Bearospace at UCLA
(LoL)
Leveling on Land
2020 - 2021 NASA Student Launch
Payload Modification Vehicle Redesign (PMVR)

University of California, Los Angeles
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Table of Contents

List of Figures

List of Tables

1. Summary of PMVR Report

1.1. Team Name and Mailing Address

Team Name:	Bearospace at UCLA
Mailing Address:	420 Westwood Blvd Boelter Hall Room 6291 Los Angeles, CA 90095

1.2. Number of Hours Spent on PMVR

Number of Hours Spent on PMVR: 100

2. Vehicle Criteria

2.1. Design and Rationale of Launch Vehicle

2.1.1. Mission Statement

Since the team is competing in the Design Competition of USLI this year, Bearospace at UCLA will design and virtually test a vehicle capable of reaching an apogee 3600 feet, deploying parachutes at major events, and lands safely. The vehicle will deliver a payload specific to this year's competition. Lastly, minimizing cost will be at the forefront during the manufacturing phase while not jeopardizing the structural integrity of the launch vehicle nor violating any vehicle requirements.

2.1.2. New Mission Success Criteria

A successful mission for the launch vehicle will be determined as completion of the following tasks for the Design Competition of USLI:

1. Virtually simulate the flight of the launch vehicle and reach within 100 feet of the targeted apogee
2. Virtually test all components of the launch vehicle through SolidWorks Simulations and making sure no components fail or receive considerable damage under predicted forces
3. Safely retaining both payloads during the virtual flight with no signs of damage to the structure and electronics of the original payload as well as the new payload container, as verified through simulations

2.1.3. Vehicle Design

Changes since the FRR

To accommodate the new payload challenge, our team decided to add a 13 in long stainless-steel tank to the nosecone and extended the nosecone to 23 inches in order to accommodate this. We made this decision after analyzing the available space in our rocket, locating where we could fit a tank capable of containing 3 liters of fluid, and analyzing how the addition of this tank would affect the weight, stability, and apogee of our rocket.

Adding this component required us to alter the internal components of the nosecone, removing the eyebolt and bulkhead setup we had previously and adding a locking mechanism similar to that that holds in the payload and electronic bay, in order to safely secure the tank in the nosecone, and allow removal once the mission is completed.

After adding this feature, the apogee of our rocket dropped a significant amount, and so, in order to reach target apogee, we needed to choose a new motor selection. After analyzing all our options and running simulations with different motor types, our team chose the Cesaroni Tech. K1620-Vmax-0 motor.

Overview

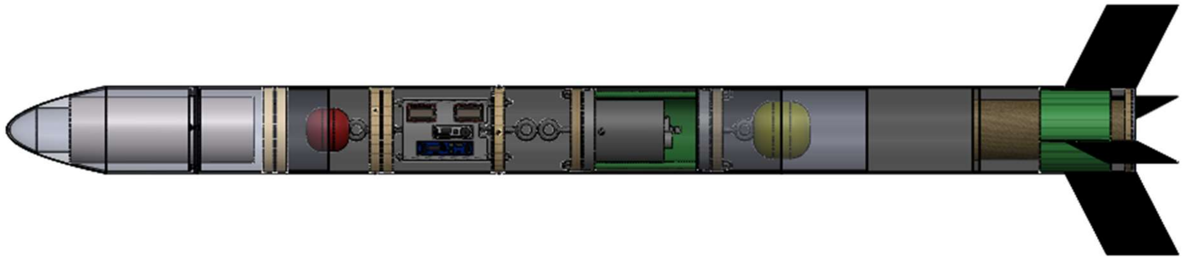

Figure 1: Launch Vehicle Overview

Total Estimated Weight: 29.6 lb.
Stability Margin: 3.06

In the following section, each component of the rocket will be examined as to the structure and material it will be comprised of. Each component will be reviewed in accordance with which parent component it is harbored in. There are three parent components: the nose cone, the upper body tube, and the lower body tube.

Nose Cone & Fuel Storage Tank

The fuel tank within the launch vehicle will be stored within a modified version of the nose cone. While changes to the original payload retention system could be made to retain the fuel tank, modifying the nose cone is the most cost-effective option. Placing the fuel tank within where the previous payload retention system was located would involve changes to the structure of the upper body tube. This would involve creating an entirely new carbon fiber upper body tube to accommodate the longer length of the fuel tank. This would involve buying a new carbon fiber body tube and recreating the entire ebay with all its associated bulkheads. Manufacturing the nose cone is cheaper and easier to fabricate as the nose cone only needs to be 3D printed. To increase structural integrity of the nose cone sections, the printed components will be lined with fiber glass.

ITEM NO.	PART NUMBER	QTY.
1	Upper Nose Cone	1
2	Lower Nose Cone	1
3	Nose Cone Locking Mechanism Assembly	1
4	Tank	1
5	Spacer	1
6	3/8" Galvanized Steel Eyebolt	1
7	8-32 Thread Size Phillips Flat Head Screw	4
8	8-32 Thread Size Hex Nut	4

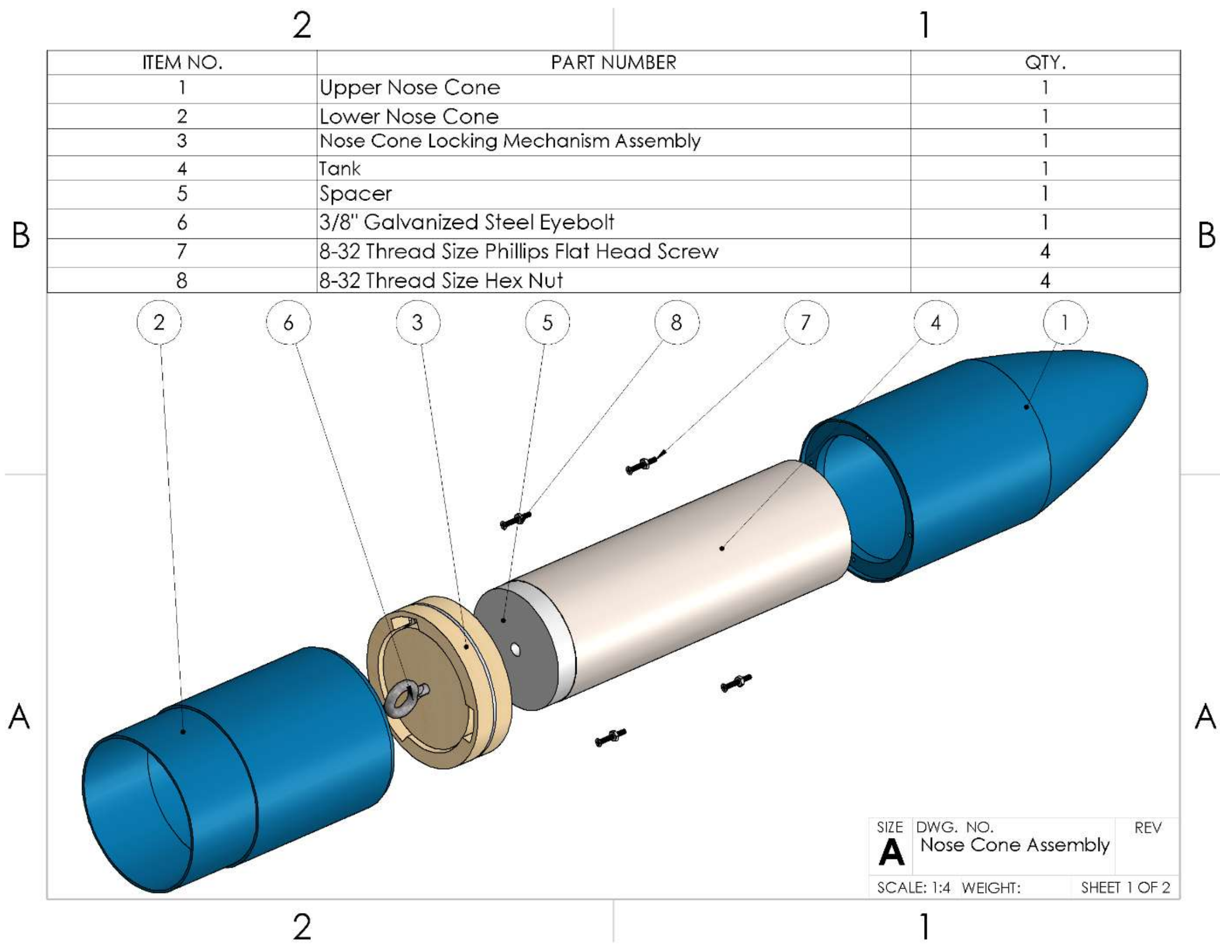

Figure 2: Exploded View of Nose Cone Assembly with Payload Fuel Tank

The fuel storage system within the launch vehicle features a two-part 6” diameter nose cone with a wooden locking mechanism for ease of access to the inside of the nose cone. The locking mechanism used is a modified version of the locking mechanism used for accessing the ebay while providing an attachment point for recovery hardware. The locking mechanism is reinforced with a sheet of aluminum to withstand impulse forces caused by the tank and its fuel after the deployment of recovery systems. Testing must be conducted on the locking mechanism to assess the components’ ability to withstand the impulse exerted by the 6.61 lb. liquid fuel and recovery hardware. The locking mechanism is epoxied into the lower nose cone section where the shoulder of the lower nose cone section ends. A 3D printed spacer component prevents the tank from interacting with the eyebolt of the locking mechanism. Four sets of #8-32 thread Phillips flat head screws and nuts are used to combine the upper and lower nose cone sections into a singular cohesive unit. The fuel tank is retained within the nose cone due to proper sizing. As shown in the cross-section below, the tank is nestled with little tolerancing to prevent the tank from rattling within the nose cone. The fuel tank has an outer diameter of 4.6” and a length of 13”. The inner dimensions of the tank are 4.4” diameter by 12.8” length for a total inner volume of 194.63 in^3 (~3.19 L). The inner volume accommodates for 3 liters of fuel and an additional 188 cm^3 of gaseous headspace. Additional dimensions for the nose cone assembly are provided below.

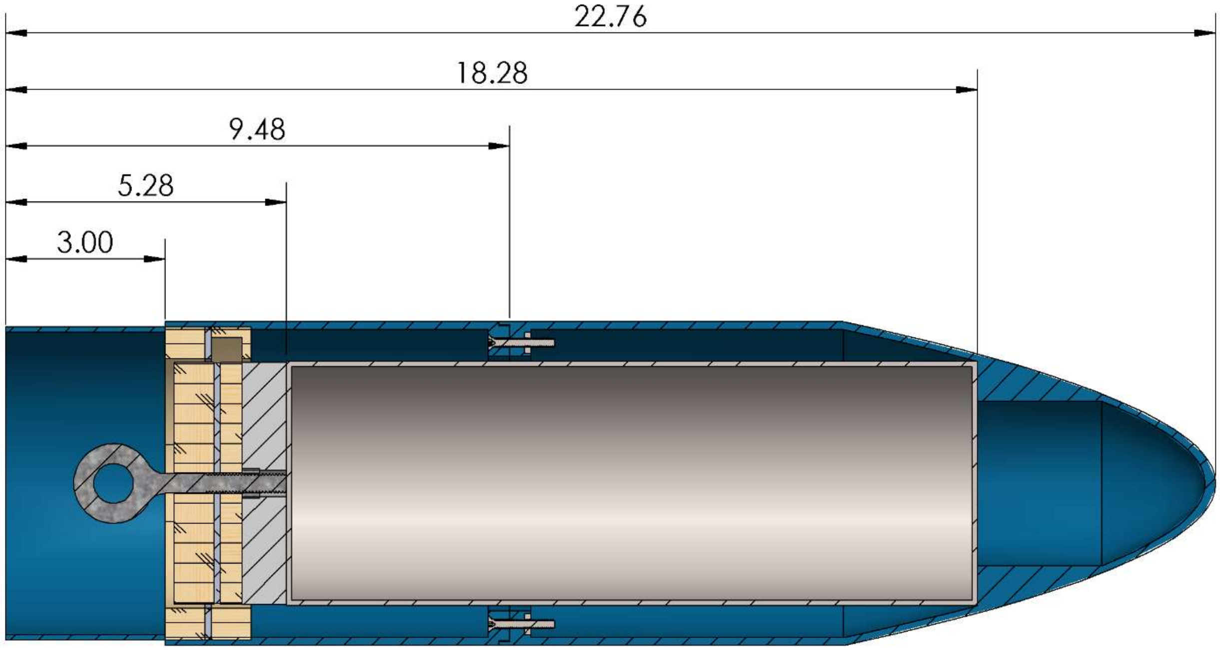

Figure 3: Cross-Section of Nose Cone with Payload Fuel Tank and Relevant Dimensions

Since the payload now contains liquid fuel with an additional gaseous headspace, sloshing during flight must be accounted for. Vibrations inherent to a rocket launching will cause the fuel to oscillate and slosh within the tank. Fuel sloshing causes the rocket’s center of gravity to sway around, moving the trajectory of the rocket off course and potentially resulting in a rocket’s stability well below 2. To counter this, the movement of the fuel must be reduced. The optimal behavior of the payload is to have it slosh such that it does not significantly impact the calculated trajectory of the rocket. The method by which sloshing will be minimized in the fuel storage tank in the rocket revolves around the concept of baffles.

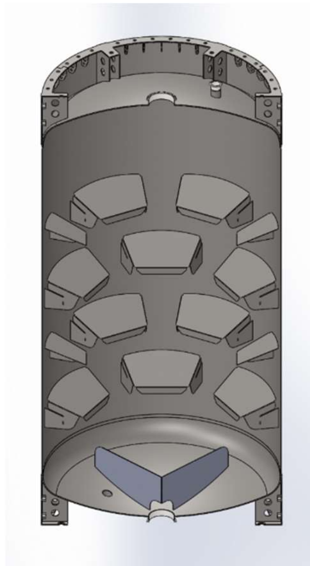

Figure 4: Cross Section of an Example of Baffles in a Storage Tank[1]

As seen in the figure above, the tank will have similarly curved baffles inside the tank to prevent fuel movement. As the fuel moves around, the baffles provide small walls that stop the liquid from moving in that direction. Additionally, the baffles are angled downwards to have any fuel that splashes to the top drop back down.

Table 1: Nosecone Section Components

Component	Material	Dimensions
Nose Cone	ABS Plastic with Fiberglass reinforcement	Cone Length: 23 in. Cone Thickness: 0.2 in. Cone Outer Diameter: 6.1 in. Shoulder Length: 3 in. Shoulder Thickness: 0.1 in. Shoulder Outer Diameter: 5.9 in.
	ABS Plastic is selected as the material that the nose cone will be made out of as the material is used in the 3D printers available and allows a greater capability of conforming the structural design to team design parameters. The fiberglass is added to provide extra structural stability for the new fuel tank	Ogive shape and length are given by the need for a desirable stability and apogee; an ogive nose cone of this length resulted in both a stability and apogee that was adequate with a margin for potential weight gain.
Tank	Stainless steel	Tank Length: 13 in. Thickness: 0.1 in. Outer Diameter: 4.6 in.

[1] “Spica Tanks,” Copenhagen Suborbitals, August 9, 2019, https://copenhagensuborbitals.com/spica-tanks/.

	Tank was chosen and designed to hold the fuel needed for the new payload challenge	The dimensions selected retain 3 liters of fuel with 188 cm^3 of gaseous headspace.
Locking System	See Locking Mechanism Section. This locking mechanism has a spacer between the locking mechanism itself and the payload container so that all the weight of the payload container is not concentrated on the eyebolt attached to the locking mechanism	

Upper Body Tube

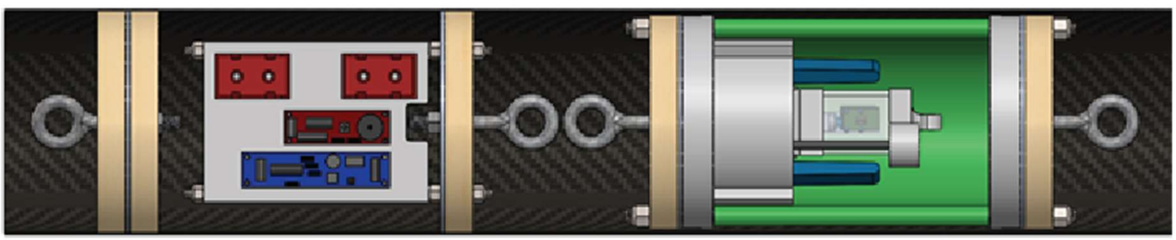

Figure 5: Upper Body Tube Overview

Estimated Rocket Vehicle Section Weight: 9.55 lb.

The lower body tube vehicle section is composed of nine different components:

- The upper body tube parent component
- The payload which will be ejected in flight.
- The electronics bay which houses the electronic “brain” of the rocket, recording data on the rocket vehicle’s flight and triggering the payload’s activation upon landing.
- The locking mechanism, which is both the anchor point for the drogue chute assembly and the access point for the electronics bay.
- The bulkhead, which is used as a base for the payload and separates the payload from the electronics bay, as well as an anchor point for the main parachute assembly to the upper body tube parent component.
- The eyebolt, of which there are two: one for attaching the main parachute assembly to the bulkhead supporting the payload, and another for attaching the drogue chute assembly to the retention mechanism.
- The quicklink, of which there are two: one for securing the main parachute assembly to the eyebolt attached to the bulkhead, and another for securing the drogue chute assembly to the eyebolt attached to the locking mechanism.
- The nut, of which fastens the eyebolt of the main parachute assembly to the bulkhead.

Table 2: Upper Body Tube Section Components

Part	Material	Dimensions
Upper Body Tube	Carbon Fiber	Length: 35 in. Thickness: 0.07 in. Outer Diameter: 6 in.
	Carbon Fiber is the preferred material of choice for the body tubes, as it is both stronger and lighter in comparison to fiberglass, though is not as competitive when comparing cost or radiolucency. Due to the large weight of the rocket, the necessity for a strong body tube for landing and payload survival becomes paramount, as well as ensuring a higher apogee capability at the same weight. As such, carbon fiber was selected over fiberglass.	The body tube at minimum must be long enough to house the payload, the electronics bay, the nose cone shoulder, and half the coupler. As can be seen above, the length is enough to have space dedicated to all of the aforementioned parts, as well as more empty space towards the rear of the upper body tube, intended to allow further distancing of mass components from the center of pressure to obtain a desirable stability
Electronics Bay	Filled with various electronic components necessary for the completion of our mission. See past reports for more detail	Length: 8 in.
Locking System	*See Locking Mechanism Section Below*	
Bulkhead	Pine Wood and Epoxy	Thickness: .75 in. Diameter: 5.86 in.
	Pine wood is selected as the base material due to its relative ease of sourcing, price point, and ability to precisely manufacture in student engineering and manufacturing shops. Epoxy will be used as the bonding adhesive between the bulkhead and the body tube interior wall, as well as between different layers of the pine wood, as it is the stronger adhesive in comparison to wood glue, despite its increased price point.	The dimensions are given so the bulkhead is thick enough to secure an eyebolt to which the main parachute recovery assembly is attached
Eyebolt	Stainless Steel	Length: 3 in. Diameter: 1 in.
	Stainless steel is the material of choice for eyebolts due to their high strength, a necessary consideration for the loading forces presents during the main parachute assembly's deployment and drogue chute assembly's deployment.	The diameter of the eyebolt must be wide enough such that a quicklink can be fed through the eye and secured, serving as the attachment point of the parachute assemblies. Additionally, the length of the forward eyebolt's shank must be long enough

		to pass through the entirety of the bulkhead, and still have enough length left to fasten a nut to the eyebolt, securing the eyebolt against the bulkhead and thus the upper body tube parent component.
Quicklink	Stainless Steel	Length: 1 in.
	Stainless steel is the material of choice for quicklinks due to their high strength, a necessary consideration for the loading forces presents during the parachute assemblies' deployment.	The quicklink must be long enough to secure both the eyebolt eye and the shock cords together, and thick enough to withstand the loading forces of the parachute assemblies' deployment.
Nut	Stainless Steel	Thread Diameter: 0.5 in.
	Stainless steel is the material of choice for nuts due to their high strength, a necessary consideration for the loading forces presents during the main parachute's deployment.	The nut's inner diameter must match the shank diameter of the eyebolt for the nut to be effective in securing the eyebolt to the bulkhead.

Locking Mechanism

The Inner and Outer components of the locking mechanism are made from pine wood, while the reinforcement is made from aluminum.

ITEM NO.	PART NUMBER	QTY.
1	Inner Ring Top	1
2	Inner Ring Reinforcement	1
3	Inner Ring Bottom	1
4	Outer Ring Top	1
5	Outer Ring Reinforcement	1
6	Outer Ring Bottom	1
7	3/8" Galvanized Steel Eyebolt	1

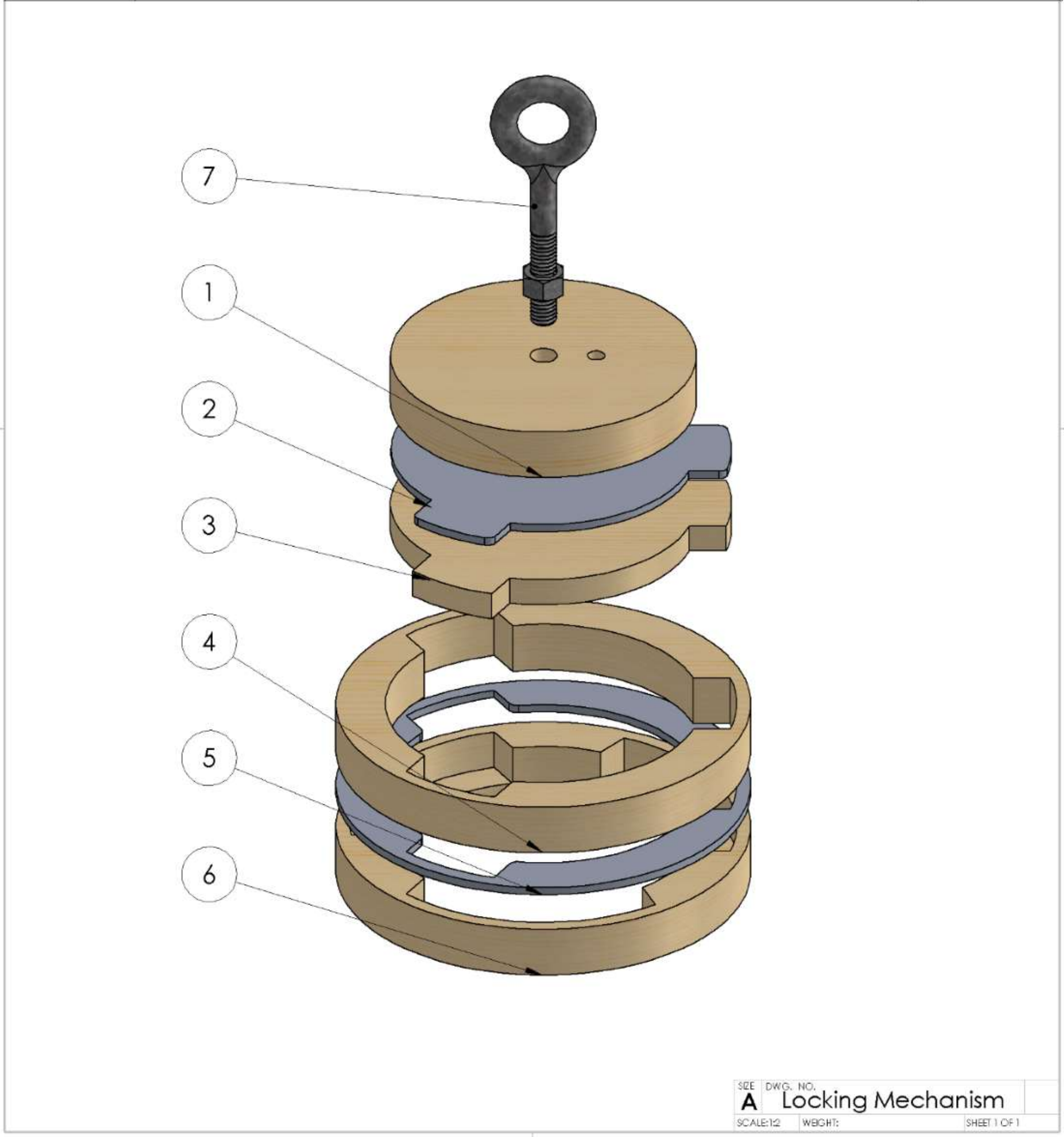

Figure 6: Exploded View of Locking Mechanism

All wooden components for the locking mechanism are CNC'ed to specification from 0.75" thick pine wood slabs found at hardware stores using a 1/4" drill bit. The wooden area on the unmodified 0.75" thick pine wood slab from which to fabricate the wooden pieces should show no visible knots or cracks to eliminate potential stress concentrations. Aluminum pieces show in the figure above are fabricated from 0.12" thick aluminum sheets using a waterjet. Fabrication of all parts require the use of safety glasses during fabrication.

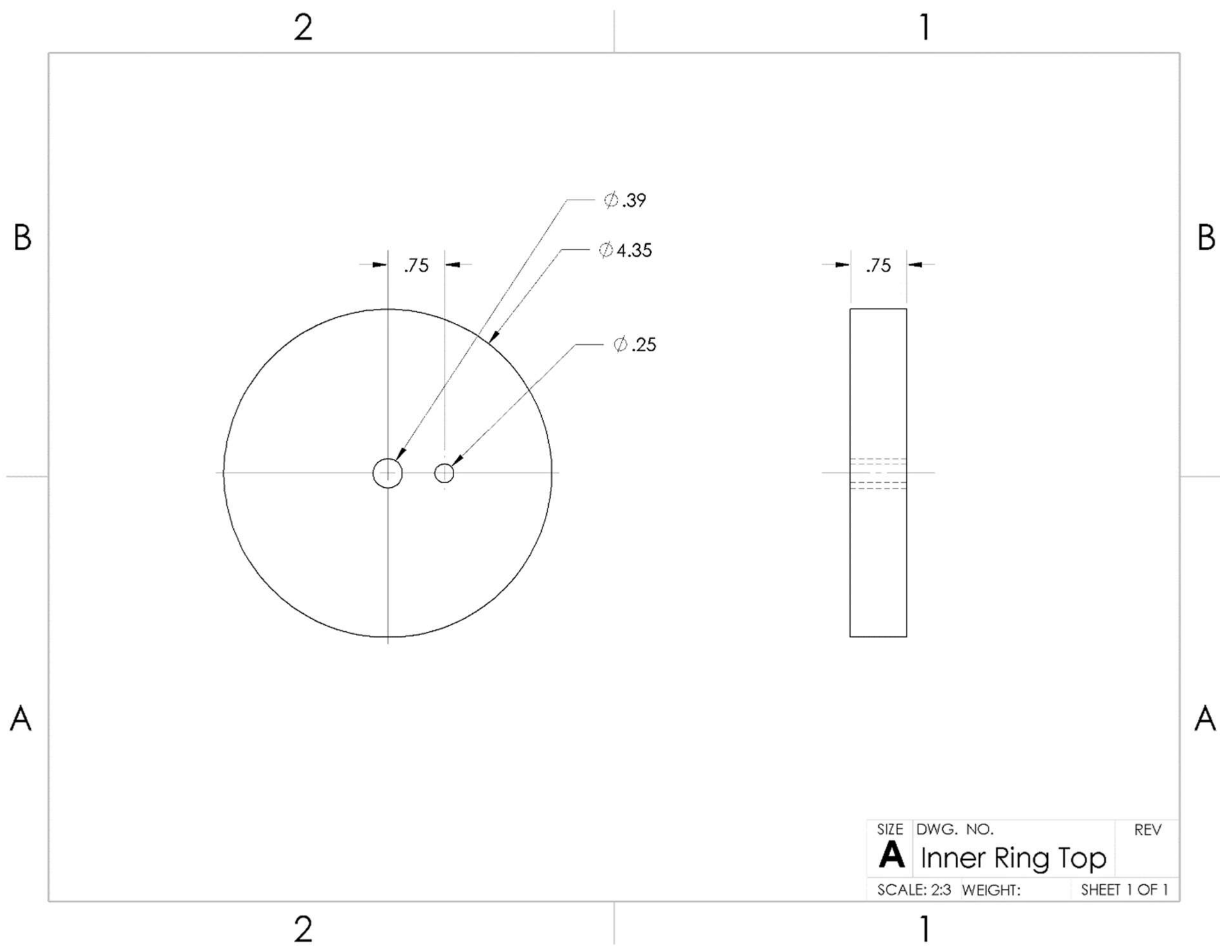

Figure 7: Locking Mechanism Inner Ring Top Drawing

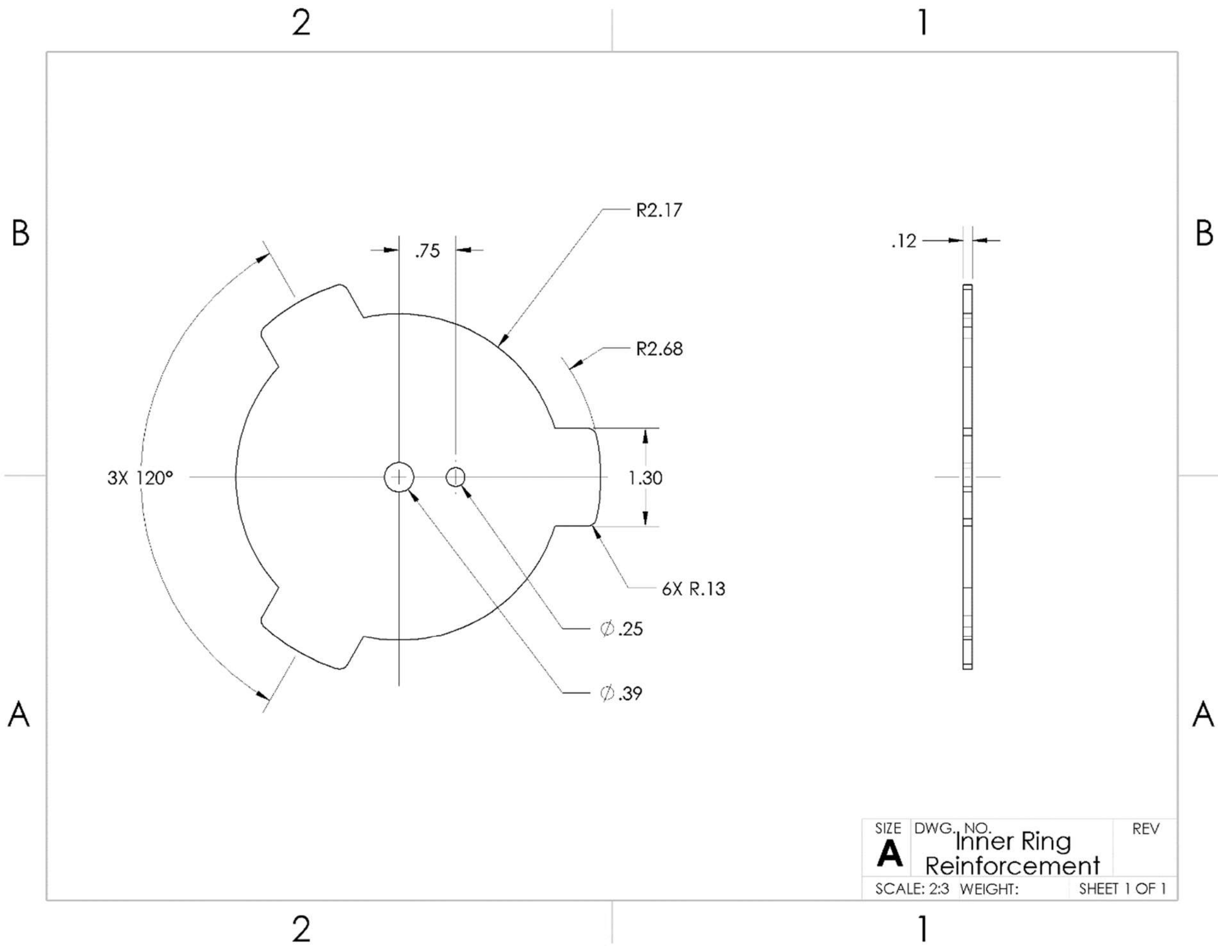

Figure 8: Locking Mechanism Inner Ring Reinforcement Drawing

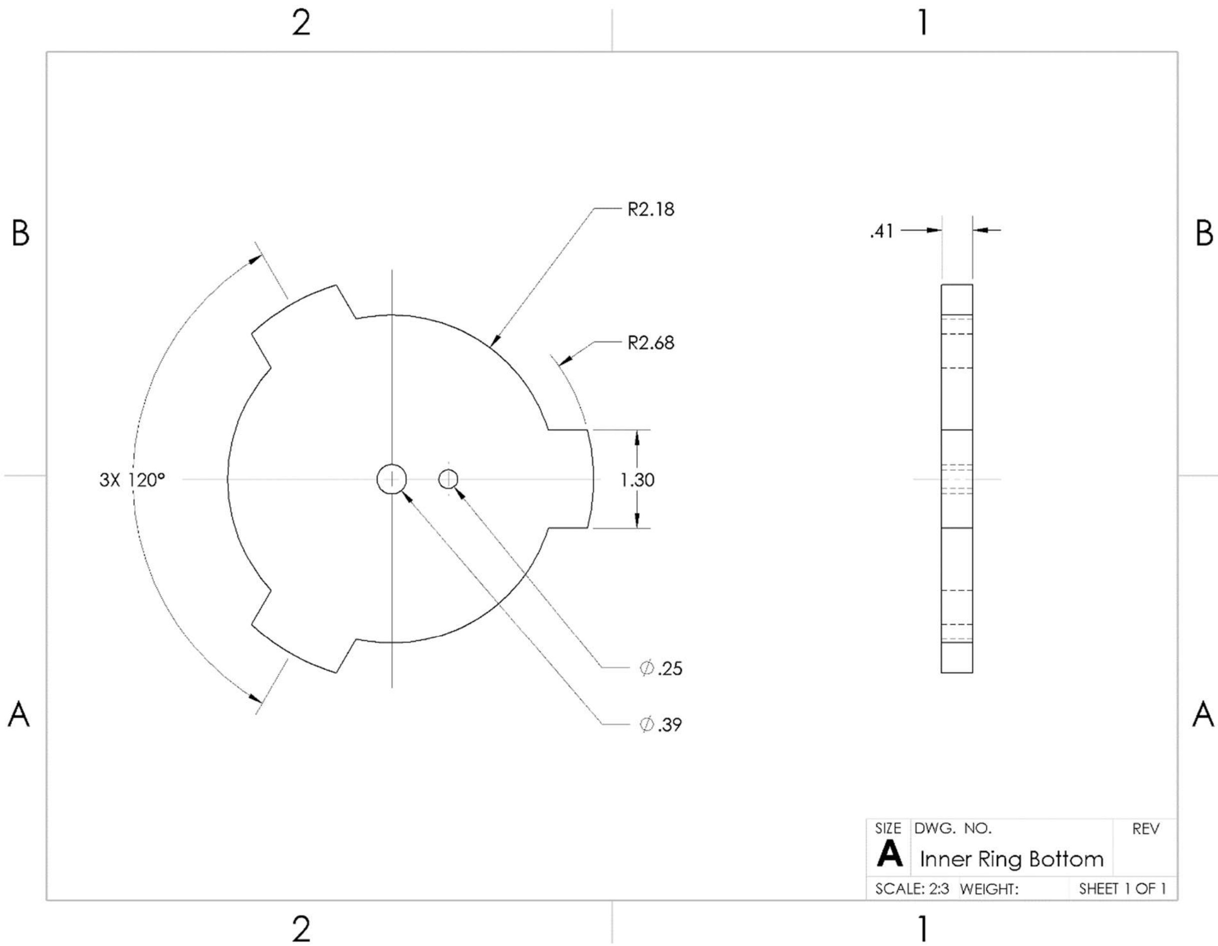

Figure 9: Locking Mechanism Inner Ring Bottom Drawing

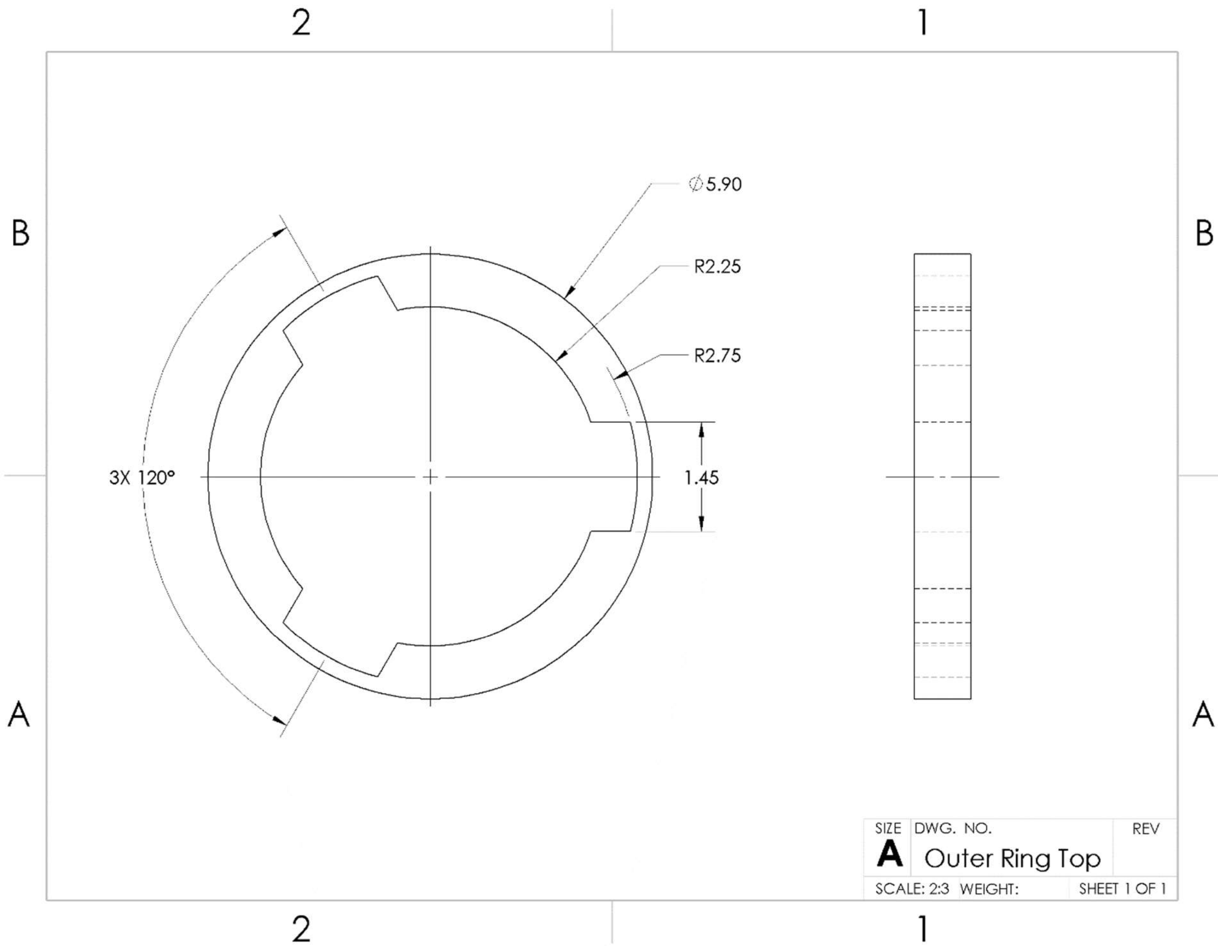

Figure 10: Locking Mechanism Outer Ring Top Drawing

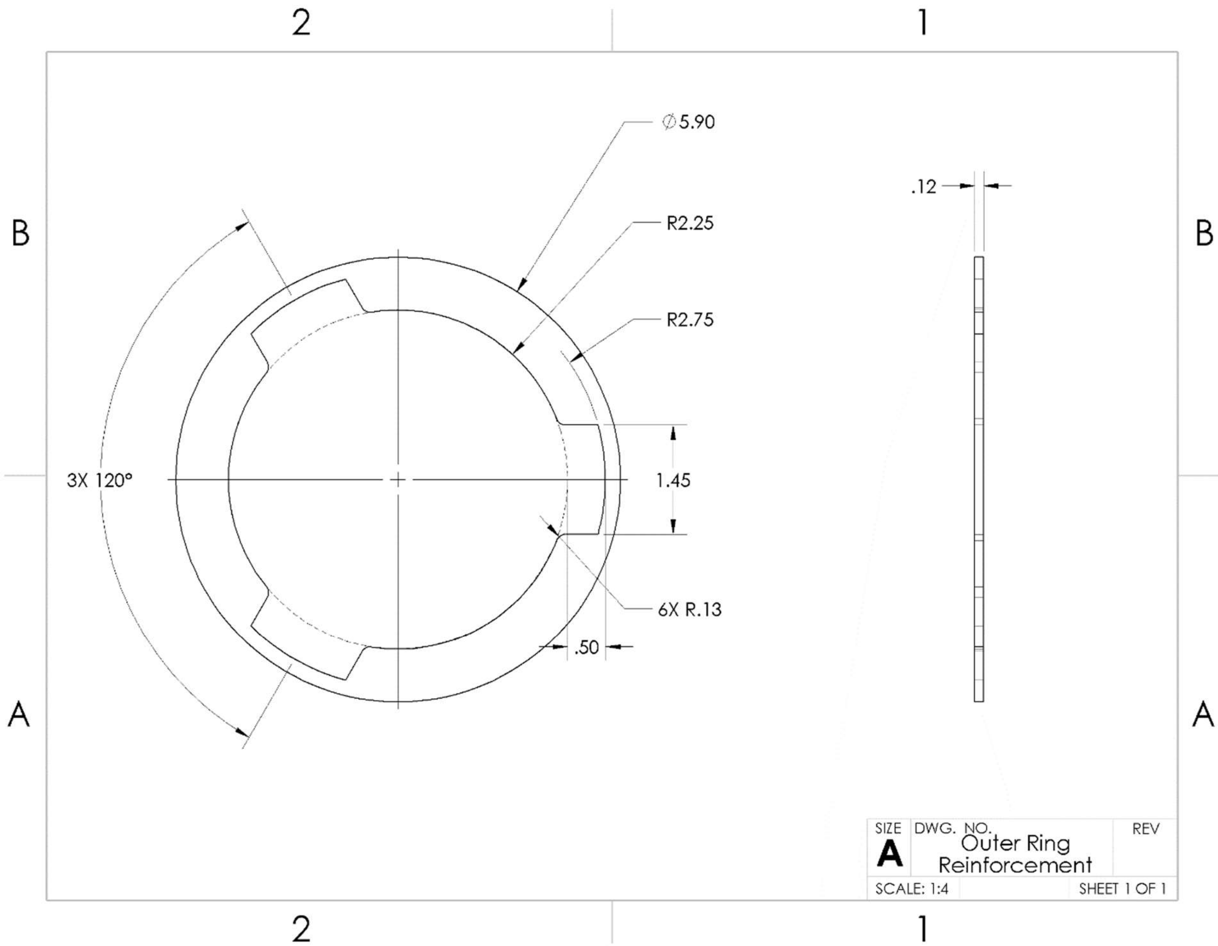

Figure 11: Locking Mechanism Outer Ring Reinforcement Drawing

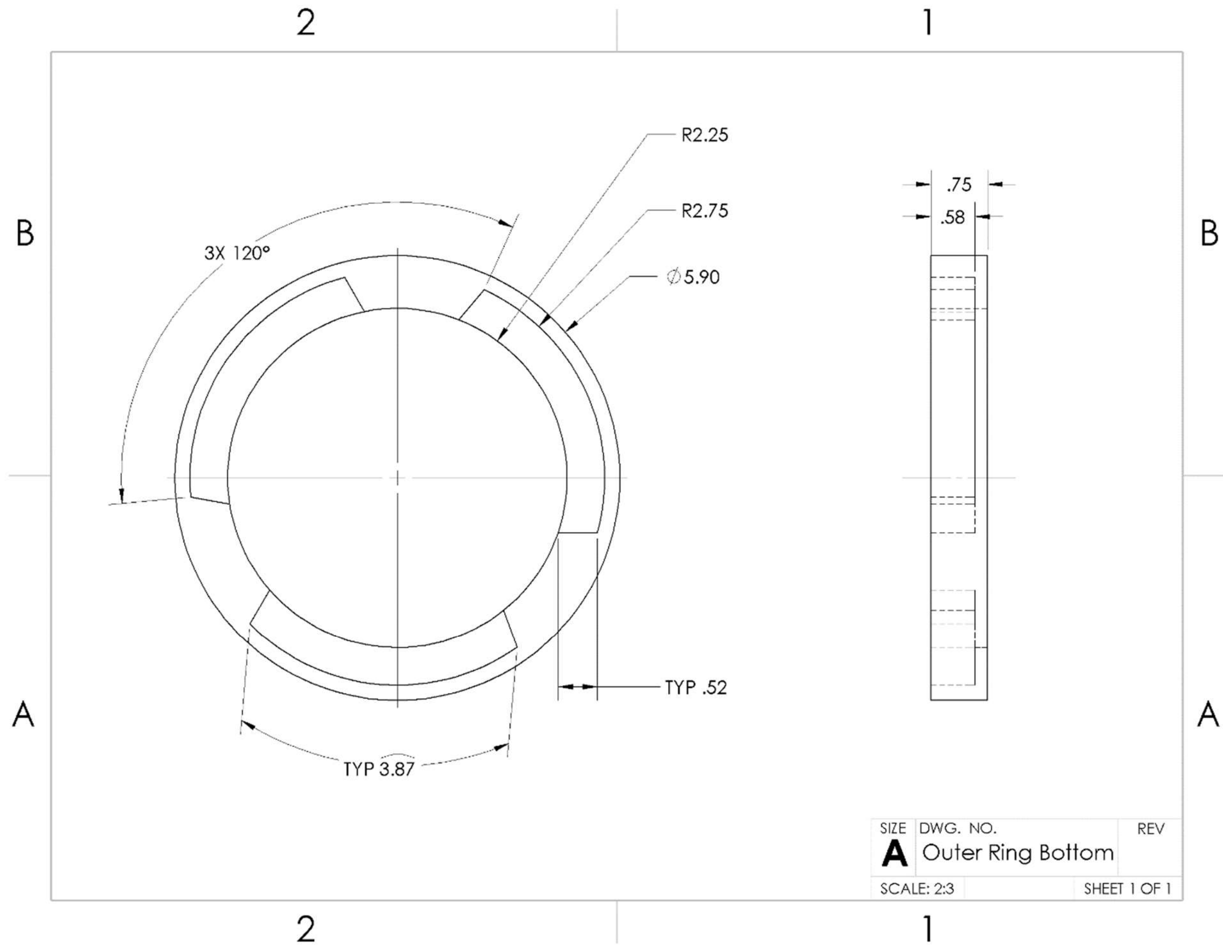

Figure 12: Locking Mechanism Outer Ring Bottom Drawing

A diagram of general spacing with in the upper body tube is found below. More detail on the rover and REA will be given in their respective sections to omit repetition.

Lower Body Tube

Estimated Rocket Vehicle Section Weight (with motors before motor burnout): 11.16 lb.
Estimated Rocket Vehicle Section Weight (with motors after motor burnout): 8.49 lb.
Estimated Rocket Vehicle Section Weight (without motors): 4.63 lb.

The lower body tube vehicle section is composed of eight different components:

1. The lower body tube parent component
2. The centering ring, of which there are two: the forward is used as an anchor point for the main parachute assembly to the nose cone parent component and as a stabilizing anchor point for securing the phenolic tube and thus the motor to the lower body tube parent component, and the rear which acts solely as another anchor point at the rear of the phenolic tube.
3. The eyebolt, which attaches the drogue parachute assembly to the bulkhead and by extension the lower body tube parent component.

4. The quicklink, which secures the drogue parachute assembly to the eyebolt.
5. The nut, which fastens the eyebolt to the bulkhead.
6. The motor mount, which serves as a housing for the motor.
7. The trapezoidal fins, which serve to provide stability to the rocket during flight.
8. The fin securement mechanism (FSM), which serves as an anchor point, brace, and alignment device for the trapezoidal fins so that they remain attached and straight during flight and landing.
9. The aluminum centering ring, which serves as a flexible brace for the lower body tube parent component for the motor.

Table 3: Lower Body Tube Section Components

Part	Material	Dimensions
Lower Body Tube	Carbon Fiber	Length: 25 in. Thickness: 0.07 in. Outer Diameter: 6 in.
	Carbon Fiber is the preferred material of choice for the body tubes, as it is both stronger and lighter in comparison to fiberglass, though is not as competitive when comparing cost or radiolucency. Due to the large weight of the rocket, the necessity for a strong body tube for landing and payload survival becomes paramount, as well as ensuring a higher apogee capability at the same weight. As such, carbon fiber was selected over fiberglass.	The body tube at minimum must be long enough to house half the coupler, the phenolic tube, the drogue chute assembly, and the centering rings. As can be seen above, the length is enough to have space dedicated to all of the aforementioned parts.
Centering Ring	Pine Wood and Epoxy	Thickness: 0.5 in. Outer Diameter: 5.9 in. Inner Diameter: 2.25 in.
	Pine wood is selected as the base material due to its relative ease of sourcing, price point, and ability to precisely manufacture in student engineering and manufacturing shops. Epoxy will be used as the bonding adhesive between the bulkhead and the body tube interior wall, as well as between different layers of the pine wood, as it is the stronger adhesive in comparison to polyester resin, despite its increased price point.	The dimensions are given so the centering is thick enough to secure an eyebolt to which the drogue parachute recovery assembly is attached and also to withstand the loading forces experienced during the drogue chute assembly deployment.
Eyebolt	Stainless Steel	Length: 3 in. Diameter: 1 in.
	Stainless steel is the material of choice for eyebolts due to their high strength, a necessary consideration for the loading forces presents during the drogue parachute assembly's deployment.	The diameter of the eyebolt must be wide enough such that a quicklink can be fed through the eye and secured, serving as the attachment point of the drogue parachute assembly.

		Additionally, the length of the eyebolt's shank must be long enough to pass through the entirety of the centering ring, and still have enough length left to fasten a nut to the eyebolt, securing the eyebolt against the centering ring and thus the lower body tube parent component.
Quicklink	Stainless Steel	Length: 1 in.
	Stainless steel is the material of choice for quicklinks due to their high strength, a necessary consideration for the loading forces presents during the drogue parachute assembly's deployment.	The quicklink must be long enough to secure both the eyebolt eye and the shock cords together, and thick enough to withstand the loading forces of the drogue parachute assembly's deployment.
Nut	Stainless Steel	Thread Diameter: 0.5 in.
	Stainless steel is the material of choice for nuts due to their high strength, a necessary consideration for the loading forces present during the drogue parachute assembly's deployment.	The nut's inner diameter must match the shank diameter of the eyebolt for the nut to be effective in securing the eyebolt to the centering ring.
Motor Mount / Phenolic Tube	Phenolic Tubing	Length: 16 in. Outer Diameter: 2.25 in. Inner Diameter: 2.21 in. Thickness: 0.2 in.
	Phenolic tubing is the material of choice for the motor mount, as it is a material stiff and sturdy enough to handle the forces involved with the motor burning and not deform under these forces, it is cost effective in comparison to stronger materials such as carbon fiber and fiberglass, and as comparatively lighter to the aforementioned materials.	Most of the dimensions are given by the manufacturer/vendor of the phenolic tubing, and so when purchasing the buyer needs to make sure that the phenolic tubing is wide and long enough for the motor to fit.
Trapezoidal Fins	Carbon Fiber	Refer to FSM and Fin drawing
	Carbon Fiber is the preferred material of choice for the trapezoidal fins, as it is both stronger and lighter in comparison to fiberglass, though is not as competitive when comparing cost. Due to the large weight of the rocket, the necessity for a strong body tube for landing and payload survival becomes paramount, as well as ensuring a higher apogee capability at the same weight. As such, carbon fiber was selected over fiberglass.	The sizing of the trapezoidal fins is directly a result of trying to influence the stability of the rocket in flight while ensuring a generally streamlined aerodynamic shape for good airflow.

FSM	ABS Plastic	Refer to FSM and Fin drawing
	ABS Plastic is selected as the material that the FSM will be made out of as the material is used in the 3D printers available and allows a greater capability of conforming the structural design to team design parameters.	The FSM must be able to fully encircle the phenolic tubing, and provide enough thickness for there to be
Aluminum Ring	Aluminum	Thickness: 0.15 in. Inner Diameter: 3. in. Outer Diameter: 5.86 in.
	Aluminum is the material of choice for the motor retainer's centering ring, as the force of thrust during motor burn is applied to this ring directly; as such, a material with a high enough melting point, is non-brittle or somewhat elastic, and can be machined here at the shops at UCLA is desirable. Aluminum is the greatest balance between strength, elasticity, and cost, and is among the highest strength materials that can be used on the machinery needed.	The aluminum ring is mounted at the very end of the phenolic tube, and so must conform to its diameter for the inner diameter. As for the outer diameter, it is more structurally sound to support the aluminum ring on the rim/lip of the body tube rather than the interior wall, so the outer diameter of the aluminum ring matches the outer diameter of the body tube.

The placement overview of the lower body tube can be seen below.

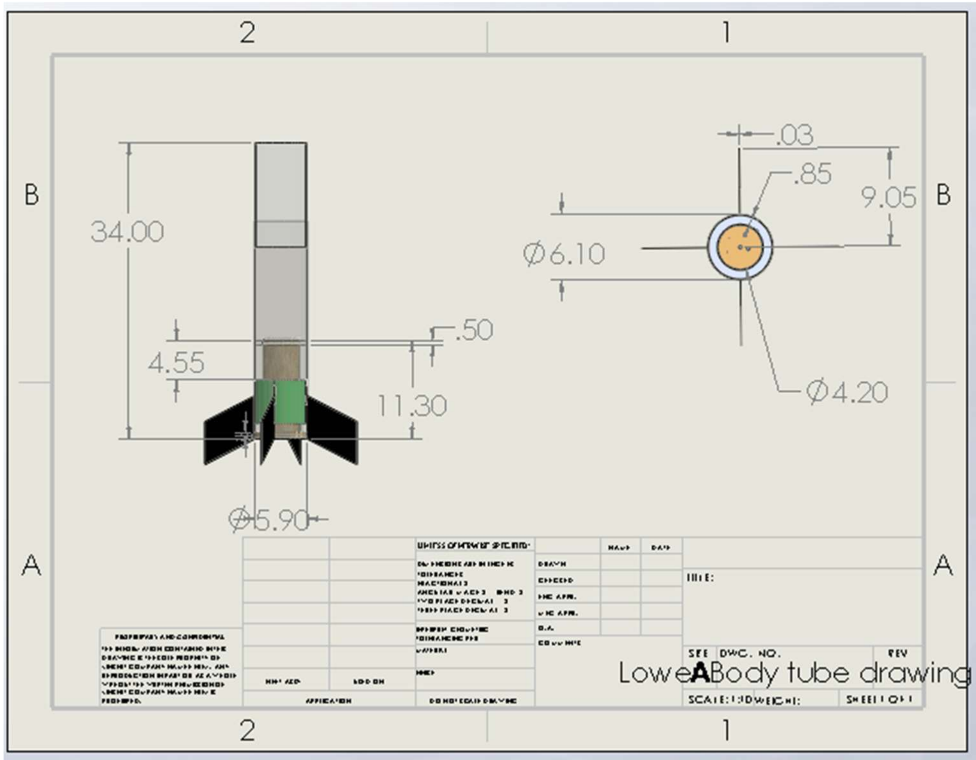

Figure 13: Lower Body Tube Drawing

One component that was specifically focused on was the FSM. Between the CDR and FRR, the structures team wanted to increase the structural integrity of the fins by creating larger fin tabs. To support this, it was decided the FSM will be printed out of PLA plastic rather than cut out of pine. This allows for longer fin tabs without sacrificing manufacturing precision. It also ensures that the fins will be perfectly vertical when manufacturing since a 3D printer will be aligning it. Below is a physical and dimensional view of the FSM holding the four fins and being supported by the phenolic tube.

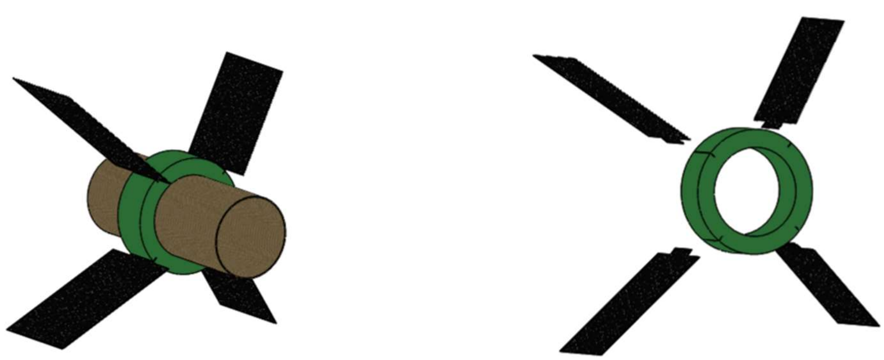

Figure 14: FSM Overview

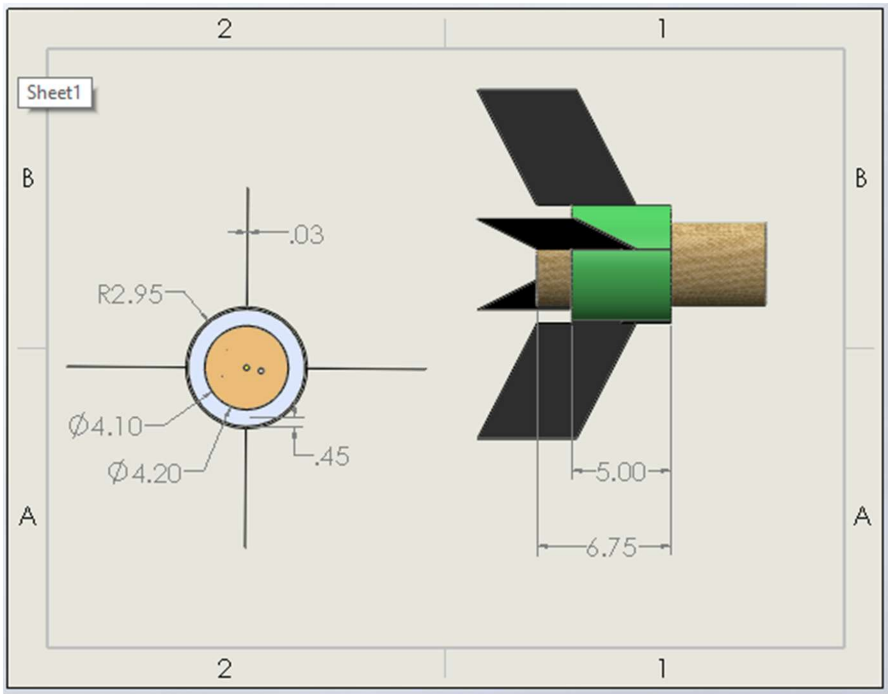

Figure 15: FSM Drawing

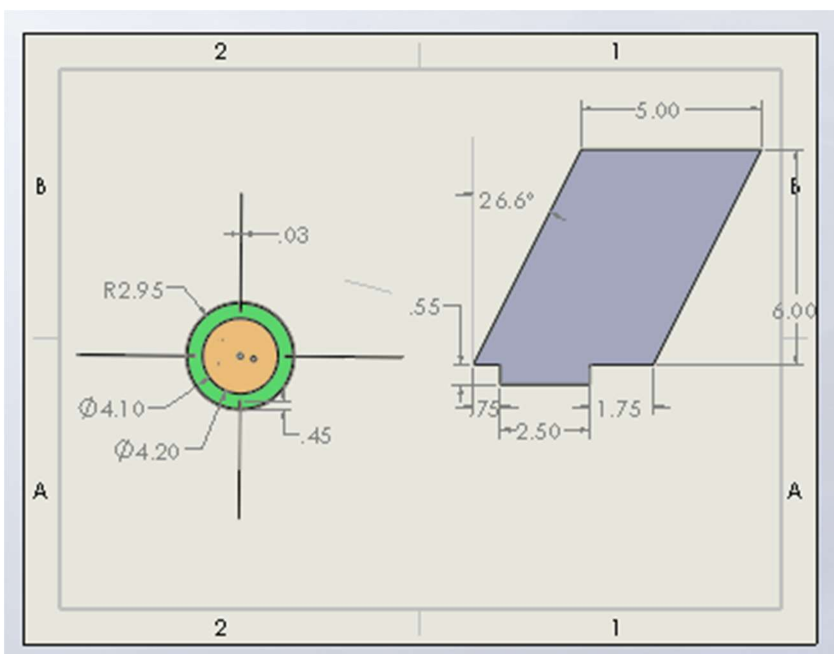

Figure 16: Fin Drawing

2.1.4. Motor Alternatives

To maintain the target altitude from the PDR milestone (3600 ft), a new motor is needed to adjust for the added weight of the new payload. There are three candidates for the motor selection that are being considered, given below. All motor data is taken from OpenRocket.

Alternative Design 1 Motor: AeroTech K458W-0- not selected

Alternate Design 1:

The AeroTech K458W-0 motor is a candidate mainly because it maintains a similar predicted apogee and stability as before. The new payload mission added an additional 6.62 lbs. to the rocket so a more powerful motor is needed to reach the target apogee of 3600 feet. The stability of the rocket also needs to be carefully considered when choosing a motor. For the team's rocket, the effects of over stability need to be considered due to the placement of the new payload being in the nosecone. An over stable rocket can lead to weathercocking amongst other unforeseen consequences. From the three candidate motors, this motor provides the rocket one of the lowest stabilities out of all the motors with a stability of ~3.05 calibers. This lower stability avoids any potential consequences from an over stable rocket. On the other hand, this motor offers a large increase in the simulated apogee (from 3526 feet to ~3663 feet). This is an issue because the simulated apogee from both RockSim and OpenRocket is a lot higher than the target apogee which goes against the mission predictions as well as the mission success criteria. This is the main reason why this motor will not be chosen. Also, the launch vehicle would be more susceptible to wind speed and instability because the average thrust of the motor is very low which produces a lower lift-off velocity. The low average thrust of the motor also provides a very low thrust to weight ratio which is an issue the rocket can become unstable if there is not enough thrust to keep it on course. The short length of this motor provides the team with more space in the lower body tube but the increased size of the diameter of this motor leaves less room for the fin tabs.

Table 4: Alternate Design 1 Motor – AeroTech K458W-0 Motor Data

Motor Diameter	3.86 in	**Motor Length**	10.8 in
Average Thrust	424 N	**Max Thrust**	623 N
Burn Time	6.22 s	**Total Motor Mass**	6.97 lbs.
Total Impulse	2643 Ns	**Propellant Mass**	3.14 lbs.
Thrust to Weight Ratio	3.21	**Post-burn Mass**	3.83 lbs.

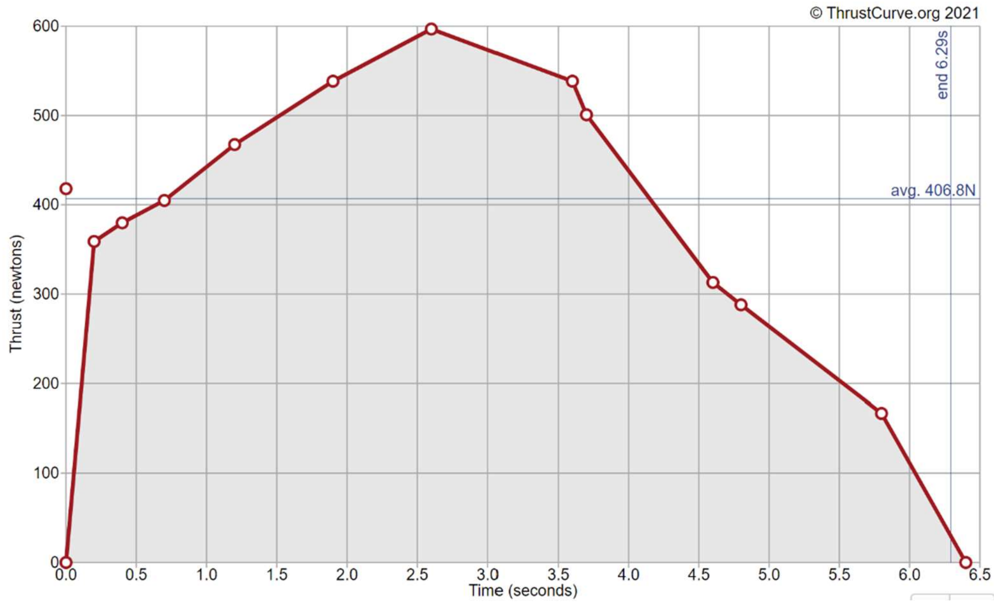

Figure 17: Motor Thrust Curve - AeroTech K458W-0

The motor specifications along with the motor thrust curve are shown above for the AeroTech K458W-0 motor. After looking at all candidate motors, this motor is not the primary candidate. This choice was made based on this motor's effect on the stability and predicted apogee of the launch vehicle.

Alternative Design 2 Motor: AeroTech K560W-P- not selected

Alternate Design 2:

The AeroTech K560W-P is mainly a candidate motor because it produces a similar simulated apogee as before. This motor produces a simulated apogee of ~3619 feet compared to 3526 feet before the new payload mission. This motor creates a more accurate simulated apogee to the target apogee of 3600 feet than the alternate design 1 motor. One drawback of this motor is that it makes the stability of the rocket turn out to be 3.30 calibers which is the highest of all the candidate motors. Due to the high stability created by the motor, the AeroTech K560W-P motor will not be used. This higher stability makes the rocket susceptible to potential consequences from an over stable rocket such as flying into the wind. As with alternate design 1 motor, this motor has a low average thrust which creates a low thrust to weight ratio. This can become an issue during flight if there is not enough thrust to keep the rocket on course. Out of the three candidate motors, this motor is most like the original motor (AeroTech K1103X-14) in terms of size. The length of the motor is shorter than the original motor, creating a bit more space in the lower body tube for the shock chords. On the other hand, the diameter of this motor is larger than the original motor, decreasing the room for the fin tabs.

Table 5: Alternate Design 2 Motor – AeroTech K560W-P Motor Data

Motor Diameter	2.95 in	**Motor Length**	15.6 in
Average Thrust	551 N	**Max Thrust**	789 N
Burn Time	4.47 s	**Total Motor Mass**	5.98 lbs.
Total Impulse	2467 Ns	**Propellant Mass**	3.10 lbs.
Thrust to Weight Ratio	4.32	**Post-burn Mass**	2.88 lbs.

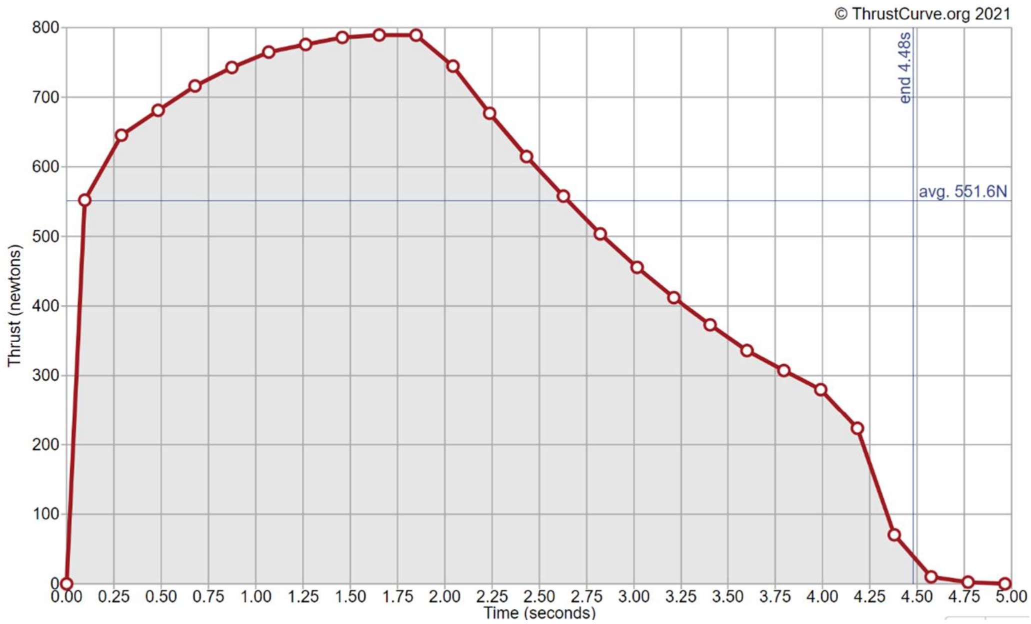

Figure 18: Motor Thrust Curve - AeroTech K560W-P

The motor specifications along with the motor thrust curve are shown above for the AeroTech K560W-P motor. After looking at all candidate motors, this motor is not the primary candidate. This choice was made based on this motor's effect on the stability and low thrust to weight ratio of the launch vehicle.

Alternative Design 3 Motor: Cesaroni Tech. K1620-Vmax-0- selected

Alternate Design 3:

The Cesaroni Technology Inc. K1620-Vmax-0 motor will be the selected motor for this launch vehicle to carry out the new payload mission. This motor is the primary motor because it provides a simulated apogee closest to the target apogee (3560 feet, 3600 feet) while keeping a very reasonable stability at 3.06 calibers. With this low stability compared to the alternative design 2 motor, the launch vehicle will not be as susceptible to consequences of over stability and will have a better chance of flying as close to the mission predictions as possible. The combination of low stability and accurate simulated altitude is the reason why this motor is the primary candidate.

Table 6: Alternate Design 3 Motor – Cesaroni Tech. K1620-Vmax-0 Motor Data

Motor Diameter	3.86 in	**Motor Length**	9.45 in
Average Thrust	1616 N	**Max Thrust**	1845 N
Burn Time	1.5 s	**Total Motor Mass**	6.78 lbs.
Total Impulse	2433 Ns	**Propellant Mass**	2.67 lbs.
Thrust to Weight Ratio	12.31	**Post-burn Mass**	4.11 lbs.

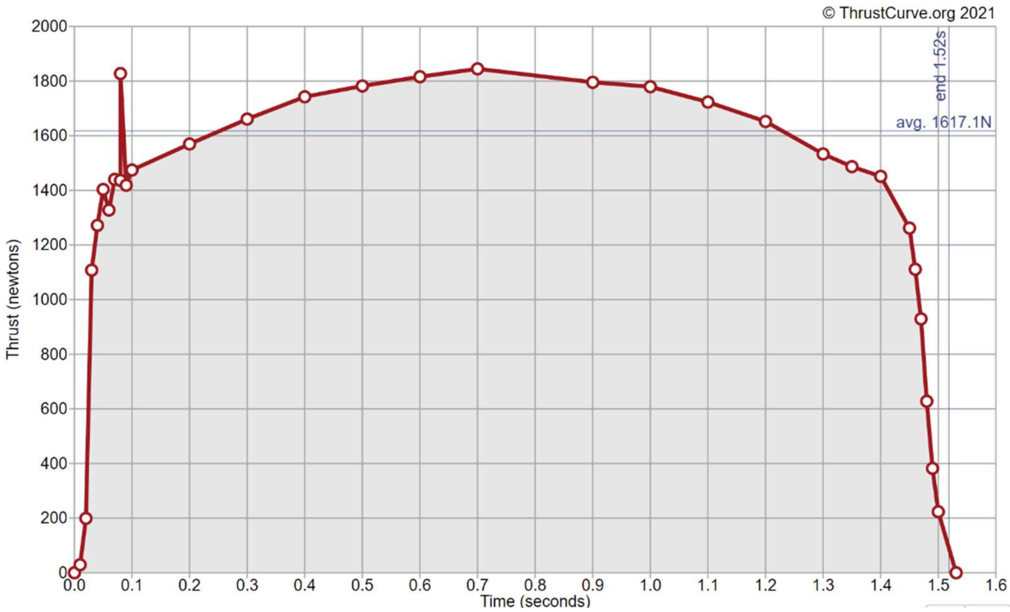

Figure 19: Motor Thrust Curve - Cesaroni Tech. K1620-Vmax-0

The motor specifications along with the motor thrust curve are shown above for the Cesaroni Tech. K1620-Vmax-0 motor. After looking at all candidate motors, this motor is the primary candidate and will be used for the mission performance predictions. This choice was made because this motor kept the stability (~3.06 calibers from OpenRocket) and simulated apogee (~3560 feet from OpenRocket) relatively low compared to the other motors. Another reason this motor was chosen over the others is because the behavior of this motor was very similar to the original motor. Both this motor and the original have very quick burn times (1.5 and 1.65 seconds) and high initial thrusts so many of the issues from high initial thrust motors have been considered and tested on already such as fin flutter for this launch vehicle. Both motors are very similar so every test and precaution taken for the original motor will carry over to this new motor since they have very similar behaviors.

2.2. Recovery Subsystem

2.2.1. Design Review

The following section will cover the recovery subsystem design at a component level of all structural and electrical components. Testing plans and completed simulations will also be included in this section to verify that the vehicle is robust enough to withstand the expected loads.

It should be noted that there were no drastic changes to the overall design of the recovery system. The same structural and electrical components will be used. The only changes made to the recovery system are the increased sizing of the drogue and main parachutes to accommodate for the increased weight of the rocket from the new nosecone and payload and changing the bulkhead in the nosecone to a locking mechanism, the same one used in the avionics bay. This locking mechanism will have a plastic cover on top of it to protect the payload container from being punctured by the eyebolt. This locking mechanism will now be used in the recovery system instead of the original bulkhead when the drogue parachute deploys.

2.2.1.1. Structural Elements

Structural components of the vehicle's recovery system include the bulkheads, eyebolts, quicklinks, and locking mechanism discussed earlier. Since placement of each component has already been outlined in the Final Rocket Design, specific design choices as well as testing strategies will be discussed here. A design diagram showing only recovery hardware is shown below to emphasize this subsystem.

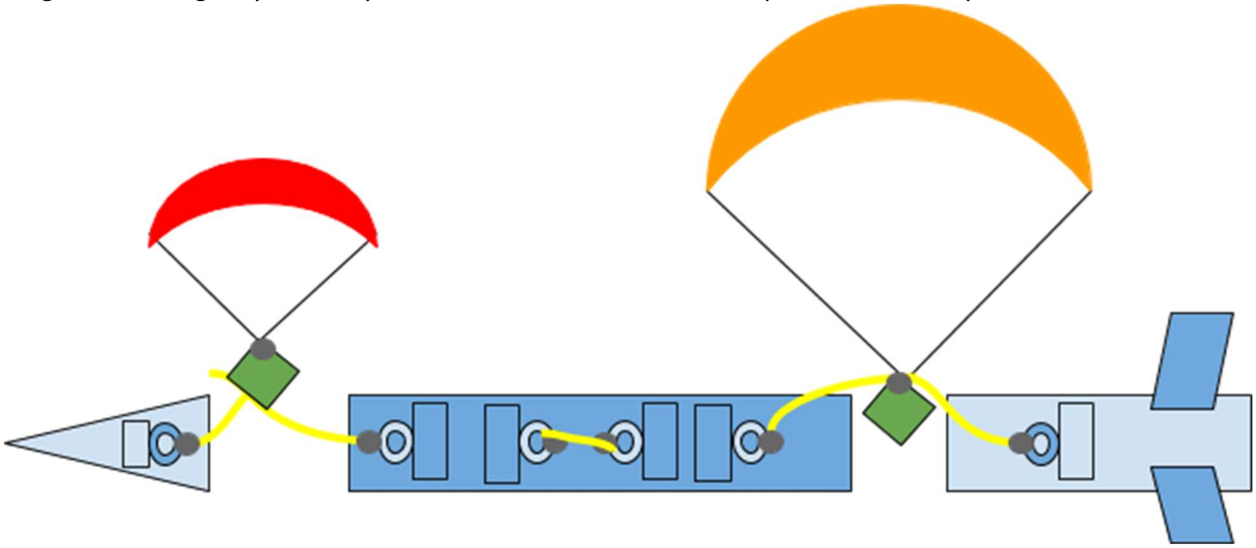

Figure 20:Recovery System Structural Overview

Above, the orange and red hemispheres are the main and drogue parachute, respectively. The rectangles within each parent component are the bulkheads or load bearing fixtures. The loops connected to each of these are a representation of the eyebolts. All grey dots are depictive of quicklinks. The green squares are firecloths that will ensure no damage to flammable portions of the recovery hardware upon ejection charge firing.

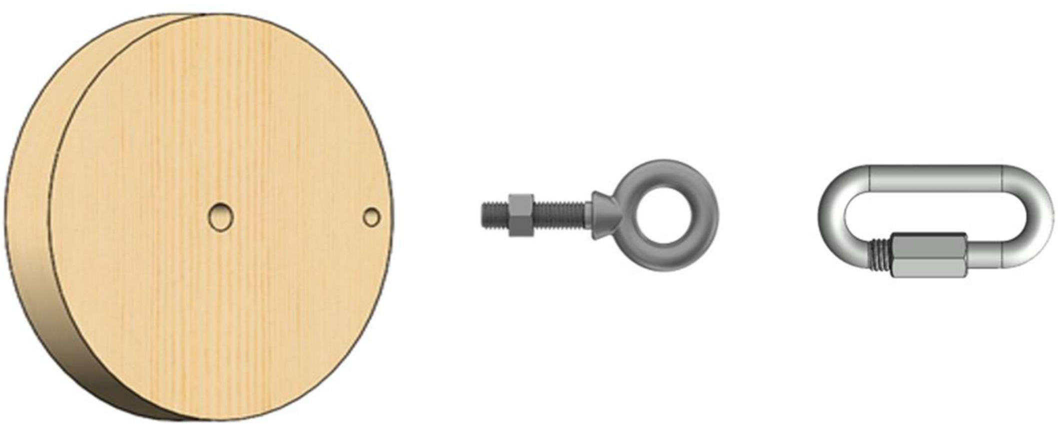

Figure 21: Structural Attachment Hardware

Pictured above is the sequence of attachment hardware from a bulkhead to the parachute shroud lines. Bulkheads were chosen to be comprised of 0.75" pine due to its strength and ease of manufacturing. Securement strategy from the bulkhead to the parachute shock cords was chosen to be an eyebolt secured to a quicklink due to their strength. Quicklinks have a capacity of 1,400 lbs., while eyebolts chosen to have a vertical capacity of 1,200 lbs., both values far surpass expected flight forces. Bulkheads are secured to the body tubes through use of epoxy and screws. Epoxy used is called RocketPoxy and has a tensile strength of 7,600 psi, well above expected flight forces.

Below is a testing plan for all recovery component of the vehicle. Virtual testing has been completed and physical testing has been outlined. Due to the nature of the design division, physical testing is not planned to be completed.

Table 7: Nosecone Locking Mechanism Structural Integrity (Virtual)

Objective:	Ensure that forces experienced during launch do not exceed the simulated yield strength.
Success Criteria:	Maximum force felt by the locking mechanism during launch does not surpass the expected yield strength.
Variables	118.5 lbf of shear force (Factor of safety: 4)
Constants:	• Locking mechanism geometry • Aluminum reinforcement sheet geometry • Locking mechanism material (all values are mean estimates of pine wood roughly perpendicular to the direction of the grain) ○ Elastic Modulus: 1460000 psi ○ Poisson's Ratio: 0.35 ○ Mass Density: 0.0156 lb./in^3 ○ Yield Strength (shear): 899 psi
Step-by-Step Execution:	1. Fix outer tabs of locking mechanism. 2. Place shear force of 118.5 lbs. on the hole that will be containing eyebolt. 3. Evaluate Results.
Relevant Safety Concerns:	None.
Status/Results:	Planned
Justification:	Nosecone locking mechanism failure could cause detachment of nosecone from recovery hardware, posing a hazard to personnel.
Possible Necessary Changes:	If failed, a thicker nosecone locking mechanism must be implemented.

Status/Results: (if completed):

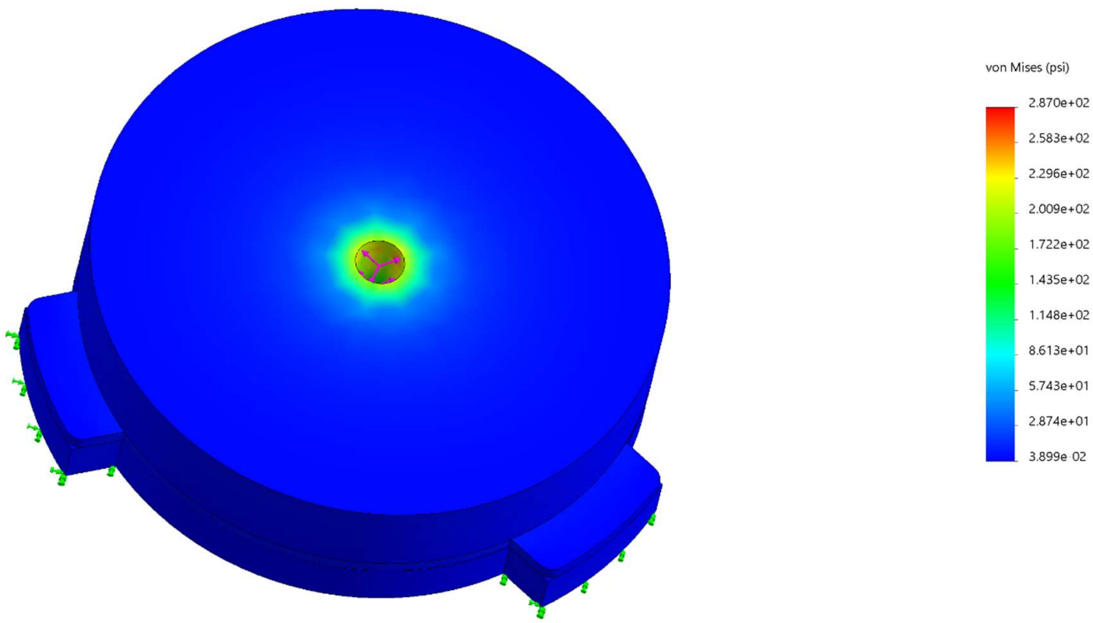

Figure 22: Nosecone Locking Mechanism Testing Results

Table 8: Nosecone Bulkhead Interface Testing

Objective:	Determine if the interface between the nosecone and its bulkhead will withstand the force of the drogue chute deploying.
Success Criteria:	Shear strength of the epoxy exceeds the force imposed by the drogue chute deployment.
Variables:	Force: 78 lbf of shear force
Constants:	1. Contact area between the two components. a. Can be found by finding the surface area of the bulkhead. 2. Epoxy shear strength a. 7,600 psi
Step-by-Step Execution:	• Divide the total force by the total contact area. • Compare to the strength of the epoxy used. • Examine results
Relevant Safety Concerns:	None.
Status:	Planned
Justification:	If interface fails nosecone may detach from recovery hardware, posing a safety concern.
Possible Necessary Changes:	If failed another epoxy could be altered or bulkhead could be extended so more contact area is created.

Results (if completed):

Equations used to complete this test are listed below.

$$\text{Area of Interface} = \pi * D * t\_bulkhead$$

$$\text{Stress} = \text{Shear Force} / \text{Area of Interface}$$

With known variables this becomes the following.

$$14.14\ [in] = \pi * 6\ [in] * 0.75\ [in]\ \mathit{14.14\ [in] = \pi * 6\ [in] * 0.75\ [in]}$$

$$5.52\ psi = \frac{78\ [lbf]}{14.14\ [in]}$$

This is well below the manufacturer's maximum tensile strength of the epoxy, so the test is passed.

Table 9: Retention System Testing

Objective:	Analyze the effect of the fixed nuts on the pine bulkhead and aluminum reinforcement sheet due to the force experience by the eyebolt
Success Criteria:	The maximum force felt by the bulkhead and aluminum sheet during launch does not exceed the expected yield strength.
Variables:	Force: 81.20 lbf of axial force

Constants:	• Aluminum reinforcement sheet geometry
	• Pine Bulkhead material (all values are mean estimate of pine wood roughly perpendicular to the direction of the grain)
	  ○ Elastic Modulus: 1460000 psi
	  ○ Poisson's Ration: 0.35
	  ○ Mass Density: 0.0156 lb./in^3
	  ○ Yield Strength (shear): 899 psi

Step-by-Step Execution:	• Fix the surface of the bulkhead and aluminum sheet in contact with the .375" nuts. • Place an axial force of 81.20 lbf on the hole that will be containing the eyebolt. • Evaluate Results
Relevant Safety Concerns:	None.
Status:	Complete.
Justification:	The pine bulkhead and aluminum sheet serve as an interface between the payload and force due to parachute deployment during launch. By examining the behavior of this retention system, we can determine the likelihood of avoiding failure and damage to the payload during flight.
Possible Necessary Changes:	No necessary changes needed since the force examined with a safety factor of 4 is significantly less than the expected yield strength of both pine and aluminum that are included in the retention assembly.

Results (if completed):

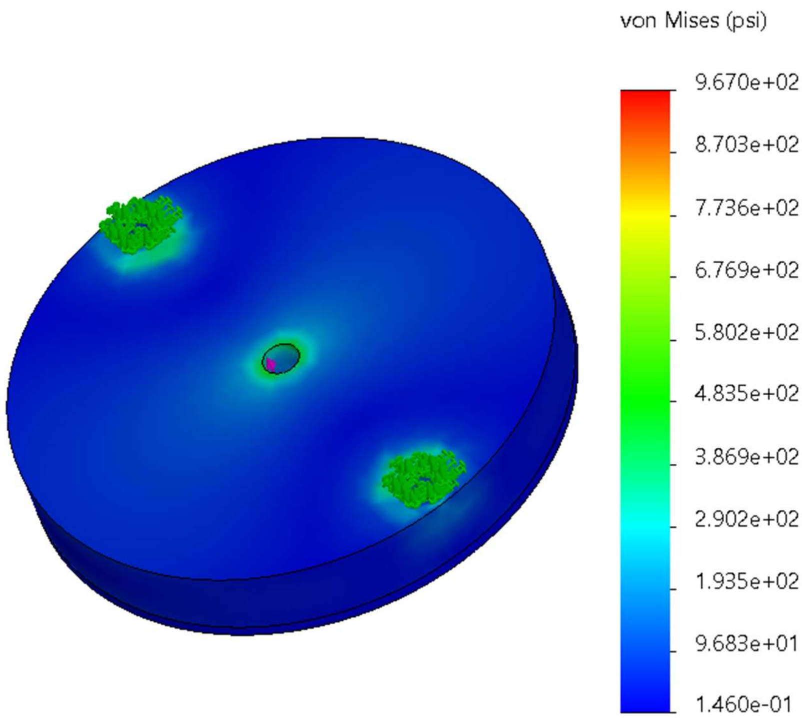

Figure 23: Retention System Testing Results

Table 10: Retention System Interface Testing

Objective:	Determine if the interface between the bulkhead and the upper body tube will withstand the force of the main chute deploying.
Success Criteria:	Shear strength of the epoxy and wood screws exceeds the force imposed by the main chute deployment.
Variables:	Force: 85 lbf of shear force

Constants:	• Contact area between the two components.
	    ○ Can be found by finding the surface area of the bulkhead.
	• Epoxy shear strength
	    ○ 7,600 psi

Step-by-Step Execution:	1. Divide the total force by the total contact area. 2. Compare to the strength of the epoxy used. 3. Examine results
Relevant Safety Concerns:	None.
Status:	Planned
Justification:	If interface fails upper body tube may detach from recovery hardware, posing a safety concern.
Possible Necessary Changes:	If failed another epoxy could be concerned or bulkhead could be extended so more contact area is created.

Results (if completed):
Equations used to complete this test are listed below.

$$\text{Area of Interface} = \pi * D * t\_bulkhead$$

$$\text{Stress}=\text{Shear Force} / \text{Area of Interface}$$

With known variables this becomes the following.

$$14.14 \text{ [in]}= \pi * 6 \text{ [in]} * 0.75 \text{ [in]} \; 14.14 \, [in]= \pi * 6 \, [in] * 0.75 \, [in]$$

$$6.01 \text{ psi}=85 \text{ [lbf]} 14.14 \text{ [in]}$$

This is well below the manufacturer's maximum tensile strength of the epoxy, so the test is passed.

Table 11: Centering Ring Structural Integrity (Virtual)

Objective:	Ensure that forces experienced during launch do not exceed the simulated yield strength.
Success Criteria:	Maximum force felt by the bulkhead during launch does not surpass the expected yield strength.
Variables:	Force: 85 lbf of shear force

Constants:	• Centering Ring geometry
	• Bulkhead material (all values are mean estimates of pine wood roughly perpendicular to the direction of the grain)
	  ○ Elastic Modulus: 1460000 psi
	  ○ Poisson's Ratio: 0.35
	  ○ Mass Density: 0.0156 lb./in^3
	  ○ Yield Strength (shear): 899 psi

Step-by-Step Execution:	1. Fix outer and inner edges of centering ring. 2. Place shear force of 85 lbf on the hole that will be containing eyebolt. 3. Evaluate Results.
Relevant Safety Concerns:	None.
Status/Results:	Completed.
Justification:	Nosecone bulkhead failure could cause detachment of lower body tube from recovery hardware, causing a major safety hazard.
Possible Necessary Changes:	If failed, a thicker centering ring or a different material must be considered.

Status/Results: (if completed):

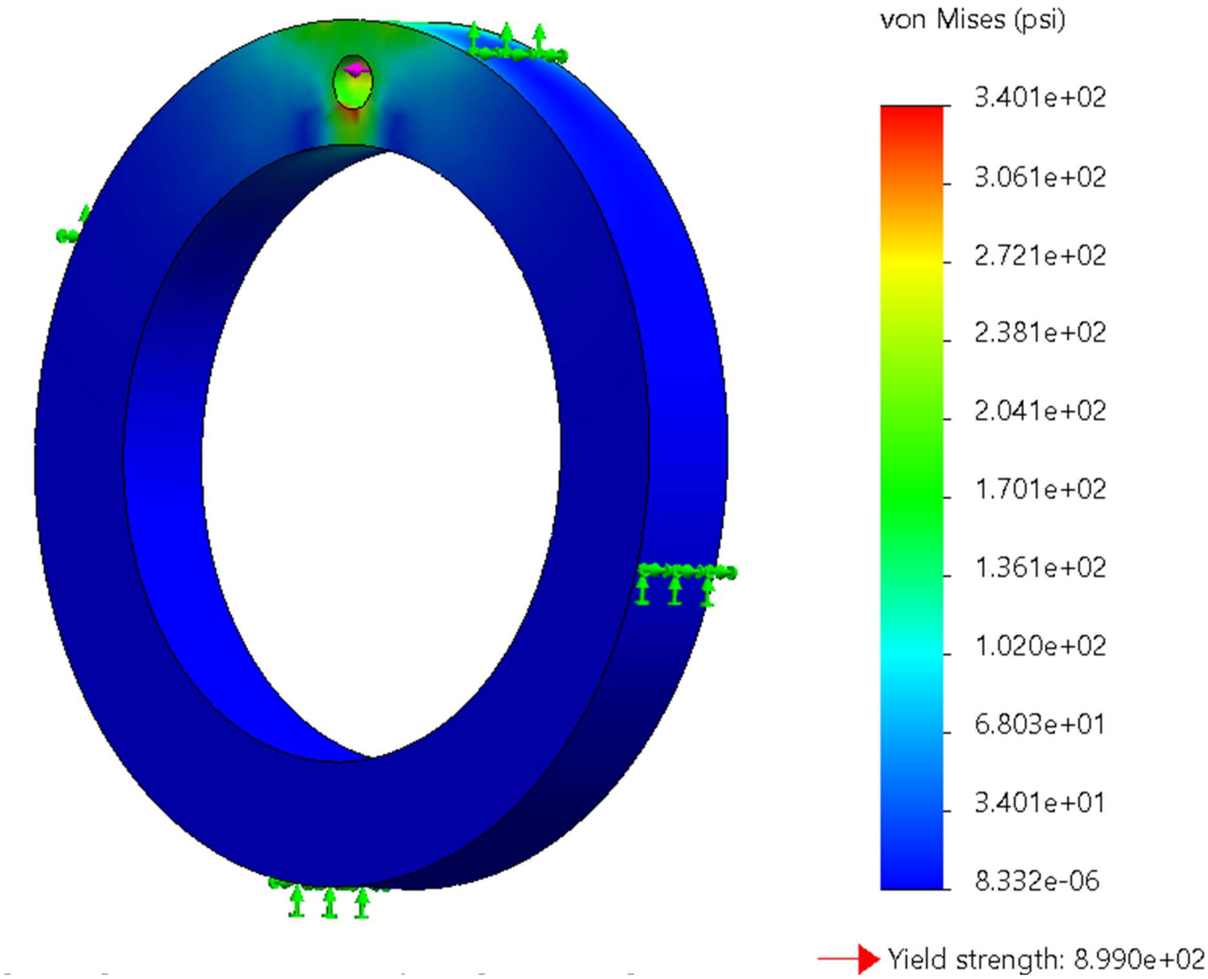

Figure 24: Centering Ring Testing Results

Table 12: Centering Ring Interface Testing

Objective:	Determine if the interface between the centering ring and the lower body tube will withstand the force of the main chute deploying.
Success Criteria:	Shear strength of the epoxy exceeds the force imposed by the main chute deployment.
Variables:	Force: 85 lbf of shear force
Constants:	1. Contact area between the two components. a. Can be found by finding the surface area of the centering ring. 2. Epoxy shear strength a. To be acquired from the manufacturer
Step-by-Step Execution:	• Divide the total force by the total contact area. • Compare to the strength of the epoxy used. • Examine results
Relevant Safety Concerns:	None.
Status:	Planned
Justification:	If interface fails lower body tube may detach from recovery hardware, posing a safety concern.

Possible Necessary Changes:	If failed another epoxy could be concerned or centering ring could be extended so more contact area is created.

Results (if completed):
Equations used to complete this test are listed below.

$$\text{Area of Interface} = \pi * D * t\_bulkhead$$

$$\text{Stress} = \text{Shear Force} / \text{Area of Interface}$$

With known variables this becomes the following.

$$14.14\ [in] = \pi * 6\ [in] * 0.75\ [in]$$

$$6.01\ psi = 85\ [lbf] 14.14\ [in]$$

This is well below the manufacturer's maximum tensile strength of the epoxy, so the test is passed.

Table 13: Inner Locking Mechanism Testing

Objective:	Analyze the stress experienced by the tabs of the inner locking mechanism composed of a top and bottom pine bulkhead and an aluminum reinforcement because of the force expended on the eyebolt.
Success Criteria:	The maximum force felt by the tabs of the inner locking mechanism on the during launch does not exceed the expected yield strength.
Variables:	Force: 74.79 lbf of axial force
Constants:	1. Aluminum reinforcement sheet geometry 2. Pine Bulkhead material (all values are mean estimate of pine wood roughly perpendicular to the direction of the grain) a. Elastic Modulus: 1460000 psi b. Poisson's Ration: 0.35 c. Mass Density: 0.0156 lb./in^3 d. Yield Strength (shear): 899 psi
Step-by-Step Execution:	1. Fix the surface of the aluminum tab reinforcement and the pine tabs that make up the inner locking mechanism. 2. Place an axial force of 74.79 lbf on the hole that will be containing the eyebolt. 3. Evaluate Results
Relevant Safety Concerns:	None.
Status:	Complete.
Justification:	The aluminum reinforcement tabs, and the pine bulkhead tabs of the inner locking mechanism are directly affected by the force exerted on the eyebolt during launch. By examining the behavior of this interface, we can determine the likelihood of avoiding failure during launch.

Possible Necessary Changes:	No necessary changes needed since the force examined with a safety factor of 4 is significantly less than the expected yield strength of aluminum and pine that make up the locking mechanism that enclosed the avionics bay.

Results (if completed):

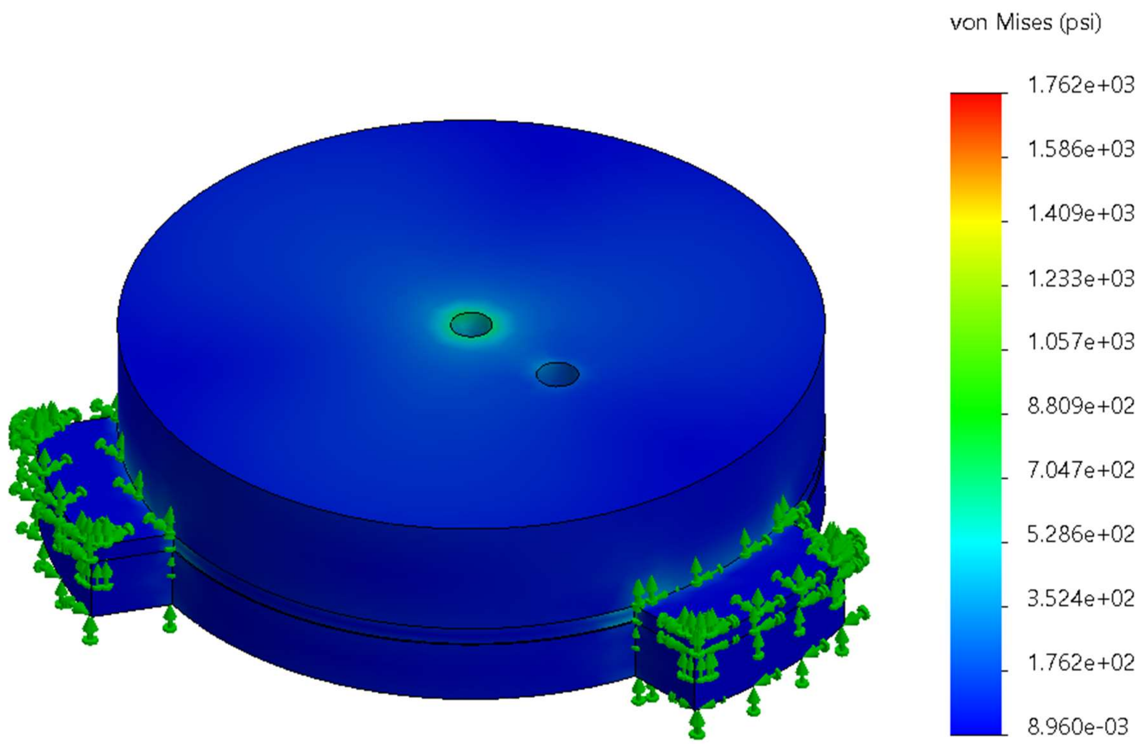

Figure 25: Inner Locking Mechanism Stress Results

Table 14: Outer Locking Mechanism Testing

Objective:	Analyze the stress experienced by the slots of the outer locking mechanism composed of a top and bottom pine bulkhead and an aluminum reinforcement because of the force expended by the tabs on the slots.
Success Criteria:	The maximum force felt by the slots of the outer locking mechanism on the during launch does not exceed the expected yield strength.
Variables:	Force: 74.79 lbf of normal force.
Constants:	• Aluminum reinforcement sheet geometry • Pine Bulkhead material (all values are mean estimate of pine wood roughly perpendicular to the direction of the grain) ○ Elastic Modulus: 1460000 psi ○ Poisson's Ration: 0.35 ○ Mass Density: 0.0156 lb./in^3

	○ Yield Strength (shear): 899 psi
Step-by-Step Execution:	• Fix the interface of the aluminum reinforcement slot and the pine bulkhead slot that make up the outer locking mechanism. • Place a normal force of 74.79 lbf on the interface that will be in direct contact with the inner tabs. • Evaluate Results
Relevant Safety Concerns:	None.
Status:	Complete.
Justification:	The aluminum reinforcement slot, and the pine bulkhead slot of the outer locking mechanism are directly affected by the force exerted by the tabs during launch. By examining the behavior of this interface, we can determine the likelihood of avoiding failure during launch.
Possible Necessary Changes:	No necessary changes needed since the force examined with a safety factor of 4 is significantly less than the expected yield strength of aluminum and pine that make up the locking mechanism that enclosed the avionics bay.

Results (if completed):

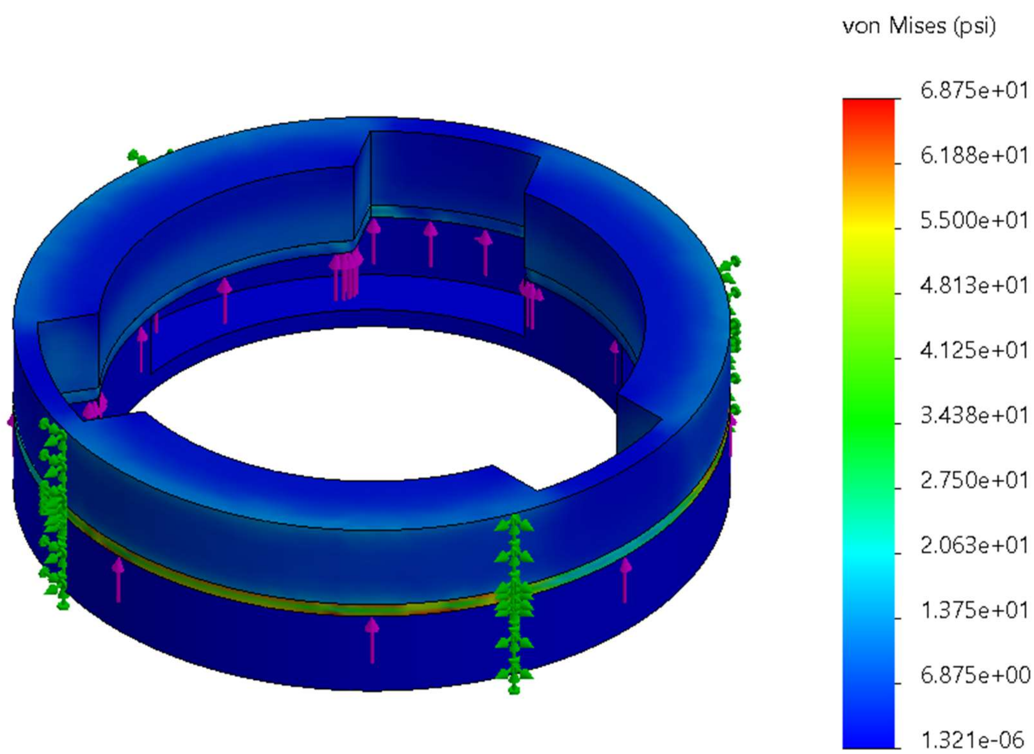

Figure 26: Outer Locking Mechanism Stress Analysis

Table 15: Locking Mechanism Test

Objective:	Test and verify the validity of the locking mechanism during the drogue chute's deployment phase
Success Criteria:	No physical cracks, warping, or any other deformities are observed
Variables:	Force: 74.79 lbf of normal force (Safety factor of 4) Pine bulkhead grain pattern (random)
Constants:	1. Aluminum reinforcement sheets and pine bulkhead geometries 2. Aluminum material properties
Step-by-Step Execution:	• Epoxy the locking mechanism to a scrap piece of body tube and wait 1 full day for the epoxy to cure. • Locate a bridge that is safe to drop heavy objects from. Ensure the test area is free of bystanders. • Place the locking mechanism against the guardrail of the bridge, ensuring the locking mechanism is unable to move after the weight has been dropped. • Tether a ~18.7 lb. weight to the locking mechanism's eyebolt using a shock cord and quicklink through the guardrail of the bridge. • Drop the weight. • Evaluate locking mechanism
Relevant Safety Concerns:	Potential harm to team members or bystanders if no precautions are taken to clear the test area prior to dropping the assembly. Communication is necessary.
Status:	Incomplete
Justification:	While virtual testing of the locking mechanism has been verified to pass with a safety factor of 4, physical testing is necessary as this assembly deals with the launch vehicle's drogue parachute deployment. Ensuring the system is capable of working even with a safety factor of 4 correlates to a safe mission.
Possible Necessary Changes:	None since the components in question will be tested with a safety factor of 4

Results (if completed):
Incomplete due to virtual nature of competition

Table 16: Locking Mechanism Interface Testing

Objective:	Determine if the interface between the locking mechanism and body tube will withstand the force of the drogue chute deploying.
Success Criteria:	Shear strength of the epoxy and wood screws exceeds the force imposed by the drogue chute deployment.
Variables:	Force: 78 lbf of shear force

Constants:	1. Contact area between the two components.
	    a. Can be found by finding the surface area of the locking mechanism.
	2. Epoxy shear strength
	    a. To be acquired from the manufacturer

Step-by-Step Execution:	• Divide the total force by the total contact area.

	• Compare to the strength of the epoxy used. • Examine results
Relevant Safety Concerns:	None.
Status:	Planned
Justification:	If interface fails vehicle may detach from recovery hardware, posing a safety concern.
Possible Necessary Changes:	If failed another epoxy could be altered or locking mechanism could be extended so more contact area is created.

Results (if completed):
Equations used to complete this test are listed below.

$$\text{Area of Interface} = \pi * D * t\_bulkhead$$
$$\text{Stress} = \text{Shear Force} / \text{Area of Interface}$$

With known variables this becomes the following.

$$30.54\ [in] = \pi * 6\ [in] * 1.62\ [in]\ 30.54\ [in] = \pi * 6\ [in] * 1.62\ [in]$$

$$2.55\ psi = 78\ [lbf] 30.54\ [in]\ 2.55\ psi = 78\ [lbf] 30.54\ [in]$$

This is well below the manufacturer's maximum tensile strength of the epoxy, so the test is passed.

2.2.1.2. Electrical Components

In order to deploy the recovery parachute system, two commercially available altimeters are used. They are the Strologger SL 100 Altimeter and the RRC3 Sports Altimeter. Both altimeters are individually powered by standard 9V alkaline batteries, which will be turned on via individual turnkey switches outside the body of the launch vehicle for easier powering of avionics electronics.

The T3 (Tiny Telematics Tracker) GPS is used to track the rocket's position, which will be placed inside the rocket's nose cone. It has the ability to track through a Bluetooth connection with an Android device, with an operational range of up to 9 miles. It is powered by 9V nickel hydride battery and a push button, which will act as an external method of turning the GPS on, as well as a way to decrease air drag.

2.2.2. Parachute Sizing

Parachutes have been sized to meet handbook requirements on maximum descent time and kinetic energy at landing. Parachute dimensions as well as reported descent rates have been summarized in the table below along with the vendor. Parachute sizing has been modified to accommodate for the added weight of the new payload mission.

Table 17: Parachute Sizes and Descent Rates

Parachute	Diameter [ft]	Weight [oz]	Coefficient of Drag	Vendor	Descent Rate [ft/s]
Drogue	2	0.6	.75	Apogee Rockets	99.2

Main	8	10	0.97	Rocketman Enterprise	21

The estimated mass of each rocket component is given below. Each of these values was used to find kinetic energies at landing, drift calculations, and descent time so that all the recovery requirements were being followed. These values were also used to determine the sizing of the parachutes.

Table 18: Weights of Each Component After Motor Burnout

Nosecone with Modified Payload	Upper Body Tube	Lower Body Tube (including empty motor)
8.6 lbs.	9.54 lbs.	8.49 lbs.

Descent rates were found by using the parachute equation and solving for velocity. Once the descent rates were found, these values were compared to the OpenRocket ground hit velocities after all the corresponding parachute information was inputted. The OpenRocket ground hit velocities were used to verify all recovery system requirements were met such as the kinetic energy at landing, drift, and descent time. Once this was achieved, the required parachute sizing for a safe landing was achieved and can be used for the full-scale launch.

2.2.3. Redundancy

Redundancy within the system exists in the use of two altimeters, which are used to activate black powder charges in order to release the main and the drogue chute. The RRC3 was selected as the main altimeter, while the StratoLogger was selected as the redundant altimeter. The redundancy is set by the fact that each altimeter will be individually connected to their own set of black powder charges, and they will be offset from each other when they go off. The main altimeter is set to go off at apogee for the drogue chute, and then at 700 ft above ground level for the main chute. In contrast, the redundant altimeter is set to go off 2 seconds after the rocket reaches apogee for the drogue, and then at 500 ft above ground level for the main chute. Furthermore, each altimeter is powered individually by the separate batteries, and they will be powered on by individual turn switches. This is done to ensure that if something goes wrong with one of the altimeters, such as a failure in its function, there will be another altimeter that can still activate the black powder charges and release the chutes.

2.3. Mission Performance Predictions

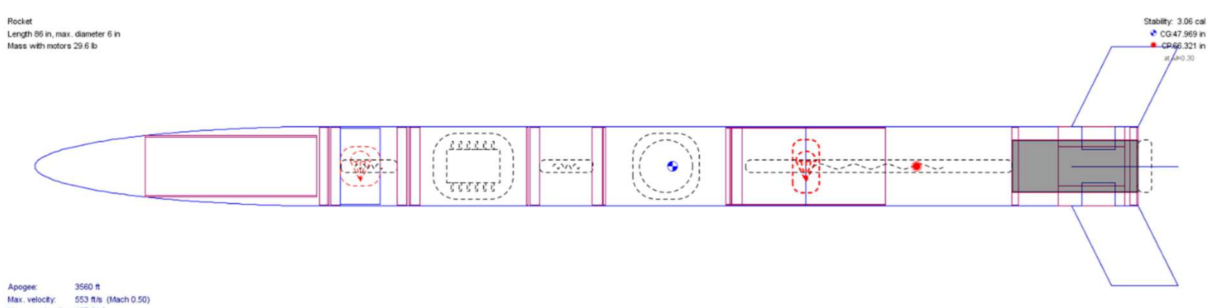

Figure 27: OpenRocket Model

Provided above in Figure 27 is the new OpenRocket Model of the full-scale launch vehicle with the new payload located in the nosecone along with the new Cesaroni Tech. K1620-Vmax-0 motor. The new motor along with the minor changes to the full-scale launch vehicle were all made to fulfill the mission success criteria along with keeping the simulated altitude as close to the original as possible.

To determine whether the rocket vehicle is robust enough, virtual, and experimental testing must be applied, as discussed in Section 2.3.1.2.

For component weights, refer to Section 2.1.3.

2.3.1. Flight Profile Simulations

The official target altitude is set to 3600 ft AGL. Based off the final rocket vehicle design, the estimated apogee from the simulations is 3530ft AGL using an average of 10 mph for windspeed and an 8-foot launch rod. Without using any windspeed, the simulated apogee is 3560 feet. The velocity of the vehicle at main parachute deployment is simulated to be 99.1 ft/s while the velocity at drogue parachute deployment is 2.3 ft/s. Probable additional loss in apogee height through other factors such as launch rail friction may be accounted for.

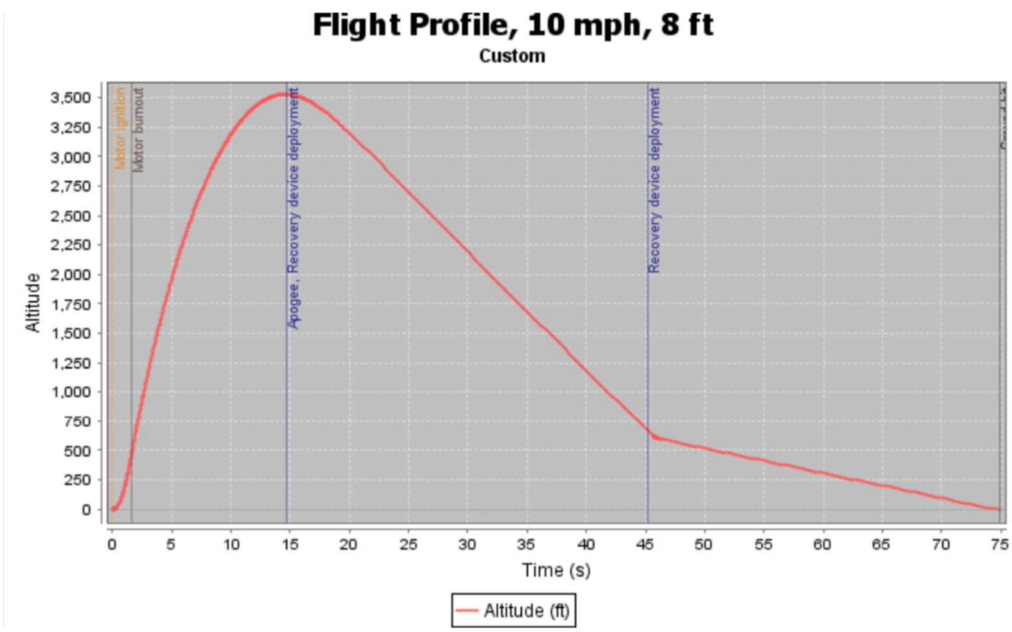

Figure 28: Flight Profile, 10mph Winds, 8 ft Launch Rail from OpenRocket

The predicted altitude with 10 mph winds is 3530 feet using OpenRocket. When using RockSim, the flight profile and predicted altitude slightly vary and is shown below.

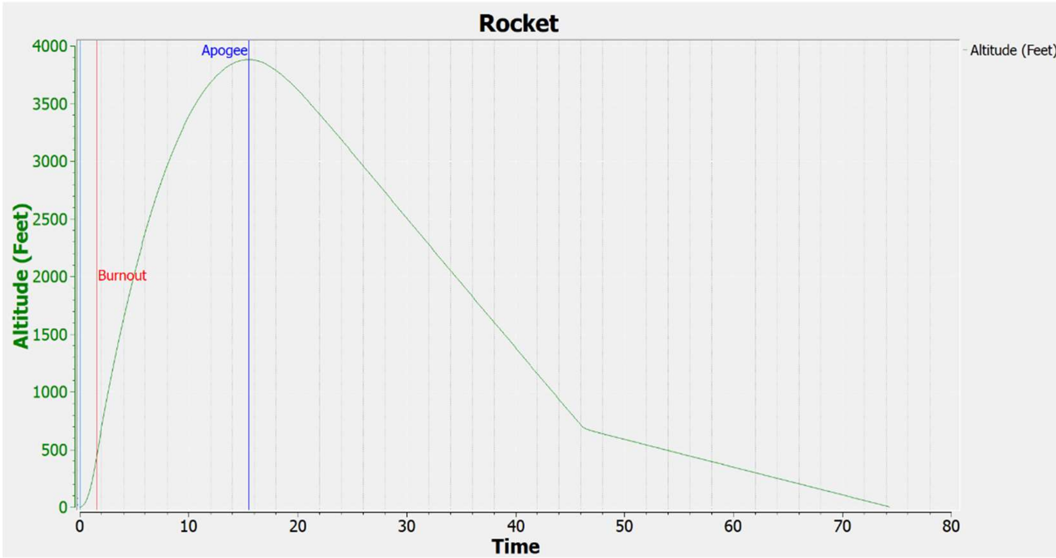

Figure 29: Flight Profile, 10mph Winds, 8 ft Launch Rail from RockSim

The predicted altitude with 10 mph winds is 3880 feet using RockSim. As can be seen in the two figures above, the overall flight profiles are very similar with both having flight times of about 75 seconds. The main difference between the two flight profiles is the simulated apogee. To get the best estimate on the simulated apogee, an average simulated apogee will be taken from both software to produce the best estimate. That value is 3705 feet with 10 mph winds and an 8-foot launch rod. This redesign is still very close to the original simulated apogee.

2.3.1.1. Motor Configurations

The motor selected for the final version of the vehicle changed to adjust to the new payload mission. Below are both the motor data and the thrust curve for the Cesaroni Tech. K1620-Vmax-0 motor.

Table 19: Alternate Design 3 Motor – Final Design Motor – Cesaroni Tech. K1620-Vmax-0 Motor Data

Motor Diameter	3.86 in	**Motor Length**	9.45 in
Average Thrust	1616 N	**Max Thrust**	1845 N
Burn Time	1.5 s	**Total Motor Mass**	6.78 lbs.
Total Impulse	2433 Ns	**Propellant Mass**	2.67 lbs.
Thrust to Weight Ratio	12.31	**Post-burn Mass**	4.11 lbs.

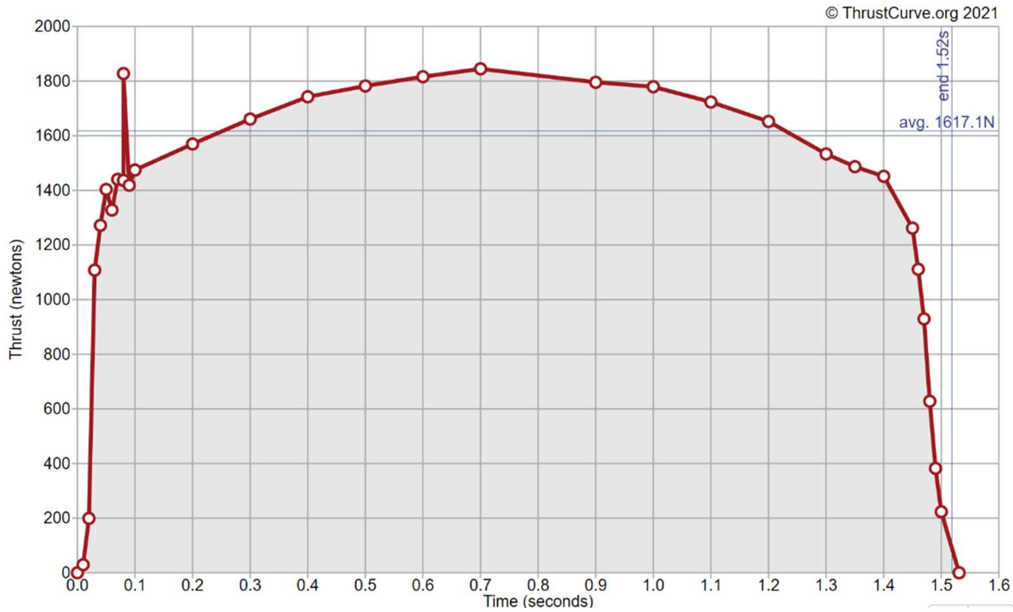

Figure 30: Motor Thrust Curve - Cesaroni Tech. K1620-Vmax-0

2.3.1.2. Vehicle Robustness

This section will cover vehicle testing, both virtual and physical, to showcase the robustness of the vehicle design.

Table 20: Nosecone Structural Integrity (Virtual)

Objective:	To ensure that the nose cone can withstand both the normal forces during flight as well as the shear stresses put onto it from the bulkhead upon deployment of the main parachute.
Success Criteria:	Stress placed onto nose cone in both scenarios do not exceed the approximated yield stress of the structure.
Variables:	Stresses/Directions • Maximum normal force due to acceleration through air: 1620 N • Maximum shear force due to deployment of recovery hardware: 78 lbf
Constants:	• Nose Cone geometry • Nose Cone material: ABS plastic ○ Flexural strength of ABS plastic: 10800 PSI.
Step-by-Step Execution:	For normal force: 1. Fix shoulder of nose cone. 2. Enforce 1620 N force in a singular direction coming into the leading edge of the nose cone, as in launch. 3. Evaluate results. For shear force: 1. Fix outer edge of nose cone. 2. Enforce 78 lbf in a singular direction along the inside face of the nose cone, as the bulkhead would create. 3. Evaluate results.

Relevant Safety Concerns:	None.
Status:	Planned
Justification:	Nosecone failure during ascent can compromise its interface with the main parachute and possibly interfere with deployment. This could cause a personnel hazard from parts falling with a large kinetic energy. Similarly nose cone failure during parachute deployment can cause detachment of recovery hardware, posing a personnel hazard.
Possible Necessary Changes:	If failed, a thicker nosecone must be implemented.

Table 21: Fin Flutter Structural Integrity

Objective:	To ensure that the fin design can withstand the velocity the rocket travels at without failing.
Success Criteria:	Maximum velocity of the rocket does not exceed the fin flutter velocity.
Variables:	Dimensions on the Fin design • Thickness • Root Length • Chord Length • Height
Constraints	• Fin Material • Carbon Fiber
Step-by-Step Execution:	• Using equation found on apogee rockets, calculate the maximum fin flutter velocity • Using OpenRocket, find altitude and value of greatest velocity of rocket • Computer fin flutter velocity at given altitude and compare to max rocket velocity • If fin flutter is greater, fin design will not fail
Relevant Safety Concerns:	None.
Status:	Completed
Justification:	If fin set breaks, the rocket cannot accurately fly, and continual structural failures are likely to occur, compromising the safety of those near the rocket and the rocket integrity.

Table 22: Body Tube Buckling Physical Testing

Objective:	Determine if the body tube may be subject to buckling under peak loading of the motor.
Success Criteria:	Buckling factor of safety is not between 0 and 1 inclusive.
Variables:	Force: 1620 N of axial force
Constants:	Physical body tubes and coupler
Step-by-Step Execution:	Place body tube and coupler assembly in Instron machine Start compressive loading

	Measure stress throughout test during increased loading until failure or until a factor of safety of 2.0 is reached (3240 N). If buckling occurs before the maximum loading is reached, the test fails.
Relevant Safety Concerns:	None.
Status:	Complete
Justification:	Since selected motor has a very high initial force, the body tube may be subject to buckling which can highly jeopardize the structure of the vehicle. By examining behavior, we can make necessary changes to vehicle design, as necessary.
Possible Necessary Changes:	If failed, a thicker body tube is necessary.

Results (if completed):
Uncomplete.

Table 23: Locking Mechanism Test

Objective:	Test and verify the validity of the locking mechanism during the drogue chute's deployment phase
Success Criteria:	No physical cracks, warping, or any other deformities are observed
Variables:	Force: 74.79 lbf of normal force (Safety factor of 4) Pine bulkhead grain pattern (random)
Constants:	Aluminum reinforcement sheets and pine bulkhead geometries Aluminum material properties
Step-by-Step Execution:	Epoxy the locking mechanism to a scrap piece of body tube and wait 1 full day for the epoxy to cure Locate a bridge that is safe to drop heavy objects from. Ensure the test area is free of bystanders Place the locking mechanism against the guardrail of the bridge, ensuring the locking mechanism is unable to move after the weight has been dropped Tether a ~18.7 lb. weight to the locking mechanism's eyebolt using a shock cord and quicklink through the guardrail of the bridge Drop the weight Evaluate locking mechanism
Relevant Safety Concerns:	Potential harm to team members or bystanders if no precautions are taken to clear the test area prior to dropping the assembly. Communication is necessary.
Status:	Incomplete
Justification:	While virtual testing of the locking mechanism has been verified to pass with a safety factor of 4, physical testing is necessary as this assembly deals with the launch vehicle's drogue parachute deployment. Ensuring the system is capable of working even with a safety factor of 4 correlates to a safe mission.

Possible Necessary Changes:	None since the components in question will be tested with a safety factor of 4

Results (if completed):
Uncomplete.

2.3.2. Stability Margin

The CG and CP locations are as follows:

1. CG: **47.969 in.** from the tip of the nose cone.
2. CP: **66.321 in.** from the tip of the nose cone.

Together, with a 6 in. diameter body tube, the resulting stability is anticipated to be **3.06.**

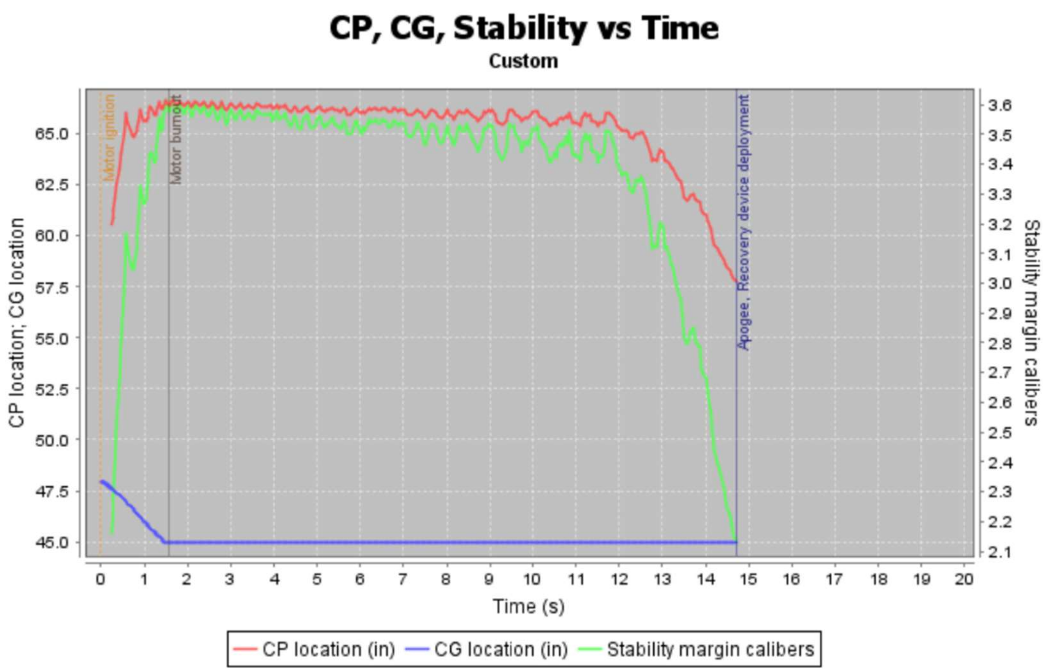

Figure 31: Stability, CP, CG vs. Time

2.3.3. Kinetic Energy at Landing

Per the NASA Student Launch Statement of Work (SOW), the maximum kinetic energy any rocket component can experience is 75 ft-lbf. With this understanding, any rocket vehicle section upon landing must not exceed this given value, or else the risk of an unsafe landing involving damage to interior components becomes significant.

$$KE_{max} = 75\ ft * lbf = 0.5 * m_{max} * v_{descent}^2$$

Using the kinetic energy equation above and the vehicle section mass values (where 1, 2, and 3 denote the nose cone, upper body tube, and lower body tube vehicle sections respectively), and the descent rate for the main parachute given by the vendor, the landing kinetic energy of each vehicle section is determined. The descent velocity under the main parachute was found by using the parachute equation and solving for velocity. This value was verified with the ground hit velocity from OpenRocket. The ground hit velocity from OpenRocket was used over the calculated value because the calculated value did not consider the effect of the drogue chute. The ground hit velocity from OpenRocket turned out to be 21 ft/s and is used in the kinetic energy at landing calculations for each vehicle section.

$$m_1 = 8.6\ lbs, m_2 = 9.54\ lbs, m_3 = 8.49\ lbs$$

It should be noted that the mass of the lower body tube (m3) includes the empty motor after burnout.

*m1= (8.6 lbf) / (32.2 ft/s^2) -> KE1 = 0.5*m1*vdescent^2 => KE1 = 58.89 ft-lbf.*
*m2= (9.54 lbf) / (32.2 ft/s^2) -> KE2 = 0.5*m2*vdescent^2 => KE2 = 65.33 ft-lbf.*
*m3= (8.49 lbf) / (32.2 ft/s^2) -> KE3 = 0.5*m3*vdescent^2 => KE3 = 58.14 ft-lbf*

As can be seen, all kinetic energy at landing values for each vehicle section is under the requirement of 75 ft-lbf, meaning that the parachutes are large enough and deployed within an altitude to create a safe landing.

2.3.4. Descent Time

For a simulated apogee of 3705 ft AGL and the descent rates for the main parachute and drogue chute, the approximate descent time can be calculated, assuming no inclination of the launch rail.

vmain, descent = 21 ft/s, v_drogue, descent = 99.2 ft/s (for a post-burn mass of lb.)
apogee = 3705 ft AGL, height_main-deploy = 700 ft AGL

Descent Time= (apogee-height_main-deploy)/v_drogue + height_main-deploy/vmain
Descent Time= 63.6 s

When using OpenRocket to calculate the descent time, it turns out to be 60.7 as compared to the calculated time of 63.6 s. This shows the preciseness and accuracy of the calculations. Although, the team will use the simulated descent time of 60.7 s.

2.3.5. Drift

With the calculated descent time, the amount of horizontal drift of the rocket can be determined for several wind speeds:

Table 24: Drift Relation to Wind Speed with OpenRocket

Wind Speed	0 mph	5 mph	10 mph	15 mph	20 mph
Horizontal Drift	0 ft.	440.7 ft.	884.4 ft.	1309 ft.	1780.5 ft.

Using the RockSim simulation software, these calculations can be verified against a rigorously tested and trusted simulation code. Predictions of the descent time, and the horizontal drift estimates are enumerated below.

To ensure precision of simulation estimates, simulations were run four times:

Table 25: Drift relation to Wind Speed with RockSim

Wind Speed	0 mph	5 mph	10 mph	15 mph	20 mph
Horizontal Drift (1)	0 ft.	433.3 ft	864.4 ft.	1291.7 ft.	1713.6 ft.

When using RockSim to calculate the descent time, it turns out to be 58.9 s compared to the calculated time of 63.6 s and OpenRocket descent time of 60.7 s. This shows the preciseness and accuracy of the calculations as well as the software. This confirms that the use of both software to verify values is well-founded. Although, the team will use the simulated descent time of 60.7 s.

2.3.6. Result Verification

The structures team is in the process of writing a code in MATLAB that can verify the calculations used in this report. This program will serve to verify the accuracy of the simulated data, despite the belief amongst the team of OpenRocket and RockSim being very reliable sources. The team has also decided to utilize both RockSim and OpenRocket and compare the simulations between the two programs.

The team used both RockSim and OpenRocket to verify that the original results are accurate. Both simulations can be found in section 2 with the flight profile and drift calculations.

There are no large differences between the different calculations. The only large difference comes from using different simulations software with OpenRocket and RockSim. The main difference between the two simulation programs is the difference in apogee. OpenRocket gives the team an apogee of about 3560 feet while RockSim gives about 3880 feet. The team ultimately decided to use an average of OpenRocket and RockSim to predict the simulated apogee as discussed in the FRR.

2.3.7. Differences Between Different Calculations

As for the descent time calculations, a little discrepancy could be seen in the final trial, which could be attributed to a slight delay in drogue chute deployment at apogee.

In the drift calculations, a greater discrepancy can be observed. The farthest drift calculations vary by several feet. This can best be attributed to the constant wind speed assumed in Section 2.3.5, whereas the simulation software accounts for a wind speed distribution depending on altitude. In this case, it would be best to revise future drift calculations to account for a similar distribution and continue using RockSim to check precision of those calculations.

2.3.8. Preciseness Verification

This has been talked about in Sections 2.3.5 and 2.3.6. As seen, the multiple simulations are shown to be precise. Simulations with both OpenRocket and RockSim have also been conducted which display a much larger difference in results so the team will use a variety of both to best predict vehicle performance.

3. Safety

Close inspection of our redesign has been done and many hazards that can be expected have been identified. This list is made in conjunction with past hazard experience and will be assessed on a leveled pattern based on likelihood and impact.

3.1. Defining Risks Levels

Likelihood

The likelihood of each potential hazard and predetermined risk will be assigned one of three levels. These levels are assigned after analyzing and comparing the risks, estimating the possibility that they would occur.

Table 26: Risk Likelihoods

Description	Qualitative Probability	Quantitative Probability, x
-1- High or Frequent	High probability of occurrence and expected to occur more often than not.	100%> x >67%
-2- Medium or Occasional	Likely to occur and expected to occur half of the time, on average.	67%> x >34%
-3- Low or Remote	Unlikely to somewhat likely to occur. Expected to occur after a large amount of time.	34%> x >0%

Impact

The impact of each potential hazard and predetermined risk will be characterized by one of three levels based on the effects and severity of human injury, equipment damage, effects on project timeline and sustainability, and any potential environmental harm.

Table 27: Risk Impact & Consequence Level

Description	Member and Personnel Safety	Equipment and Facility	Project Plan & Timeline	Environment
-A- High or Severe	Fatal injury/death. Permanent disability or impairment with serious repercussions.	Elimination and loss of equipment. Irreparable damage and possible dissipation of location.	Immense effect on project lifetime and results on complete halt and/or termination of project.	Irreparable and immense physical damage to the surroundings. Violates codes/laws and regulations.
-B- Medium or Moderate	Fair amount of damage, usually repairable, moderate pain, or adequate illnesses	Significant or notable enough damage to systems,	May result in temporary but notable pause in project timeline	Possibly reversible but noteworthy damage. Subject to review based

		equipment, or facilities.	and redesign of methods.	on law compliances.
-C- Low or Minor	Minimal or infinitesimal damage that is repairable and yields little to no repercussions	Small and/or repairable damage to equipment, materials, facilities. Does not compromise any state	Minor to extremely minimal delay in the project plan or timeline. Any delays due to cost or funding.	Infinitesimal and/or repairable damage that is in compliance with regulations.

Risk Assessment Levels

Using the definitions and level placements for both the likelihood and impact of predetermined hazards listed above, each potentially identified risk will be assigned an official risk level (shown in color) in the matrix formed below:

Table 28: Risk Assessment Matrix

Likelihood	**Severity**		
	-A- High	**-B- Medium**	**-C- Low**
-1- High	1A	1B	1C
-2- Medium	2A	2B	2C
-3- Low	3A	3B	3C

Green boxes are deemed low risk with low severity: they are unlikely to occur often or at all, and they may be completely avoidable. They are rare and result in minimal overall effect on the project, personnel, facilities, or environment. Mitigation strategies will and should be implemented, if possible, but they are not critical to mission success.

Yellow boxes denote medium risk levels: likely and possessing moderate severity. These risks may or may not be acceptable, and they should be evaluated thoroughly for potential mitigation strategies.

Red boxes denote high risk levels: highly likely and very severe, these risks are potentially catastrophic and need not be risked unless documented approval is given by the project manager, faculty mentor, safety officer, or in extreme cases, the range safety officer. ALL risks categorized as red must be mitigated to a yellow or green level before the vehicle is considered safe enough to be flight-ready.

3.2. Predetermined Hazard Analysis and Rankings

All risks recognized by team members have been recorded, evaluated, and modified by the team safety officer. Although not all risks have been encountered at the current design and fabrication stage, each risk has been given an expected risk assessment rating both prior to mitigation efforts (BM) and post-mitigation (PM) to better prepare and anticipated hazards.

Personnel Hazard Analysis

Table 29: Personnel Hazard Assessment

Risk	Cause	Effect	BM	Mitigation Strategy	PM	Verification
Black powder explosion while handling	Accidental connection to voltage source; static discharge	Epidermal injury/burn; Hearing loss; Ataxic gait	2A	Black powder handlers will only work with small amounts at a time and ground themselves prior. To reduce the gravity of the explosion, small amounts of ejection powders are to be handled at any given time.	3A	Consultation of MSDS before working near or handling powder charges. Members will be adequately trained and certified to handle. Only small amounts are to be handled.
Shop Fire	Incorrect / improper wiring; Equipment overheating/explosion	Potential for serious injury or death; irreparable damage to equipment and lab space	2B	High power circuitry completed with safety officer present; Avoid overheating with proper ventilation and usage of equipment; fire extinguishers kept in shop.	3C	All lab coats are fire resistant. Fire protocol and exit route is included in all lab safety certified courses.

Note that all materials and equipment are to be stored appropriately, as outlined by the respective guidelines. These hazards are preemptively identified in an effort to mitigate and facilitate an elevated degree of understanding for all members regarding safe practices and procedures.

Environmental Concerns & Hazard Analysis

The following table will exhibit any potential risks associated with interactions between the rocket and the environment before, during, and after launch, and vice versa. We will focus on exclusive interactions between the rocket and various environmental & natural phenomena.

Table 30: Environmental Hazard Assessment

Environmental Hazard Risk Assessment: On Environment						
Risk	**Cause**	**Effect**	**BM**	**Mitigation Strategy**	**PM**	**Verification**
Explosion of rocket and/or excess powder charge combustion	Failure of electronic or payload assembly; motor failure	Large scattering of vehicle debris after explosion	3A	All electronic and payload components adequately secured; motor is pre-approved.	3C	Complete design analysis of components to ensure withstanding internal forces.
Recovery system deployment malfunction	Excess powder charges for number of shear pins	Vehicle destruction upon ground impact; debris scattering	1A	Establish extensive recovery system ground tested & ensure appropriate parachute wrapping.	1C	Verify using analysis of expected deployment of parachute time & ejection necessary. Consult launch operation procedures.

Environmental Hazard Risk Assessment: On Rocket						
Risk	**Cause**	**Effect**	**BM**	**Mitigation Strategy**	**PM**	**Verification**
Launch pad fire	Loose wiring or exposure to outside environment; water damage	Electronics for recovery and payload short circuit	3A	Electronics enveloped separate and sealed away from outside exposure	3C	Fire extinguisher is on hand & taken to launch site. Consultation of launch operations procedure during launch.
Untethered hardware blown around	Excessive wind	Final vehicle assembly made more difficult; personnel hazard	3A	Minimization of hardware requirement on launch day; securement of hardware in labeled boxes	3C	Design and consultation of launch hardware list.
Excess weather-rocking	Large wind speeds; additional gaseous headspace contained in new payload	Increase drift & unexpected vehicle trajectory; vertical stability complication	2A	Ensure launch vehicle has an ample margin of stability.	2C	Enhanced analysis of vehicle design choice of fins and mass distribution.

Difficulty assembling vehicle components at launch site	Excessive humidity	Swelling/warping of body tube and internal components, especially wooden bulkheads	3B	Inner surface of body tube and internal components weatherproofed with polyurethane spray; sandpaper taken to launch site as potential minor resizing tool	3C	Review launch hardware list and adhere to fabrication design

Vehicle Launch Failure Modes and Hazard Analysis

Table 31: Vehicle Launch and Risk Assessment

Vehicle Launch Failure Modes and Risk Assessment						
Risk	**Cause**	**Effect**	**BM**	**Mitigation Strategy**	**PM**	**Verification**
Main parachute deployment failure	Parachute fails to eject from nosecone upon separation event; weak/failed blast charges do not eject parachute	Excessive landing energy for successful recovery; damage to or loss of launch vehicle	2A	Backup drogue chamber ejection charge firing at a slightly reduced altitude from desired main deployment altitude	3B	Ground-based deployment testing
Bulkheads do not sustain intended force	Incorrect calculation of forces that bulkheads can support	Intended support provided by bulkheads will no longer secure internal parts. Possible explosion, payload and recovery system damage, and destruction of vehicle	3B	We will ensure the accuracy of calculations using OpenRocket software and test the strength of materials, physically and virtually, used prior to assembly.	3C	Verify that forces encountered by bulkheads can be supported through future flight tests.
Propellant fails to ignite	Improper motor packing; faulty propellant grain; damage during transportation	Rocket does not launch; necessary replacement	2A	Proper ignition setup; safety advisor/RSO oversees motor packing by student safety officer	2C	Consult safety protocol regarding motor and

						propellant issues
Propellant burns out prematurely	Improper motor packing; faulty propellant grain	Estimated altitude not reached; main parachute may not deploy	2A	Proper motor assembly; safety advisor/RSO oversees motor packing by student safety officer	2B	Consult safety protocol regarding motor and propellant issues
Improper motor assembly	Incorrect spacing between motor grains; motor case and/or end caps improperly secured	Motor failure; estimated altitude not reached; damage or loss of rocket; unpredictable rocket trajectory	2A	Ensure safety advisor/RSO oversees and properly trains student safety officer for motor assembly	2B	Consult safety protocol regarding motor and propellant issues
Shroud lines or shock cords tangle after deployment	Excessive rotation of rocket	Potential for parachute to not fully deploy; catastrophic damage to/loss of rocket	1B	Proper packing of recovery system; proper and consistent method of folding and storing after each use	2B	Verify roper packing of recovery system
Motor is misaligned	Centering rings misaligned; fins assembled to motor tube at an angle	Unstable/ unpredictable rocket trajectory	2B	Careful machining of center rings; proper assembly using centering rings and fin alignment jig	3C	Pre-flight visual inspection of motor alignment
Propellant failure	Improper motor packing; faulty propellant grain; damage during transportation/ handling	Loss of thrust and stability; potential injury to personnel	2B	Proper motor assembly; safety advisor/RSO oversees motor packing by student safety officer	3B	Consult safety protocol regarding motor and propellant issues
Improper deployment of parachute	Failure in electronics. Failure in black powder to separate sections	Will cause damage to launch vehicle as well as payload	2B	Allow time for ground testing of electronics Perform ground tests to ensure a sufficient amount of black powder.	3B	Consult project timeline and operational procedures.
Sections separate prior to	Structural failure. Failure in electronics,	Rocket does not reach apogee	2B	Increased redundancy incorporated into the system. Increased	3C	Consultation of Operation

indicated altitude of deployment	premature activation of black powder	and may follow ballistic path		amount of shear pins or creating a more robust coupler.		and Pre-Launch Checklist.
Motor retention failure	A drogue chute applies a force great enough to push out motor, not accounted for with original motor.	The motor may be lost as it detaches completely from the launch vehicle	3A	Ensure centering rings have been well epoxied to inner walls of the body tube.	3C	Ample ground testing to the motor retention system can resist the forces place. Consult Operation and Pre-Launch Checklist.
Launch vehicle does not reach minimum velocity before leaving the launch rail	Miscalculation of rocket's mass while considering redesign. Motor failure	Decrease in stability of the launch vehicle; rocket plummets down; possible explosion	3A	Simulations are conducted virtually and physically, checked against one another for redundancy.	3C	Verify with and consult simulations.

Project Management Risk and Mitigation

The following table details difficulties that may be encountered regarding both self-imposed and NASA deadlines, resources and budget associated with the redesign.

Table 32: Project Management Risk and Mitigation

Project Management Risk and Mitigation				
Risk	**Cause**	**BM**	**Mitigation Strategy**	**PM**
Vehicle testing failure	Vehicle parts are destroyed or damaged during ground testing or flight testing. Could lead to ordering new materials late in the year and running the risk of not completing the project on time.	2A	Design the vehicle components after extensive mathematical and physics analysis in order to ensure that a damaging failure will not occur. Only conduct tests with the potential to cause damage once a robust design has been developed and implemented. Set up an inventory of spare parts and components for building a second rocket within a week	2B

Weather launch delays	Inability to meet CDR and FRR timelines and obligations	1B	Have multiple possibilities for launch by working with launch clubs in Southern California.	3B
Rushed timeline	Low quality in manufacturing, vehicle safety, payload safety, and risks to mission success in all aspects	2B	Well defined component verification metrics and workmanship standards, internal launch readiness reviews, no culture of go fever	2C
Communic-ation breakdown between team members	Failure to meet deadlines; failure to show results	3A	Frequent meetings to improve team morale and stress the importance of timelines, and chain of command. Recalibration of deliverables based on progress.	3C
Delays in timeline	If a portion of the project that is necessary to complete the next portion takes longer to complete than expected, there could be delays in project development.	2B	Make sure that realistic expectations are set for completion of elements set in the timeline.	2C
Ambiguous product lead time	If the amount of time it takes for parts to ship is ambiguous or unknown, there could be unexpected delays in project development.	3B	Ensure somebody is responsible for knowing the lead times on all parts, and trying to eliminate all the ambiguity.	3C
Excessive academic responsibil-ity	Fabrication, testing, or launch deadlines would be compromised	2B	Regularly scheduled team meetings cover individual availability to ensure adequate personnel are available for each scheduled task	3C
High budget costs	Could threaten the feasibility of the project, as well as a violation of the rules of the competition.	2B	Keep a detailed budget and projected budget to minimize the chance of overspending. Make sure that every purchase is justified.	2C
Misplaced or lost component	Machine shop or laboratory equipment breakdown could cause a slowdown in production and threaten the timely completion of the project.	2B	Ensure that the team has access to multiple machine shops in case equipment in one place fails. Also, ensure that equipment is used and stored properly to minimize the likelihood that such a failure will occur.	3C
Equipment breakdown	Structural failure. Failure in electronics, premature activation of black powder	2C	Increased redundancy incorporated into the system. Increased amount of shear pins or creating a more robust coupler.	3C
Motor retention failure	A drogue chute applies a force great enough to push out motor	2C	Ensure centering rings have been well epoxied to inner walls of the body tube.	3C
Unavailabil-ity of parts	Delays in construction of the rocket and payload	2C	Start the design process very early, and allow room in the design for the use of parts	3C

or delays in parts delivery	attachment scheme; rushing through work or settling with parts that are not compatible with the ideal design		other than those initially selected: flexibility in design without the compromise of safety or science value	
Limited access to machine shops	Delays in fabrication of various parts or rushed work. Impact on timely completion of the project.	2C	Ensure that contact with the machine shop operators is constant, and that available times for access are established.	3C
Personnel shortage	Student or faculty members could be unavailable, which can lead to higher workloads for others, or the lack of technical knowledge of some system aspect.	2C	Make sure that the knowledge of rocket construction and testing techniques is known by the entire team. Make sure that the schedule is known by everyone so that people are not voluntarily absent/unavailable at inopportune times.	3C
School closure (holidays)	Slows down the project and threatens timely completion and available times for testing.	2C	Ensure that the schedule for work and testing is designed with school holidays in mind, such that the team does not expect to have full access to equipment or personnel during those times.	3C

4. Project Plan

4.1. Budget

Table 33: Budget

Grand Total					$13,544
	Expense	Vendor	Projected Units	Projected Unit Price	Projected Total Price
Structures	**Totals:**				**$2,423**
	Contingency (Includes unexpected tax and shipping costs)			15%	$316
	Body Tube	Public Missiles	1	$450	$450
	Rocket Kit	Apogee Components	1	$265	$265
	Subscale Motor	Apogee Components	1	$72	$72
	L-91 C-Star Motors	Cesaroni Technologies	3	$268	$804
	Coupler	Public Missiles	1	$94	$94
	Carbon Fiber Sheet	McMaster-Carr	1	$34	$34
	Pine Wood Stock	Anawalt Lumber	4	$12	$48
	75mm Motor Casing	Off We Go Rocketry	1	$144	$144
	Motor Retainer	Apogee Components	1	$76	$76
	Phenolic Tube	Apogee Components	1	$15	$15
	RocketPoxy	Apogee Components	1	$49	$49
	RockSim License	Apogee Components	1	$20	$20
	Fiber Glass Sheets	McMaster-Carr	2	$18	$36
Electrical / Payload	**Totals:**				**$529**
	Contingency (Includes unexpected tax and shipping costs)			15%	$69
	Soldering Spool	Adafruit	5	$8	$40
	RRC3 Sport Altimeter	Missile Works	1	$70	$70
	Radiolink 2.4GHz Transmitter	Amazon	1	$54	$54
	Furious FPV 2.4GHz TRX	GetFPV.com	1	$55	$55
	BosCam 2.4GHz VRX	DronesVision	1	$18	$18
	OpenPilot CC3D Evo Flight Controller	Amazon	1	$23	$23
	Racestar BR2212 Brushless DC Motor	Amazon	4	$8	$31

	Micro High Torque Servo	Adafruit	1	$12	$12
	PCB	Amazon	1	$9	$9
	25A 4-in-1 ESC w/ Brake	Amazon	4	$9	$36
	120 Degree NTSC Mini Camera	GetFPV.com	1	$8	$8
	11.1V 3S 4000mAh LiPo	SMC Racing	1	$44	$44
	2.4GHz SMA Antenna (RHCP)	Amazon	2	$30	$60
Recovery	**Totals:**				**$236**
	Contingency (Includes unexpected tax and shipping costs)			15%	$31
	Steel Eyebolts	McMaster-Carr	4	$3	$11
	Shear Pins	Apogee Components	1	$4	$4
	Main Parachute	Rocketman Enterprises	1	$120	$120
	Shock Chord	Apogee Components	1	$50	$50
	Fire Cloth	Apogee Components	2	$10	$20
Safety	**Totals:**				**$361**
	Contingency (Includes unexpected tax and shipping costs)			15%	$46
	Particle Mask filters		3	$16	$48
	Particle Mask		3	$55	$165
	Gloves (100 pack)	Fisher Scientific	3	$31	$92
Travel	**Totals:**				**$10,005**
	Contingency (Includes unexpected tax and shipping costs)			15%	$1,305
	Lodging	Hotel	4	$500	$2,000
	Uber to LAX	Uber	4	$30	$120
	Car Rental	Enterprise	4	$575	$2,300
	Gas	Gas Stations	4	$50	$200
	Plane Tickets (Round Trip)	Southwest Airlines	18	$220	$3,960
	Uber to UCLA	Uber	4	$30	$120

4.2. Timeline

A timeline for vehicle completion post vehicle redesign is presented below. Timeline is based off the assumption that the full vehicle was already assembled and successfully flown in original configuration presented in FRR so previous payload and unaltered vehicle components do not have to be re-manufactured. Only aspects needed to alter the original vehicle are presented below.

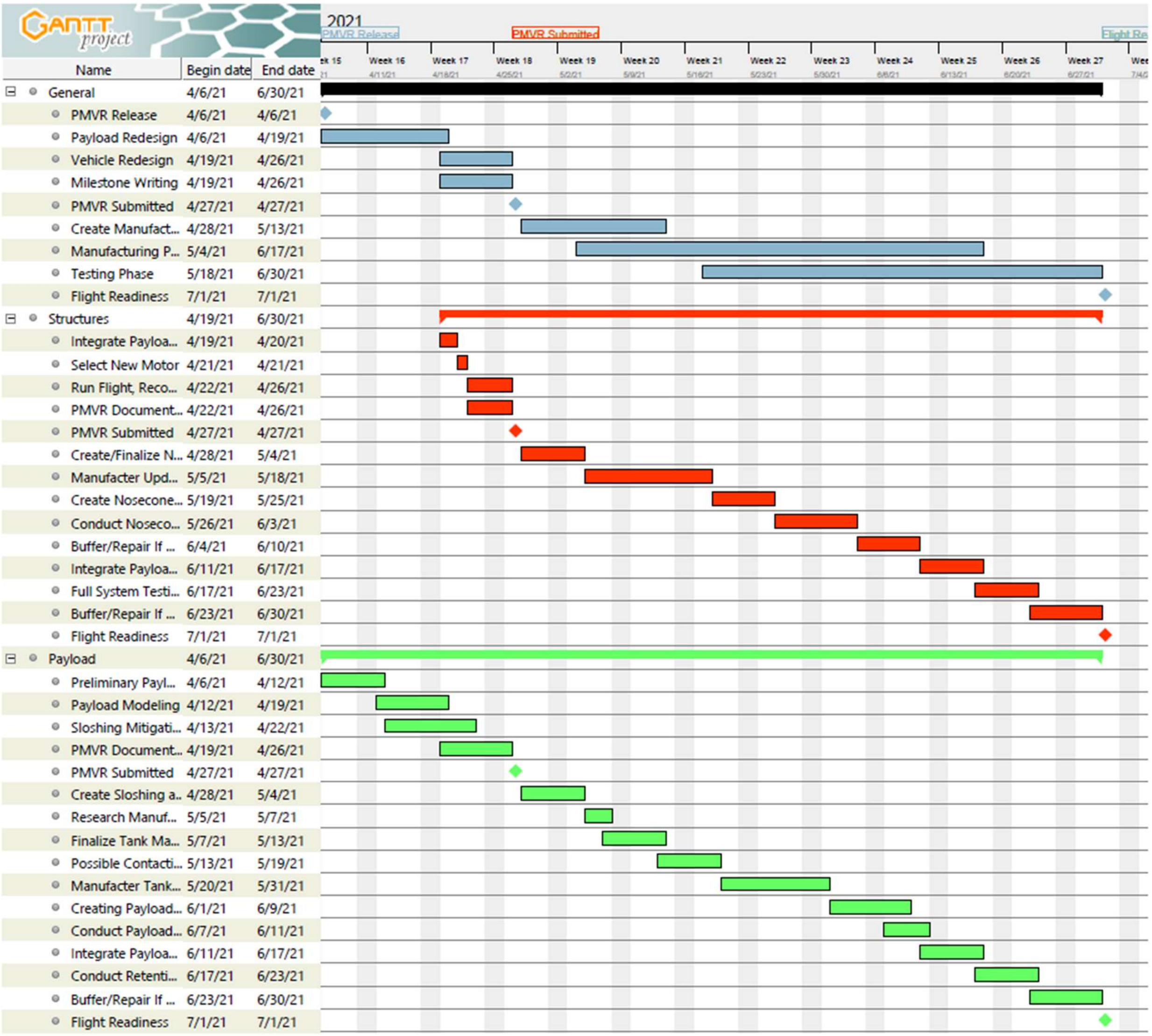

Figure 32: PMVR Gantt Chart

Name	Begin date	End date
General	4/6/21	6/30/21
PMVR Release	4/6/21	4/6/21
Payload Redesign	4/6/21	4/19/21
Vehicle Redesign	4/19/21	4/26/21
Milestone Writing	4/19/21	4/26/21
PMVR Submitted	4/27/21	4/27/21
Create Manufacturing Plan	4/28/21	5/13/21
Manufacturing Phase	5/4/21	6/17/21
Testing Phase	5/18/21	6/30/21
Flight Readiness	7/1/21	7/1/21
Structures	4/19/21	6/30/21
Integrate Payload Redesign to Current Vehicle	4/19/21	4/20/21
Select New Motor	4/21/21	4/21/21
Run Flight, Recovery, and FEA Analysis	4/22/21	4/26/21
PMVR Documentation	4/22/21	4/26/21
PMVR Submitted	4/27/21	4/27/21
Create/Finalize Nosecone Fabrication Plan	4/28/21	5/4/21
Manufacter Updated Nosecone	5/5/21	5/18/21
Create Nosecone Testing Plan	5/19/21	5/25/21
Conduct Nosecone Testing	5/26/21	6/3/21
Buffer/Repair If Needed For Nosecone and Vehicle	6/4/21	6/10/21
Integrate Payload with Vehicle	6/11/21	6/17/21
Full System Testing	6/17/21	6/23/21
Buffer/Repair If Needed	6/23/21	6/30/21
Flight Readiness	7/1/21	7/1/21
Payload	4/6/21	6/30/21
Preliminary Payload Redesign	4/6/21	4/12/21
Payload Modeling	4/12/21	4/19/21
Sloshing Mitigation Researching	4/13/21	4/22/21
PMVR Documentation	4/19/21	4/26/21
PMVR Submitted	4/27/21	4/27/21
Create Sloshing and Tank Nozzle Integration Plan	4/28/21	5/4/21
Research Manufacturing Options	5/5/21	5/7/21
Finalize Tank Manufacturing Plan	5/7/21	5/13/21
Possible Contacting Potential Sponsors for Manufacturing Support	5/13/21	5/19/21
Manufacter Tank System	5/20/21	5/31/21
Creating Payload Testing Plan	6/1/21	6/9/21
Conduct Payload Testing	6/7/21	6/11/21
Integrate Payload with Vehicle	6/11/21	6/17/21
Conduct Retention Testing	6/17/21	6/23/21
Buffer/Repair If Needed Period	6/23/21	6/30/21
Flight Readiness	7/1/21	7/1/21

Figure 33: PMVR Gantt Chart List of Tasks