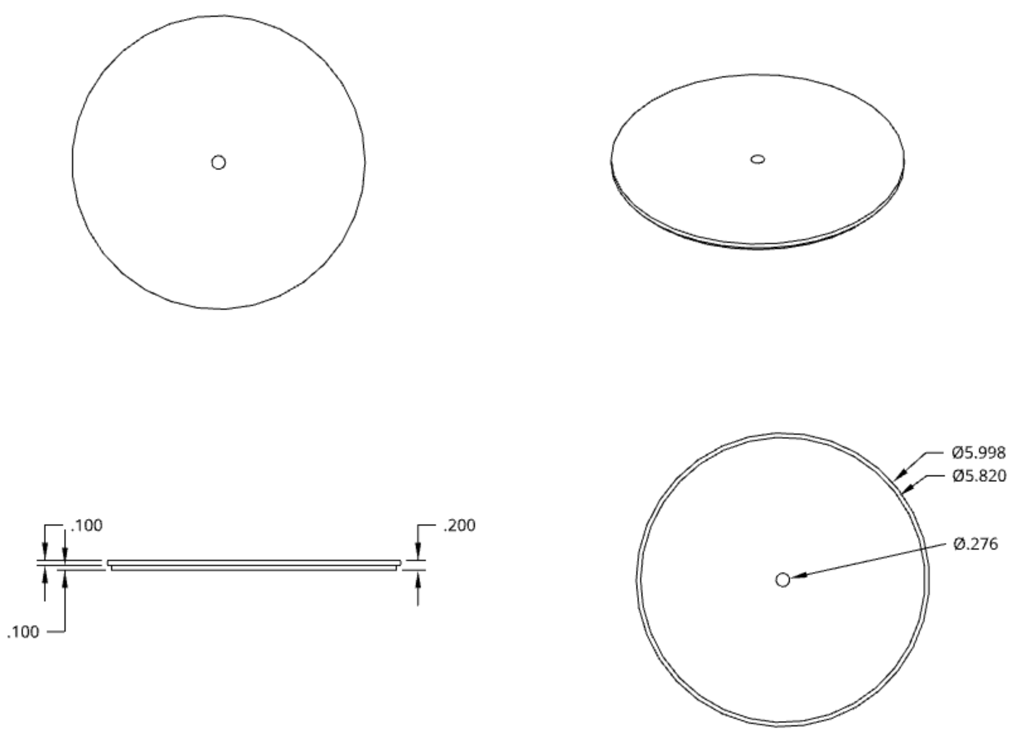


Figure 3.1.9

Payload Section:

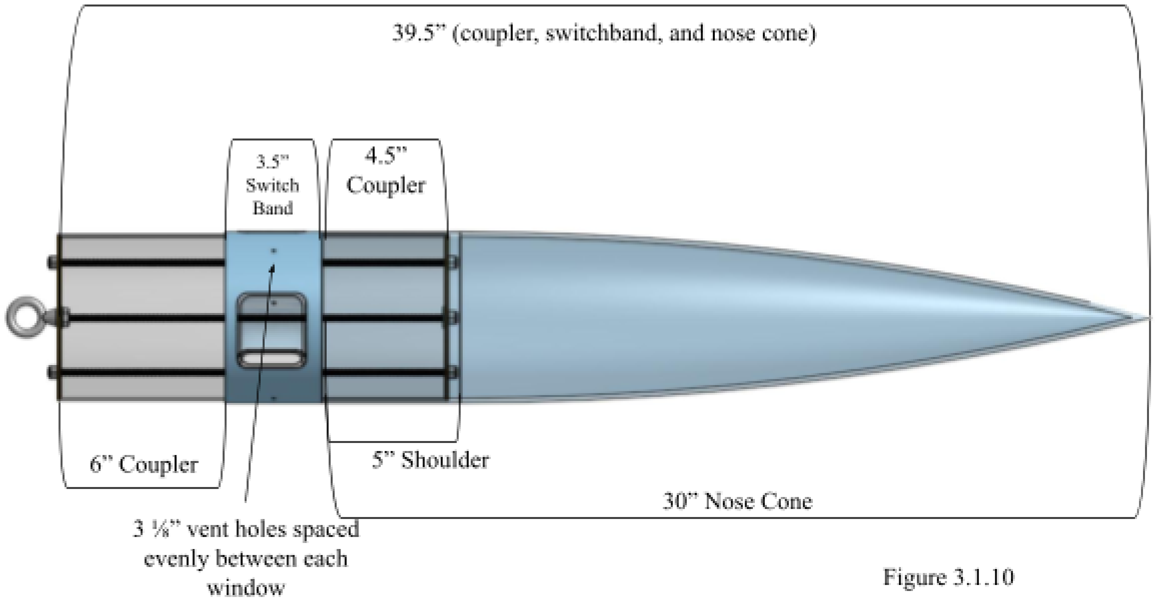


Figure 3.1.10

The 30" Nose Cone is secured to the coupler using 4 evenly spaced plastic rivets, 2.25 inches from the end of the nose cone. Window size is specified below.

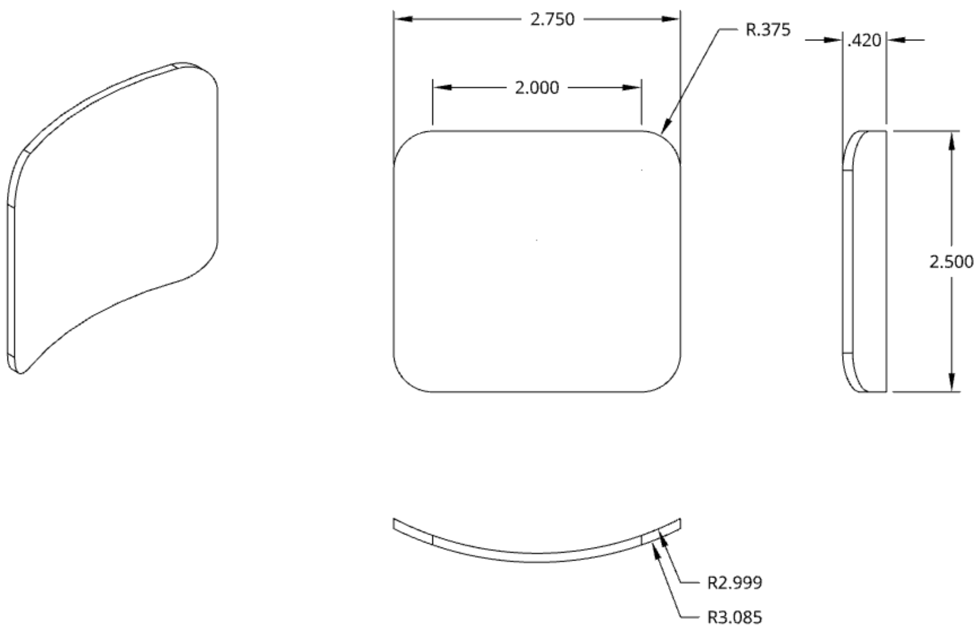
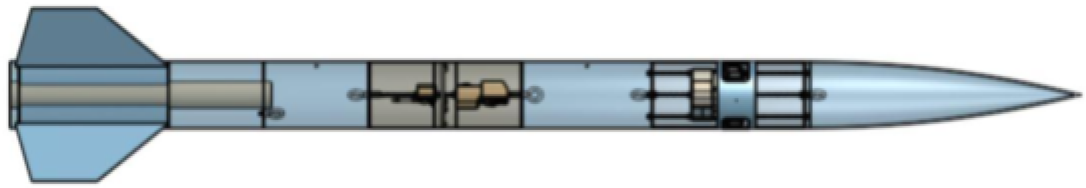
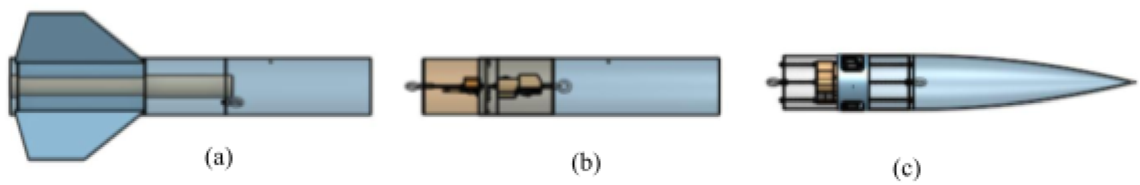
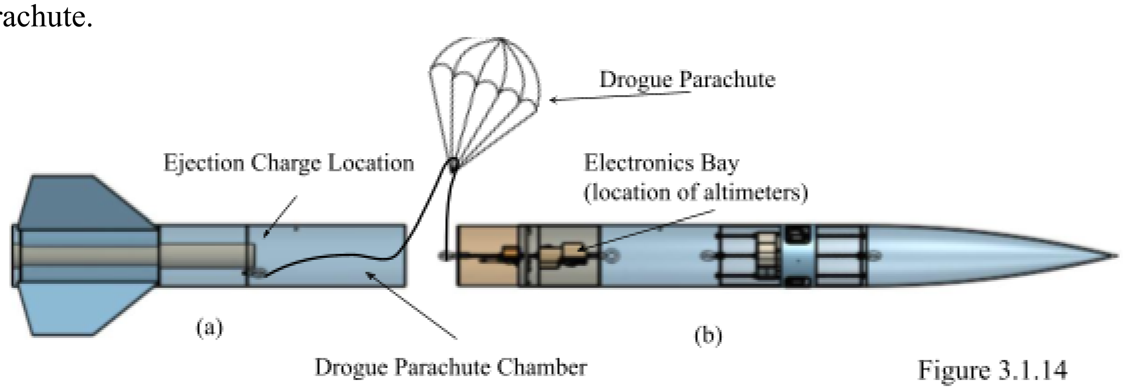


Figure 3.1.11

- Using the final designs, locate points of separation on each design and show location(s) of energetic materials.

The full assembly of the vehicle depicted below will separate at two locations into 3 seperate sections. These separations happen for the purpose of recovery.

 Figure 3.1.12
These three sections (booster, a; recovery, b; and payload, c) are depicted below.  Figure 3.1.13
The first separation occurs at apogee (back up at apogee +1 second) and deploys the drogue parachute.  Figure 3.1.14
The second separation happens on descent at 600 ft. AGL (with a back up at 500 ft. AGL). This separation deploys the main parachute.

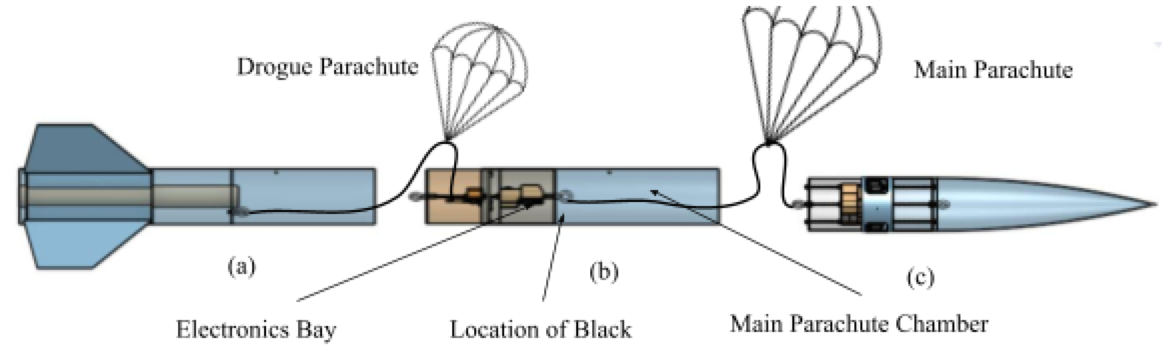


Figure 3.1.15

Note: More information on the separation process in terms of the recovery system can be found in sections 3.3 and 3.4.

- Demonstrate that the designs are complete and ready to manufacture.

As shown in the drawings and images under the previous two bullet points, the team has constructed a CAD model of the vehicle that matches the dimensions and masses used in RockSim. The components in this digital design use actual masses measured from the real components that the team has already ordered and received. The design includes details about exact component placement and even has detailed assemblies for the payload and recovery electronics bay. Design details as small as vent hole size and placement, rivet placement, rail button placement, and shear pin placement have also all been determined (included with CAD diagrams above). Figure 3.1.16 below shows electronics bay assembly. All components of this assembly that require 3D printing or CNC milling are ready to produce and the team has the equipment and materials on hand to produce them.
A video of the test for the CNC lathe milling process that will be used to cut out windows can be seen at this link:
https://youtu.be/lqQEM3SZzeU

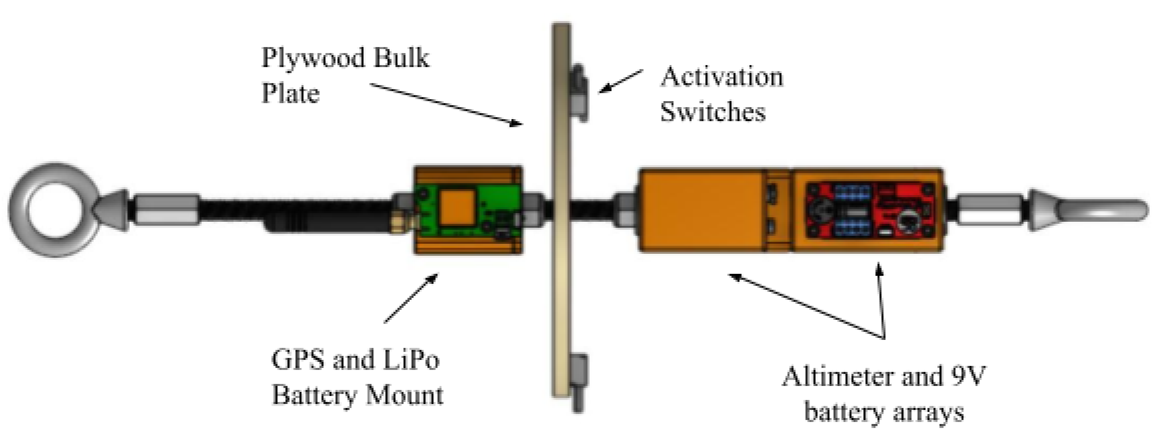


Figure 3.1.16

- Discuss the integrity of design.
    - Suitability of shape and fin style for mission
        - The team selected a trapezoidal fin shape with tapered ends. This selection was made because of its naturally aerodynamic shape. Additionally, it is offset from the end of the rocket, thus reducing the chance of the fins impacting first and taking the brunt of the force on landing. Because the vehicle will be flying multiple times, this will prevent fin damage, an event that could prevent the vehicle from flying again. The tapered thickness on the front and rear edge was selected because the rocket will be traveling at subsonic speeds throughout flight. Because it will be traveling at subsonic speeds, a rounded front edge of the fin allows for lower drag than other fin shapes.
    - Proper use of materials in fins, bulkheads, and structural elements
        - All structural elements of the vehicle are made of fiberglass. The tubes (couplers, motor mount, body tubes) are made of G12 fiberglass and all centering rings, bulk heads, and fins are made of G10 fiberglass. Fiberglass is a very rigid material and is therefore suitable for the vehicle fins. With a rigid material and fastening process that extends a fin tab through a slot in the body tube to make contact with the internal motor mount tube, fin flutter is limited. The fins are already rigid, but with the fin tab and extra point of contact inside the vehicle, the chances of the fin fluttering at the connection point also decreases significantly. The bulkheads are also made of fiberglass due to the same rigid properties. When the bulkheads receive stress forces (either from ejection charges, or from the parachute harness) they are far less likely to crack than plywood and other bulkhead materials.
        - The other structural element used is the adhesive. The team will be using RocketPoxy to glue the fins to the rocket because of the extreme strength of this epoxy and the high temperatures it is able to withstand. Despite taking longer to cure and being hard to work with, RocketPoxy is far stronger than 5 minute epoxy rands and in some cases has shown itself to be stronger than the fiberglass material being used to construct the rest of the vehicle.
        - The bulkheads will be held in place using steel and aluminum rods along with forged steel eye-bolts. This retention system has maxed out the machinery available to the team in preliminary testing, displaying that it has tensile strength of over 1,000 pounds.
    - Sufficient motor mounting and retention

        - The motor will be mounted using three separate centering rings, both glued to the motor mount tube and body tube using RocketPoxy fillets on both sides of each ring. The fins will be glued to the motor mount tube as well, raising the amount of surface area glued to the motor mount tube and providing extra retention through the fintabs and the contact they make with the body tube of the booster. The glue will again be RocketPoxy, since the heat of the motor will be very high and RocketPoxy will be one of the few connective materials able to withstand the high temperatures.
        - The motor retention system is an Aeropack 54mm motor retainer. This system involves a specifically sized motor casing that the K-1440 slides into and is then held in the casing with a screw on cap. This casing then slides into the motor mount tube, where a lip at the bottom of the motor keeps it from sliding too far forward. Another cap then screws onto the end, holding the lip of the case in place and retaining the motor in all directions. Both of the caps have a hole included in the middle so the igniter can reach into the motor and thrust is directed down. The team has used this Aeropack system for numerous past launches and has never experienced failure.
    - Estimate the final mass of the launch vehicle as well as the individual subsystems.
        - Gross Lift Off Weight: 31.70 pounds
            - Booster: 14.246 pounds
            - Recovery Section: 8.495 pounds
            - Payload Section: 8.959 pounds
        - Weight After Motor Burn Out: 29.21 pounds
            - Booster: 11.756 pounds
            - Recovery Section: 8.495 pounds
            - Payload Section: 8.959 pounds
        - Recovery Electronics Bay internal components (including steel rod)
            - 1.2 pounds
        - Payload Internal Components (including aluminum rods)
            - 2.86 pounds
- Provide justification for material selection, dimensioning, component placement, and other unique design aspects.
    - Materials
        - Fiberglass is the primary material because it offers the strength and durability needed for a vehicle of this size that will be launched multiple times. More thorough justification for material selections of all vehicle components can be seen at the beginning of section 3.1.
    - Dimensions

- While a 6 inch diameter body tube adds a significant amount of mass and drag, inhibiting the maximum altitude of the vehicle, this diameter was considered necessary for the payload. The camera payload requires a minimum diameter of 5.1 inches. While a 5.5 inch diameter tube would work, the team struggled to find commercially available components for a vehicle this size. With that diameter, the length was then greatly influenced due to the nose cone ratio and sizing to achieve stability. An example of the cameras arranged in the minimum 5.1 inch cylinder is shown below (Figure 3.1.17)

Figure 3.1.17

- Component Placement
    - To keep the payload separate from recovery systems and to achieve a good stability margin, the payload was based just under the nose cone. It was not placed in the nose cone because the curve of the cone would have made implementing windows much more difficult. Instead, a 3.5 inch switchband (or "window band") was placed under the nose cone to allow a flat surface for windows.
- Recovery Electronics Retainment
    - One unique aspect of the vehicle design is the way in which the altimeters, batteries, and GPS for the recovery system are retained. Because the vehicle is so large, the team was looking for ways to cut weight. One part of the vehicle that the team identified as having the potential to be much lighter is the recovery electronics bay. The typical large plywood sled with two steel rods is quite massive. Instead, the team designed a retainment system that uses specifically sized 3D printed mounts along a singular 5/16" center steel rod. These mounts are held in place with nuts on the threaded rods and the wires are zip tied and taped to the rod using electrical tape. This design (excluding fiberglass bulk plates and coupler, for easier viewing) can be seen in Figure 3.1.16 above. The plywood plate in the middle holds a chicken wire grid that acts as a faraday cage and mounts the activation switches. The individual mounts can be seen below.

<table>
<tr>
<td>Altimeter Array

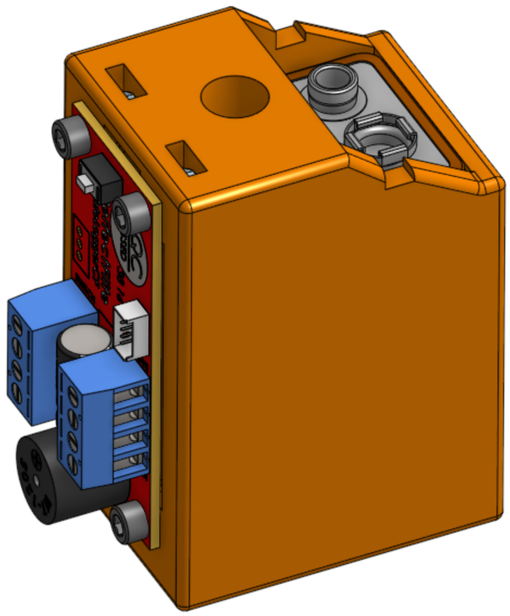



Figure 3.1.18a
Two of these mounts are used in the recovery electronics bay. The battery is secured in the mount using a zip tie that runs the length of the battery and loops over the top.</td>
<td>GPS Mount

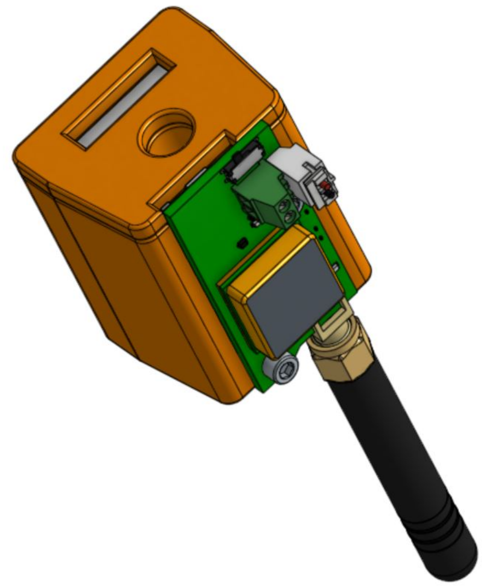



Figure 3.1.18b
The LiPo battery (grey component boxed in by orange) is retained differently, using a top cover, as seen in the picture above, with smaller dimensions to hold the battery in place.</td>
</tr>
</table>

3.2 Subscale Flight Results

- At least one data gathering device shall be onboard the launch vehicle during the test launch. At a minimum, this device shall record the apogee of the rocket. If the device can record more than apogee, please include the actual flight data in the report.

Flight 1: 12-20-21

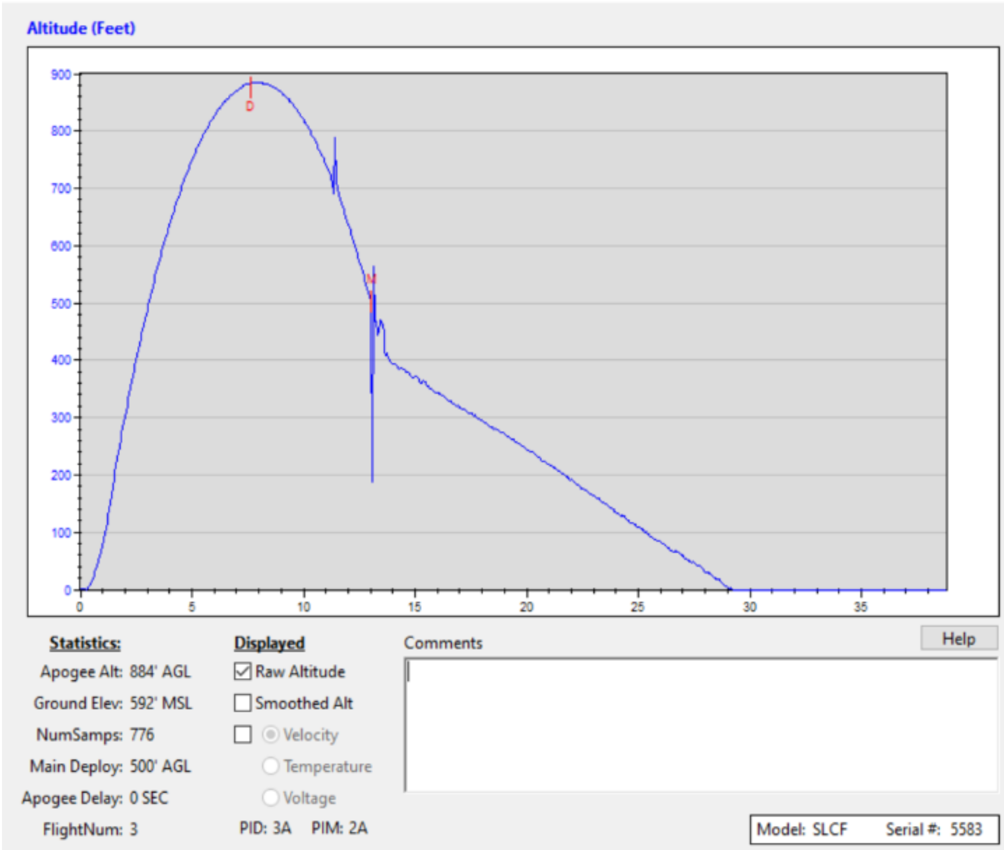


Figure 3.2.1

Flight Description: As this data shows, apogee was reached at 884 feet AGL. The altimeter identified this and sent electrical current to the igniter for the main ejection. However, after the flight the team discovered that the igniter failed (this influenced the decision for electric matches in the full scale model, explained more in 3.3). Because the drogue was not deployed at apogee, the vehicle went into a nosedive until 500 feet when the main chute was properly deployed.

Note: The drogue for this vehicle is just a piece of 12x12 nomex. Given the weight of the vehicle, using an actual parachute would slow it down to a velocity slower than a typical drogue descent.

Quick Data Chart:

Apogee	884 ft. AGL
Total Flight Time	29.25 Seconds
Max Velocity	158 mph

Although the vehicle landed safely, the team considered the first launch a failure. If such an error were to occur with the full scale vehicle, the main chute could detach at deployment due to very high descent rate at deployment. This would result in loss of the vehicle and extreme safety hazards. Due to this, the team decided to relaunch the subscale after making a few changes. These changes also were made to increase the efficiency of flight. Due to relatively high winds (15 mph) during the launch, the vehicle experienced weather cocking at rail exit. This decreased the max altitude of the vehicle.

Launch 2: 12-23-21
Changes Made - Firewire igniters for the recovery system instead of Quest Q2G2 (mentors and online rocketry forums referenced these as more reliable). To limit weather cocking off the pad, a higher exit velocity was required. So, the starting point of the vehicle on the guide rail was moved about 1.5 feet down to allow a greater distance for the vehicle to accelerate.

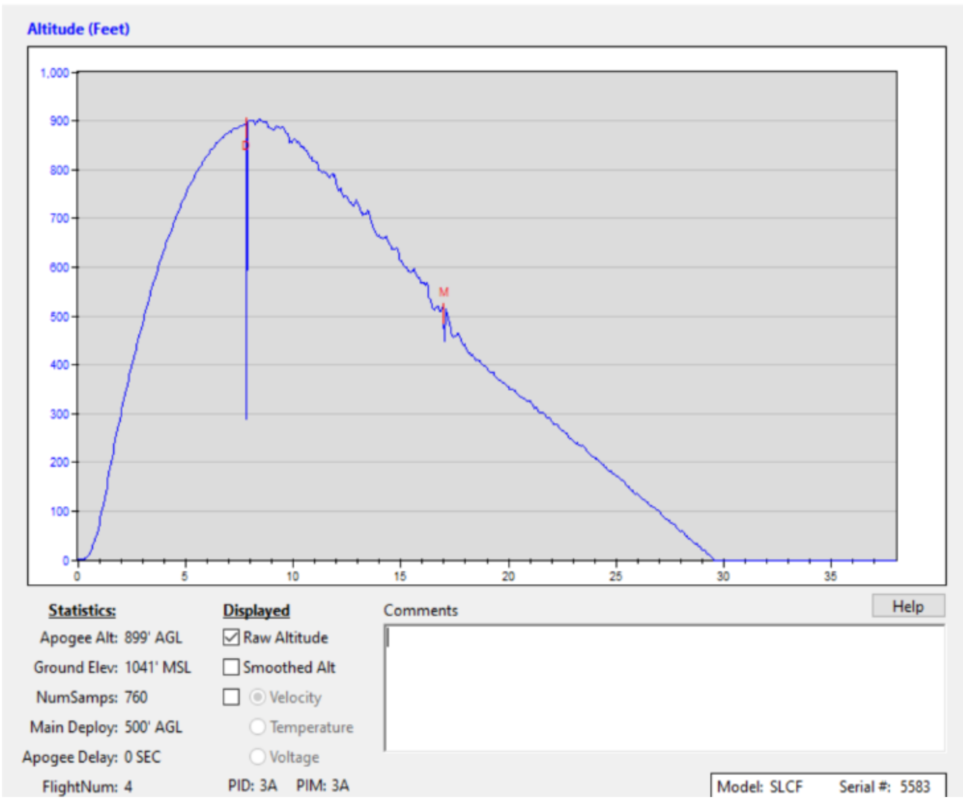


Figure 3.2.2

Flight Description: This flight went more as planned. The recovery system allowed for vehicle separation at desired altitudes and the vehicle reached a slightly higher altitude due to the greater exit velocity to limit weather cocking.
There was one slight error during recovery. In order to decrease the weight of the vehicle, the team did not use quick links to attach nomex and parachutes. When attaching the nomex parachute protector, the team did not tie a separate loop in the shock cord like they did for the parachute and instead left the shock cord simply threaded through the nomex and assumed the opening on the nomex was not large enough for it to slip over the parachute swivel. This assumption was false. The nomex slipped over the swivel and slid up the shroud cords of the parachute when it was deployed, keeping the parachute from reaching its fully opened size. This resulted in a greater descent rate. With this error in mind, the team now will ensure that the parachute protectors of the full scale vehicle are tied into their own loop so they can not slide along the shock cord and obstruct the parachute.

Quick Data Chart:	
Apogee	899 ft. AGL
Total Flight Time	29.5 seconds
Max Velocity	160 mph

A video of both launches can be viewed at this link:
Project Heimdall Subscale Launch
https://youtu.be/ixz6bJyDyOg

- Describe the scaling factors used when scaling the rocket. What variables were kept constant and why? What variables do not need to be constant and why?

When designing the vehicle, the primary goal was to consistently scale down all of the airframe components. This meant that the body tube, nose cone, and fins were all scaled down by 50%. This scaling was done because it would give the team the best estimate for the vehicle coefficient of drag and stability.

Other components, such as rail button size, motor mounting configuration, and parachute size were not scaled by the same 50% factor. This is because these components were adjusted in size to accommodate a safe and successful flight to test airframe design. Simply scaling the motor mount down by 50% would not allow the team to use the right motor, so instead the appropriate size was selected. This is the same with rail buttons. Scaling 15:15 rail down by 50% is, to the best knowledge of the team, impossible, so 10:10 was used instead. Scaling the parachutes down by 50% would also result in very low descent rates that would not be representative of the vehicle.

Two variables that the team would have liked to keep constant but was unable to was thrust to weight ratio and stability margin. Because no existing team members have ever designed a vehicle using dual-deployment recovery, the team decided it was important to test the dual-deployment design on the sub-scale model so the team could ensure the design works and could gain experience with set up. Because dual deployment involves an electronics bay with an altimeter, nine volt battery, and other electronic components, the weight was too great to achieve the desired thrust to weight ratio on an appropriately sized motor for the vehicle's flight. This also impacted stability margin. Because there was no drogue chute (just a nomex parachute protector), the electronics and main chute resulted in a center of mass farther forward on the vehicle than what would be representative of the full scale design. This then caused the stability margin to be 3.05. However, even with this high stability margin, the vehicle experienced little weathercocking, indicating that the stability margin of 2.08 on the full scale will not be overstable.

- Describe launch day conditions and perform a simulation using those conditions.

Flight 1	12-20-21	Flight 2	12-23-21
Temperature	35 ºF	Temperature	55 ºF
Humidity	69.7%	Humidity	65.8%
Wind Speed	13 mph	Wind Speed	6 mph
Air Pressure	29.2 Hg	Air Pressure	28.8 Hg
Cloud Cover	60%	Cloud Cover	40%
Ground Level	960 ft. ASL	Ground Level	960 ft. ASL

Flight 1: 12-20-21

	Results	Engines loaded	Max. altitude Feet	Max. velocity Miles / Hour	Optimal delay	Max. acceleration Gees	Altitude at deployment Feet	Velocity at launch guide departure Miles / Hour	Velocity at deployment Miles / Hour	WeatherCocking
1		[G80NT-Plugged]	989.11	165.18	6.55	6.39	n/a	38.23	n/a	Safe
2		[G80NT-Plugged]	885.58	161.52	6.01	6.34	n/a	38.21	n/a	Safe

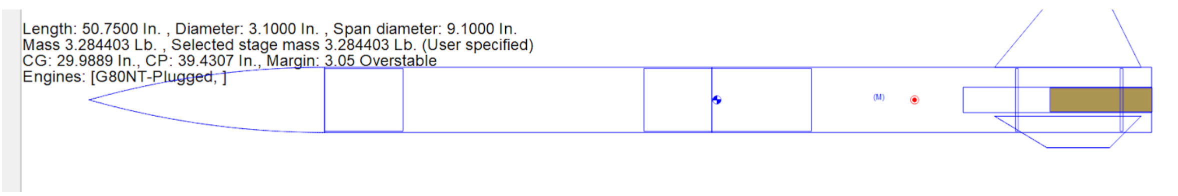


Figure 3.2.3

Flight 2: 12-23-21

	Results	Engines loaded	Max. altitude Feet	Max. velocity Miles / Hour	Optimal delay	Max. acceleration Gees	Altitude at deployment Feet	Velocity at launch guide departure Miles / Hour	Velocity at deployment Miles / Hour	WeatherCocking
1		[G80NT-Plugged]	1008.96	165.74	6.64	6.39	n/a	38.23	n/a	Safe
2		[G80NT-Plugged]	900.77	161.98	6.08	6.34	n/a	38.21	n/a	Safe

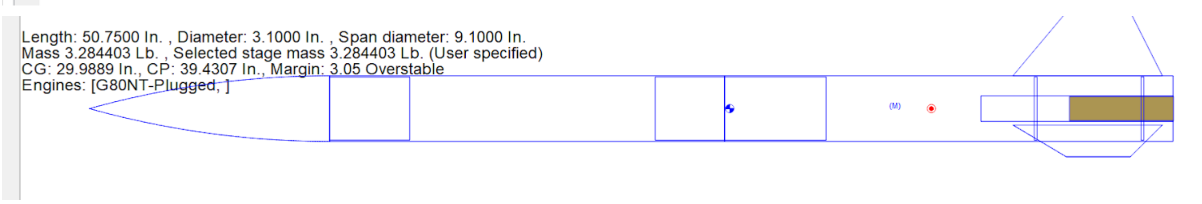


Figure 3.2.4

- Perform an analysis of the subscale flight.
  - Compare the predicted flight model to the actual flight data. Discuss the results.

In Figures 3.2.3 and 3.2.4 above, the first listed simulation is the expected results using the launch day conditions and the RockSim estimated coefficient of drag.

As shown, each flight was slightly more than 100 feet under the predicted altitude and had slightly slower maximum velocity.

Flight 1 (12-20-21)	Flight 2 (12-23-21)
Predicted Appogee: 989.11 ft. AGL	Predicted Appogee: 1008.96 ft. AGL
Actual Appogee: 884 ft. AGL	Actual Appogee: 899 ft. AGL
Difference from prediction: -105.11 ft.	Difference from prediction: -109.96 ft.

- Discuss any error between actual and predicted flight data.

The cause of the difference between the predicted flights and actual flights is a combination of the coefficient of drag and actual flight path.

The actual vehicle likely has a coefficient of drag higher than the RockSim prediction. This is most likely due to the finish of the vehicle body. The Blue Tube was unpainted and the spirals were not filled in. Although it seems minimal, having a smooth finish like the simulation software expected, can make a big difference in coefficient of drag.

Additionally, the subscale had a large stability margin due to the focus on testing the dual-deploy recovery system. This, along with strong winds, resulted in some weather cocking during rail exit. While RockSim can incorporate the effects of wind speed on maximum altitude, the impact that the wind has on flight path and therefore on maximum altitude, is less accurate. Due to the shift in flight path that can be observed in the launch video, the team also concludes that the high stability margin and wind contributed to this discrepancy.

- Estimate the drag coefficient of the full-scale rocket with subscale data.

The second listed simulation for each flight in figures 3.2.3 and 3.2.4 are after the coefficient of drag was overridden to achieve similar results as the actual flight. The coefficient of drag used in both of these simulations was 0.61. However, as explained above, the coefficient of drag was likely higher due to the vehicle finish and the difference in altitude was also due to the flight path. The full scale vehicle will have a high gloss finish with no cardboard spirals and will also have a more stable stability margin, limiting the impact that wind has on flight path and therefore altitude. With this in mind, the team recognizes that the Cd of 0.61 found for the subscale vehicle is an overestimate of the fullscale Cd. The team has also looked back at the past two years of student launch vehicle data, and found that the past two vehicles had actual coefficients of drag of approximately 0.35. With this year‘s rocket being similar in length with the same planned finish, but larger in diameter, the team will use an estimated coefficient of drag of 0.40.

- Discuss how the subscale flight data has impacted the design of the full-scale launch vehicle.

The subscale flight raised three important considerations for the design of the full scale vehicle.

The first is the igniters in the recovery system. Originally, Quest Q2G2 igniters were used. However, during the first subscale flight, the drogue ejection failed due to an igniter failure (the igniter never fired, even though continuity was held the whole time and the altimeter sent the signal to ignite). For the second flight, the team decided to use firewire igniters after receiving several recommendations that the product is more reliable. These igniters did not fail and the team now plans to use the same product for the full-scale.

The second consideration focuses on the attachment of the Nomex. During the second subscale flight the team experienced an issue of the Nomex sliding along the shot cord to a point where it affected the parachute's ability to fully deploy. This has caused the team to make sure that the Nomex on the full scale rocket is securely mounted along the shock cord to ensure that it does not slide and affect the full scale rocket's ability to deploy it's parachutes completely.

The last consideration is stability margin. Because of the high stability margin, the subscale vehicle experienced weather cocking while exiting the pad. This impacts maximum altitude and in extreme cases can be a safety hazard. With this observation made, the team has paid close attention to mass distribution in the final design steps. Because the full scale vehicle is very large, the team has been looking for areas to cut weight. In this process, the areas where weight has been cut have been carefully selected to achieve a stability margin between 2 and 2.5 and limit the risk of weather cocking. One such selection was the length of the booster section, which was shortened by 3 inches from 42 to 39.

3.3 Recovery Subsystem

- Identify which of the design alternatives from PDR were chosen as the final components for the recovery subsystem. Describe why those alternatives are the best choices.

Component	Selection	Justification
Main Parachute	Fruity Chutes 72” Iris Ultra	As shown in section 3.4, this parachute provides an optimal descent rate. The Iris Ultra design was chosen over others because of its higher coefficient of drag. This allows the slightly smaller parachute to be as effective in slowing the descent of the vehicle as parachutes of larger sizes. This lets a smaller parachute be used in the vehicle, limiting lift off weight.
Drogue Parachute	Fruity Chutes 24” Elliptical Drogue	As shown in section 3.4, this parachute also provides for an optimal descent rate. While many manufacturers offer a standard drogue parachute such as this, the team selected fruity chutes because the drogue could be shipped with the main, saving shipping costs. While this was the most expensive drogue chute option, a black friday sale took 20% off the price,

		making it one of the cheaper options at $51.
Shock Cord (drogue and main)	3/8" tubular kevlar (3600lb strength) 25’ Long	The team selected kevlar as the shock cord material because of its flame resistant properties and extreme strength. During parachute deployment, the black powder ejection charges could ignite flammable materials nearby. Because kevlar is flame retardant, this risk is mitigated. Because kevlar does not stretch when pulled taught, a 25 foot length was selected for each parachute deployment. This allows each section to separate a greater distance during ejection. Over this distance, forces such as gravity and drag will decrease the velocity of each section, limiting jerk that could possibly break the interface with the vehicle when the kevlar reaches its maximum length.
Protective Wadding	Nomex Parachute Protectors Disposable Wadding	To protect the parachutes from the ejection charges, the team plans to use a combination of Nomex parachute protectors and disposable wadding. For the main chute, a 21 inch octagonal parachute protector will be used and a 12x12 inch square parachute protector will be used for the drogue. The sizes of these protectors allow each parachute to be fully folded within, protecting them from ejection charge flames and hot embers. Disposable wadding composed of fireproof insulation will be used as well (commonly referred to as “dog barf” in sport rocketry groups). This wadding is light and adds extra protection for the parachutes and kevlar. It also fills any excess volume in the ejection chamber, helping to ensure enough pressure is produced for proper ejection.
Altimeters	PerfectFlight Stratologger CF Altimeter	This altimeter was chosen primarily due to familiarity and accessibility. The team has used Stratologgers for flights in the past and have never once experienced a product failure. The team also used a Stratologger for the subscale launch. The altimeter records altitude, velocity, acceleration and temperature. It also identifies apogee and recorded data can be easily graphed to show flight performance (as seen in section 3.2). The team also found the altimeter easy to use. It simply plugs into a computer for programming and data download and uses a simple series of beps to identify ejection charge continuity when on the pad. The altimeters will run off of 9-volt duracell batteries. These batteries provide a high enough voltage to run the altimeter and ignite the ejection charges. The team has also always used duracell and trusts the brand. A duracell battery was used and worked well in the subscale.
GPS Tracker	Featherweight GPS Tracker	The Featherweight GPS was also selected due to its familiarity and user-friendly design. This model of GPS is focussed purely

		on GPS tracking instead of being a combined tracker and recovery system altimeter like other models. It also offers an iPhone app that can be connected to the ground station receiver, allowing the altitude and position of the vehicle to be viewed in real time. The tracker also allows a variety of frequencies that can be used and easily changed if frequency conflict needs to be avoided on launch day. The team currently plans to use channel 24B, which operates at 921.400 MHz. The GPS will run off of a 3.7V, 400 mAh lithium polymer battery (comes included with tracker, provides 4.5 hours of active tracking time and is rechargeable).
Electric Matches	MJG Firewire	The team decided to use firewire electric matches after the subscale launch. Originally, Quest Q2G2 igniters were used because they were conveniently ordered along with subscale components from Apogee Rockets. However, during the first subscale flight, the drogue chute ejection failed due to an igniter failure (the igniter never fired, even though continuity was held the whole time and the altimeter sent the signal to ignite). With this failure having the potential to be catastrophic during the full scale flight, the team elected to use Firewire igniters for the second subscale flight after team mentors recommended them as a more reliable option. These igniters performed well in the second subscale flight and therefore will be used for the full scale.
Shear Pins	4 “2-56” Shear pins at each separation point	Because the vehicle has large fins and a relatively heavy payload, 4 shear pins are included at drogue separation to avoid pre-apogee drag separation and parachute deployment. For the main parachute, 4 shear pins are also included to avoid early deployment of the parachute. During drogue deployment, this separation point could experience acceleration that could possibly deploy the main chute too early. With 4 shear pins that each have a breaking force of 21.4 pounds of force to break, a total of 85.6 pounds of force would need to be present to deploy the main chute (this is realistically even higher due to friction). With a 25 foot long kevlar shock cord it is highly unlikely that these pins break during drogue deployment. With these shear pins in mind, the black powder charges are then calculated to ensure great enough force is present for deployment. A ground demonstration will occur to ensure the shear pins break during propper deployments and do not break early or prevent deployment.
Black Powder	Goex FFFFG (4F black	4F black powder ignites and burns faster than other varieties. The team wants pressure to build up quickly. If it were to build

	powder) Main Chute 4g Primary 6g Secondary Drogue Chute 3.3g Primary 5g Secondary	up too slowly, too much of the gas creating the pressure could escape through the vent hole or gaps at the separation point and never fully separate the vehicle. 4F was selected to avoid this. Because each separation point is reinforced with 4 shear pins, a pressure of at least 15 psi would produce a net force on the bulkhead of over 424 pounds, more than enough force for the shear pins to be broken (requiring 85.6 pounds) and for ejection to happen properly, as advised by Hara Rocketry and Team Mentors. The amount of black powder needed for each ejection can be calculated using the ideal gas law (PV=nRT). This equation can be rearranged to find n, the amount of black powder (n = $\frac{PV}{RT}$) The ideal gas constant, R, with these imperial units (Pounds force, pounds mass, inches and ^{o}R) is 266. The volume of the body tube is V = $\pi r^2 h$, where r = 3 inches, and h = 18 inches (even though the main parachute chamber is only 12 inches long, the length of the 6 inch coupler is included because this volume will still need to be filled with gas for a complete ejection). $V = \pi r^2 h = \pi(9)(18) = 508.94$ in^3 The absolute temperature of gas after combustion of black powder is T = 3307 ^{o}R. Because charges are usually reported in grams, the results will be multiplied by the conversion factor 454 (there are 454 grams in a pound). This leads to the final equation of: $n = \frac{15(508.94)}{266(3307)} \cdot \frac{454}{1}$ = 3.94 grams Online calculators from Rocketry Calculator and Hara Rocketry both verify these results. To ensure that enough pressure is generated to cause a proper ejection, these results will be rounded up to 4 grams for the primary charge. The secondary charge will need to be more powerful than the first to ensure separation if the first charge did not separate the vehicle completely. A charge that is composed of 6 grams of black powder would result in 22.84 psi, or 646 pounds of force

		on the bulkhead, a sufficient amount for backup, as recommended by Hara Rocketry and Team Mentors. Repeating these same calculations for the 9 inch drogue parachute chamber (15 inches including the coupler length), the required amount of black powder is found to be 3.28g. This can be rounded up to 3.3g to ensure enough pressure is generated. For the back up charge, a larger amount of 5g will be used, resulting in 22.84 psi or 646 pounds of force on the bulkhead, the same pressure used as the back up for the primary parachute deployment.

- Describe the parachutes, harnesses, bulkheads, and attachment hardware.

Component	Description
Main Parachute	The main Parachute is 72” Iris Ultra Standard Parachute. Fruity Chutes advertises this parachute as able to bring 28 pounds down at 20 fps. The actual descent rate using the Heimdall vehicle weight is shown in Figure 3.4.7. Due to this parachute's unique shape, it has a higher coefficient of drag than other parachute designs. This coefficient is 2.2. The parachute has 12 gores. It is made of nylon with 5/8" webbing. The parachute load is suspended on flat nylon cords rated to 400lbs for each cord. It includes a 1500lb rated swivel. It is 13.4oz and packs into a volume of 3.9” (diameter) x 6.2” (length): 74.1in^3. An image provided by fruity chutes of the parachute design (not the actual size) is included below (Figure 3.3.1)  Figure 3.3.1
Drogue Parachute	The selected drogue parachute is the Fruity Chute 24” Elliptical Parachute. It is advertised as being able to bring down 2.2 pounds at 20 fps. The actual descent rate with the load of the Heimdall vehicle can be seen in figure 3.4.8. The coefficient of drag for this specific parachute is between 1.5 and 1.6. The parachute is made of ripstop nylon fabric and secures its load using 220 lb

	rated nylon shroud lines rated to 220 pounds each. It includes a 1000 pound rated swivel. The total weight of the parachute is 2.2oz and it packs into a volume of 1.9” (diameter) x 4.3” (length): 12.2in^3 (assumes a tight pack). An image provided by fruity chutes of the parachute design (not the actual size) is included below (Figure 3.3.2)  Figure 3.3.2
Harnesses	The harness that supports each parachute is ⅜ Tubular Kevlar, 25 feet long. Each harness has two attachment points on it: one for the parachute (attached to the swivel) and one for the nomex parachute protector. At these attachment points, a loop will be tied in the kevlar and the nomex and parachute will be directly knotted to these loops. These knots are done by passing the end of the parachute, or corner of the nomex, through the loop and then pulling the parachute or the nomex protector through the end (commonly called a girth hitch). These knots are shown below in figure 3.3.3  Figure 3.3.3a  Figure 3.3.3b Note: the components pictured above are not the actual components being used for the full scale Project Heimdall vehicle. The upper image depicts the connection of the shock cord to the parachute swivel and the lower image

<table>
<tr><td></td><td>shows the connection of the shock cord to the nomex parachute protector.</td></tr>
<tr><td>Bulkheads</td><td>The bulkheads are composed of 0.2” thick G10 fiberglass. Each bulkhead is secured to the rest of the vehicle by threaded rods that extend through the couplers and connect to a bulkhead on the other end of the coupler. The bulkheads secure each other around the coupler and stay fixed to the vehicle in that way.
The diameter of the plates fit into the inside of the couplers but they each have a slightly wider lip that matches the outer diameter of the coupler, allowing it to rest on the edge. This then lets the bulkheads be tightened down on the threaded rods to be secured in place, without sliding inside the coupler. A picture of an actual bulkhead is shown below (figure 3.3.4) as well as a CAD screenshot (figure 3.3.5).

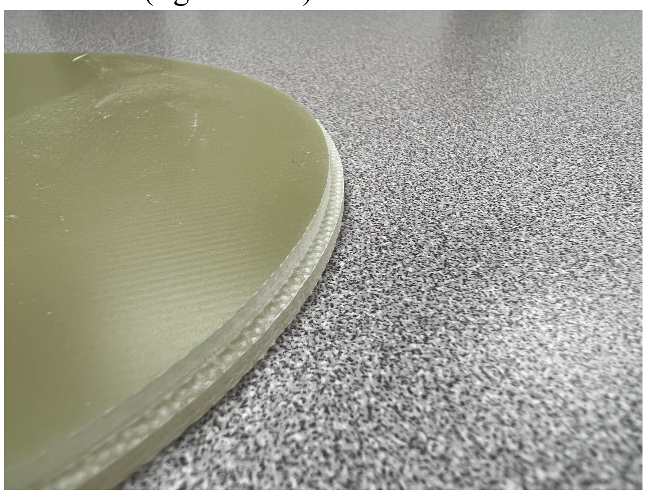



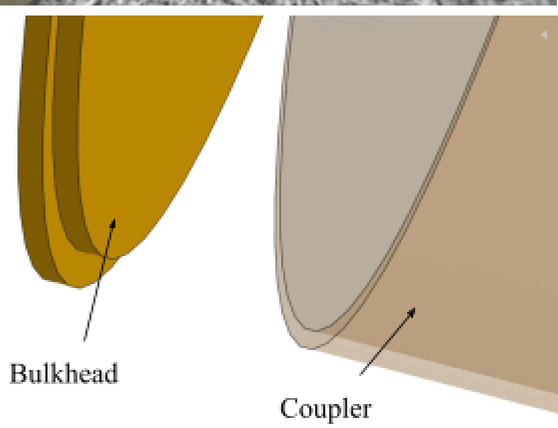
Figure 3.3.4


Figure 3.3.5</td></tr>
<tr><td>Attachment Hardware</td><td>To attach the parachute harness (shock cord) to the bulk plates, 5/16” forged steel eye bolts are used. They extend through the bulk plates and are secured on the other side with a lock nut. Washers also lie between the nut and the fiberglass to distribute force and prevent cracking. The harness attaches to the eye bolts using a steel quick link that attaches the eye bolt and a loop tied in the end of the kevlar (Figure 3.3.6).</td></tr>
</table>

	 Figure 3.3.6 Note: the components pictured above are not the actual components being used for the full scale Project Heimdall vehicle.

- Discuss the electrical components and prove that redundancy exists within the system.

The electronics of the recovery system consist of two completely separate systems composed of a StratologgerCF Altimeter, 9V battery and two ejection charges (one for drogue and one for main).

At apogee, the main altimeter will trigger the primary ejection charge. This 4g black powder charge will separate the booster section from the rest of the vehicle, deploying the 24” drogue parachute. In case of altimeter, electric match, or charge failure, the secondary altimeter will activate a secondary 6g black powder charge to ensure the booster section separates from the rest of the vehicle and the drogue chute properly deploys. This 6g charge will ignite at apogee +1. A tertiary charge, composed of the manufactured ejection charge on the CTI K-1440 will also be included to ensure deployment.

At 600 feet AGL, the primary altimeter will activate the primary charge for the main parachute deployment. This 4g black powder charge will separate the payload section from the recovery section, deploying the main parachute. At 500 feet AGL, the secondary altimeter will activate the secondary 6g black powder ejection charge, ensuring the recovery and payload section separate.

- Include drawings/sketches, wiring diagrams, and electrical schematics.

Figure 3.3.7 below depicts the general wiring for the recovery electronics. Notice how it involves three separate systems that are completely independent of each other. The three different colored coded wires depict this distinct separation.

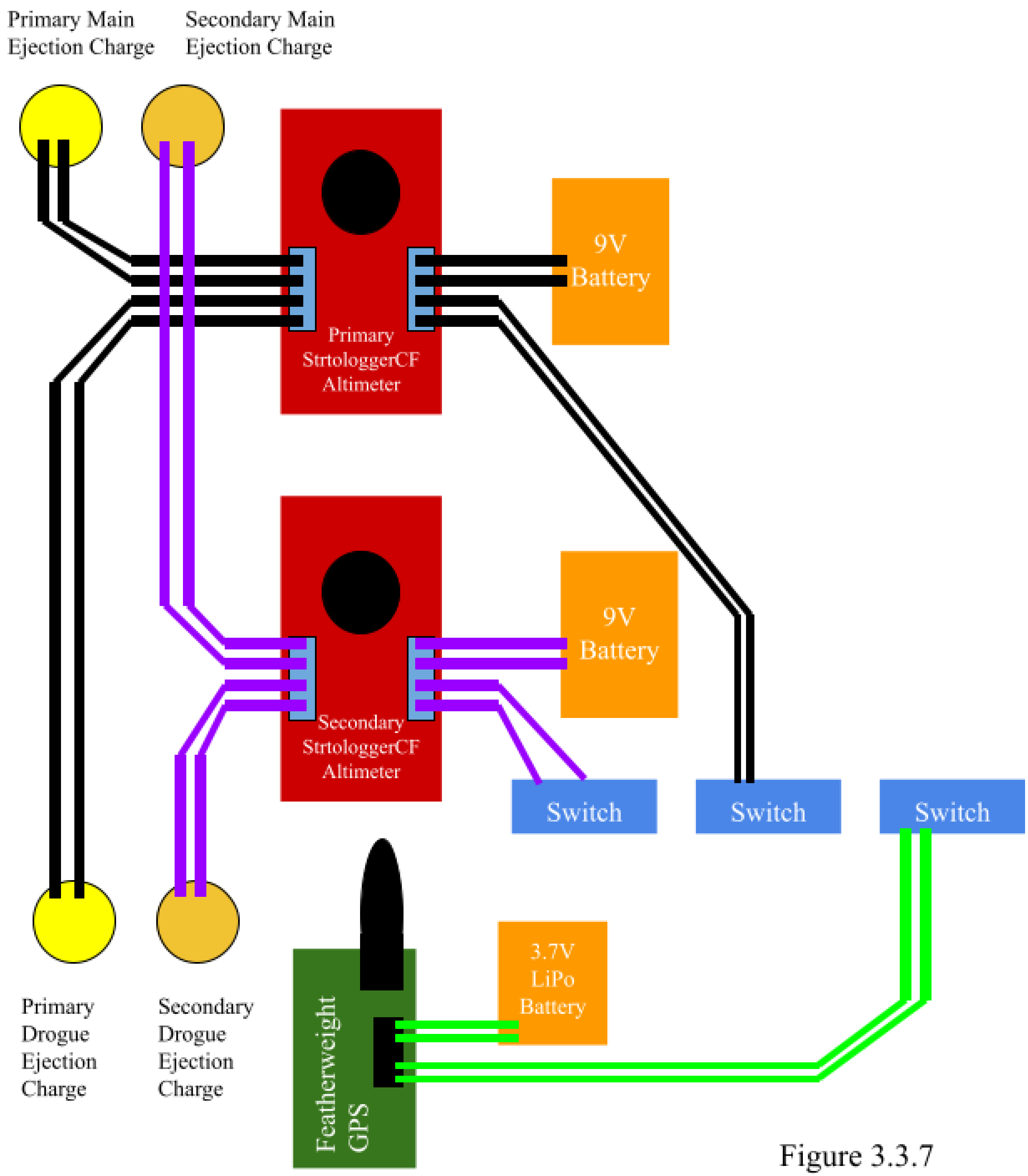


Figure 3.3.7

Note: The components, spacing, and positioning depicted above is not to scale.

- Provide the operating frequency of the locating tracker(s).

The vehicle will use only one locating tracker located in the recovery electronics bay. The team currently plans to use channel 24B on the featherweight GPS, which uses the operating frequency of 921.400 MHz. However, the team can use different frequencies on launch day if RSO or any event organizers need the frequency to be changed for any reason.

3.4 Mission Performance Predictions

- Show flight profile simulations. This includes altitude, velocity, and acceleration versus time predictions with simulated vehicle data, component weights, and simulated motor thrust curve. Verify that the vehicle is robust enough to withstand the expected loads.

Altitude vs. Time Graph (blue)
Velocity vs. Time Graph (pink)
Acceleration vs. Time Graph (light blue)
and Stability Margin vs. Time Graph (red)

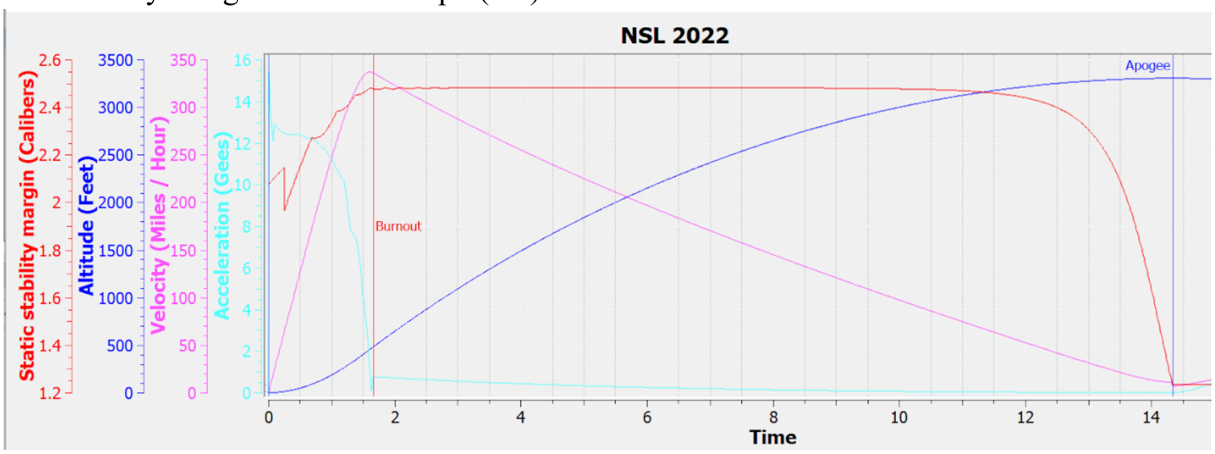


Figure 3.4.2

Vehicle Data (maximums)

	Results	Engines loaded	Max. altitude Feet	Max. velocity Miles / Hour	Optimal delay	Max. acceleration Gees	Altitude at deployment Feet	Velocity at launch guide departure Miles / Hour	Velocity at deployment Miles / Hour
2		[K1440WT-Plugged	3478.35	339.14	13.15	14.40	3478.36	64.54	11.56
3		[K1440WT-Plugged	3302.56	336.95	12.68	14.40	3302.56	64.53	11.04

Figure 3.4.3

The first listed simulation is using the RockSim estimate Cd of 0.32. The second simulation is using the team's estimated Cd of 0.4. Simulation parameters and other results are shown below (using 0.40 Cd).

NSL 2022 - Simulation results

Engine selection

[K1440WT-Plugged]

Engine manufacturer

Cesaroni Technology Inc.

Simulation control parameters

- Flight resolution: 800.000000 samples/second
- Descent resolution: 1.000000 samples/second
- Method: Explicit Euler
- End the simulation when the rocket reaches the ground.

Launch conditions

- Altitude: 900.00000 Ft.
- Relative humidity: 65.800 %
- Temperature: 55.000 Deg. F
- Pressure: 28.7918 In.

Wind speed model: Custom speed range

- Low wind speed: 7.0000 MPH
- High wind speed: 7.0000 MPH

Wind turbulence: Some variablility (0.04)

- Frequency: 0.040000 rad/second

- Wind starts at altitude: 0.00000 Ft.
- Launch guide angle: 0.000 Deg.
- Latitude: 0.000 Degrees

Launch guide data:

- Launch guide length: 144.0000 In.
- Velocity at launch guide departure: 64.5271 MPH
- The launch guide was cleared at : 0.255 Seconds
- User specified minimum velocity for stable flight: 29.9996 MPH
- Minimum velocity for stable flight reached at: 31.2554 In.

Figure 3.4.4

Component Weights (on the pad)

- Booster Section: 11.756 lbs (motor weight: 4.2 pounds)
- Recovery Section: 8.495 lbs
- Payload Section: 8.959 lbs

Motor Thrust Curve (K-1440)

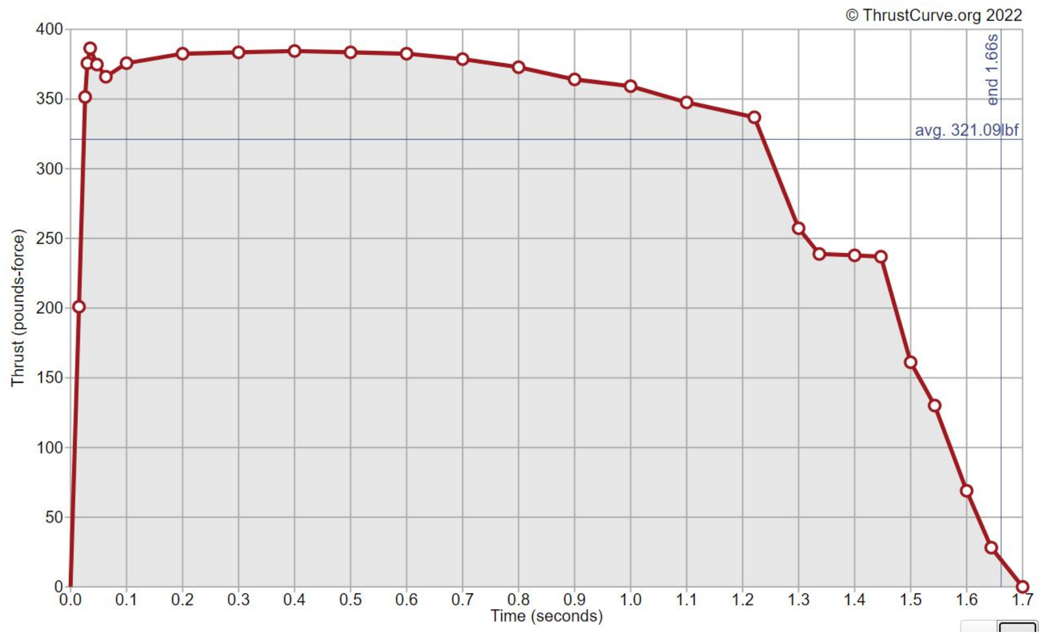


Figure 3.4.5

The launch vehicle will be able to withstand expected loads during flight. In research, the team found that similar sized G12 fiberglass has been used for vehicles much heavier and using motors with significantly greater maximum thrust. With higher weight, greater thrust, acceleration, and maximum velocity, these vehicles underwent significantly higher stress during flight and the airframe materials and design withstood this stress. In using the same materials, with a similar design but lower weight and less acceleration, the team has concluded the vehicle can withstand the expected loads during flight.

- Show stability margin and simulated Center of Pressure (CP)/Center of Gravity (CG) relationship and locations.

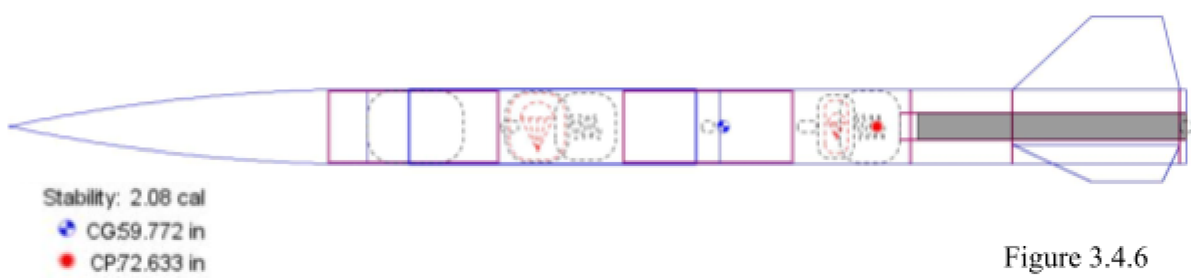
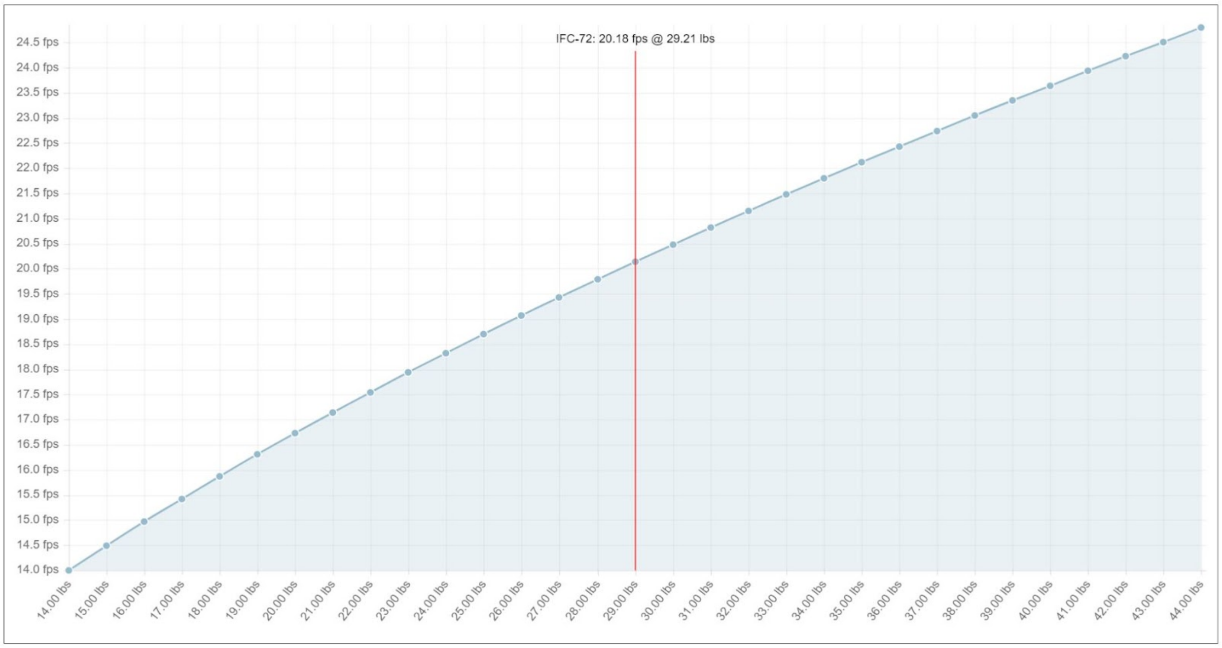


Figure 3.4.6

The vehicle has a stability margin of 2.08 on the pad and 2.15 upon rail exit. The value of 2.15 was determined using the stability margin over time graph above at the time (t) where the vehicle exits the guide rail (t=0.255 seconds)

- Calculate the kinetic energy at landing for each independent and tethered section of the launch vehicle.

The descent rate under the main 72" Iris Ultra Parachute using the mass of the vehicle after motor burn (29.21 pounds) is shown in the graph provided by fruity chutes below (Figure 3.4.7):  Figure 3.4.7
Booster Section
(1 J = 0.737562 ft-lb) (1 m = 3.28084 ft) (1 kg = 2.20462 lbs) Given the graphs provided by Fruity Chutes for descent rate (Graph 3.4.7), the kinetic energy can be calculated using the estimated descent rate of 20.18 fps. $\frac{20.18\ ft}{1s} \cdot \frac{1m}{3.28084\ ft} = 6.151\ m/s$ $11.756\ lbs \cdot \frac{1\ kg}{2.20462\ lbs} = 5.332\ kg$ KE = $\frac{1}{2}mv^2$ KE = $\frac{1}{2}(5.332)(6.151^2)$ KE = 100.87 J $88.26\ J \cdot \frac{0.737562\ ft-lbs}{1J}$ =74.40 ft-lbs 74.40 < 75, therefore the booster meets the kinetic energy requirements. Even though this kinetic energy is close to the maximum limit, the actual descent rate will be slightly slower because the drogue chute and actual vehicle will add extra drag, contributing to a slightly slower descent rate and therefore lower kinetic energy at landing.
Recovery Section

(1 J = 0.737562 ft-lb) (1 m = 3.28084 ft) (1 kg = 2.20462 lbs) Given the graphs provided by Fruity Chutes for descent rate (Graph 3.4.7), the kinetic energy can be calculated using the estimated descent rate of 20.18 fps. $\frac{20.18\,ft}{1s} \cdot \frac{1m}{3.28084\,ft} = 6.151\ m/s$ $8.495\ lbs \cdot \frac{1\ kg}{2.20462\ lbs} = 3.853\ kg$ KE = $\frac{1}{2}mv^2$ KE = $\frac{1}{2}(3.853)(6.151^2)$ KE = 72.89 J $72.89\,J \cdot \frac{0.737562\ ft-lbs}{1J}$ =53.76 ft-lbs 53.76 < 75, therefore the booster meets the kinetic energy requirements.
Payload Section
(1 J = 0.737562 ft-lb) (1 m = 3.28084 ft) (1 kg = 2.20462 lbs) Given the graphs provided by Fruity Chutes for descent rate (Graph 3.4.7), the kinetic energy can be calculated using the estimated descent rate of 20.18 fps. $\frac{20.18\,ft}{1s} \cdot \frac{1m}{3.28084\,ft} = 6.151\ m/s$ $8.959\ lbs \cdot \frac{1\ kg}{2.20462\ lbs} = 4.064\ kg$ KE = $\frac{1}{2}mv^2$ KE = $\frac{1}{2}(4.064)(6.151^2)$ KE = 76.88 J $76.88\,J \cdot \frac{0.737562\ ft-lbs}{1J}$ =56.70 ft-lbs 56.70 < 75, therefore the booster meets the kinetic energy requirements.

- Calculate the expected descent time for the rocket and any section that descends untethered from the rest of the vehicle.

$t = \frac{x}{v}$,where x represents altitude in feet and v represents descent rate in feet per second. The descent is divided into two stages, stage 1 (drogue chute) and stage 2 (main chute). Since the main chute opens at 600 ft. AGL, the descent covered by the drogue chute will be from 3303 ft - 600 ft = 2703 ft, and the main chute will cover the descent of the last 600 ft.
Descent rate under under the 24" drogue chute can be found using predictions on the Fruity Chute website using vehicle weight after motor burn out (29.21 pounds) (see Figure 3.4.8 below)

Descent Rate Under Drogue Chute: 73.66 fps

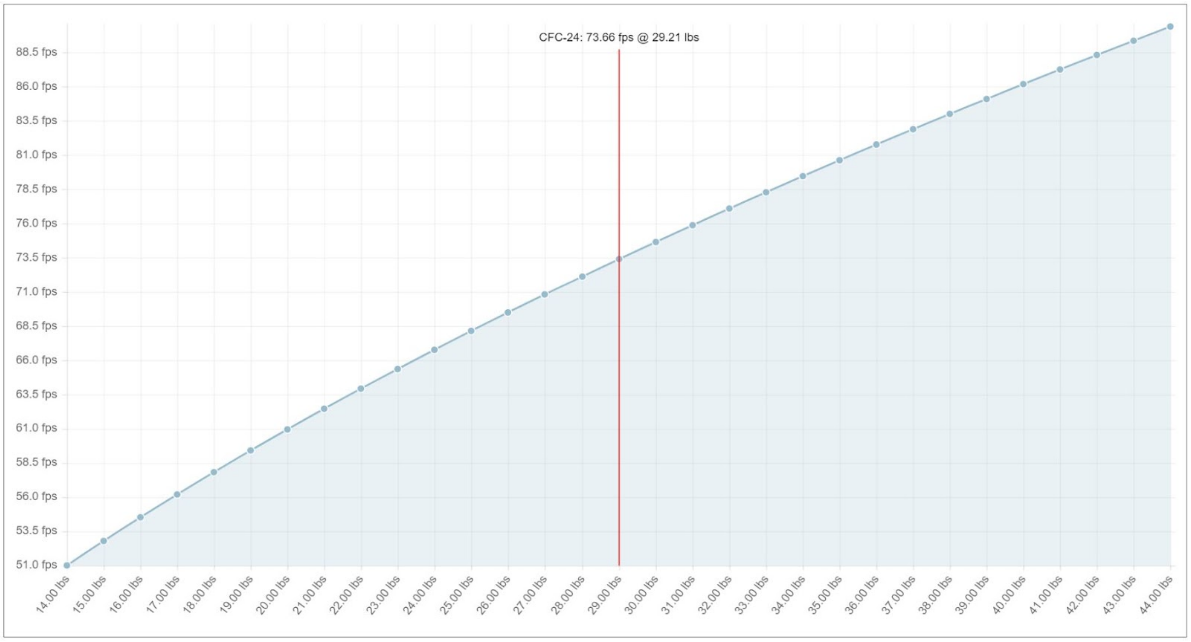


Figure 3.4.8

Time descending under drogue chute:

$t = \frac{2702}{73.66} = 36.70$ seconds

Time descending under main chute (using rate determined in Figure 3.4.7):

$t = \frac{600}{20.18} = 29.73$ seconds

Total descent time

36.68 + 29.73 = 66.43 seconds

66.43 < 90, meeting the descent time requirement

- Calculate the drift for each independent section of the launch vehicle from the launch pad for five different cases: no wind, 5-mph wind, 10-mph wind, 15-mph wind, and 20-mph wind. The drift calculations should be performed with the assumption that apogee is reached directly above the launch pad.

1 mile = 5280 feet	1 hour = 3600 sec.
Wind Speed	Vehicle Drift (in 66.43s descent)
0 mph	None
5 mph	$\frac{5\ miles}{1\ hour} \cdot \frac{1\ hour}{3600\ s} \cdot \frac{5280\ ft}{1\ mile} = 7.33$ fps $7.33\ fps \cdot 66.43\ s = 487$ foot drift

10 mph	$\frac{10\ miles}{1\ hour} \cdot \frac{1\ hour}{3600\ s} \cdot \frac{5280\ ft}{1\ mile} = 14.67$ fps $14.67\ fps \cdot 66.43\ s = 975$ foot drift
15 mph	$\frac{15\ miles}{1\ hour} \cdot \frac{1\ hour}{3600\ s} \cdot \frac{5280\ ft}{1\ mile} = 22.00$ fps $22.00\ fps \cdot 66.43\ s = 1461$ foot drift
20 mph	$\frac{20\ miles}{1\ hour} \cdot \frac{1\ hour}{3600\ s} \cdot \frac{5280\ ft}{1\ mile} = 29.33$ fps $29.33\ fps \cdot 66.43\ s = 1948$ foot drift
	All wind speeds up to at least 20 mph result in landing drift contained within the designated 2500 foot radius (assuming apogee occurs directly above launch pad).

4. Payload Criteria

4.1 Design of Payload Equipment

- Identify which of the design alternatives from PDR was chosen for the payload. Describe why that alternative and its components were chosen.

Camera Array		
Component	Selection	Justification
Cameras	3x GoPro Hero 9	The team decided that the best route for the creation of a VR experience would be the highest quality video available. Small arduino cameras do not provide nearly the quality the team desires, so the current leader in high quality action cameras was selected. The GoPro Hero 9 can record 4k video at 30 frames per second with a field of view of 121 degrees. With three cameras, a high-quality 360 Degree video can be created using Adobe Premiere Pro.
Battery	2x Charmast Smallest 10000 USB C PD Quick Charge Portable Charger	After testing the battery life of the internal GoPro batteries, it was found that the batteries do not provide sufficient power to the cameras for the minimum required time on the pad. The test results are shown below.

Quality	Screens and Power Source	Battery Life TIme
[redacted]		
4k30SV	All On - everything necessary and unnecessary (Full Time)	1hr:14mins

<table>
<tr>
<td></td>
<td></td>
<td>
<table>
<tr><td>4k30SV</td><td>[redacted]</td><td>Everything not necessary off
(1 minute screen shutoff)
(Leds & Wifi off)</td><td>[redacted]</td><td>1hr:17mins</td><td>[redacted]</td></tr>
<tr><td>4k30SV</td><td>[redacted]</td><td>1 min screen shutoff - LED's off, Wifi off, wired power</td><td>[redacted]</td><td>Stopped @ 2hr:25min Manually</td><td>[redacted]</td></tr>
<tr><td>4k30SV</td><td>[redacted]</td><td>1 min screen shutoff - (LED's off, WIFI OFF)</td><td>[redacted]</td><td>1hr:26mins</td><td>[redacted]</td></tr>
<tr><td>4k30SV</td><td>[redacted]</td><td>Everything necessary and unnecessary on - wired power</td><td>[redacted]</td><td>Stopped manually @ 1hr:40mins - hot to touch</td><td>[redacted]</td></tr>
<tr><td>4k30SV</td><td>[redacted]</td><td>Battery Power - Everything unnecessary off, Outside (54F)</td><td>[redacted]</td><td>1hr:40mins</td><td>[redacted]</td></tr>
</table>
The payload needs to be able to sit on the pad for a minimum of 2 hours before launch and still be functional for flight. Because GoPros are not compatible with practical remote starting systems, they need to be initiated during setup and record for the duration on the pad before flight. As shown above, using wired power with other unnecessary parts of the camera off, battery life can easily go beyond two hours, given a substantial power source.

To provide power, the team decided to use 2 x 10,000 mAh Charmast portable chargers as a power source. They are very small and carry a lot of energy for their size. Having 2 batteries with 2 outputs on each battery allows for one battery to supply energy to 2 GoPros and the other battery to supply energy to the third GoPro and the PCB (flight data collection computer). The total 10,000 mAh in each battery going to 2 outputs means each electronic device onboard the vehicle gets about 5,000mAh of usable power. This will provide 3.7 hours of film time. This was determined by using the GoPro’s battery lifetime of 77 minutes for a battery size of 1720mAh and the external battery having a size of 5000mAh dedicated to each GoPro, resulting in 2.9 times higher capacity total. This means that each GoPro should last about 223 minutes, or 3.7 hours.
</td>
</tr>
<tr>
<td>Windows</td>
<td>Acrylic</td>
<td>Acrylic windows were selected due to their superior strength and resistance to scratching. This resistance to scratching prevents dirt and other debris from becoming trapped in micro scratches and creating a haze, blocking views from the cameras. Additionally, acrylic was used for mock windows in the subscale model. The team found the material easy to work with</td>
</tr>
</table>

		and implement into the vehicle.
Data Collection (PCB: printed circuit board)		
Component	Selection	Justification
Main Computer	Teensy 4.1	The Teensy 4.1 is the source of power for all other components via the microUSB port to the boards 5V and ground pin. It also records data to a built in microSD Card slot on its far side. The Teensy 4.1 was chosen for its superior performance in processor speed and ram size.
Orientation Sensor	BNO-055	The BNO-055 utilizes 3 different sensors (magnetometer, gyroscope, and accelerometer). They output data individually or as quaternions, Euler angles, or Vectors and can also measure magnetic field strength vs gravity vectors. It can also record temperature. All of these measurements except temperature and magnetic field strength can be measured up to 100 times per second (100hz). Due to on-board communication limits with I2C it will be collected at about 20 times per second (20hz). The BNO-085 was removed from the PCB, as its limitations of 8G and non-determinate “higher accuracy” made it less of an asset to the team.
Barometric Pressure Sensor	BMP390	This sensor measures barometric pressure and temperature extremely accurately. The accuracy is within 0.03hPa (+- 25cm altitude accuracy). Temperature wise, it's accurate within 0.5 ºC. This component was chosen over others because, while it lacked the ability to record humidity and air quality, it recorded more accurate altitude and temperature, data that the team places as more important for the virtual display.
Secondary Computer	Feather M0	This secondary computer also looks at the same data but at a slightly slower rate. The secondary computer is for experimental purposes for progression in understanding how well a personally coded computer can guess launch, apogee, firing of drogue and main parachutes, and touching the ground. If this computer accurately guessed these data points, it will be included in the virtual flight display, otherwise it will be put in by hand into the virtual flight display where possible.
LED Indicators	WS2812B	These 4 LEDs placed on either side of the Feather M0 are full RGB and individually controllable, allowing the team to use them for "debugging" (green means everything is good, if the code thinks anything else is malfunctioning, it can change the color of the LED's according to what's wrong). These LEDs

		were selected due to their cost and color range, which can greatly aid in determining any issues during initialization. Previously, with our Rockets For Schools Rocket, when attempting to collect data our MicroSD Card was not fully plugged in, and we weren't aware of it because of lack of indicators, this will reduce the likelihood of missing something as obvious.
Power Source	Charmast Portable Charger	The data collection system will be powered by the same battery array as the cameras because these batteries offer one extra USB port that can be used and no foreseeable major consequences otherwise.

- Review the design at a system level.
    - Include drawings and specifications for each component of the payload, as well as the entire payload assembly.

Dimensional Drawing of Cameras:

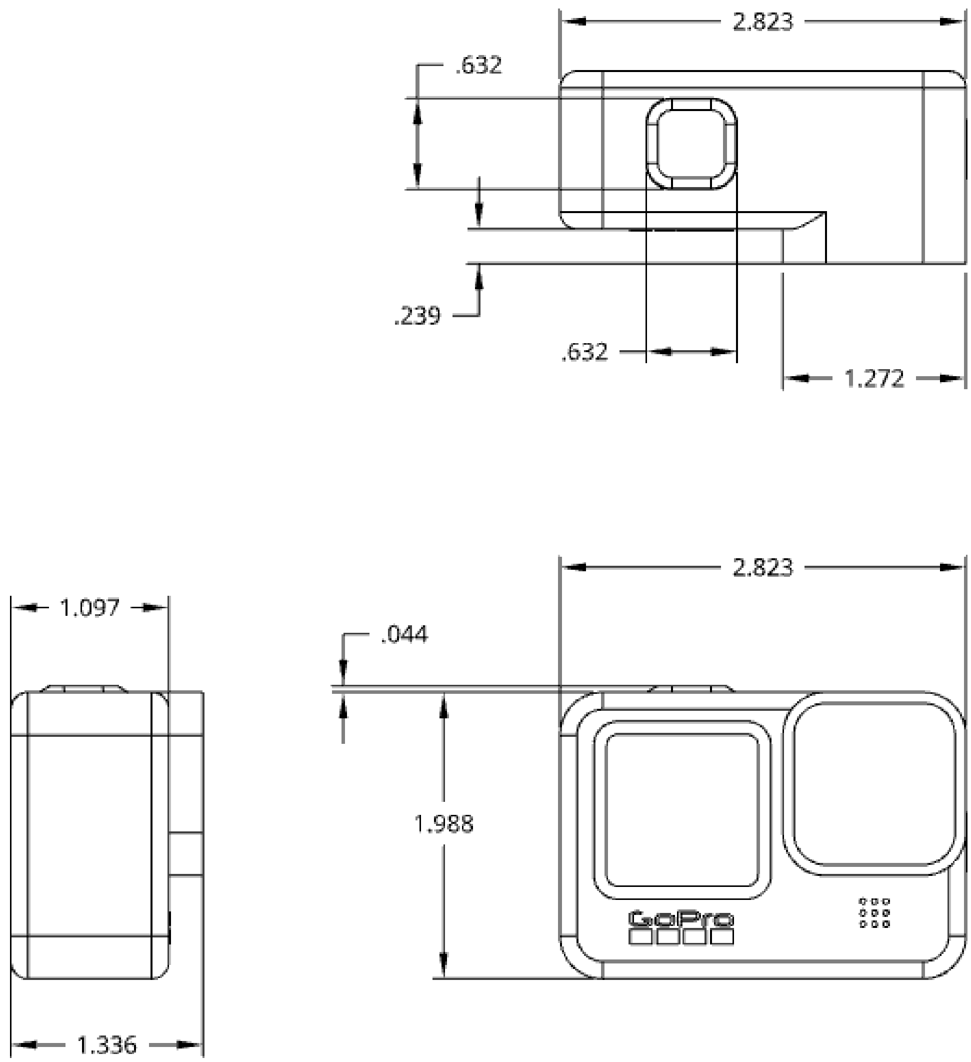


Figure 4.1.1

Dimensional Drawing of PCB

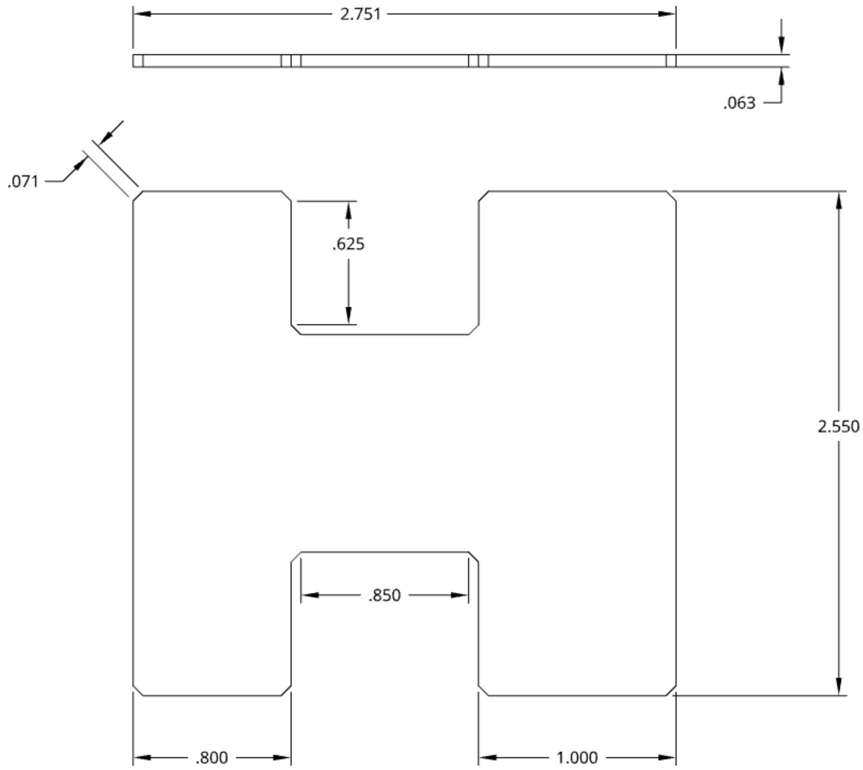


Figure 4.1.2

Dimensional Drawing of Battery

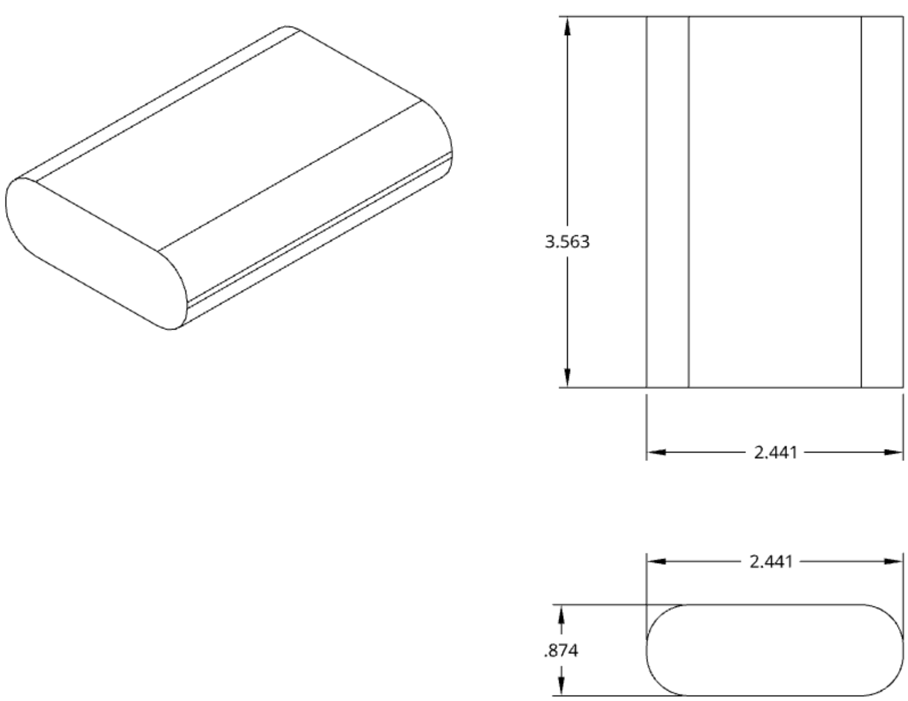


Figure 4.1.3

Dimensional Drawing of PCB Housing:

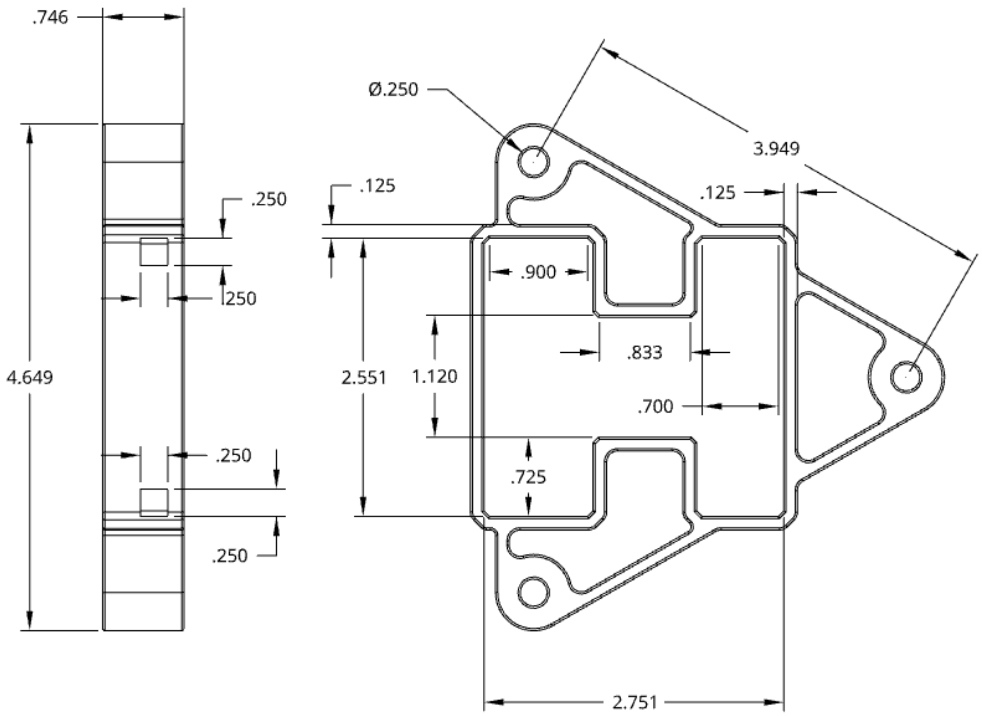


Figure 4.1.4

Dimensional Drawing of battery retainment:

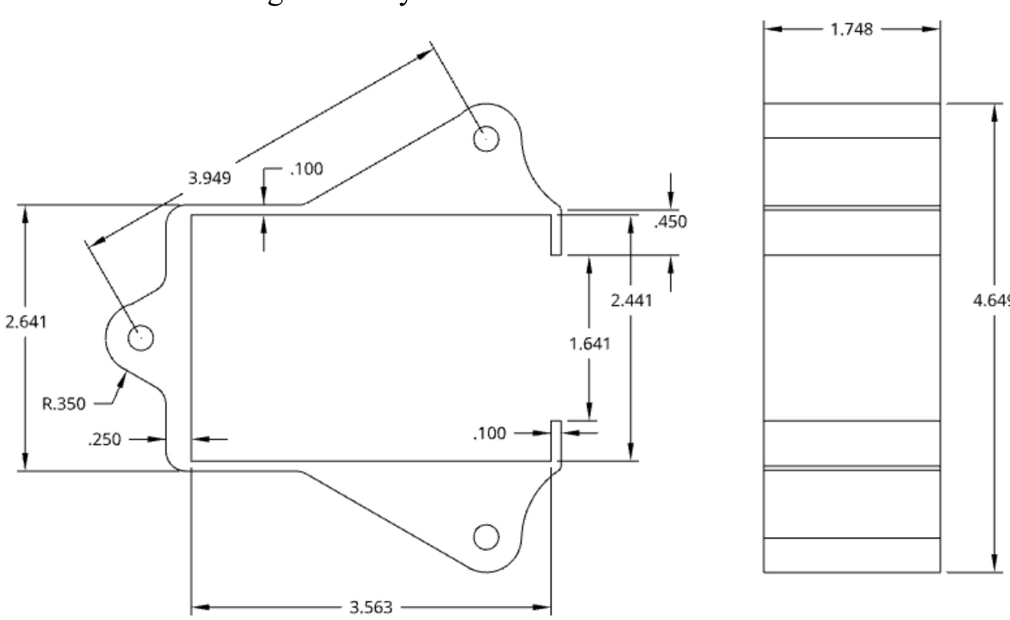


Figure 4.1.5

Drawings of Aluminum Rings
Top Camera Ring

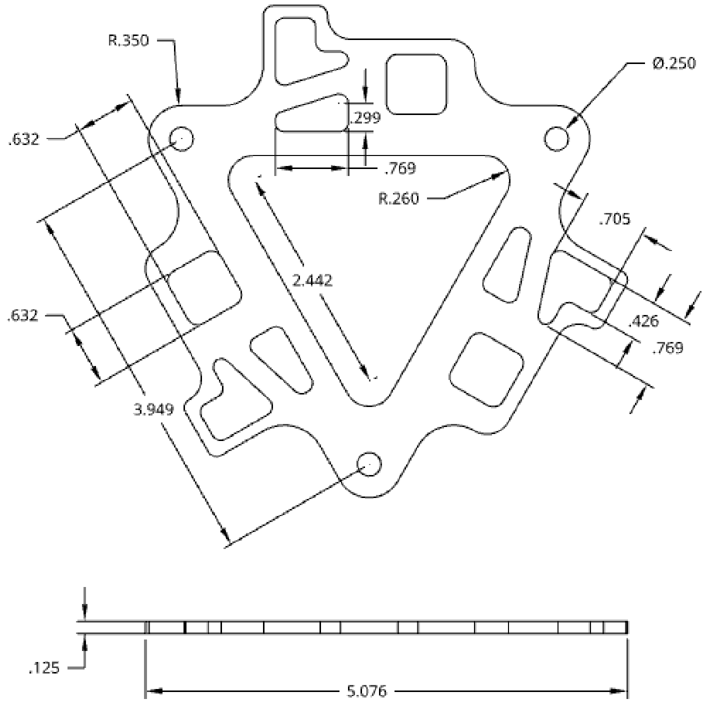


Figure 4.1.6a

Middle Camera Ring

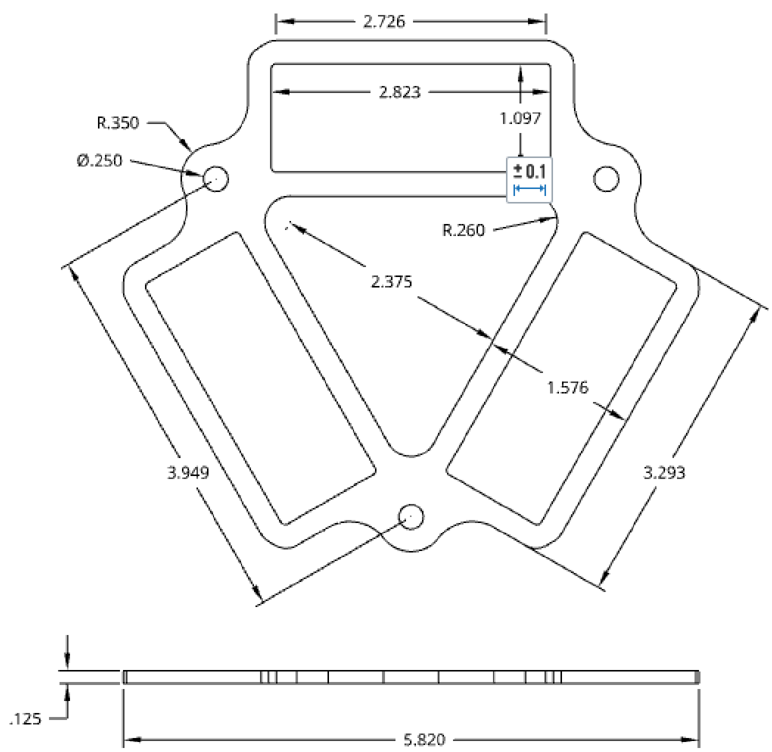


Figure 4.1.6b

Bottom Camera Ring

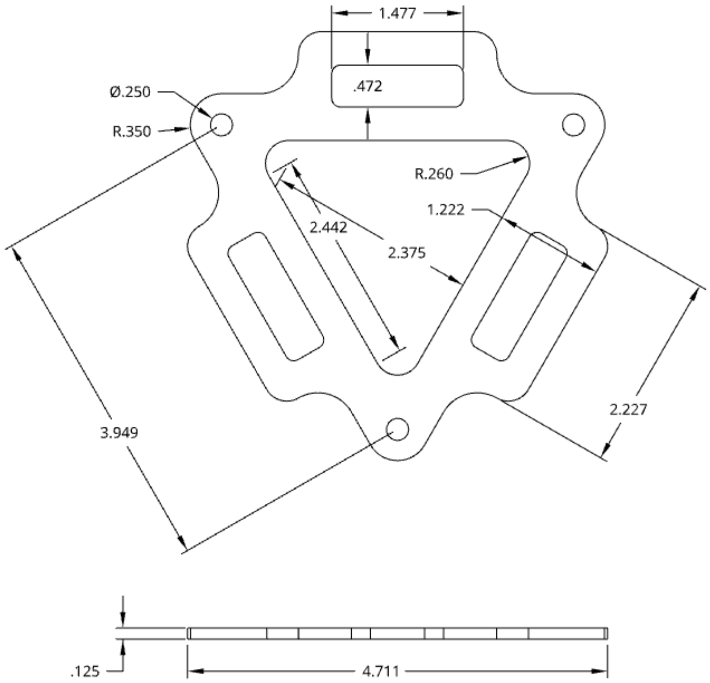


Figure 4.1.6c

Battery Support Rings

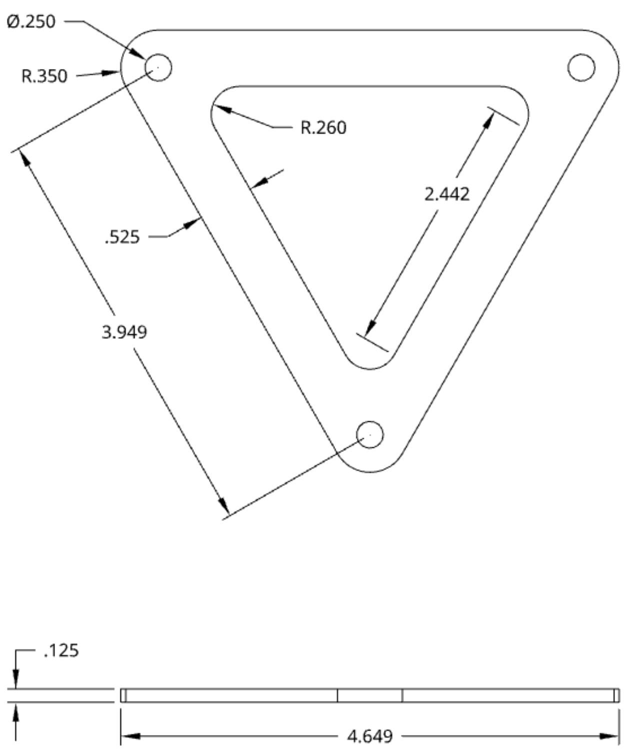


Figure 4.1.6d

Full Assembly

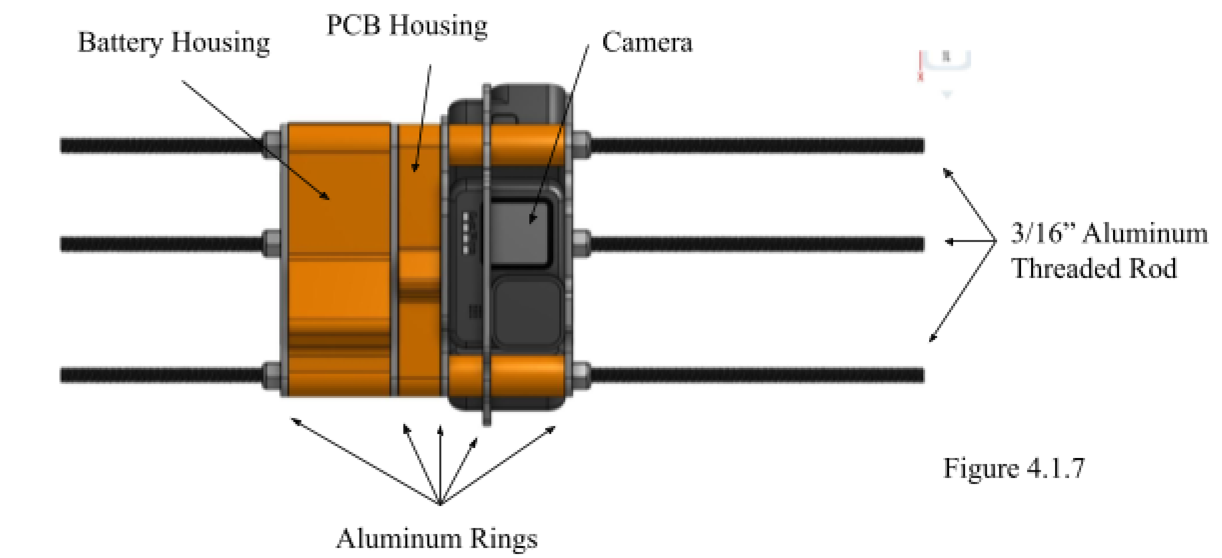


Figure 4.1.7

- Describe how the payload components interact with each other.
  - There are three main component groups of the payload: The batteries, the Cameras, and the PCB. The batteries interact with all three cameras and the PCB by supplying power to each of these components. The PCB and each individual camera do not directly interact with each other. Video footage is stored on a separate microSD card for each camera and data is recorded on a seperate card for the PCB. The only way in which these components interact is through the power source, which powers them all. Within the actual PCB, the components directly interact with each other. The main computer routes power to the individual sensors and records data from these sensors. The secondary computer also receives data from the sensors but instead analyzes this data and attempts to predict launch events (apogee, main deployment, ground contact).
- Describe how the payload integrates within the launch vehicle.
  - The payload integrates into the launch vehicle only through housing considerations. There is no way in which the payload actively influences the flight of the vehicle, causes any separation or deployment during recovery, or activates any energetic or separate vehicle systems. The housing considerations in which the payload integrates with the vehicle are quite simple. The entire payload is contained within a coupler in the way that many av-bays in high powered rockets are. This is depicted below.

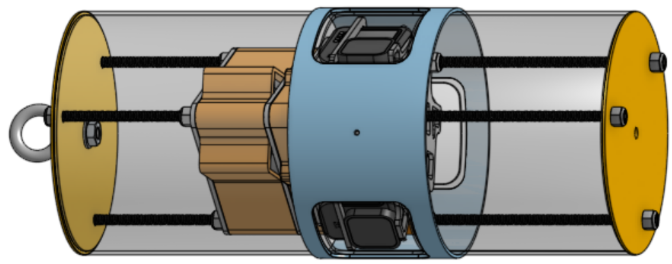


Figure 4.1.8

As shown, the payload components utilize the aluminum rods that hold the fiberglass bulk plates in place. They use these rods to stay retained in place during flight. This image also shows how part of the fiberglass is cut away to allow for acrylic windows. The hole in the switch band is slightly larger to allow a lip for the acrylic to sit on. This retention system is shown in more detail below.

- Describe the payload retention system.
    - The payload retention system uses three aluminum rods supported by bulk plates on either side of the coupler to hold all components in place. On these rods, there are 3 arrays for each of the major component categories (cameras, PCB, batteries). These arrays involve Triangular plates made of aluminum using a CNC mill and 3D printed plastic components that serve as spacers and lateral retainment. The retention is designed so that the aluminum bears most of the load during flight. These three arrays are shown below.

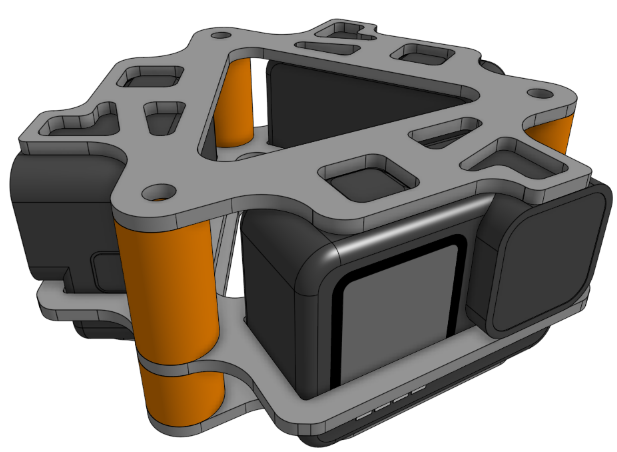


Figure 4.1.9

Figure 4.1.10

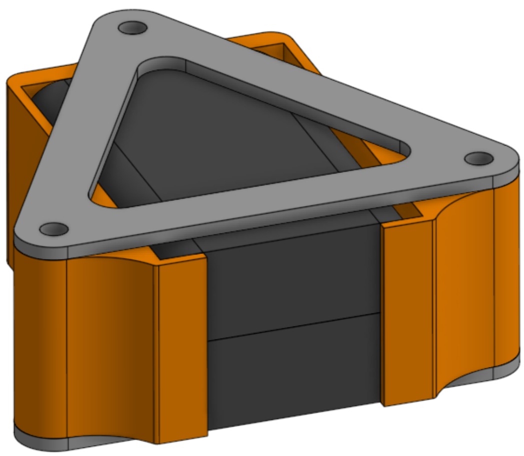


Figure 4.1.11

These arrays all slide separately onto the threaded rods and are held together as a whole in place with lock nuts. When fully assembled in the coupler it appears as below:

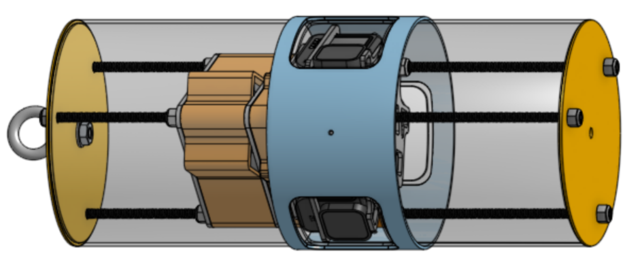


Figure 4.1.12

- Demonstrate that the design is complete.
    - As shown under the bullet points above and under the bullet point below, the team has created an Onshape CAD model of the entire assembly and the PCB has also been designed on Fusion 360 and is ready to print. The team already possesses the proper machinery and materials to manufacture the aluminum rings and plastic retainment. The sensors and computers for the PCB have been ordered and the team is in the process of obtaining cameras (currently waiting on a donation opportunity, but ready to purchase if this falls through).
- Discuss the payload electronics with special attention given to safety switches and indicators. Include the following:
    - Drawings and schematics

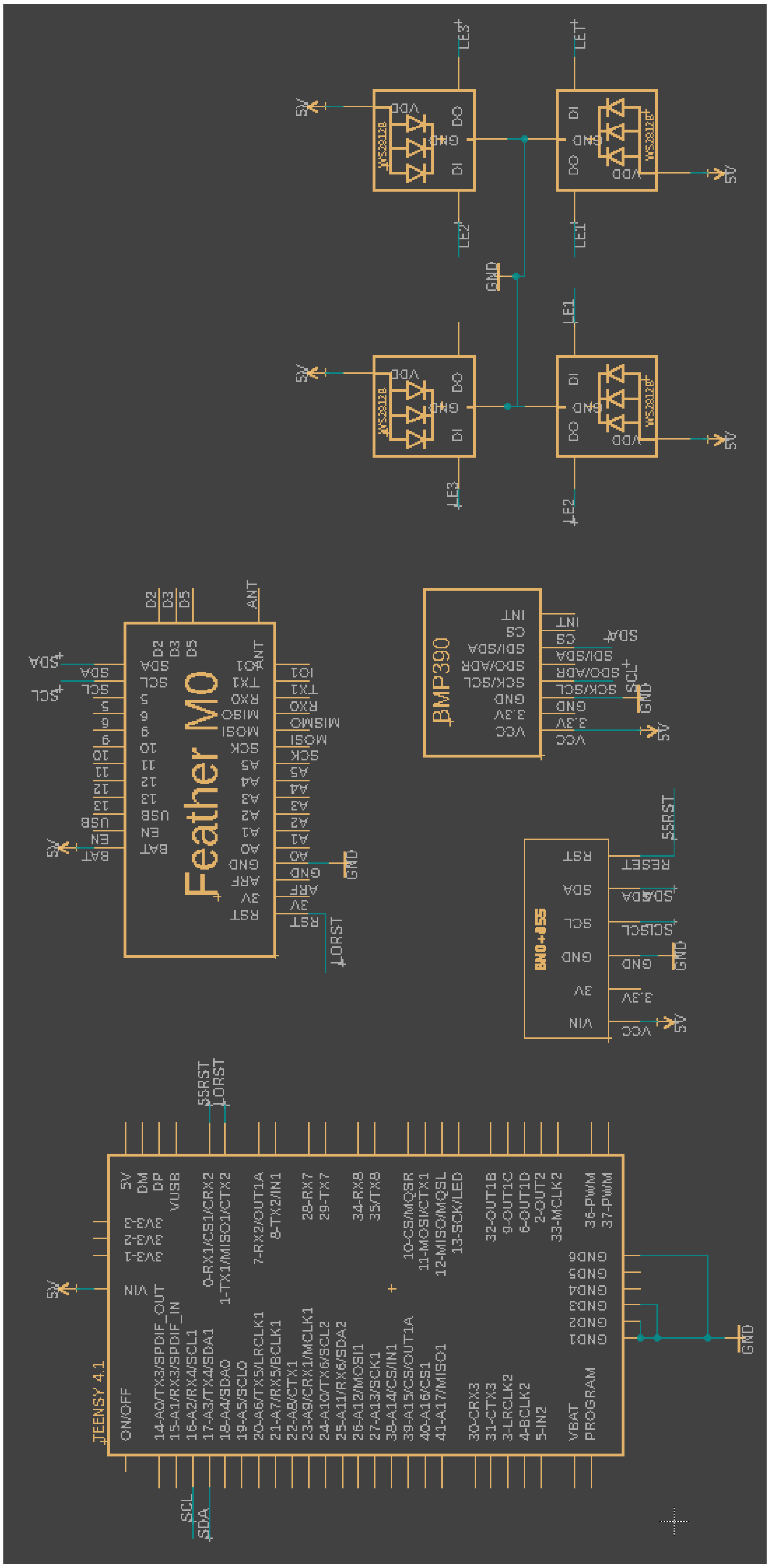


Figure 4.1.13

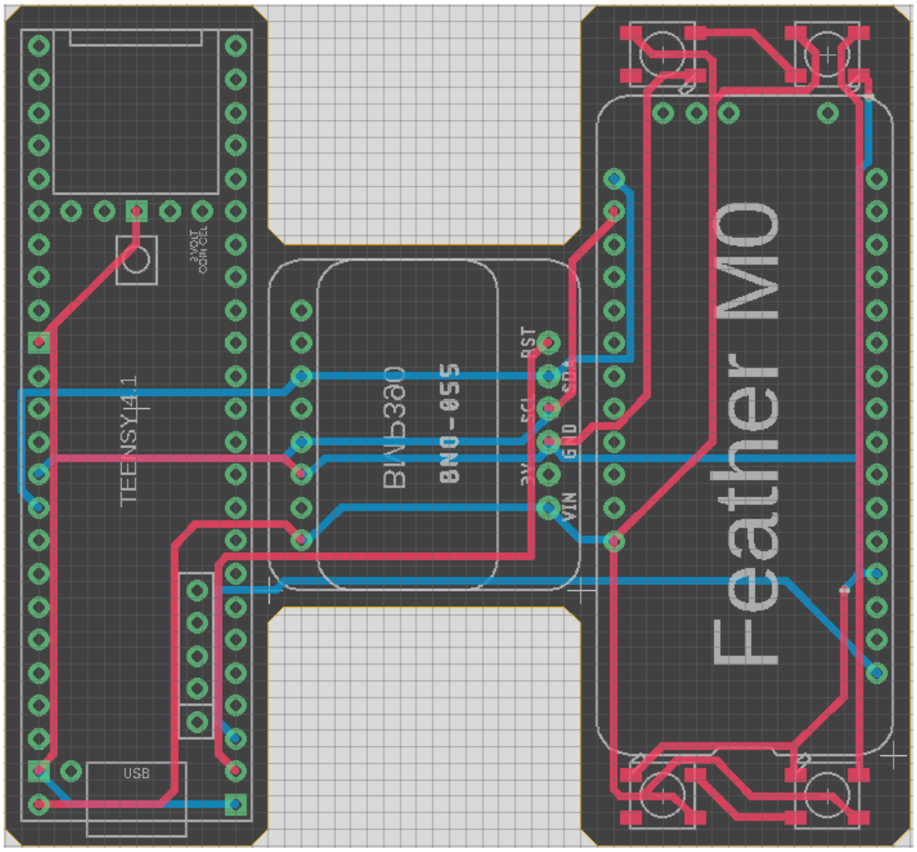


Figure 4.1.14

- ○ Block diagram

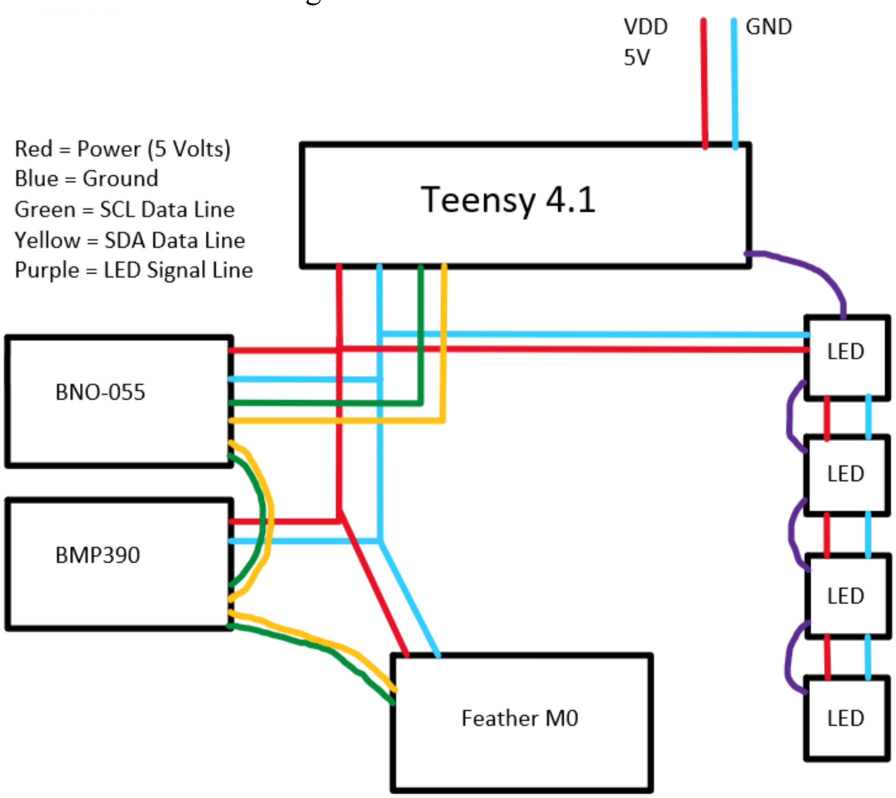


Figure 4.1.15

- Batteries/power
  - The team decided to use the same batteries that the GoPro's utilize to power all three cameras and the PCB, as there is one USB port unused. A simple sketch of the batteries and connections is shown below.

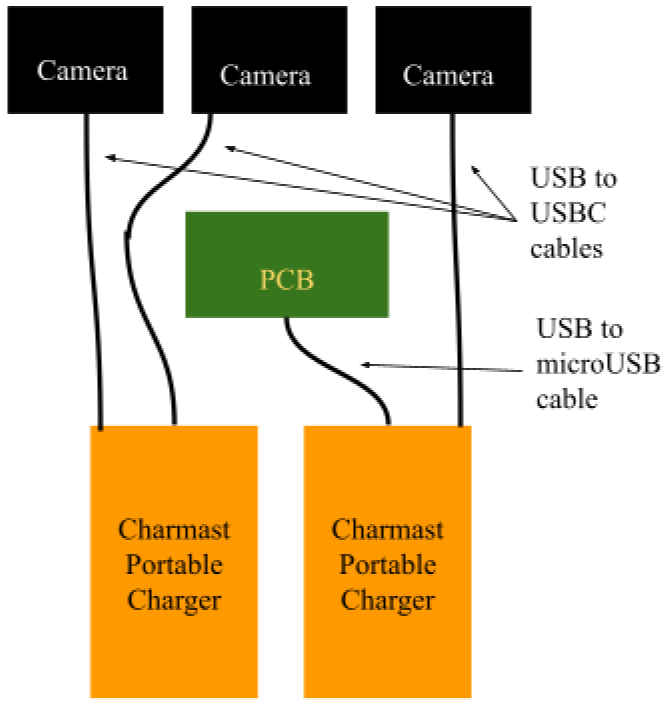


Figure 4.1.16

- Switch and indicator wattages and locations
  - The design includes plenty of power for running the system over a long amount of time. As soon as the GoPros and the PCB are plugged in during payload set up, they will be manually powered on. No switch activates the batteries, they simply provide power to whatever is plugged in. There are buttons that have to be pressed to turn on the GoPro, but the PCB will automatically start collecting as soon as it is plugged in. As power is being provided through a battery, the DC current is stable and does not need any additional capacitors or resistors to stabilize electricity flow. The Teensy 4.1 has a built in "pull-up" resistor which enables the use of I2C communication across the board, not needing an additional resistor. The code language the PCB will be running on is C++.

- Provide justification for all unique aspects of your payload (like materials, dimensions, placement, etc.)
  - The team decided to use aluminum and 3D printed parts due to the nature of the payload. Retaining relatively large action cameras requires more than typically used plywood, screws, and zipties. During the design process, the team found that using aluminum parts with certain 3D printed casings decreased the weight of the

vehicle significantly when compared to using full plywood or full 3D Printed mounts. The design also allows for the use of computer assisted manufacturing, ensuring the precision that will be needed to properly align the cameras to create a 360 video. Aluminum is also much stronger than plywood, and offers support, reinforcing 3D printed parts that would otherwise be considered weak.

- The team used 3 threaded rods opposed to the typical 1 or 2 used for payload retention because this fit best with three cameras. Aluminum has about ⅓ the strength of steel, and using 3 Aluminum threaded rods equates to about one strong steel rod in tensile strength through the payload assembly.

5. Safety

5.1 Launch Concerns and Operation Procedures

5.1.1 Recovery Preparation

- Attach parachutes to kevlar using girth hitch
    - Attachment must be secure, so that parachutes stay connected to the vehicle during descent
- Place and hook up the ejection charges in the booster and payload sections
    - Must be done by a level 1 high powered certified team member or mentor
- Attach Nomex to parachute cord
- Neatly fold the parachute over on itself so it is long and skinny, and then fold in half or thirds
- Wrap the folded parachute in the nomex
- “Z” fold the parachute cord neatly
- Place wrapped parachute and folded cord into the vehicle

5.1.2 Payload Preparation

- Assembly Outside of Fiberglass Bay
    - Attach one bulkplate with eyebolt (washer and nut for eyebolt put on) to the three threaded rods. Use 3 Ny-Lock Nuts to ensure tightness (one for each rod).
    - Put on 3 more Ny-Lock Nuts and put up from bottom 9.05 inches up to top of the nut.
    - Put the Top Camera Plate on - Ensure GoPro side cover is correct (with USB Outlet Hole) - Put long spacers on and the Harness Middle Plate following.
    - Put Smaller Spacers on and the Bottom Camera Plate.
    - Ensure PCB is plugged in (only on its side, not power), and mount has been placed in the proper direction, majority of components facing upwards, towards cameras. Slide PCB mount and PCB up into position.
    - Slide Electrical Taped Battery Plate up to the bottom of the PCB Mount.

- Slide Battery Mount up to Battery Plate and put Batteries in place.
- Slide Last Battery Plate up to bottom of the Battery Mount and put 3 Ny-Lock Nuts up to it.
- Plug in Cameras, assign dates and times to initialize startup (Dates do not matter as they will be the only recording on the GoPros)
- Insert full assembly into fiberglass tube, and align cameras, using their front screen to check for height and squareness alignment with the switch band, remove assembly and modify height of top and bottom nuts as necessary.
- Once height and orientation is correct, plug in PCB, Verify after a few seconds that all LEDs on PCB are Green. If not, refer to the color sheet for problems and errors.
- Insert into fiberglass tubing., and ensure the cameras are aligned with the windows. Put the bottom bulk plate, with its eyebolt, nut, and washer, on, and complete assembly by tightening 3 Ny-Lock Nuts on the bottom.

5.1.3 Electronics Preparation

- Once the vehicle is fully loaded and on the launch pad activate the altimeters. Do this BEFORE putting the ignitor into the motor
- Take a small screwdriver and press the button on the altimeters. It is as simple as sticking it through the hole in the body tube and pressing the button.

5.1.4 Rocket Preparation

- Before the rocket is put on the pad, wipe it down to clean the outside to ensure that no dirt or other debris is obstructing the gloss finish of the vehicle.
- Polish the acrylic windows with a microfiber cloth to ensure the view of the cameras is all clear.

5.1.5 Motor Preparation

- All of these steps must be performed by a level 1 high powered certified team member or mentor
- Inspect the exterior of the motor for any breaks in the wrapping of the motor. If the wrapping is broken, do not use the motor.
    - Flawed motors cannot be used. If there is a flaw it may seriously impact the performance of the motor, and potentially injure a spectator.
- If the delay grain of the motor needs to be altered, drill it now. To drill a delay carefully use a drill or the delay grain drilling tool for as long as you need to remove the desired amount of grain.
- Put the motor into the motor casing, making sure it is pushed to the back of the casing
- Put the motor and the casing into the motor mount tube of the rocket
- Screw the retention device over the motor and the motor mount tube

5.1.6 Set Up on the Launch Pad

- Check to make sure that the motor is properly retained. Is the cap screwed on? Turn the rocket to see if the motor stays retained. Is the motor correctly oriented inside the casing? Look for the hole the ignitor is placed in?
    - If not followed could lead to serious issues with the launch, and is a large safety hazard.
    - Must be performed by the mentor, or an L1 certified member of the team.
- If the motor is properly installed, carry the rocket to the launch pad. Be careful not to drop the rocket, as the impact could damage the body of the vehicle or the payload.
    - If dropped the rocket must go through the entire pre-flight checklist again, to ensure it sustained no damage.
- Tilt rail down to make sliding the rocket onto it easier. Be careful not to jostle the rocket while it is being put onto the rail, as the rail buttons could sustain damage or become unaligned. If there is concern due to wind, or the location of spectators, adjust the tilt of the rail to avoid any accidents.
    - If the rail buttons become unaligned the flight path of the rocket may not be straight, and this could potentially steer the rocket towards buildings or spectators.
    - If there is wind or spectators the level of the rail can be adjusted to avoid a collision with any sort of obstacle on descent.
- Make sure to exit the minimum safe distance as required by the NAR. For the subscale launch this is 200 feet.
    - Standing within this 200 foot distance could result in injury from a motor related malfunction.

5.1.7 Ignitor Installation

- Install the ignitor. Make sure to uncoil it completely, and straighten any kinks out of the wire. Insert it into the motor, making sure it reaches as deep as it can go. Retain it using the supplied plug, or a piece of masking tape. Split the end of the ignitor into the two separate strands.
    - Must be performed by a mentor or an L1 certified team member.
- Check to make sure the ignitor is properly installed. Is it retained in the motor? Pull it lightly to make sure it is retained, but do not apply much pressure, it just needs to be held in place. Are the wires properly split? Make sure the anode and cathode wires are separated.
    - Must be performed by the mentor or an L1 certified member of the team.
- Hook the clips from the launch box to the two strands of the ignitor. Do not let them touch, keep them separated. Before doing this make sure the cord from the launch box is unplugged.
    - Must be performed by a mentor or L1 certified team member.
    - The cord MUST be unplugged from the launch box during this step. It is an extra safety precaution to make sure that the motor is not ignited prematurely.

5.1.8 Launch Procedure

- Make sure the minimum spectator and participant safe distance is cleared. For any low to mid powered launch this is 100 feet. When using a K motor in the full scale launch this distance is 200 feet. Refer to the image taken from the Tripoli Association of Rocketry below.
    - The safety officer for the team must enforce this rule. In case something goes wrong with the motor or the vehicle during take off spectators must be adequately far away. Serious injury could be sustained by an exploding motor, and someone too close to the launch pad.
- Clear the established minimum safe distance of any large debris, mostly things like sticks. Double check the area directly around the pad to make sure there is nothing flammable on the ground. You can't get rid of the grass, but you can remove any other fire hazards from the immediate area.
    - This step helps to ensure that during ignition the motor does not accidentally start a fire. Skipping this step could result in a fire. In that case the on site fire extinguisher should be used to put it out as quickly as possible.
- Once the minimum safe distance is cleared, make sure the launch box is switched off, yell out a warning to the spectators, and plug the launch cord into the launch box.
    - It is important to give a verbal warning when plugging the cord into the box, in case the rocket were to launch after this step. While the odds of this are very slim, it could happen; so a warning must be given.
    - Must be performed by the mentor, or an L1 certified member of the team.
- Check for continuity by flipping the first of the two switches on the launch box. You must give a verbal countdown that all spectators can hear when performing this step. It is unlikely that flipping this switch will launch the rocket, but a countdown must be given to prepare the audience anyways. If there is continuity a red light on the launch box will light up.
    - Must be performed by the mentor, or an L1 certified member of the team.
    - If the rocket were to launch during this step the spectators must be prepared. You don't want to launch the rocket while nobody's expecting it, in case something were to malfunction and the rocket become dangerous to spectators. You need them to be paying attention to what is going on on the launch pad.
- If there is no continuity, check to make sure that the launch cord is fully plugged into the box. If it is, unplug it, wait one minute since you flipped the switch, and go inspect the launch pad. Check to make sure that the ignitor is installed correctly, and that it is wired to the launch box cord correctly. After checking to make sure the ignitor is set up correctly, go back and repeat the check for continuity.
    - Must be performed by the mentor, or an L1 certified member of the team.
- If the second check for continuity does not work, replace the ignitor, and try again.

- If the check for continuity succeeds, the rocket is ready to launch. Perform a count down, and flick the second switch on the launch box. This should launch the rocket if the continuity test worked.
    - If the rocket does not launch, wait one minute after flicking the switch, then go inspect the rocket on the pad. Make sure the ignitor didn't come undone, and is far enough in the motor it will ignite.
    - Must be performed by the mentor, or an L1 certified member of the team.

5.1.9 Troubleshooting

- If the motor fails to ignite
    - Check to see if the launch box says there is continuity
    - Check to make sure the ignitor is properly installed
    - Check if the launch box is wired to the ignitor
    - If the motor is still not igniting switch to a different motor
- If the altimeters are not turning on
    - Remove the rocket from the pad and remove the altimeters. See if the altimeters are properly connected to the battery source
- Altimeters are not saying the main and drogue ejection charges are connected
    - Remove the rocket from the pad and check the connections between the altimeters and the ejection charges
    - Do not fly if there is not a connection between either ejection charges and the altimeters. These are vital to the success of the launch, and must be operating to fly.

5.1.10 Post-flight Inspection

- Do not begin to search for rocket until it has landed, and has been stationary for at least 60 seconds
- If the rocket appears to be landing close to you do not attempt to catch the rocket on descent, instead move out of its path
    - While it is improbable the rocket landing on someone would injure them, spectators still must try to avoid the rocket landing on them
- Upon recovery of the rocket look for any damage to the exterior. This includes: damage to the fins, damage to the body tube, damage to the nose cone, and damage to the parachutes
- Upon return to the launch site inspect the interior of the rocket for damage. Check the centering rings, electronics, and payload.
- Record flight data from the altimeters and electronics

5.2 Safety and Environment (Vehicle and Payload)

5.2.1 Personnel Hazard Analysis

Hazard	Cause	Effect	Controls and Mitigations	Likelihood and Severity	Verification
Injury when sawing PVC pipe for stomp rocket activity	A lack of knowledge of tool operation, or insufficient use of PPE.	This could result in a serious injury of one of the team members.	Ensuring Personal Protection Equipment (PPE) is worn while any tools are used will appropriately mitigate risk.	L:1 S:5	Visual inspection of personnel who are working with tools by safety officer. If they are not wearing the proper aye and hand protection they will be required to stop and go put on their PPE.
Children being hit by a stomp rocket during activity	Caused by children being children and the team members not instructing them on safety.	This could result in one of the children being injured.	Soft foam rockets are being used, so being hit will not cause any serious injury. Instructing children not to launch rockets at or towards anyone will also help mitigate.	L:3 S:2	Students were told not to shoot the rockets at other people, and were required to stand behind the launcher.
Children injuring themselves with scissors	Caused by a lack of the skills needed to operate scissors.	Could result in a child injuring themselves.	The children we are working with will be around sixth grade. Sixth graders should know how to handle scissors well, and how not to hurt themselves. One of the reasons we chose to work with slightly older kids is because they should be better able to work with scissors and to be mature with the stomp rocket activity.	L:2 S:4	Very minimal scissor work was done. Team members supervised the students with all cutting work. Safety scissors were used to reduce the risk of injury.
Lack of public outreach	Caused by the team not reaching out to the community enough.	Could result in not enough fundraising.	We have a large social media presence, and have reached out to some local organizations to establish a partnership. We have tried to spread the word about our rocket club as far and wide	L:2 S:3	N/A

			as we can.		
Failing to meet fundraising goals	Caused by not going out and fundraising or being unsuccessful in our attempts.	This would cause the entire project to fail, because we would not have enough money.	We have tried to keep our budget as small as possible, to decrease the amount of money we need to fundraise. Then, our fundraising team has been working non-stop to raise the money we need. We have been talking to a wide variety of local and state businesses.	L:2 S:5	N/A
Company failing to deliver on promised funds	Caused by the company going back on its promise to donate.	This would affect the amount of money we would fundraise.	This is not a risk we can control very well, but it is one we can mitigate. We have reached out to a large number of businesses, instead of just a couple, so that if any of them fall through it's not a large percentage of our funds gone.	L:2 S:4	N/A
Unforseen costs due to poor planning	This would be caused by failing to properly analyze the risks of the project when budgeting.	This could cause us to be short on money, and potential lead to the project not being finished.	We have built a budget that should cover everything we need, but have also considered unforeseen costs due to unforeseen events and have budgeted extra to cover these potential costs.	L:2 S:4	Budget in section 6.1
Team being unable to meet	We are all busy people with other things going on outside of rocket club.	The team is unable to complete the milestones on time or as well as we could.	We have scheduled team meetings twice a week to increase the amount of time spent on the project, and to give people choices on when to come to meetings. We also meet outside of school and encourage anyone who can to come.	L:3 S:2	Calendar in section 6.1
Late submission	The team procrastinatin	Possible disciplinary	We have set deadlines for	L:2 S:3	Calendar in section 6.1

of milestone documents	g working on the documents or issues with deciding what goes into the project.	action from NASA.	ourselves days before the documents are due, so we can complete them and have time to review them.		
Late arrival of components of the vehicle or of the payload	The supply chain backup is a serious problem in the country as a whole right now. Due to these backups we may be unable to get things we need for the project, or they may take a long time to arrive.	Difficulty meeting deadlines, inability to complete the project as we have planned	We have already begun to order things we don't need for months, to make sure we have them when we need them. We have also looked into different alternatives to the things we need, in case we are unable to procure them.	L:3 S:3	N/A
Inhalation of dust while sanding	Sanding the body tube or fins of the vehicle without wearing a protective mask.	Irritation of the nose, throat, mouth, and lungs that could result in a team member being ill.	Requiring team members to wear protective masks when doing any sandig. Requiring all sending to be done in the school's wood shop, which is equipped with equipment to ventilate the area.	L:2 S:2	N/A
Dust in eyes when sanding	Sanding the body tube or fins of the vehicle without proper eye protection.	Irritation of the eyes that could result in injury to a team member.	Requiring team members to wear eye protection when sanding, and to perform all sanding in the school's woodshop.	L:2 S:2	N/A
Bodily injury when using sanding tools	Improperly using sandpaper or an electric sanding tool.	Injury to the skin of hands or to the rest of a team member's body, that could result in a need for medical attention.	Requiring team members to wear protective gloves when sanding, and having an adult supervisor present when handling any electrical tools.	L:1 S:3	N/A
Exposure to epoxy fumes during	Use of epoxy in an enclosed space.	This could cause irritation of the	Epoxying must be done in a large, open, well ventilated space.	L:1 S:2	N/A

rocket construction		respiratory system, leading to team members being unable to continue construction.			
Breathing in solder fumes or particulates	Soldering in an enclosed space.	This could cause irritation of the respiratory system, leading to team members being unable to continue construction.	Soldering must be done in a large, open, well ventilated space.	L:1 S:2	N/A
Injury during subscale launch related to the motor	This could be caused by a number of things: improper installation of the motor, a faulty motor from the manufacturer, touching the hot motor casing after recovery, inhalation of fumes from the motor, burn from standing too close to the launch pad.	Various injuries. Chiefly, burns or the irritation of the respiratory system.	Only the team supervisor will handle the motors, unless the team member is level one high powered certified and knows how to handle the motors. Motor installation will only be performed by the team supervisor. Only commercially manufactured motors from reliable companies will be used, NAR guidelines on safe distance from the launch pad will be followed, and NAR guidelines on the safe recovery of the vehicle will be followed.	L:1 S:2-4	N/A
Injury during subscale launch related to improper assembly	This could be caused by a number of things: improper installation of the motor mount tube, fins, parachutes, or druuge chutes; forgetting to rivet nose cone on; not	Failure to complete a successful flight, and possibly injury of a team member.	We have a lot of experienced rocket builders on our team, so mitigating this risk comes down to listening to experienced members and just taking the time to do everything right.	L:1 S:2-4	Inspection of construction. Looking to make sure that the components are assembled correctly. Double checking measurements to make sure centering rings are in the right spot, dry fitting

	tying parachutes in properly.				pieces before epoxying them together. Analysis of the epoxy used revealed it was more than capable of withstanding the rigors of the subscale. Demonstration during construction to ensure components were properly installed. Wiggle the fin to make sure it has been set properly, or a tug on an eye-bolt to make sure it is secure. There are not the most official tests, but they do prove that the construction is sound.

5.2.2 Failure Modes and Effects Analysis

Hazard	Cause	Effect	Controls and Mitigations	Likelihood and Severity	Verification
Body tubes do not separate	Failure of ejection charges	Parachutes do not deploy, so the vehicle descends too quickly.	A secondary and a tertiary ejection charge will be used to have two redundancies in place to ensure separation.	L:1 S:5	N/A
Camera systems run out of battery	Cameras will be connected to a power source located within the rocket. If	The cameras run out of battery, and do not record the flight. Or they run out of	Testing will be done to make sure that the battery is large enough to support the cameras through the entire flight and while	L:1 S:4	The GoPro cameras were set to film then timed to see how long they would record

	this power source dies, then the cameras could die.	battery and do not record a portion of the flight.	sitting on the pad.		for, and to see what would happen to the recording when they died. It was found they would not have enough battery life to meet the requirements set for how long they may sit on the pad. Another test will be done with them hooked up to an external battery pack, and with the battery pack they have more than enough battery life.
SD card on flight data recorder is not plugged in	The SD card came unplugged while handling the flight data recorder.	The data we plan to collect on the flight path of the rocket would not be collected.	Preflight check to insure the SD card is plugged in.	L:1 S:2	Verified through inspection during pre-flight check.
Window fogs up, and cameras can not see outside of the rocket	Changes in pressure during flight, differences in internal and external temperature and humidity.	The cameras would not get a clear shot of the flight.	Vent holes in the rocket that are already in place should equalize the temperature between the inside and the outside.	L:2 S:2	N/A
Motor fails to ignite	Problems with the motor, problems with the igniter, problems with the launch box.	The vehicle does not launch.	Using commercially produced motors from a trusted manufacturer to reduce the chance of having a faulty motor. Performing a check on the launch pad to make sure the ignitor is properly connected to the motor, and that all wiring is connected. Using a	L:1 S:2	N/A

			safe launch box, that has been tested and proven to work.		
Motor explodes on the launch pad	Faulty motor	Possible damage to the booster section of the vehicle.	Only using commercially produced motors, and not tampering with the motor before launch.	L:1 S:5	Inspection of motors during pre-flight check.
Fins break when rocket touches down	Flaw in construction, or in the material the fin is made of.	Launch is not considered successful, fin needs to be replaced, money needs to be spent to replace/ fix the fin.	Parachutes should reduce the kinetic energy upon landing to a safe amount.	L:1 S:4	Inspection of parachutes during pre-flight check.
Parachutes do not deploy	Ejection charges do not force the body tubes to separate, backup charges do not work.	Parachute does not open, and the vehicle crashes, possibly damaging the vehicle and payload systems.	Multiple ejection charges will mitigate the risk of the parachutes not deploying.	L:1 S:4	Analysis to determine the amount of ejection charge needed. Inspection of the ejection charges during pre-flight check.
Parachute gets tangled	Improper tying the parachute into the rocket, or improper folding of the parachute and cute cord.	Parachutes do not deploy, and the booster section of the rocket hits the ground with too much force, potentially damaging the vehicle itself or the payload.	Preflight check to ensure the parachute cord was folded in the proper “Z” pattern.	L:1 S:4	Inspection during pre-flight check.
Inclimate weather on launch day	Misfortune	Delay or cancellation of the launch, setting the team back in terms of time and money.	Looking at the weather when planning dates to launch. Following all NAR regulations on launching in inclimate weather.	L:2 S:3	N/A

5.2.3 Environmental Hazard Analysis

Hazard	Cause	Effect	Controls and Mitigations	Likelihood and Severity	Verification
Inclimate weather damages rocket	Launching the rocket in weather it should not be launched in.	Damage to the rocket, or the loss of the entire rocket.	Following all weather related NAR launch rules and regulations. Preflight weather check to determine if the weather is safe to launch in.	L:1 S:2-5	N/A
Uneven landing ground	Launching in a location with uneven ground.	Leg system does not work, and the vehicle does not land upright.	Building in some play in the leg system to allow for contortion to the shape/ level of the ground. Not launching in an area where the ground would affect the landing of the vehicle.	L:2 S:2	N/A
Motor of the rocket contaminates the ground under the launch site.	Launching without a pad underneath the vehicle.	Damage to the earth around the launch site, possible contamination of the launch site with the chemicals found in the motor.	Preflight check to make sure the vehicle is positioned above the launchpad, and that the motor is pointed into the pad.	L:1 S:1	N/A

6. Project Plan

6.1 Testing

- Identify all tests required to prove the integrity of the design.
- For each test, present the test objective and success criteria, as well as testing variables and methodology.
- Justify why each test is necessary to validate the design of the launch vehicle and payload.
- Discuss how the results of a test can cause any necessary changes to the launch vehicle and payload.

Test	Ground Ejection Demonstration
Objective	The objective of this demonstration is to verify the recovery system can properly separate the vehicle and deploy parachutes. In this demonstration, a dead weight will be used for the payload and the vehicle will be fully assembled with igniters running through the electronic bay vent holes to the ejection charges. The vehicle will be propped up at a 35 degree angle. First, the drogue ejection will be tested. Next, the upper section that just seperated from the booster will then return to the angled mount and main parachute ejection will be tested alone.
Success Criteria	For demonstration success, the primary charge of each section must shear all 3 shear pins and separate the vehicle components with enough distance that the parachute and harness can unravel. The parachute must remain undamaged and the harness intact. During the first (drogue) seperation, the rest of the vehicle components must be held together by the shear pins.
Necessity	This test is necessary to make sure that the number of shear pins, size of ejection charges, and packaging method of the parachutes will allow for effective recovery deployment.
Impact of Failure	If separation fails, more balck powder will be needed for the ejection charges. If the components separate prematurely, more shear pins will be needed. If the parachutes are damaged or do not unravel on deployment, the packaging method will need to be reexamined. If the harness detaches or breaks, stronger (or thicker) material will need to be selected for the herness or interface with the vehicle.

Test	Payload Battery Test
Objective	Determine the length of time the payload cameras will record for with the addition of an external battery. The camera will be plugged into the battery pack, and set to run until they run out of battery. That time will be recorded.
Success Criteria	Battery allows for payload operation in excess of 150 minutes.
Necessity	This test must be performed because we need to know that the cameras will record for at least two and a half hours. They must record for this long because the fully loaded vehicle may need to sit on the pad for upwards of two hours.
Impact of Failure	We would need to increase the size of the battery pack to allow for more recording time for the cameras.

Test	Window Alignment Demonstration

Objective	The objective is to ensure the GoPros can record without interference from the rocket. This will involve using an extra coupler length to cut out the planned window size. The camera arrangement will then be inserted inside this test-manufactured component to make sure the window size and placement does not impact the view of the cameras.
Success Criteria	GoPros record at their maximum field of view without any obstruction.
Necessity	This test is necessary because a large success criteria of our payload design requires us to record a fluid 360 video with our cameras. Obstruction from the vehicle would prevent payload success.
Impact of Failure	Based on the results, we would need to change the size of the windows and acrylic cut outs and/or change the side of our payload camera mount

Test	Tensile test for steel and aluminum rods that hold coupler bulkheads in place.
Objective	The objective of this test is to ensure that the metal components of the electronics bay will hold the bulk plates together. The rod will be placed in our universal testing machine and stretched. It will continue to stretch until the component breaks or the machine maxes out at 1000 pounds.
Success Criteria	The threaded rod of the electronics bay withstands the 1000 lb force
Necessity	It’s necessary that we test this because the recovery of our rocket depends on the strength of the electronics bay and payload section to hold the shock of the parachutes
Impact of Failure	If our threaded rods failed the tensile strength test, we would be required to select a stronger material or a thicker rod to withstand the tensile forces.

6.2 Requirements Compliance

- Create a verification plan for every requirement from sections 1-5 of the project requirements listed in this handbook. Identify if tests, analysis, demonstration, or inspection are required to verify the requirement. After identification, describe the associated plan needed for verification.

General Requirements

- 1.1. Students on the team will do 100% of the project, including design, construction, written reports, presentations, and flight preparation with the exception of assembling the motors and handling black powder or any variant of ejection charges, or preparing and installing electric matches (to be done by the team's mentor). Teams will submit new work. Excessive use of past work will merit penalties.

Method	Inspection
Outcome	The team has created a new design and has only referenced previous work for data purposes (see section 3.4, under simulation and estimated Cd). No other people or groups have designed any part of the vehicle. Installation of igniter and ejection charges was done by the team mentor in accordance with section 5.1.1 and 5.1.7 of the CDR.
Status	Ongoing

- 1.2. The team will provide and maintain a project plan to include, but not limited to the following items: project milestones, budget and community support, checklists, personnel assignments, STEM engagement events, and risks and mitigations.

Method	Inspection
Outcome	The team has a project plan in the Proposal, PDR, and CDR (section 6). A project plan will also be included and updated in the FRR.
Status	Ongoing

- 1.3. Foreign National (FN) team members must be identified by the Preliminary Design Review (PDR) and may or may not have access to certain activities during Launch Week due to security restrictions. In addition, FN's may be separated from their team during certain activities on site at Marshall Space Flight Center.

Method	Inspection
Outcome	The team has no FN members and therefore none were identified in the PDR.
Status	Complete

- 1.4. The team must identify all team members who plan to attend Launch Week activities by the Critical Design Review (CDR). Team members will include:
    - 1.4.1 Students actively engaged in the project throughout the entire year.
    - 1.4.2 One mentor (see requirement 1.13).
    - 1.4.3 No more than two adult educators.

Method	Inspection
Outcome	The team members who will be attending launch week have all submitted forms in NASA Gateway. One member who is under 16 will also be attending and his media release is being submitted along with the CDR package. The

	members on Gateway also include the team mentor and two adult advisors.
Status	Completed upon submission of CDR package

- 1.5. The team will engage a minimum of 250 participants in direct educational, hands-on science, technology, engineering, and mathematics (STEM) activities. These activities can be conducted in-person or virtually. To satisfy this requirement, all events must occur between project acceptance and the FRR due date.

Method	Inspection
Outcome	As of now, the team has engaged over 40 individuals in direct educational hands-on STEM activities. A partnership with elementary schools is being set up to reach the target number by FRR due date.
Status	Ongoing

- 1.6. The team will establish and maintain a social media presence to inform the public about team activities.

Method	Inspection
Outcome	The team has an active twitter and instagram account that can be viewed at the handles @CFHSRocketClub (twitter) and @cfhsrocketclub (Instagram). The pages will stay updated throughout the course of the project.
Status	Ongoing

- 1.7. Teams will email all deliverables to the NASA project management team by the deadline specified in the handbook for each milestone. In the event that a deliverable is too large to attach to an email, inclusion of a link to download the file will be sufficient. Late submissions of milestone documents will be accepted up to 72 hours after the submission deadline. Late submissions will incur an overall penalty. No milestone documents will be accepted beyond the 72-hour window. Teams that fail to submit milestone documents will be eliminated from the project.

Method	Inspection
Outcome	As of 1/3/2022, all deliverables have been submitted by the deadline and any revisions have been submitted in the 72 hour period.
Status	Ongoing

- 1.8. All deliverables must be in PDF format.

Method	Inspection
Plan	As of 1/3/2022 all submittables have been submitted in PDF format and they will continue to be that way.
Status	Ongoing

- 1.9. In every report, teams will provide a table of contents including major sections and their respective sub-sections.

Method	Inspection
Outcome	Every report has included a table of contents (reference the beginning of this CDR). All reports will continue to have one.
Status	Ongoing

- 1.10. In every report, the team will include the page number at the bottom of the page.

Method	Inspection
Outcome	Every report has included page numbers (reference this report). All reports will continue to have them.
Status	Ongoing

- 1.11. The team will provide any computer equipment necessary to perform a video teleconference with the review panel. This includes, but is not limited to, a computer system, video camera, speaker telephone, and a sufficient Internet connection. Cellular phones should be used for speakerphone capability only as a last resort.

Method	Inspection
Outcome	For all video teleconferences so far, the team has had sufficient technology for the virtual meeting. During the PDR addendum presentation, an unknown technical error prevented video connection. For future meetings, the team will use the actual app opposed to the browser software to prevent this issue.
Status	Ongoing

- 1.12. All teams attending Launch Week will be required to use the launch pads provided by Student Launch's launch services provider. No custom pads will be permitted at the NASA Launch Complex. At launch, 8-foot 1010 rails and 12-foot 1515 rails will be provided. The launch rails will be canted 5 to 10 degrees away from the crowd on Launch Day. The exact cant will depend on Launch Day wind conditions.

Method	Inspection
Outcome	The team plans to use the provided 12 foot 15:15 rail. See section 1.2 of CDR.
Status	Complete

- 1.13. Each team must identify a "mentor." A mentor is defined as an adult who is included as a team member, who will be supporting the team (or multiple teams) throughout the project year, and may or may not be affiliated with the school, institution, or organization. The mentor must maintain a current certification, and be in good standing, through the National Association of Rocketry (NAR) or Tripoli Rocketry Association (TRA) for the motor impulse of the launch vehicle and must have flown and successfully recovered (using electronic, staged recovery) a minimum of 2 flights in this or a higher impulse class, prior to PDR. The mentor is designated as the individual owner of the rocket for liability purposes and must travel with the team to Launch Week. One travel stipend will be provided per mentor regardless of the number of teams he or she supports. The stipend will only be provided if the team passes FRR and the team and mentor attend Launch Week in April.

Method	Inspection
Outcome	The team has identified Tyler Sorensen as the team mentor (see section 1.1 of CDR, which details his certifications)
Status	Complete

- 1.14. Teams will track and report the number of hours spent working on each milestone.

Method	Inspection
Outcome	Through CDR the team has tracked and included the number of hours spent working on milestones. The team will continue to do this. See section 1.1 for reference.
Status	Ongoing

2. Vehicle Requirements

- 2.1. The vehicle will deliver the payload to an apogee altitude between 3,500 and 5,500 feet above ground level (AGL). Teams flying below 3,000 feet or above 6,000 feet on their competition launch will receive zero altitude points towards their overall project score and will not be eligible for the Altitude Award.

Method	Analysis

Outcome	The team currently has a predicted altitude 3302 ft. AGL. While this does not reach the ideal altitude range, it still meets the slightly larger range. Due to the size of the vehicle and payload, reaching an altitude much higher is unlikely. However, the team's estimate of 3302 ft. is a conservative estimate and it could end up being higher.
Status	Ongoing (pending actual flight and data collection)

- 2.2. Teams shall identify their target altitude goal at the PDR milestone. The declared target altitude will be used to determine the team's altitude score.

Method	Inspection
Outcome	The team declared 3,750 ft. AGL as the target altitude at the PDR. This is stated in vehicle summary, section 1.2 of CDR.
Status	Complete

- 2.3. The vehicle will carry, at a minimum, two commercially available barometric altimeters that are specifically designed for initiation of rocketry recovery events (see Requirement 3.4). An altimeter will be marked as the official scoring altitude used in determining the Altitude Award winner. The Altitude Award winner will be given to the team with the smallest difference between the measured apogee and their official target altitude for their competition launch.

Method	Inspection
Outcome	The final design includes 2 strattologgerCF altimeters that have the capability to record max altitude. See section 3.3 of CDR.
Status	Design complete, components acquired, construction ongoing.

- 2.4. The launch vehicle will be designed to be recoverable and reusable. Reusable is defined as being able to launch again on the same day without repairs or modifications.

Method	Demonstration, Analysis, and Inspection
Outcome	The subscale vehicle was launched and found to be reusable. As the subscale is very close to what the actual vehicle is, if the subscale was found to be reusable the full scale will be as well. The full scale vehicle also utilizes a reloadable motor retainment and recovery system that brings the vehicle back to the ground and makes ground impact with less than 75 foot pounds of kinetic energy, greatly limiting the amount of damage the vehicle will take. These details can be found in section 3.

Status	Design completed, construction ongoing

- 2.5. The launch vehicle will have a maximum of four (4) independent sections. An independent section is defined as a section that is either tethered to the main vehicle or is recovered separately from the main vehicle using its own parachute.

Method	Inspection
Outcome	The vehicle will only have three independent sections. Sections 1.2 and 3.1 of the CDR showcase the design of the vehicle and section 3.3 explains how these separations are used for the recovery system and how they stay tethered together during descent.
Status	Design complete, construction ongoing

  - 2.5.1. Coupler/airframe shoulders which are located at in-flight separation points will be at least 1 body diameter in length.

Method	Inspection
Outcome	Section 3.1 shows the design of the couplers. Each coupler extends at least six inches into the body tube, which is the diameter of the body tube. The coupler that includes the switch band is an extra two inches in length to still allow for six inches of coupler within each body tube.
Status	Design complete, construction ongoing

  - 2.5.2. Nosecone shoulders which are located at in-flight separation points will be at least ½ body diameter in length.

The design in 3.1 shows that the nose cone shoulder is not an inflight separation point. Regardless of this, the coupler is still greater than 3 inches in length, even though in flight separation will not occur.

- 2.6. The launch vehicle will be capable of being prepared for flight at the launch site within 2 hours of the time the Federal Aviation Administration flight waiver opens.

Method	Demonstration
Plan	Based on the vehicle and payload design in sections 3 and 4, the team will be able to fully assemble the vehicle and have it ready to launch in less than two hours. This will be demonstrated at the vehicle/payload demonstration flight.
Status	Scheduled for 2-12 (backup 2-19)

- 2.7. The launch vehicle and payload will be capable of remaining in launch-ready configuration on the pad for a minimum of 2 hours without losing the functionality of any critical on-board components, although the capability to withstand longer delays is highly encouraged.

Method	Testing, analysis
Outcome	A test was done to determine the battery life of the camera without an additional battery. These results were analyzed and it was determined that the batteries of the camera's would not be enough, section 4.1. From those results it was found that the Charmast batteries would support the cameras for over two hours. A test will be conducted to prove that the Charmast batteries and camera batteries will last beyond two hours, section 6.1. The gps's have a battery life of over three hours. We know this because the manufacturer of the gps's says the battery life will last over three hours. The altimeters will last much longer than two hours. We know this because we have used them in the past and found that they have a very long battery life.
Status	In progress - test scheduled for 1/31

- 2.8. The launch vehicle will be capable of being launched by a standard 12-volt direct current firing system. The firing system will be provided by the NASA-designated launch services provider.

Method	Inspection and Analysis
Outcome	As shown in section 1.2 and section 3, the team selected a K-1440 motor. This motor can be ignited using a firewire initiator. The team used firwires for the subscale launch as explained in section 3.2 and 3.3. These firewires were activated with a 9V DC battery, therefore, the 12V DC system will also work.
Status	Design Complet, Construction Underway

- 2.9. The launch vehicle will require no external circuitry or special ground support equipment to initiate launch (other than what is provided by the launch services provider).

Method	Inspection
Outcome	As shown in sections 3 and 4, the vehicle uses all internal batteries to power payload and recovery systems. The only support needed at launch is through the 12V DC firing system already provided.
Status	Complete

- 2.10. The launch vehicle will use a commercially available solid motor propulsion system using ammonium perchlorate composite propellant (APCP) which is approved and certified by the National Association of Rocketry (NAR), Tripoli Rocketry Association (TRA), and/or the Canadian Association of Rocketry (CAR).

Method	Inspection
Outcome	The team selected a Cesaroni K-1440 motor according to 1.2. This is commercially available (has already been purchased) and is approved by NAR/CAR/TRA.
Status	Complete

  - 2.10.1. Final motor choices will be declared by the Critical Design Review (CDR) milestone.

Method	Inspection
Outcome	The team will be using a Cesaroni K-1440 motor, section 1.2.
Status	Completed

  - 2.10.2. Any motor change after CDR must be approved by the NASA Range Safety Officer (RSO). Changes for the sole purpose of altitude adjustment will not be approved. A penalty against the team's overall score will be incurred when a motor change is made after the CDR milestone, regardless of the reason.

Method	Inspection
Outcome	The motor will not change after the CDR. The Cesaroni K-1440 has been selected and will not change.
Status	Completed

- 2.11. The launch vehicle will be limited to a single stage.

Method	Inspection
Outcome	The vehicle has been designed to be single stage. Sections 3.1 and 3.4 show the completed design of the vehicle and the motor selection.
Status	Completed

- 2.12. The total impulse provided by a High School or Middle School launch vehicle will not exceed 2,560 Newton-seconds (K-class).

Method	Inspection
Outcome	The team selected the K-1440 which has a max impulse of 2437 newton seconds according to the NAR. This is less than the maximum 2560.
Status	Complete

- 2.13. Pressure vessels on the vehicle will be approved by the RSO and will meet the following criteria:
  - 2.13.1. The minimum factor of safety (Burst or Ultimate pressure versus Max Expected Operating Pressure) will be 4:1 with supporting design documentation included in all milestone reviews.
  - 2.13.2. Each pressure vessel will include a pressure relief valve that sees the full pressure of the tank and is capable of withstanding the maximum pressure and flow rate of the tank.
  - 2.13.3. The full pedigree of the tank will be described, including the application for which the tank was designed and the history of the tank. This will include the number of pressure cycles put on the tank, the dates of pressurization/depressurization, and the name of the person or entity administering each pressure event.

The vehicle has no pressure vessels on board as shown in section 3.

- 2.14. The launch vehicle will have a minimum static stability margin of 2.0 at the point of rail exit. Rail exit is defined at the point where the forward rail button loses contact with the rail.

Method	Analysis
Outcome	As shown in section 3.4, the vehicle has a stability margin of 2.15 at rail exit. The initial stability margin on the pad is 2.08. Since as the motor burns, the CG moves forward and the stability margin increases, the vehicle is guaranteed to have a stability margin greater than 2.0 at rail exit.
Status	Design complete, construction underway

- 2.15. The launch vehicle will have a minimum thrust to weight ratio of 5.0 : 1.0.

Method	Analysis
Outcome	The average thrust of the K-1440 motor is 323 pounds. The weight of the vehicle on the pad is 31.7 pounds. This gives a thrust to weight ratio of 10.19:1. Using the max thrust, the ratio is 11.83:1.

Status	Design complete, construction ongoing

- 2.16. Any structural protuberance on the rocket will be located aft of the burnout center of gravity. Camera housings will be exempted, provided the team can show that the housing(s) causes minimal aerodynamic effect on the rocket's stability.

Method	Inspection
Outcome	The only structural protuberances are the vehicle's fins which are located afte of the burnout center of gravity. As the motor burns, the center of gravity moves forward because the propellant mass decreases. Because the CG is already far in front of the fins as shown in section 3.4, it will remain in front of the fins after the motor burns out.
Status	Design complete, construction ongoing

- 2.17. The launch vehicle will accelerate to a minimum velocity of 52 fps at rail exit.

Method	Analysis
Outcome	RockSim predicts the vehicle will exit the guide rail at a velocity of 94.64 fps. This can be seen (in mph) under the simulations in section 3.4.
Status	Design complete, construction ongoing

- 2.18. All teams will successfully launch and recover a subscale model of their rocket prior to CDR. The subscale flight may be conducted at any time between proposal award and the CDR submission deadline. Subscale flight data will be reported at the CDR milestone. Subscales are required to use a minimum motor impulse class of E (Mid Power motor).

Method	Inspection
Outcome	Flights have been completed and results have been included in the CDR under section 3.2. The vehicle flew on a G80 motor.
Status	Complete

  - 2.18.1. The subscale model should resemble and perform as similarly as possible to the full-scale model; however, the full-scale will not be used as the subscale model.

Method	Inspection
Outcome	As explained in section 3.2, the vehicle is directly scaled to represent the full

	scale vehicle. It also used the same recovery system.
Status	Complete

- 2.18.2. The subscale model will carry an altimeter capable of recording the model's apogee altitude.

Method	Inspection
Outcome	The subscale carried such an altimeter. Results are included in section 3.2.
Status	Complete

- 2.18.3. The subscale rocket shall be a newly constructed rocket, designed and built specifically for this year's project.

Method	Inspection
Outcome	Section 3.1 shows the design of the vehicle, which was done from scratch this year. In section 3.1, a link to a youtube video of part of the construction process is also included, demonstrating how the vehicle is newly constructed.
Status	Complete

- 2.18.4. Proof of a successful flight shall be supplied in the CDR report. Altimeter flight profile graph(s) OR a quality video showing successful launch and recovery events as deemed by the NASA management panel are acceptable methods of proof.

Method	Inspection
Outcome	Both a video and altimeter graphs are included in section 3.2.
Status	Complete

- 2.18.5. The subscale rocket shall not exceed 75% of the dimensions (length and diameter) of your designed full-scale rocket. For example, if your full-scale rocket is a 4" diameter 100" length rocket your subscale shall not exceed 3" diameter and 75" in length.

Method	Inspection
Outcome	Section 3.2 explains how the subscale vehicle was scaled down to 50% of the full scale design.

Status	Complete

- 2.19. All teams will complete demonstration flights as outlined below.
  - 2.19.1. Vehicle Demonstration Flight - All teams will successfully launch and recover their full-scale rocket prior to FRR in its final flight configuration. The rocket flown shall be the same rocket to be flown as their competition launch. The purpose of the Vehicle Demonstration Flight is to validate the launch vehicle's stability, structural integrity, recovery systems, and the team's ability to prepare the launch vehicle for flight. A successful flight is defined as a launch in which all hardware is functioning properly (i.e. drogue chute at apogee, main chute at the intended lower altitude, functioning tracking devices, etc.). The following criteria shall be met during the full scale demonstration flight:
    - 2.19.1.1. The vehicle and recovery system will have functioned as designed.

Method	Demonstration
Plan	When the full scale is launched the function will be proved by the recovery system working as designed.
Status	Demonstration will occur during the full scale launch on February 12, 2022

- 2.19.1.2. The full-scale rocket shall be a newly constructed rocket, designed and built specifically for this year's project.

Method	Inspection
Plan	The rocket will be constructed from new materials following this year's design detailed in the CDR.
Status	Design complete, construction underway

- 2.19.1.3. The payload does not have to be flown during the full-scale Vehicle Demonstration Flight. The following requirements still apply:
  - 2.19.1.3.1. If the payload is not flown, mass simulators will be used to simulate the payload mass.

The payload will be flown during the full-scale vehicle demonstration flight.

- 2.19.1.3.2. The mass simulators will be located in the same approximate location on the rocket as the missing payload mass

The payload will be flown during the full-scale vehicle demonstration flight.

- 2.19.1.4. If the payload changes the external surfaces of the rocket (such as camera housings or external probes) or manages the total energy of the vehicle, those systems will be active during the full-scale Vehicle Demonstration Flight.

Method	Inspection
Plan	The payload will have minimal impact on external surfaces because they are designed to be flush. The windows will be in place for the Vehicle demonstration flight.
Status	Scheduled for 2-12 (backup 2-19)

- 2.19.1.5. Teams shall fly the competition launch motor for the Vehicle Demonstration Flight. The team may request a waiver for the use of an alternative motor in advance if the home launch field cannot support the full impulse of the competition launch motor or in other extenuating circumstances.

Method	Inspection
Plan	The team will use the Cesaroni K-1440 motor for the full scale demonstration, which is the same motor that will be used for the competition launch.
Status	Will be completed during full scale launch on February 12, 2022

- 2.19.1.6. The vehicle shall be flown in its fully ballasted configuration during the full-scale test flight. Fully ballasted refers to the maximum amount of ballast that will be flown during the competition launch flight. Additional ballast may not be added without a re-flight of the full-scale launch vehicle.

The vehicle does not have any ballast weight.

- 2.19.1.7. After successfully completing the full-scale demonstration flight, the launch vehicle or any of its components will not be modified without the concurrence of the NASA Range Safety Officer (RSO).

Method	Inspection
Plan	The vehicle will not be modified after the full scale demonstration flight.
Status	TBD

- 2.19.1.8. Proof of a successful flight shall be supplied in the FRR report. Altimeter flight profile data output with accompanying altitude and velocity versus time plots is required to meet this requirement.

Method	Inspection
Plan	Flight data from the full scale launch, the altimeter flight data profile and altitude and velocity vs time plots, will be included in the FRR.
Status	TBD

- 2.19.1.9. Vehicle Demonstration flights shall be completed by the FRR submission deadline. No exceptions will be made. If the Student Launch office determines that a Vehicle Demonstration Re-flight is necessary, then an extension may be granted. THIS EXTENSION IS ONLY VALID FOR RE-FLIGHTS, NOT FIRST TIME FLIGHTS. Teams completing a required re-flight shall submit an FRR Addendum by the FRR Addendum deadline.

Method	Demonstration
Plan	The vehicle demonstration is scheduled for 2-12 (bakup 2-19), before the FRR submission deadline.
Status	Scheduled for 2-12 (backup 2-19)

- 2.19.2. Payload Demonstration Flight - All teams will successfully launch and recover their full-scale rocket containing the completed payload prior to the Payload Demonstration Flight deadline. The rocket flown shall be the same rocket to be flown as their competition launch. The purpose of the Payload Demonstration Flight is to prove the launch vehicle's ability to safely retain the constructed payload during flight and to show that all aspects of the payload perform as designed. A successful flight is defined as a launch in which the rocket experiences stable ascent and the payload is fully retained until it is deployed (if applicable) as designed. The following criteria shall be met during the Payload Demonstration Flight:
  - 2.19.2.1. The payload shall be fully retained until the intended point of deployment (if applicable), all retention mechanisms shall function as designed, and the retention mechanism shall not sustain damage requiring repair.

Method	Inspection
Plan	The payload does not have any deployment features. After flight, the

	retainment system will be inspected for cracks and other damage.
Status	Scheduled for 2-12 (backup 2-19)

- 2.19.2.2. The payload flown shall be the final, active version.

Method	Inspection
Plan	The payload will be inspected before flight to ensure all components are included and it is functional. No changes will be made after the flight.
Status	Scheduled for 2-12 (backup 2-19)

- 2.19.2.3. If the above criteria are met during the original Vehicle Demonstration Flight, occurring prior to the FRR deadline and the information is included in the FRR package, the additional flight and FRR Addendum are not required.

Requirement is noted

- 2.19.2.4. Payload Demonstration Flights shall be completed by the FRR Addendum deadline. NO EXTENSIONS WILL BE GRANTED.

Method	Inspection
Plan	The team plans to conduct a payload demonstration during vehicle demonstration flight. Scheduled for 2-12 (backup 2-19), before the FRR addendum deadline.
Status	Scheduled for 2-12 (backup 2-19)

- 2.20. An FRR Addendum will be required for any team completing a Payload Demonstration Flight or NASA required Vehicle Demonstration Re-flight after the submission of the FRR Report.
  - 2.20.1. Teams required to complete a Vehicle Demonstration Re-Flight and failing to submit the FRR Addendum by the deadline will not be permitted to fly a final competition launch.
  - 2.20.2. Teams who successfully complete a Vehicle Demonstration Flight but fail to qualify the payload by satisfactorily completing the Payload Demonstration Flight requirement will not be permitted to fly a final competition launch.
  - 2.20.3. Teams who complete a Payload Demonstration Flight which is not fully successful may petition the NASA RSO for permission to fly the payload at

launch week. Permission will not be granted if the RSO or the Review Panel have any safety concerns.

Requirement is noted

- 2.21. The team's name and Launch Day contact information shall be in or on the rocket airframe as well as in or on any section of the vehicle that separates during flight and is not tethered to the main airframe. This information shall be included in a manner that allows the information to be retrieved without the need to open or separate the vehicle.

Method	Inspection
Plan	At the completion of the construction of the rocket, the safety officer will inspect all components of the vehicle to ensure that contact information is clearly and legibly written.
Status	Inspection Scheduled 2-4

- 2.22. All Lithium Polymer batteries will be sufficiently protected from impact with the ground and will be brightly colored, clearly marked as a fire hazard, and easily distinguishable from other payload hardware.

Method	Inspection
Plan	All lipo batteries in the vehicle will be protected from impact, will be brightly colored, marked as a fire hazard, and distinguishable from other payload hardware. The safety officer will ensure that these batteries are labeled.
Status	TBD

- 2.23. Vehicle Prohibitions
  - 2.23.1. The launch vehicle will not utilize forward firing motors.

Method	Inspection
Plan	The selected K1440 motor is not forward firing as shown in the design under 3.1 and 3.4.
Status	Design Complete, construction underway

  - 2.23.2. The launch vehicle will not utilize motors that expel titanium sponges (Sparky, Skidmark, Metal-Storm, etc.)

Method	Inspection
Plan	The selected K1440 motor uses white thunder propellant and is not a "sparky"

	motor.
Status	Complete

- 2.23.3. The launch vehicle will not utilize hybrid motors.

Method	Inspection
Plan	The selected K1440 motor is not a hybrid motor.
Status	Complete

- 2.23.4. The launch vehicle will not utilize a cluster of motors.

Method	Inspection
Plan	Only one K1440 motor will be used on the vehicle as shown in the design in 3.1
Status	Complete

- 2.23.5. The launch vehicle will not utilize friction fitting for motors.

Method	Inspection
Plan	The K1440 motor uses an Aeropack retention system as explained in section 3.1 and 3.4. The aeropack system does not use friction fitting.
Status	Complete

- 2.23.6. The launch vehicle will not exceed Mach 1 at any point during flight.

Method	Analysis
Plan	The maximum velocity is Mach 0.44. Refer to simulations under section 3.4
Status	Complete

- 2.23.8. Transmissions from onboard transmitters, which are active at any point prior to landing, will not exceed 250 mW of power (per transmitter).

Method	Inspection
Plan	The Featherweight GPS included in the design has a max power output of 50 mW as defined by Featherweight. (Included in flysheet)
Status	Complete

- 2.23.9. Transmitters will not create excessive interference. Teams will utilize unique frequencies, hand-shake/passcode systems, or other means to mitigate interference caused to or received from other teams.

Method	Inspection
Plan	The Featherweight GPS uses a specific channel with designated frequency. It uses this frequency to link specifically with the ground station
Status	Complete

- 2.23.10.Excessive and/or dense metal will not be utilized in the construction of the vehicle. Use of lightweight metal will be permitted but limited to the amount necessary to ensure structural integrity of the airframe under the expected operating stresses.

Method	Inspection
Plan	No excessive or dense metal is utilized in the construction of the vehicle. Reference section 3.1. Aluminum is used for payload retainment and steel is used for recovery to vehicle interfaces. This metal is used in a limited amount.
Status	Complete

3. Recovery System Requirements

- 3.1. The full scale launch vehicle will stage the deployment of its recovery devices, where a drogue parachute is deployed at apogee, and a main parachute is deployed at a lower altitude. Tumble or streamer recovery from apogee to main parachute deployment is also permissible, provided that kinetic energy during drogue stage descent is reasonable, as deemed by the RSO.
  - 3.1.1. The main parachute shall be deployed no lower than 500 feet.

Method	Demonstration and Inspection
Plan	Reference 3.3, main chute is designed to deploy at 600ft with the backup at 500ft. Will be demonstrated on test launch.
Status	Design inspection complete, demonstrations set for 2/12 (backup date 2/19)

  - 3.1.2. The apogee event may contain a delay of no more than 2 seconds.

Method	Demonstration and Inspection
Plan	The recovery system is designed for deployment at apogee for the drogue

	parachute with a back up at apogee +1 seconds. This will be demonstrated at the vehicle demonstration flight.
Status	Design inspection complete, demonstrations set for 2/12 (backup date 2/19)

- 3.1.3. Motor ejection is not a permissible form of primary or secondary deployment.

Method	Inspection
Plan	Section 3.3 and 3.4 show that the recovery system uses motor ejection as a tertiary charge.
Status	Complete

- 3.2. Each team 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.

Method	Demonstration
Plan	The team will conduct a ground demonstration to ensure deployment and charges are large enough
Status	Scheduled for 2-8

- 3.3. Each independent section of the launch vehicle will have a maximum kinetic energy of 75 ft-lbf at landing.

Method	Analysis
Plan	As shown in section 3.4, all sections land with a kinetic energy less than 75 ft-lbs.
Status	Design complete, construction ongoing

- 3.4. The recovery system will contain redundant, commercially available altimeters. The term “altimeters” includes both simple altimeters and more sophisticated flight computers.

Method	Inspection
Plan	The altimeters of the project are commercially available. We will be using the Strattologger CF, section 3.3.
Status	Completed

- 3.5. Each altimeter will have a dedicated power supply, and all recovery electronics will be powered by commercially available batteries.

Method	Inspection
Plan	Altimeters used on the vehicle each have their own dedicated power supply from a 9V Duracell battery and all the recovery electronics are also powered by another 9V Duracell battery.
Status	Design complete, construction ongoing

- 3.6. Each altimeter will be armed by a dedicated mechanical arming switch that is accessible from the exterior of the rocket airframe when the rocket is in the launch configuration on the launch pad.

Method	Inspection
Plan	The design explained in section 3.1 and 3.3 includes a separate activation switch for each altimeter and GPS. These switches are aligned with vent holes.
Status	Design complete, construction ongoing

- 3.7. Each arming switch will be capable of being locked in the ON position for launch (i.e. cannot be disarmed due to flight forces).

Method	Inspection
Plan	The switches being used in the design (3.1, 3.3) can be locked on.
Status	Design complete, construction ongoing

- 3.8. The recovery system electrical circuits will be completely independent of any payload electrical circuits.

Method	Inspection
Plan	As shown in the full vehicle assembly in section 3.1, the recovery system is housed completely separate from the payload and they do not interact.
Status	Complete

- 3.9. Removable shear pins will be used for both the main parachute compartment and the drogue parachute compartment.

Method	Demonstration and Inspection
Plan	As shown in sections 3.3 and 3.4, four removable shear pins are incorporated at

	each separation point, which houses the main and drogue parachutes.
Status	Design complete, construction ongoing.

- 3.10. The recovery area will be limited to a 2,500 ft. radius from the launch pads.

Method	Analysis
Plan	As shown in the drift calculations in section 3.4, even with 20mph winds, the drift is limited to less than 2000 feet.
Status	Complete

- 3.11. Descent time of the launch vehicle will be limited to 90 seconds (apogee to touch down).

Method	Analysis
Plan	Analysis done by Fruity Chutes, the parachute manufacturer, showed that the descent rate of the vehicle with the parachutes we have chosen will result in a descent time of less than ninety seconds, section 3.4.
Status	Completed

- 3.12. An electronic tracking device will be installed in the launch vehicle and will transmit the position of the tethered vehicle or any independent section to a ground receiver.
    - 3.12.1. Any rocket section or payload component, which lands untethered to the launch vehicle, will contain an active electronic tracking device.

Method	Inspection
Plan	All pieces of the vehicle will be tethered together, so the one gps will cover all of the vehicle. Section 3.3 shows the plans for electronics and gps. 3.1 shows the design of the vehicle.
Status	Completed

- 3.12.2. The electronic tracking device(s) will be fully functional during the official competition launch.

Method	Inspection and Demonstration
Plan	The design includes a GPS tracker that will be used at the official launch.
Status	Scheduled for 4-23 (backup (4-24)

- 3.13. The recovery system electronics will not be adversely affected by any other on-board electronic devices during flight (from launch until landing).
    - 3.13.1. The recovery system altimeters will be physically located in a separate compartment within the vehicle from any other radio frequency transmitting device and/or magnetic wave producing device.

Method	Inspection
Plan	As shown in the recovery electronics design in sections 3.1 and 3.3, the GPS is located in a separate compartment, separated by a plywood bulk plate with a chicken wire grid that acts as a faraday cage.
Status	Design complete, construction ongoing

- 3.13.2. The recovery system electronics will be shielded from all onboard transmitting devices to avoid inadvertent excitation of the recovery system electronics.

Method	Inspection
Plan	As shown in the recovery electronics design in sections 3.1 and 3.3, the GPS is located in a separate compartment, separated by a plywood bulk plate with a chicken wire grid that acts as a faraday cage.
Status	Design complete, construction ongoing

- 3.13.3. The recovery system electronics will be shielded from all onboard devices which may generate magnetic waves (such as generators, solenoid valves, and Tesla coils) to avoid inadvertent excitation of the recovery system.

The design does not include any magnetic wave generating devices

- 3.13.4. The recovery system electronics will be shielded from any other onboard devices which may adversely affect the proper operation of the recovery system electronics.

Method	Inspection
Plan	The recovery system is separately contained in a compartment over a foot away from payload components. The main parachute and wadding are also in between.
Status	Complete

4. Payload Experiment Requirements

- 4.1. High School/Middle School Division – Teams may design their own science or engineering experiment or may choose to complete the College/University Division mission stated below. Data from the science or engineering experiment will be collected, analyzed, and reported by the team following the scientific method.
- 4.4. General Payload Requirements
    - 4.4.1. Black Powder and/or similar energetics are only permitted for deployment of in-flight recovery systems. Energetics will not be permitted for any surface operations.

Method	Inspection
Plan	Black powder is only used in the recovery system (section 3.3) and is not included in the payload (section 4.1)
Status	Complete

- 4.4.2. Teams shall abide by all FAA and NAR rules and regulations.

Method	Inspection and Demonstration
Plan	Prior to any activities, the team thoroughly reviews all FAA and NAR rules and regulations and abides by them during the related activities.
Status	Reviewing all rules and regulations complete, activities ongoing. Rules and regulations will be continually reviewed.

- 4.4.3. Any experiment element that is jettisoned during the recovery phase will receive real-time RSO permission prior to initiating the jettison event, unless exempted from the requirement at the CDR milestone by NASA.

Method	Inspection
Plan	Nothing will be jettisoned from the vehicle at any point during the flight.
Status	Completed

- 4.4.4. Unmanned aircraft system (UAS) payloads, if designed to be deployed during descent, will be tethered to the vehicle with a remotely controlled release mechanism until the RSO has given permission to release the UAS.

No UAS is being used for the payload

- 4.4.5. Teams flying UASs will abide by all applicable FAA regulations, including the FAA's Special Rule for Model Aircraft (Public Law 112-95 Section 336; see https://www.faa.gov/uas/faqs).

No UAS is being used for the Payload

- 4.4.6. Any UAS weighing more than .55 lbs. will be registered with the FAA and the registration number marked on the vehicle.

No UAS is being used for the Payload

5. Safety Requirements

- 5.1. Each team will use a launch and safety checklist. The final checklists will be included in the FRR report and used during the Launch Readiness Review (LRR) and any Launch Day operations.

Method	Inspection
Plan	The team's safety officer has made these, and they can be found section 5.1 of the CDR.
Status	Preliminary checklists completed, will be finalized by FRR.

- 5.2. Each team shall identify a student safety officer who will be responsible for all items in section

Method	Inspection
Plan	The team's safety officer had been named, and can be found on the team roster in section 1.e of the team's proposal document. The safety officer is Jefferson Roberts (22jefrob@student.cfschools.org).
Status	Completed

- 5.3. The role and responsibilities of the safety officer will include, but are not limited to:
  - 5.3.1. Monitor team activities with an emphasis on safety during:
    - 5.3.1.1. Design of vehicle and payload

Method	Inspection
Outcome	Design of vehicle and payload meet all safety requirements found in section 6.2. The safety officer monitored the design process to ensure these requirements were met.
Status	Completed

- 5.3.1.2. Construction of vehicle and payload components

Method	Inspection
Plan	Team members were shown a presentation on safety hazards during construction and how to avoid them. The safety officer was monitoring construction of the subscale to ensure safe practices. He will continue to do so for the construction of the full scale. The safety presentations can be found in section 7.1, and safety incident reports can be found in section 7.2.
Status	In progress

- 5.3.1.3. Assembly of vehicle and payload

Method	Inspection
Plan	The safety officer monitored the assembly of the vehicle and payload for the subscale vehicle, and will for the full scale vehicle as well. Safety incident reports can be found in section 7.2.
Status	In progress

- 5.3.1.4. Ground testing of vehicle and payload

Method	Inspection
Plan	Safety officers will monitor all ground testing that occurs, and ensure that all members present follow safety procedures.
Status	In progress

- 5.3.1.5. Subscale launch test(s)

Method	Inspection
Plan	In the first subscale launch the drogue parachute did not deploy at apogee, only the main deployed at 500 feet agl. To make sure that the system was safe, and would not have this problem again, the team reflew the subscale. The results of the subscale launches can be found in section 3.2. It was determined that to fully ensure the system was safe a relaunch must occur. Team members were shown a presentation on launch safety that can be found in section 7.1.
Status	In progress

- 5.3.1.6. Full-scale launch test(s)

Method	Inspection
Plan	The safety officer will monitor the full scale test launch to ensure that all safety precautions are being followed. This includes all NAR and FAA regulations on launching. Team members have been shown a presentation on launch safety that can be found in section 7.1.
Status	In progress

- 5.3.1.7. Competition Launch

Method	Inspection
Plan	The safety officer will monitor the activities of the team members during the launch in Huntsville. Team members have been shown a presentation on launch safety that can be found in section 7.1.
Status	In progress

- 5.3.1.8. Recovery activities

Method	Inspection
Plan	The safety officer will monitor the actions of the team members to ensure they are following the safety requirements discussed before each launch. Before each launch team members are briefed on the rules about standing the minimum safe distance away, not trying to catch the rocket, waiting until it has landed to recover it, ect. Team members were shown a presentation on launch safety that can be found in section 7.1.
Status	In progress

- 5.3.1.9. STEM Engagement Activities

Method	Inspection
Plan	The safety officer will monitor the activities of team members and students during the outreach activity. Team members are briefed beforehand on the hazards, and how to watch the students to keep them safe.
Status	In progress

- 5.3.2. Implement procedures developed by the team for construction, assembly, launch, and recovery activities.

Method	Inspection

Plan	The safety officer will enforce the procedures set up in the safety presentations found in section 7.1 and the procedures set up in section 6.1. Safety incident reports can be found in section 7.2.
Status	In progress

- 5.3.3. Manage and maintain current revisions of the team's hazard analyses, failure modes analysis, procedures, and MSDS/chemical inventory data.

Method	Inspection
Plan	The safety officer will update the hazard analyses, failure mode analysis, procedures, and MSDS/ chemical inventory data for each document. These can be found in section 6.2, and have been updated since the PDR.
Status	In progress

- 5.3.4. Assist in the writing and development of the team's hazard analyses, failure modes analysis, and procedures

Method	Inspection
Outcome	The team's safety officer wrote the eternity of the hazard analyses and failure mode analysis, as well as most of the procedures.
Status	Complete

- 5.4. During test flights, teams will abide by the rules and guidance of the local rocketry club's RSO. The allowance of certain vehicle configurations and/or payloads at the NASA Student Launch does not give explicit or implicit authority for teams to fly those vehicle configurations and/or payloads at other club launches. Teams should communicate their intentions to the local club's President or Prefect and RSO before attending any NAR or TRA launch.

Method	Inspection
Plan	Team will talk with the RSO before each launch to ensure that all of their requirements are met. Team will also communicate with the President of the NAR chapter and the RSO of the launch when planning to attend a launch to ensure the payload and flight is acceptable.
Status	In progress

- 5.5. Teams will abide by all rules set forth by the FAA.

Method	Inspection
Plan	FAA rules for rocketry will be reviewed by the safety officer before launching. The safety officer will brief the team on rules that need to be followed. Launch procedures show that these rules were followed for the subscale launch.
Status	In progress

● Update the ongoing list of team derived requirements in the following categories: Vehicle, Recovery, and Payload. These are a set of requirements for mission success that are beyond the minimum success requirements presented in this handbook. Create a verification plan for each team derived requirement identifying whether test, analysis, demonstration, or inspection is required with an associated plan.

- Vehicle
  - The vehicle must have a minimum inner diameter of 5.1 inches to accommodate the camera array.

Method	Inspection
Plan	Section 3.1 shows the design of the vehicle with a diameter of 6 inches. 6 inches is more than enough room for the cameras.
Status	Completed

  - The vehicle needs to have three fins in order to reduce weight. Each fin adds roughly a pound of extra weight to the vehicle.

Method	Inspection
Plan	As seen in 3.1, our vehicle is designed with three fins to allow for adequate stability and minimize drag and weight.
Status	Design complete, construction ongoing

  - The vehicle needs to have a rail button at the center of pressure and another rail button 2 calibers away to ensure stability on the pad.

Method	Inspection
Plan	The design detailed in section 3.1 includes the position of rail buttons in accordance with the requirement.
Status	Design complete, construction ongoing

- More than 0.5 inches of motor mount tube must be available at the bottom of the booster so the Aeropack retention system can make contact for the 0.5 inches it requires.

Method	Inspection
Plan	The design in section 3.1 allows access to 0.75 inches of motor mount tube at the end of the booster section.
Status	Design complete, construction ongoing

- The vehicle must have windows so the payload cameras can see out of the vehicle.

Method	Inspection
Plan	Section 3.1 shows the design of the vehicle including the design of for the addition of windows into the vehicle.
Status	Design completed, under construction

- Fins must have epoxy fillets along the body tube and along the motor mount tube to ensure they stay strongly attached with no wiggle during flight.

Method	Inspection
Plan	After (and during) construction, the vehicle will be inspected to ensure epoxy fillets maximize the contact and strength of fin attachment.
Status	Inspection pending (scheduled 2-5)

- Recovery
    - Each parachute housing chamber must have a vent hole to prevent pressure separation upon ascent.

Method	Inspection
Plan	As shown in section 3.1, each parachute chamber has a pressure vent hole.
Status	Design complete, construction ongoing

- To allow vent holes in the electronic bay to also effectively serve as switch holes, they must be aligned above the fins so the launch rail does not obstruct access on the pad.

Method	Inspection
Plan	Section 3.1 shows that vent holes are designed to also serve as switch holes by aligning the holes above the fins so the launch rail does not obstruct access on the pad.
Status	Design complete, construction ongoing

    - The vehicle must have 4 shear pins at each separation point to ensure the heavy components do not separate prematurely

Method	Inspection
Plan	Sections 3.1 and 3.3 show the design to include 4 shear pins at each point of separation.
Status	Design complete, construction ongoing

    - The primary ejection charges must generate at least double the amount of force needed to break the shear pins.

Method	Analysis
Plan	As shown in section 3.3, the pressure generated by the primary charge is more than double the force required to break the shear pins.
Status	Complete

- Payload
    - The coupler containing the camera sled and data collection computer must be at least 1 foot long. The camera sled and data collection computer will be close to 1 foot in length, so the coupler must be 1 foot long to house both pieces. This coupler will connect the nose cone to the payload section of the body tube, and also contain a bulk plate to separate it from the parachute.

Method	Inspection
Plan	The design in section 3.1 (elaborated more in section 4.1) shows the payload being housed within a 14 inch coupler, adequate size for all components.
Status	Complete

    - The payload section must have vent holes to allow for pressure equalization on the inside of the vehicle to prevent window fogging or ejection and to allow for sensor readings.

Method	Inspection
Plan	The design in section 3.1 shows 3 vent holes in the payload section, meeting this requirement.
Status	Complete

6.3 Budgeting and Timeline

- Provide an updated line item budget for all aspects of the project with market values for individual components, material vendors, and applicable taxes or shipping/handling fees.

Item:	Cost:	Quantity:	Total Cost:	Vendor:
Nose cone (Fullscale)	$122.55	1	$122.55	Wildman Rocketry
6' G12 Fiberglass Body Tube (4ft pieces)	$166.50	2	$333.00	Wildman Rocketry
AV-Bay Lid 6 inch	$22.50	4	$90.00	Wildman Rocketry
Full Scale Body Tube Fin Slotting	$20.00	1	$20.00	Wildman Rocketry
G12-2.1 (2 foot pieces) (motor mount tube)	$25.92	1	$25.92	Wildman Rocketry
RA54P-TW (Motor Retainer)	$31.00	1	$31.00	Wildman Rocketry
Fin Beveling	$30.00	1	$30.00	Wildman Rocketry
500 LB Swivel	$5.00	2	$10.00	Wildman Rocketry
Rocketpoxy 2 Quart Set	$61.75	1	$61.75	Wildman Rocketry
WM02-Ejection Lighter	$14.21	2	$28.42	Wildman Rocketry
Kevlar 3/8"	$2.25	25	$56.25	Wildman Rocketry
G12CT-6 (Coupler)	$4.40	30	$132.00	Wildman Rocketry
G10-3/16 (Fins)	$26.60	3	$79.80	Wildman Rocketry

FCR6.0-3.0 (fiberglass centering rings)	$9.00	3	$27.00	Wildman Rocketry
Charmast Smallest 10000 USB C PD Quick Charge Portable Charger	$23.99	2	$47.98	Amazon
GoPro HERO9 Black	$339.99	3	$1,019.97	Amazon
Firewire Initiator (6pk)	$19.95	1	$19.95	Apogee Components
Fruity Chutes Iris Ulta 72" Standard Parachute	$180.60	1	$180.60	Wildman Rocketry
Fruity Chutes Elliptical Parachute	$51.20	1	$51.20	Wildman Rocketry
21" Nomex Blanket - 6" (152mm) Airframe	$21.60	1	$21.60	Wildman Rocketry
OshPark PCB (Circuit Board)	$35.05	1	$35.05	OshPark
Teensy 4.1	$26.95	1	$26.95	Adafruit Industries
BMP390	$17.11	1	$17.11	Amazon
BNO-055	$19.95	1	$19.95	Adafruit Industries
LED(s) (each)	$0.60	4	$2.38	Adafruit Industries
Feather M0	$34.95	1	$34.95	Adafruit Industries
Shipping for Electronics	$9.15	1	$9.15	Adafruit Industries
Shipping (Wildman Rocketry)	$63.97	1	$63.97	Wildman Rocketry
Protective Lens Replacement for GoPro HERO9 Black	$19.99	1	$19.99	Amazon
SanDisk 256GB Extreme microSDXC UHS-I Memory Card with Adapter - Up to 160MB/s, C10, U3, V30, 4K, A2, Micro SD - SDSQXA1-256G-GN6MA	$37.99	3	$113.97	Amazon
onn SD|microSD|MiniSD|MMC|MMC Micro Plug N Play USB/Micro-USB/USB-C Memory Card Reader PC/Mac/Android Compatible	$10.88	1	$10.88	Walmart
Cesaroni K-1440	$196.26	3	$588.78	Chris' Supplies
Duracell 9V Batteries	$19.99	1	$19.99	Amazon

Forged steel eye bolts	$20.00	1	$20.00	Home Depot
5/16 Threaded Steel Rod (1.5 ft)	$6.38	1	$6.38	MacMaster Carr
3D Printing	$200.00	1	$200.00	Various Suppliers
5/16 Hex Nuts	$3.33	1	$3.33	Home Depot
Quest Recovery Wadding	$8.64	3	$25.92	Apogee Components
Shear Pins	$6.07	1	$6.07	Apogee Components
Acrylic Sheet	$14.98	1	$14.98	Home Depot
5/16 Threaded Aluminum Rod (4 ft)	$9.02	1	$9.02	McMaster Carr
Aluminum Sheet (1ftx1ft)	$7.68	1	$7.68	Home Depot
Miscellaneous Hardware	$50.00	1	$50.00	Various Stores
ULANZI Select G9-2 Protective Cover for Gopro Hero 9/10 Black, Battery Charging Door	$19.95	3	$59.85	Amazon
75mm Blue Tube	$33.65	2	$67.30	Apogee Components
75mm Blue Tube Coupler	$11.18	3	$33.54	Apogee Components
PNC-3.00" (75mm) x 11.25" for Thick Wall Tubes	$23.30	1	$23.30	Apogee Components
29mm x 34" Thick Wall Tube	$5.45	1	$5.45	Apogee Components
Kevlar Cord 1500# (1 ft)	$1.10	50	$55.00	Apogee Components
29mm Estes Retainer (2pk)	$10.50	1	$10.50	Apogee Components
Standard Rail Button (fits 1" Rail - 1010) (2pk)	$4.25	1	$4.25	Apogee Components
Subscale Motors	$31.50	2	$63.00	Apogee Components
Shipping (Apogee Components)	$44.33	1	$44.33	Apogee Components
Tax	284.3407	1	$284.34	

Total Cost	$4,346.35	

**Items highlighted in blue were used for the subscale rocket*

Hotel:	Cost per room	Number of Rooms	Number of nights	Total Cost	
	$120.00	$8.00	4	$3,840.00	
Gas:	**Cost per Gallon**	**Number of gallons for one-way trip**	**Number of Vehicles**	**Trips**	**Total Cost**
	$3.00	$50.00	3	2	$900.00
	Travel Tax:	**$331.80**		**Total Travel Costs:**	**$5,071.80**

- Provide an updated funding plan describing sources of funding, allocation of funds, and material acquisition plan.

The primary source of funding comes from donations from businesses. Members of the CFHS Rocket Club first reviewed local businesses, grading them on a few factors including the relation of their work to rocketry, their size, their likeliness to donate, and whether or not they have a relationship with the club as an entity or any individual members of the club. These reviews were then cataloged and reviewed by the members responsible for the club fundraising. The reviews were then cataloged and placed on a list in order of most likely to donate to least likely to donate. These businesses are then contacted, either by members entering the business and speaking with the owner, or by written correspondence. Some sponsors wish to purchase materials for the team. In such cases, the sponsors are provided with a list of materials, a preferred vendor, and the shipping address for the team. For larger businesses, international and national, members of the club reach out to the respective businesses with a summary of the club and it's goals, as well as a request for donation, either monetary (including product discounts) or specific material(s). The team has also pursued options in grant donations, such as those offered by John Deere. The last method of fund acquisition comes in the form of team members performing physical work for other businesses/organization entities. Examples of this include directing parking traffic or working concession stands at local university sporting events. Upon acquisition of funds, materials are acquired by various methods including buying the physical materials at local stores, or ordering them through online vendors such as Amazon, Wildman Rocketry etc., with due regard to shipping and team timelines.

- Provide an updated timeline, including all team activities and expected activity durations. The schedule should be complete and encompass the full term of the project. Deliverables should be defined with reasonable activity duration. GANTT or milestone charts are encouraged.

<u>August</u>

- 8/18- Request for Proposal Released
- 8/30- Team Meeting- 1 hr
- 8/31- Team Meeting- 1 hr

<u>September</u>

- 9/2- Team Meeting- 1 hr
- 9/7- Team Meeting- 1 hr
- 9/9- Team Meeting- 1 hr
- 9/11- Proposal Revisions- 8 hr
- 9/14- Team Meeting- 1 hr
- 9/16- Team Meeting- 1 hr
- 9/20- Submit Proposal- 5 min
- 9/21- Team Meeting- 1 hr
- 9/23- Team Meeting- 1 hr
- 9/28- Team Meeting- 1 hr
- 9/30- Team Meeting- 1 hr

<u>October</u>

- 10/5- Team Meeting- Awarded Proposals Announced- 1 hr
- 10/7- Team meeting, PDR QNA- 2 hr
- 10/12- Team meeting, begin ordering materials- 1 hr
- 10/14- Team Meeting- 1 hr
- 10/16- Outreach events Scheduled- 2 hr
- 10/19- Team Meeting- 1 hr
- 10/20- Sections 1-3 of the PDR completed
- 10/21- Team Meeting, Social media list sent- 1 hr
- 10/24- PDR revisions- 2 hr
- 10/25- Sections 4-6 of the PDR completed
- 10/26- Team Meeting- 1 hr
- 10/28- Team Meeting, PDR revisions- 1 hr
- 10/31- PDR submitted

<u>November</u>

- 11/2- Team Meeting, PDR presentation begins- 1 hr
- 11/4- Team Meeting- 1 hr
- 11/9- Team Meeting- 1 hr
- 11/11- Team Meeting- 1 hr

- 11/16- Team Meeting- 1 hr
- 11/18- Team Meeting- 1 hr
- 11/23 - Team Meeting, PDR presentation ends- 1 hr
- 11/25- Team Meeting, complete scale model- 1 hr
- 11/27- Launch Scale Model- 1 hr
- 11/29- CDR sections 1-3 completed
- 11/30- Team Meeting, CDR QNA- 1 hr

<u>December</u>

- 12/2- Team Meeting- 1 hr
- 12/7- Team Meeting- 1 hr
- 12/9- Team Meeting- 1 hr
- 12/14- Team Meeting, order full scale parts- 1 hr
- 12/16- Team Meeting, CDR sections finished- 1 hr
- 12/21- Team Meeting, finish CDR presentations- 1 hr

<u>January</u>

- 1/2- Submit CDR
- 1/3- Subscale Flight Deadline *and* Critical Design Review (CDR) report, presentation slides, and flysheet submitted to NASA project team management by 8:00 a.am CST.
- 1/4- Team Meeting- 1 hr
- 1/6- Team Meeting, CDR teleconferences begin- 1 hr
- 1/10- Team CDR presentation at 12pm to 1pm - 1hr
- 1/11- Team Meeting- 1 hr
- 1/13- Team Meeting- 1 hr
- 1/18- Team Meeting- 1 hr
- 1/20- Team Meeting- 1 hr
- 1/23- Team Meeting, finish full scale rocket- 1 hr
- 1/25- Team Meeting- 1 hr
- 1/26- CDR teleconferences end- 1 hr
- 1/27- Team Meeting, FRR QNA- 1 hr
- 1/28- Sections 1-4 of FRR complete
- 1/31 - Payload Battery Test

<u>February</u>

- 2/1- Team Meeting- 1 hr
- 2/4- Full Scale Rocket Completed, Vehicle Criteria Section of FRR complete, and Payload Criteria Section completed
- 2/8- Team Meeting and Ground Ejection Demonstration
- 2/10- Team Meeting- 1 hr
- 2/12- Full Scale Launch Date
- 2/15- Team Meeting- 1 hr
- 2/17- Team Meeting, sections 1-7 of FRR completed- 1 hr
- 2/19- Full Scale Rocket launch backup date

- 2/22- Team Meeting, FRR completed- 1 hr
- 2/24- Team Meeting- 1 hr
- 2/28- Outreach Interactions completed

March

- 3/6- Check over FRR and complete FRR presentation- 2 hr
- 3/7- FRR report, Presentation, and Flysheet due to NASA at 8am - 1 hr
- 3/8- Team Meeting- 1 hr
- 3/9- FRR teleconferences start
- 3/10- Team Meeting- 1 hr
- 3/15- Team Meeting- 1 hr
- 3/17- Team Meeting- 1 hr
- 3/22- Team Meeting- 1 hr
- 3/24- Team Meeting- 1 hr
- 3/29- Team Meeting- 1 hr
- 3/31- Team Meeting- 1 hr

April

- 4/4- Payload Demonstration Flight and Vehicle Demonstration Reflight deadlines
- 4/5- Team Meeting- 1 hr
- 4/6- Launch Week Q&A
- 4/7- Team Meeting- 1 hr
- 4/12- Team Meeting- 1 hr
- 4/14- Team Meeting- 1 hr
- 4/16- Have LRR documents ready
- 4/19- Evening Departure to Huntsville, AL.
- 4/20- Launch Readiness Review (LRR) for teams arriving early
- 4/21- Official Launch Week Kickoff, LRRs, Launch Week activities
- 4/22- Launch Week Activities
- 4/23- Launch Day and Awards Ceremony
- 4/24- Return to Cedar Falls (back up launch day)
- 4/26- Team Meeting- 1 hr
- 4/28- Team Meeting- 1 hr

May

- 5/3- Team Meeting- 1 hr
- 5/5- Team Meeting- 1 hr
- 5/9- PLAR Due

7. Appendix

7.1 Safety Presentations

9 Rules for Safe Rocket Constructioning

2021-2022 NSL Construction Safety Presentation

Safety is always the number one priority

1: Handling Motors

- Team members may only handle motors that they are certified to handle
- Only Harrison, Jefferson, and Jillian are certified to handle L1 motors

2: Handling Wood

- Unsanded wood may give splinters
- When sanding wood avoid sanding oneself

3: Handling Fiberglass

- Fiberglass will also gives splinters
- Wear gloves when handling
- Wear a mask when sanding to avoid breathing in fiberglass splinters

4: Soldering

- Only solder in a well ventilated area to avoid inhaling fumes
- Be careful not to burn yourself with soldering iron or solder

5: Handling Electronics

- Be careful not to electrocute yourself
- Do not touch exposed wires
- Do not work on anything connected to a power source

6: Handling Chemicals

- Always wear appropriate PPE (gloves, glasses, closed toed shoes, ect)
- Know proper spill or skin contact responses
- Try to avoid all contact with skin or eyes, and do no ingest any materials used in rocket construction

7: Handling Epoxies and Adhesives

- The epoxies used in construction are near permanent
- Avoid contact with skin, hair, and clothes

8: Handling Hand Tools

- Do not use any tool you do not know how to use
- Always wear proper PPE

9: Handling Power Tools

- Do not use any tool you do not know how to use
- Always wear proper PPE
- Be careful when using electricity
- Some tools may only be used by team leads or adult mentor

13 Rules For Safe Rocketing

2021-2022 NSL Launch Safety Presentation

Safety is always the number one priority

1: Certification

- May only possess and use motors one is certified to handle

2: Materials

- One will only use lightweight materials for rocket construction
- Paper, wood, rubber, plastic, fiberglass, ductile metals

3: Motors

- One may only use certified, commercial produced motors
- Motors will not be tampered with
- No smoking, open flame, or heat sources within 25 ft of motors

4: Ignition Systems

- One will only launch with an electrical launch system and electrical motor igniters
- Igniters must be installed on launch pad
- Launch system must have safety interlock in series with the launch switch, and launch switch must be returned to off after ignition

5: Misfires

- If rocket does not launch when ignition is pressed the safety interlock or battery must be disconnected and 60 second must pass before anyone can go inspect the rocket

6: Launch Safety

- One must perform a five second countdown to launch, and have means available to warn spectators of danger
- No one may be closer than the minimum safe distance (200 ft)
- Rocket must be determined to be stable before launch

7: Launcher

- Rocket must be launched from a device that provides rigid guidance until it reaches a speed that ensures stable flight, and it within 20 degrees of vertical
- If windy rocket must be launched away from spectators
- Blast deflector must be used to protect ground, and debris must be cleared from around launch pad

8: Size

- Rocket must not contain any combination of motors with more than a total of 40,960 N-sec
- Rocket must not weigh more than ⅓ the average thrust of the motor being used

9: Flight Safety

- Rocket must not be launched at a target, into clouds, near airplanes, or on a trajectory that takes it above spectators or outside of the bounds of the launch site, or with any flammable or explosive payloads
- Rocket must not be launched when wind speed exceeds 20 mph
- One must comply with FAA rules and regulations, and make sure rocket does not exceed approved ceiling

10: Launch Site

- Rocket must be launched outdoors, in an area free of trees, power lines, occupied buildings, and without persons not involved in the launch
- Open area must have a minimum diameter of half the launch ceiling, or 1500 ft

11: Launcher Location

- Launcher must be 1500 ft from any occupied building or public highway with traffic heavier than 10 vehicles per hour
- Must not be closer to launch site than minimum distance allowed (200 ft)

12: Recovery System

- A recovery system where all parts of the rocket return safely and undamaged in a way in which they can be flown again must be used
- Only flame resistant or fireproof materials may be used in recovery system

13: Recovery Safely

- One must not attempt to recover rocket from power lines, tall trees, or other dangerous places
- One must fly it under conditions where it not likely to land in spectator areas or outside of launch boundaries
- One may not attempt to catch a rocket on its descent

7.2 Safety Reports

- On December 14, 2021 team member Owen Tresemer received a warning for not wearing proper eye protection while sanding the fins of the subscale vehicle. Tresemer was told to put on the proper eye protection before continuing construction.

- On December 20, 2021 during the subscale launch team member Grant Redfern approached the launch pad during ignitor installation. Only the safety officer (Jefferson Roberts, who is level one high powered certified) and the team mentor (Tyler Sorenson, who is level two high powered certified) were supposed to be within the minimum safe spectating distance at that point in time. Redfern was told to go back to outside of the minimum safe spectating distance.