Bearospace at UCLA
(LoL)
Leveling on Land
2020 - 2021 NASA Student Launch
Flight Readiness Review (FRR)

University of California, Los Angeles
420 Westwood Plaza
Los Angeles, CA, 90095
Boelter Hall Room 6291
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Table of Contents

List of Figures

List of Tables

1. Summary of CDR Report

1.1 Team Summary

Team Name:	Bearospace at UCLA
Mailing Address:	420 Westwood Blvd Boelter Hall Room 6291 Los Angeles, CA 90095
Name of Mentor:	Rick Maschek
NAR/TRA Number:	TRA #11388
Certification Level:	2
Mentor Contact:	rickmaschek@rocketmail.com
Number of Hours Spent on FRR:	130

1.2 Launch Vehicle Summary

Target Altitude (ft.):	3600 feet
Final Motor Choice:	AeroTech K1103X-14
Size:	Length: 71 in, Diameter: 6 in
Mass:	19.6 lbs.
Recovery System:	Dual deployment of drogue and main parachutes, using two commercial altimeters for redundancy which are Missile Works RRC3 Sports Altimeter and StratoLogger SL100 Altimeter. Drogue chute will be deployed at apogee while main chute will be deployed at 700 feet above ground level (AGL). The rest of the system will consist of a series of connections between bulkheads, eyebolts, quicklinks, and shock cords.
Rail Size:	8 ft 1010 rail

1.3 Payload Summary

Payload Title: Leveling on Land (LoL)

Payload Experiment Summary: Payload features a 3-legged lander design that houses critical electronics within its main enclosure. The legs are actuated using servo motors and are used to level the payload within 5° of vertical. A central column allows the camera to be perched to obtain a greater field of view of the landing site. A camera is mounted on a servo motor to allow a 360° view of the landing site. A 1.5 ft diameter parachute is attached to the top of the central column to slow the payload's descent to a max kinetic energy of 9.22 ft-lbf. The payload is retained within an enclosure within the launch vehicle which is tethered to the main parachute's shock cord. This allows the payload and the launch vehicle's main parachute to be deployed at 700 ft AGL.

2. Changes Made Since CDR

2.1 Changes to Vehicle Criteria

Since the CDR, there has been minor changes to the vehicle design mainly to address stability concerns as well as to reach targeted altitude. Mainly, locations of components throughout the vehicle have been altered to meet the goals mentioned above. These changes are listed below, and further reasoning on why these changes are necessary will be given in greater detail in 3.1.1:

1. Coupler length has increased from 6 inches to 12 inches.
2. Nosecone length has increased from 7 inches to 8 inches.
3. Ballast location has moved from being epoxied to the bulkhead to being epoxied to the nosecone tip. Ballast amount has also been increased from 0.75 lbs. to 1.25 lbs.
4. The thickness of the leftmost centering ring (near the separation point between the upper and lower body tubes) has decreased from 0.75 inches to 0.5 inches.
5. The fins have moved back 2 inches from their original location, closer to the aft end of the vehicle. For the fin tabs, the fin height has changed from 0.38 inches to 0.55 inches and the fin length has changed from 2 inches to 2.5 inches.
6. The fin securing mechanism (FSM) has moved back 1 inch from their original location, making it closer to the aft end of the vehicle.

2.2 Changes to Payload Criteria

Minor changes were made to the payload to accommodate manufacturing processes. These include added slots and holes for screws to be positioned without interfering the screwing motion required to assemble the payload.

An additional component to the retention mechanism was implemented to shield the payload during its volatile deployment. This additional component is tethered to the retention system's eyebolt and prevents the payload from scraping the inside of the body tube during deployment.

2.3 Changes to Project Plan

Given that the team has continued in the Design Division and no major changes have been announced by the USLI team, no changes have been made to the project plan since CDR.

3. Vehicle Criteria

3.1. Design and Construction of Vehicle

3.1.1. Changes Since CDR

Several minor changes were made to the launch vehicle design from the CDR as mentioned in 2.1 to better ensure the vehicle can meet mission success criteria as well as reinforce structural robustness of the rocket. The main priority of the team was to design a rocket with high stability to make certain the vehicle can safely retain the payload during flight with no signs of damage to the structure and electronics. As a result, most of the changes reflect the team's main priority of safety and stability. Although the team is competing in the design division, it is still good practice to design a very safe vehicle while also aiming to match mission performance predictions. The specifics to why each change was necessary is given below.

1. Coupler length has increased from 6 inches to 12 inches to satisfy the coupler/airframe shoulders requirement. This was pointed out during the CDR Presentation and has been addressed to meet the requirements.
2. Nosecone length has increased from 7 inches to 8 inches to make more space for the ballast since that also increased. This was a very minor change, but it was necessary just in case the ballast ended being larger than expected. This change also slightly increased the stability of the vehicle which is a main point of interest for the team.
3. Ballast location was moved from being epoxied to the bulkhead to the nosecone tip instead. This change slightly increased the stability by about 0.05 calibers. Ballast amount was increased from 0.75 lbs. to 1.25 lbs. to greatly increase stability and to ensure a safe flight.
4. The thickness of the leftmost centering ring (near the separation point between the upper and lower body tubes) has decreased from 0.75 inches to 0.5 inches. While this change decreases stability (by 0.01 calibers), it increases the predicted apogee to similarly match the targeted altitude of 3600 feet. Most of the changes have increased the stability of the vehicle and have resulted in decreasing the predicted altitude (changes in 1-3). In response to these changes, other steps are needed to balance the decreased predicted altitude such as this one by decreasing the stability slightly in favor of increasing the predicted altitude.
5. The fins were moved back 2 inches from their original location to the aft end of the rocket. This change greatly increased the stability the most. The stability of the vehicle increased by 0.25 calibers with this change. For the fin tabs, the fin height has changed from 0.38 inches to 0.55 inches and the fin length has changed from 2 inches to 2.5 inches. This change reduces both stability and predicted apogee very slightly, but the team felt this change was needed to better secure the fins within the fin securing mechanism, especially during flight.
6. The fin securing mechanism (FSM) has moved back 1 inch from their original location, making it closer to the aft end of the vehicle. This change was only needed to match the change in location of the fins.

No changes were made to the electrical system within the launch vehicle since the CDR.

3.1.2. Separation Points

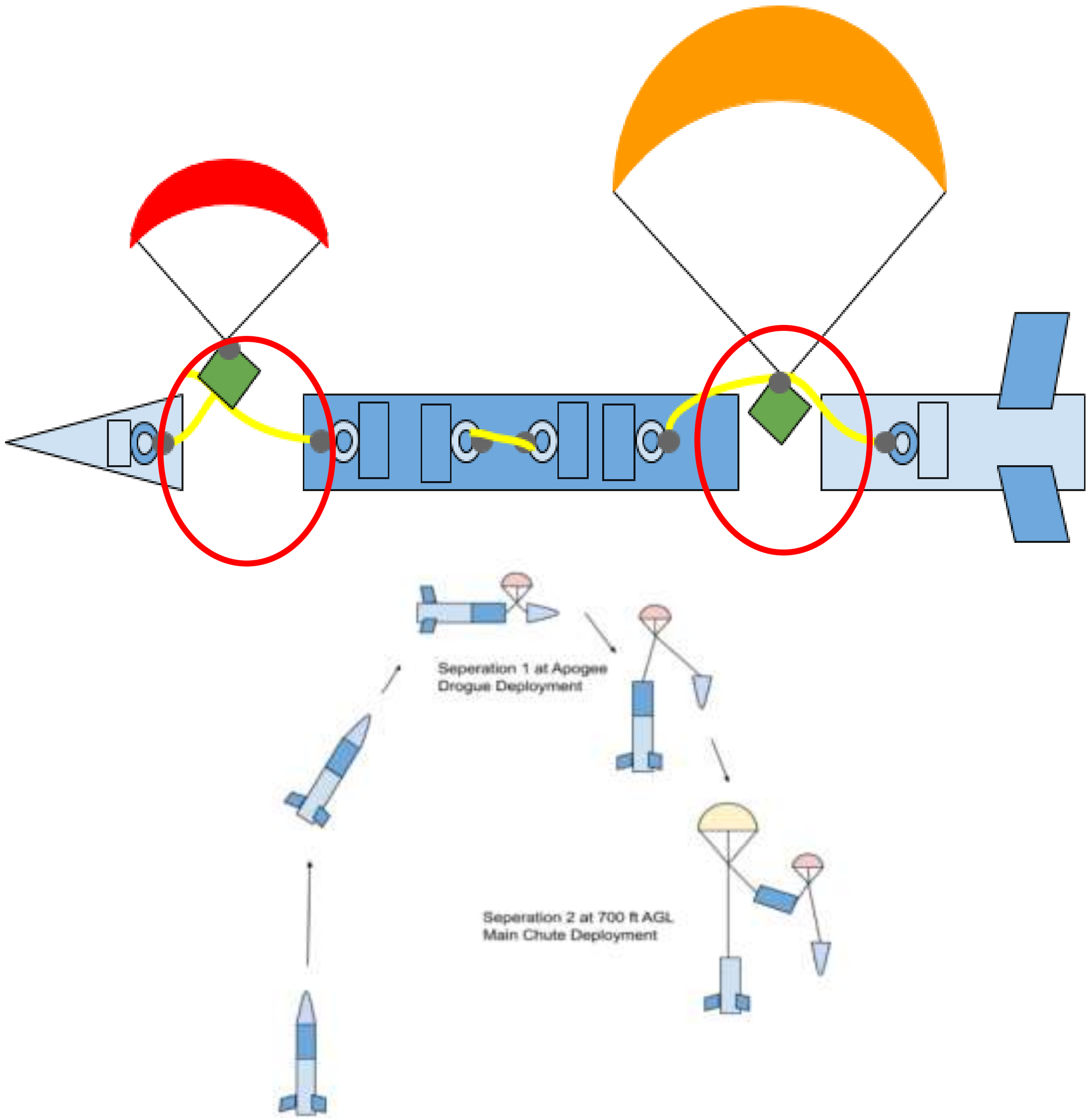

Figure 1: Locations of Separation Points

In the figure above, the separation points are shown along with the related parachute deployments. The first separation point will be between the nosecone and the upper body tube to deploy the drogue parachute at apogee. This separation point is located 8 inches from the tip of the nosecone. It should also be noted the nosecone shoulders have a length of 4 inches and are within the upper body tube. Once the nosecone shoulders clear the upper body tube, the nosecone and upper body tube will completely separate and make up separation point 1. The second separation point will be between the upper body tube and the lower body tube to deploy the main parachute at 700 feet above ground level (AGL). This separation point is 35 inches from the top edge of the upper body tube (or from separation point 1). It should be noted the coupler is 12 inches long, where 6 inches are in the upper body tube and 6 inches are in the lower body tube. Once the coupler clears the bottom end of the upper body tube, the lower and upper body tubes will separate and create separation point 2 as seen in the figure above.

In the top picture of the figure above, the red circles indicate the relative locations of the black powder charges that will be used to create the two separation points. They will be placed along the separation points to separate each component. Fire cloths, represented as green squares, will be attached to each parachute to ensure they are not damaged once the black powder charges are triggered.

3.1.3. Launch Assurance

A brief overview of all components of the launch vehicle will be given here as well as planned dimensions and materials. Specific dimensioning and material of each component along with a list of components will be given in section 3.1.3.1. Details on the manufacturing process and step-by-step instructions on how the team would construct the rocket will be given in section 3.1.5. A final table of all dimensions will be given in 3.1.6 Final Rocket Design.

3.1.3.1. Structural Elements

Overview

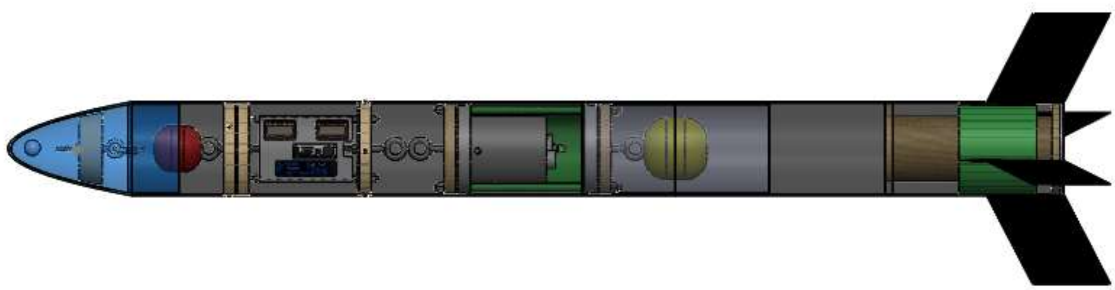

Figure 2: Launch Vehicle Overview

Total Estimated Weight: 19.5 lb.
Stability Margin: 2.29

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.

Nosecone

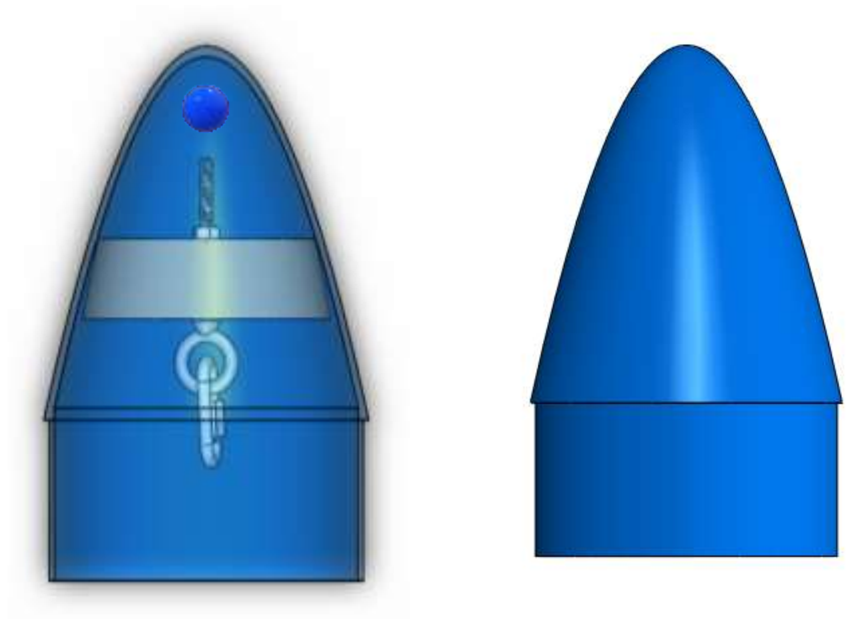

Figure 3: Nose Cone Overview

Estimated Rocket Vehicle Section Weight: 2.00 lb.

The nose cone vehicle section is composed of six different components:

1. The nose cone parent component
2. The bulkhead, which is used as an anchor point for the main parachute assembly to the nose cone parent component.
3. The eyebolt, which attaches the main parachute assembly to the bulkhead and by extension the nose cone parent component.
4. The quicklink, which secures the main parachute assembly to the eyebolt.
5. The nut, which fastens the eyebolt to the bulkhead.
6. The ballast, which is epoxied to the tip of the nosecone.

Table 1: Nose Cone Section Components

Component	Material	Dimensions
Nose Cone	ABS Plastic	Cone Length: 8 in. Cone Thickness: 0.07 in. Cone Base Diameter: 5.9 in. Shoulder Length: 3 in. Shoulder Thickness: 0.07 in. Shoulder Diameter: 5.7 in.
	ABS Plastic is selected as the material that the nose cone will be made out of	Ogive shape and length are given by the need for a desirable stability and

Table 1: Nose Cone Section Components

Component	Material	Dimensions
	as the material is used in the 3D printers available and allows a greater capability of conforming the structural design to team design parameters.	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.
Bulkhead	Pine Wood and Epoxy	Thickness: 1.5 in. Diameter: 5 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 nose cone 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, and its sides are sloped to be flush to the interior wall of the nose cone to better epoxy it to the nose cone.
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 present during the main parachute'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 main parachute assembly. Additionally, the length of the 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 nose cone parent component.
Quicklink	Stainless Steel	Length: 1 in.
	Stainless steel is the material of choice for quicklinks due to their high	The quicklink must be long enough to secure both the eyebolt eye and the

Table 1: Nose Cone Section Components

Component	Material	Dimensions
	strength, a necessary consideration for the loading forces present during the main parachute's deployment.	shock cords together, and thick enough to withstand the loading forces of the main parachute'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 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.
Ballast	Various Metals	1.25 lbs.
	We use a series of washers epoxied and attached to the nosecone to provide extra weight to aid in the flight of the rocket	

A breakdown of component placement can be seen below. Of note is that the nose cone bulkhead is specifically tapered to fit into the nose cone. Between the bulkhead and the tip of the nose cone, expanding foam is added to support the smaller brittle nose tip.

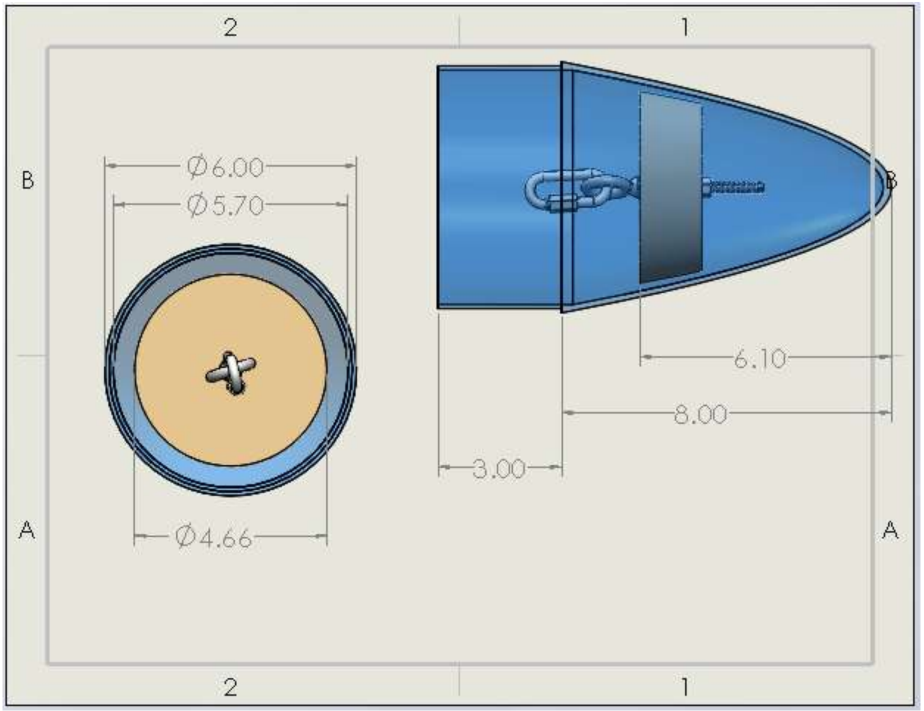

Figure 4: Nose Cone Drawing

Upper Body Tube

Figure 5: Upper Body Tube Overview

Estimated Rocket Vehicle Section Weight: 9.5 lb.

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

1. The upper body tube parent component
2. The payload which will be ejected in flight.
3. 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.
4. The retention mechanism, which is both the anchor point for the drogue chute assembly and the access point for the electronics bay.

5. 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.
6. 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.
7. 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.
8. 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	*See Section 4.2.2*	
Retention System	*See Section 4.2.2*	
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	The dimensions are given so the bulkhead is thick enough to secure an eyebolt to which the main parachute recovery assembly is attached

Table 2: Upper Body Tube Section Components

Part	Material	Dimensions
	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.	
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 present 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 present 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 present	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.

Table 2: Upper Body Tube Section Components

Part	Material	Dimensions
	during the main parachute's deployment.	

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): 7.66 lb.
Estimated Rocket Vehicle Section Weight (without motors): 4.4 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 tube at minimum must be

Table 3: Lower Body Tube Section Components

Part	Material	Dimensions
	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.	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 present 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

Table 3: Lower Body Tube Section Components

Part	Material	Dimensions
		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 present 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	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.

Table 3: Lower Body Tube Section Components

Part	Material	Dimensions
	apogee capability at the same weight. As such, carbon fiber was selected over fiberglass.	
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.

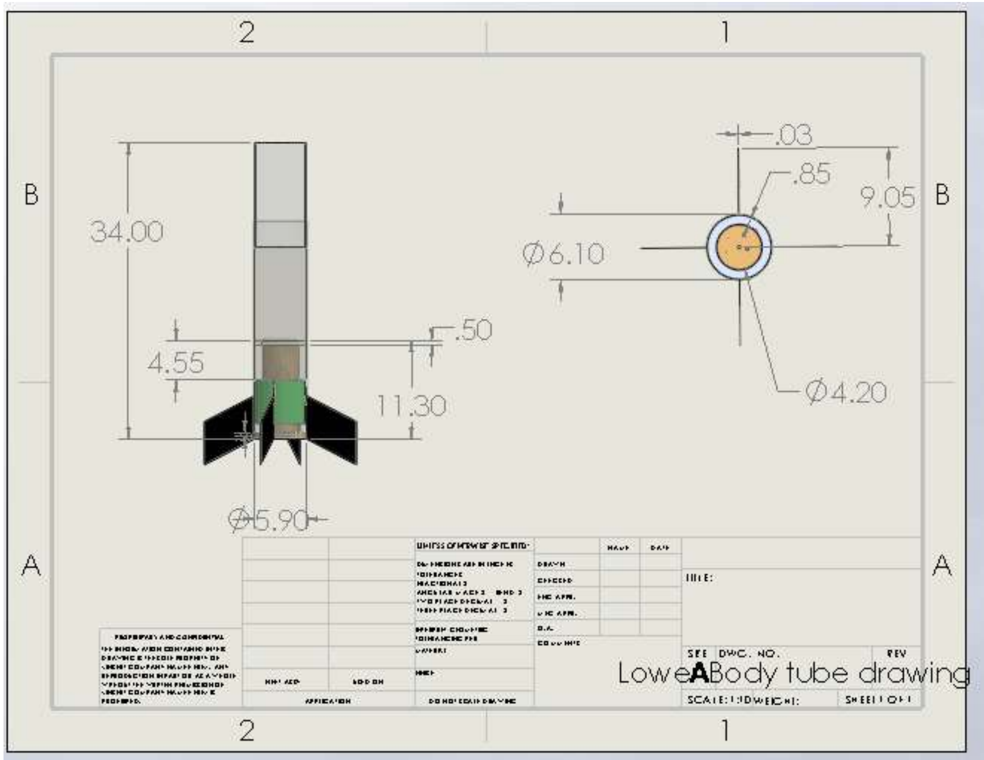

Figure 6: Lower Body Tube Drawing

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.

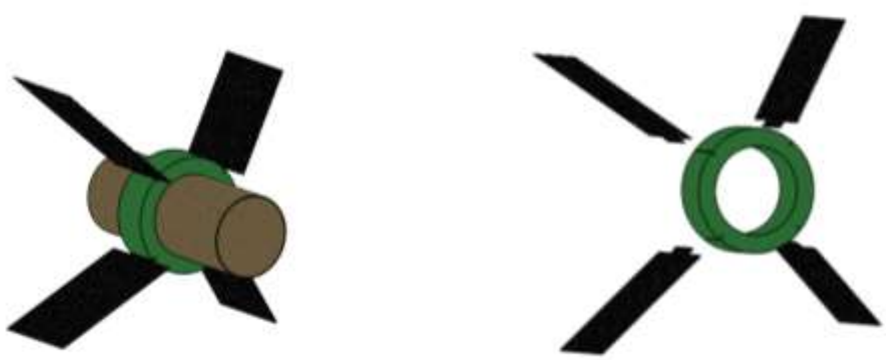

Figure 7: FSM Overview

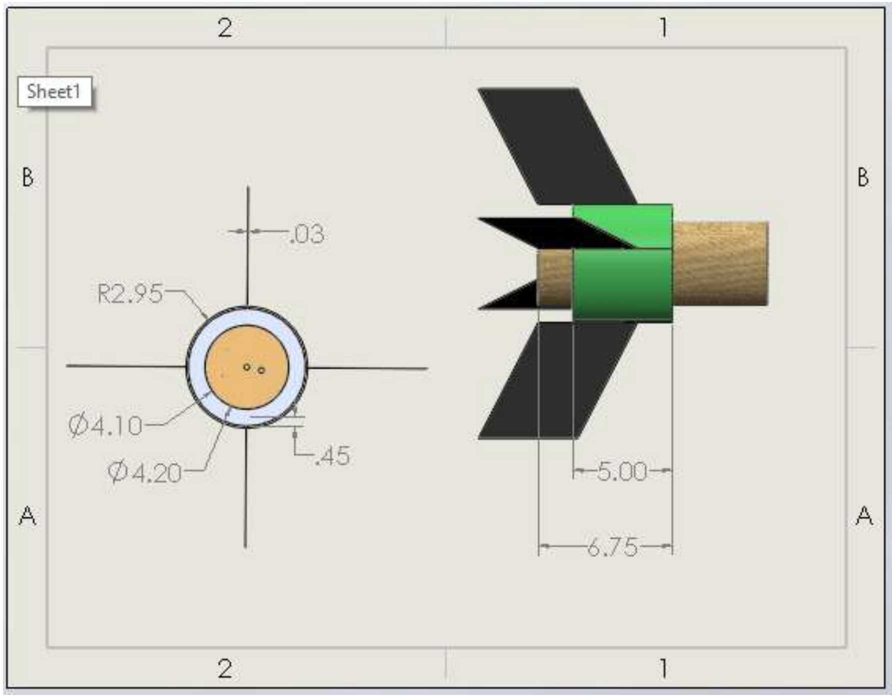

Figure 8: FSM Drawing

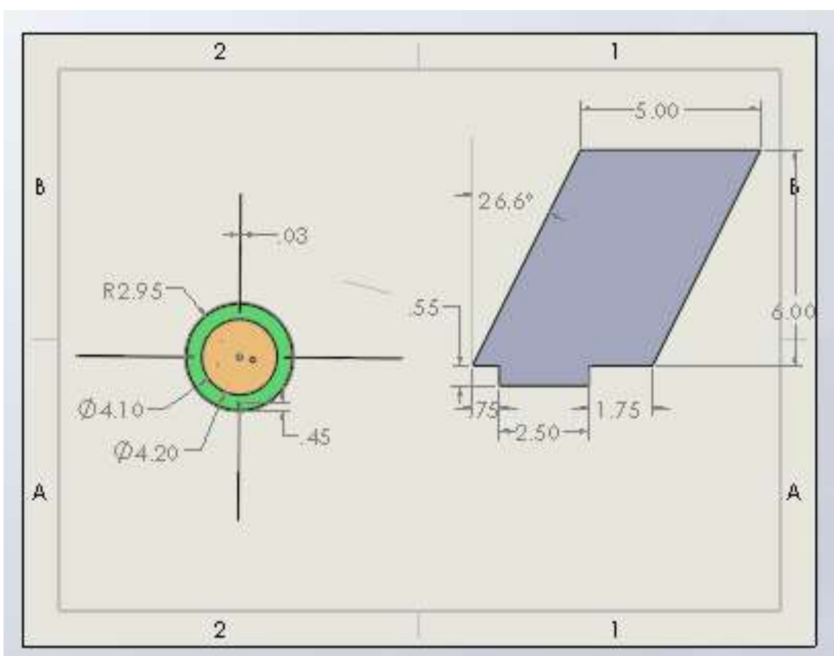

Figure 9: Fin Drawing

3.1.3.2. Electrical Elements

Switches

Figure 10: Turnkey Switch

Turnkey switches will be implemented to turn the electrical components of the rocket on and off. The switch itself functions by using a key to turn the switch in order to complete the circuit, thereby turning on the electrical components. This allows for an easier and safer launch, since the rocket will not be able to turn on by itself, unless the key is used. Furthermore, the switch allows for a clear indicator of whether the rocket electronics are on or off, since the switch can only complete the circuit if you turn it to the "on" position, as demonstrated in section 3.2.1.2. Electrical Elements.

GPS

The Missile Works Tiny Telematics Tracker (T3) GPS system will be used to locate and retrieve the launch vehicle after all launch and mission sequences are completed. This device connects to an Android device via Bluetooth using an additional component outside of the launch vehicle. The GPS has an operational range of up to 9 miles. The GPS will be located within the nose cone in order to avoid interference caused by the carbon fiber body tube. Contrary to the body tube, the nose cone is manufactured from ABS plastic which does not interfere radio waves as heavily. The GPS will be powered on by a push button to externally power the GPS while also decreasing drag during flight. The push button is connected to a 1S 1200mAh LiPo battery for a total on time of 6.9 hours.

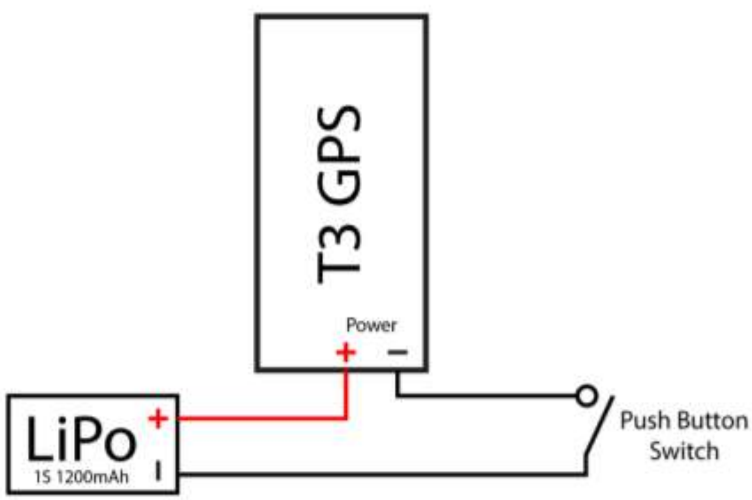

Figure 11: GPS Wiring Schematic

Avionics Retention Methods

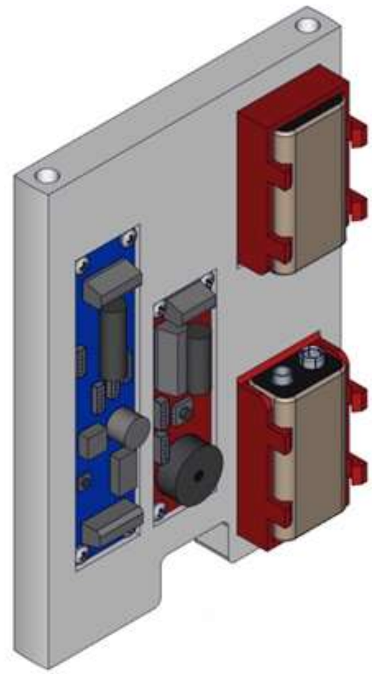

Figure 12: Avionics Sled

The avionics sled which harnesses the altimeters, and its batteries is shown above. The altimeters are attached to the sled using a set of 4-40 threaded heat set inserts and 4-40 screws. This provides a robust attachment point for the altimeters as the heat set inserts are molded into the sled itself. 9V batteries are housed in their separate 3D printed 9V battery enclosures. Additional tape is strapped across the batteries prior to launch to ensure they are securely fastened. Further details on the assembly process of the avionics sled are provided in section 3.1.5. Construction Plans and Procedures.

Altimeters

Altimeters play a critical role in the safety of the launch vehicle and spectators. The altimeters used use dual deployment systems to slow the launch vehicle's descent to a safe kinetic energy that doesn't damage the vehicle itself and to reduce the launch vehicle's descent time compared to a single deployment system. Altimeter schematics, discussion, and redundancy plans are outlined in section 3.2.1. Design Robustness.

3.1.4. Flight Reliability Confidence

A successful mission for the launch vehicle will be determined as completion of the following tasks for the Design Competition of USLI along with their proposed method of solution:

1. Virtually simulate the flight of the launch vehicle and reach within 100 feet of the targeted apogee.

   Multiple simulation software platforms will be used to determine the predicted apogee. The OpenRocket software predicts an apogee of about 3530 feet while the RockSim software predicts an apogee of about 4100 feet. Along with using multiple simulation software programs, several simulations using each program will be run to accurately approximate an apogee which *will then be compared to the targeted apogee. If the targeted apogee is within 100 feet of the approximated apogee from simulations, then this task can be considered a success. The team feels confident with the design of the vehicle and believes this task can be successfully completed due to the changes mentioned in 3.1.1. More detail on the simulations can be found in 3.3 Mission Performance Predictions that will further demonstrate that the design can meet this mission task.*

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.

   All virtual tests for all components of the launch vehicle through SolidWorks Simulations were conducted on the CDR (Section 6.1) and were shown to withstand predicted forces. The only component that was found to fail from buckling under predicted forces was the airframe of the vehicle. This simulation was updated with the correct material properties of the carbon fiber airframe and was found to withstand the predicted buckling forces. No components of the launch vehicle will fail or receive considerable damage under the predicted forces especially since a factor of safety was also included when running these simulations.

3. Safely retaining a payload during the virtual flight with no signs of damage to the structure and electronics of the payload, as verified through simulations.

   Due to the nature of the Design Division, there is no way to physically test for failure or damage on the structure and electronics of the payload. Instead, virtual simulations will have to suffice to determine if the structure and electronics of the payload will be able to withstand predicted forces both during flight as well as descent. These simulations were all conducted on the CDR in 6.1.2 Payload Testing. The simulations showed that the payload did not receive any damage both during flight as well as descent.

Reliability of the electronics system within the launch vehicle is verified through testing. As mentioned before, physical testing is not possible due to the virtual nature of the competition. However, physical tests of electrical systems are outlined below to verify all systems function as expected prior to launching.

Table 4: GPS Connectivity Testing

Objective:	Test the connectivity range of the GPS to an Android device and its ability to reconnect to the device after loss of connection.
Success Criteria:	The connectivity range is around 9 miles, and the GPS can reconnect to the Android device after losing connection.
Variables:	Distance: GPS connectivity range
Constants:	• Android device • GPS being on
Step-by-Step Execution:	1. Connect GPS to Android device. 2. Move GPS away from Android device until it disconnects from the device. 3. Move Android device towards GPS to attempt reconnection
Relevant Safety Concerns:	None.
Status:	Incomplete.

Table 4: GPS Connectivity Testing

Justification:	This test simulates the GPS moving away from the Android device as if during a rocket flight. It also simulates the team's attempt at finding the rocket with the GPS should it disconnect.
Possible Necessary Changes:	In the case the GPS has a really short connectivity range, or it cannot reconnect, the GPS itself would have to be changed with a GPS that will fulfill those functions.

Table 5: Altimeters Testing

Objective:	Test how effective the altimeters are at determining the altitude of the rocket given the pressure it is experiencing.
Success Criteria:	Altimeter can accurately determine the pressure of its surroundings.
Variables:	Pressure: Change in pressure in order to simulate change in altitude.
Constants:	• Altimeters in use. • Temperature • Actual altitude
Step-by-Step Execution:	1. Use a vacuum chamber and place the altimeters inside the chamber. 2. Modify the pressure within the vacuum chamber in order to simulate change in pressure due to change in altitude. 3. Determine whether altimeters accurately determine the pressure of their surroundings.
Relevant Safety Concerns:	None.
Status:	Incomplete
Justification:	This test simulates the change in pressure that would occur due to the change in altitude during flight. If the altimeters can accurately determine this change in pressure, this certifies that they function properly.
Possible Necessary Changes:	If the altimeters fail this test, new altimeters will have to be acquired and tested in order to have altimeters are function correctly.

3.1.5. Construction Plans and Procedures

Nosecone

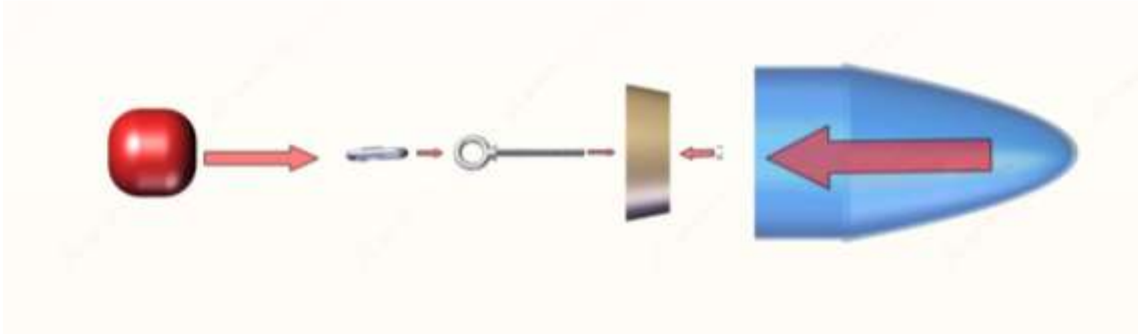

Figure 13: Nosecone Construction

PPE Required	Gloves
Instructions	• After printing out the nosecone and cutting the dimensions of the bulkhead, thread an eyebolt and secure it down with a nut to the bulkhead. • Attach a quicklink to the eyebolt to tie the shock cord to • Using epoxy, attach the bulkhead to the inside of the nosecone, so that the curve of the bulkhead lines up with the nosecone. • Position the main chute in the nosecone shoulder. • Shock cords will be attached to the quicklink on the eyebolt and to the drogue chute (represented by a red sphere)

Upper Body Tube

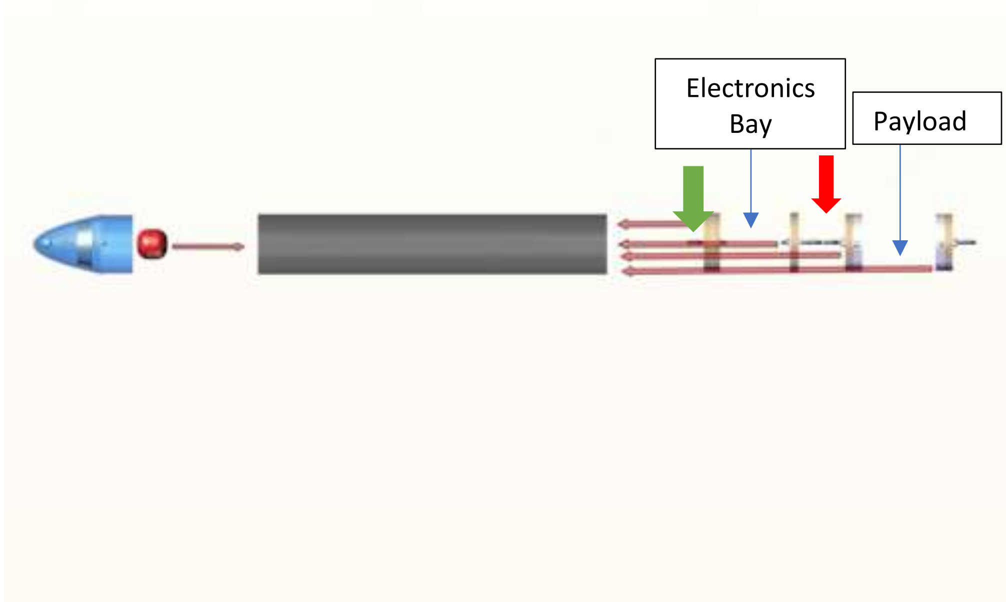

Figure 14: Upper Body Tube Construction

PPE Required	Gloves
Instructions	• Secure the Payload and Electronics Bay into the upper body tube using epoxy and screws, as described in the section above. • Once secured, attach the nosecone and main chute into the upper body tube above the securing mechanism, using epoxy on the shoulder of the nosecone to secure it in • A shock cord will be placed between the electronics bay and payload indicated by the red arrow. The connection will be between two eyebolts, one attached to the end of the Ebay and the other attached to the end of the retention assembly of the payload. • Another shock cord will be attached to the end of the electronics bay indicated by the green arrow. This shock cord will be attached to the electronics bay and to the bulkhead in the nosecone, comprising the recovery hardware for the drogue chute

Lower Body Tube

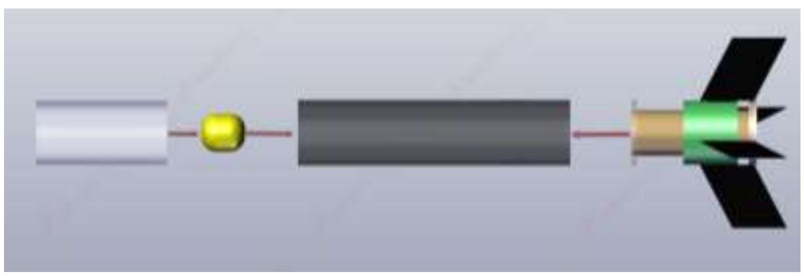

Figure 15: Lower Body Tube Construction

PPE Required	Gloves
Instructions	• After assembling the fin securing mechanism, slide the fin securing mechanism without the fins attached into the lower body tube, and secure with epoxy. • Connect coupler 6 inches into the top of the lower body tube, attaching with epoxy. • Store the drogue chute in the couple to be released at apogee. • Slide the fins into the proper slots in the fin securing mechanism, and use epoxy in the slots and on the sides of the fins to make sure they are secure

Fin Securing Mechanism and Motor Mount

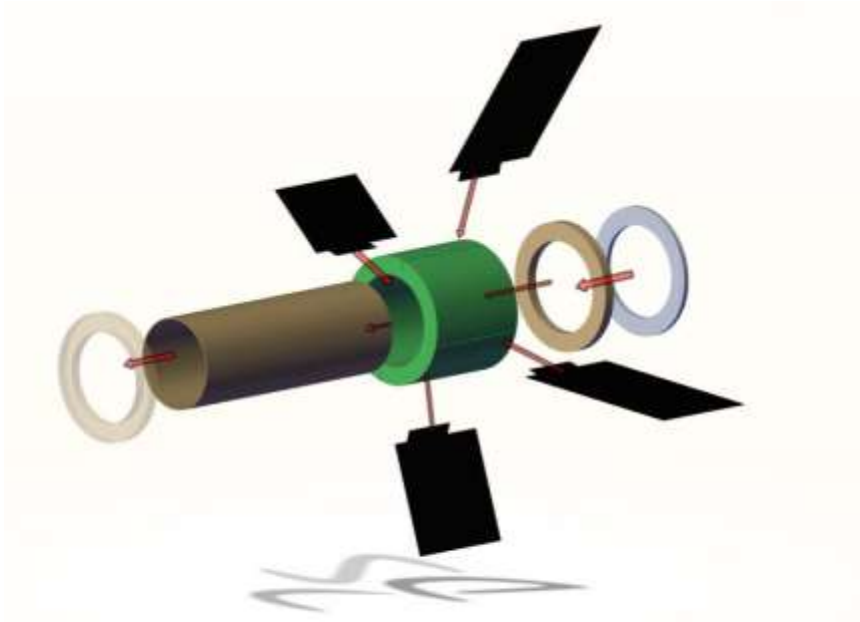

Figure 16: Fin Securing Mechanism Construction

PPE Required	Masks, Gloves, Lab Coats, Shop Vacuum
Instructions	• After securing the carbon fiber sheets for the fin construction, trace out the necessary dimensions to cut out the fins. • Using a Dremel rotary tool, cut the fins out of the carbon fiber sheets to the desired dimensions traced out earlier. • Attach the fin securing mechanism, the phenolic tube, the centering rings, and the bottom aluminum plate to each other and ensure that they are secure and connect into the lower body tube. • Once the motor fount and fin securing mechanism is secure, slide each fin tab into the appropriate slots in the securing mechanism, and use epoxy to secure the material inside.

Locking Mechanism

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

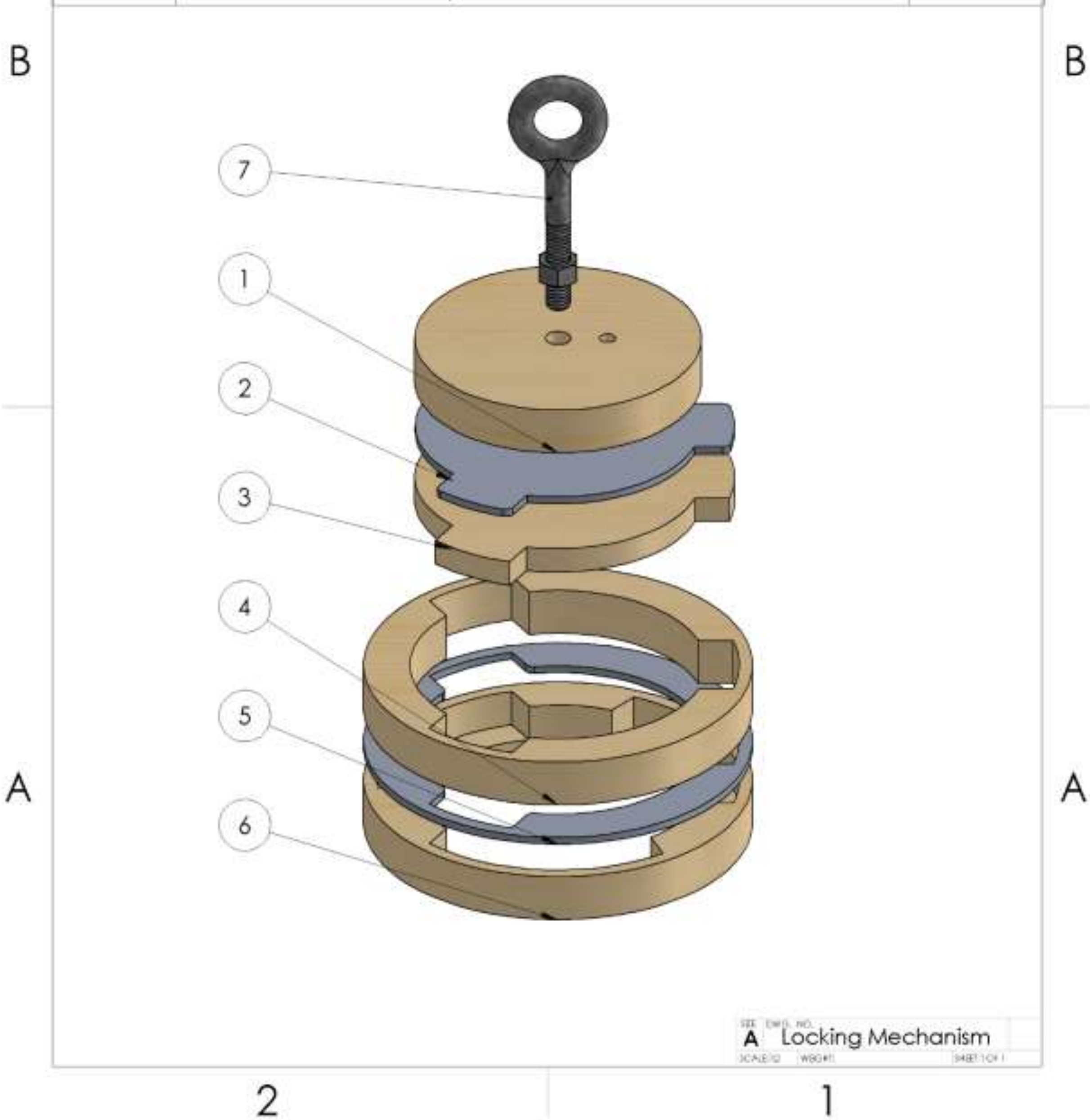

Figure 17: Exploded View of Locking Mechanism

All wooden components for the locking mechanism are CNC'd 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. Instructions on how to assemble the locking mechanism are outlined below.

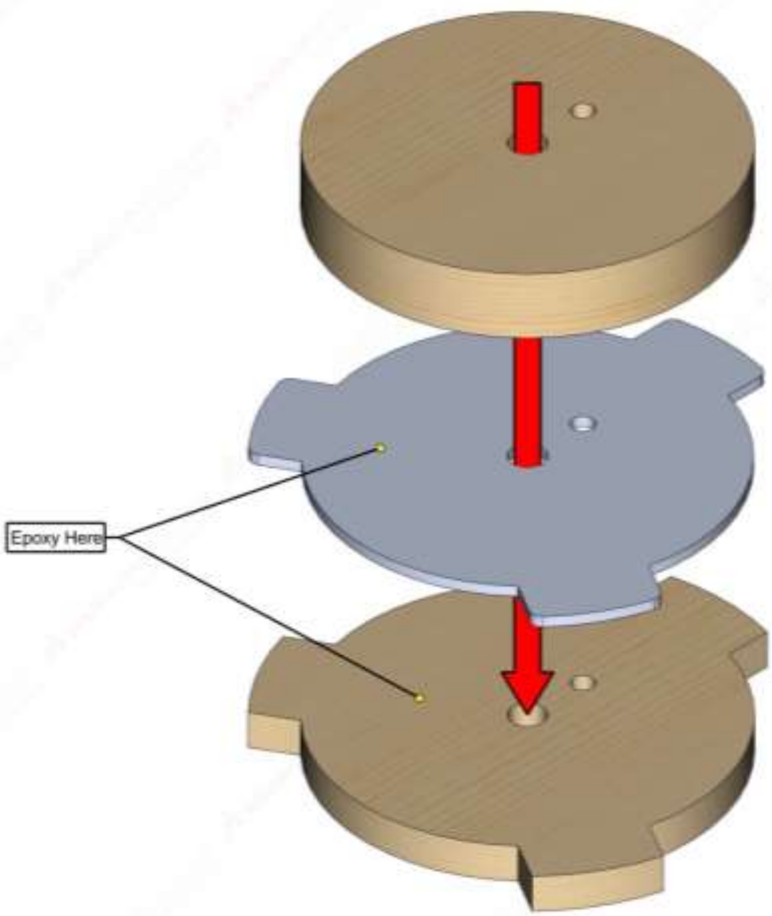

Figure 18: Locking Mechanism Assembly Step 1

PPE Required	Latex gloves and protective eyewear
Instructions	• Apply 1:1 epoxy to the surfaces indicated above using a clean wooden popsicle stick, making sure to not apply epoxy on the tabs of the aluminum reinforcement. • Stick components together and align properly. • Use multiple clamps to stick parts together. • Wipe off any excess epoxy and let dry for 24 hours with clamps

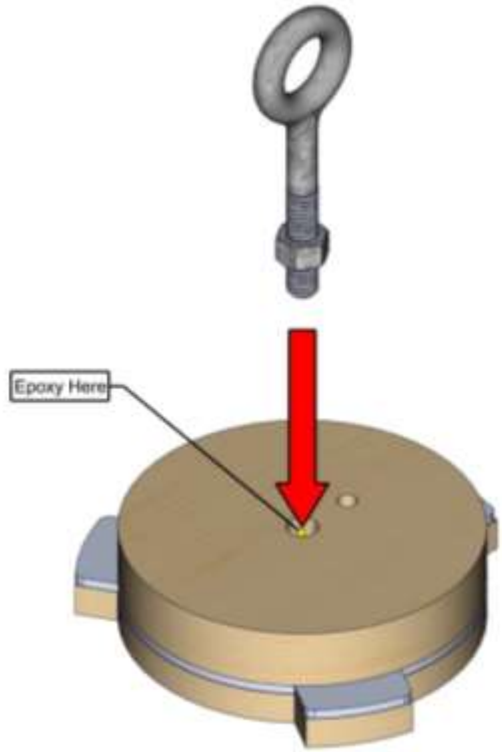

Figure 19: Locking Mechanism Assembly Step 2

PPE Required	Latex gloves and protective eyewear
Instructions	• Apply 1:1 epoxy to the central hole indicated above using a clean wooden popsicle stick, making sure to not apply epoxy on other surfaces. • Place eyebolt within central hole and wipe off any excess epoxy. • Screw nut onto eyebolt.

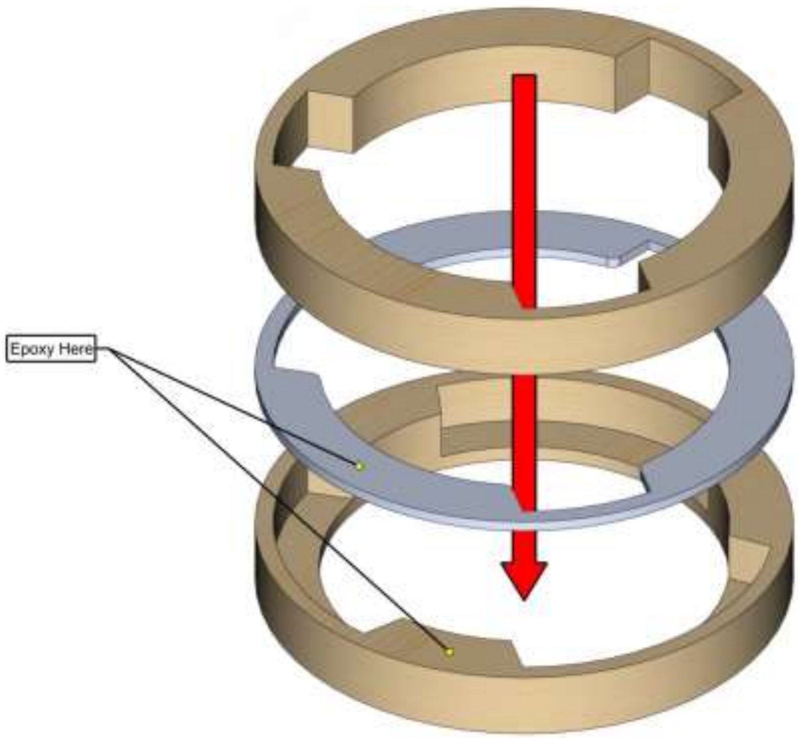

Figure 20: Locking Mechanism Assembly Step 3

PPE Required	Latex gloves and protective eyewear
Instructions	• Apply 1:1 epoxy to the top surface of the bottom two outer rings as indicated above. • Stick components together and align properly. • Use multiple clamps to stick parts together. • Wipe off any excess epoxy and let dry for 24 hours with clamps.

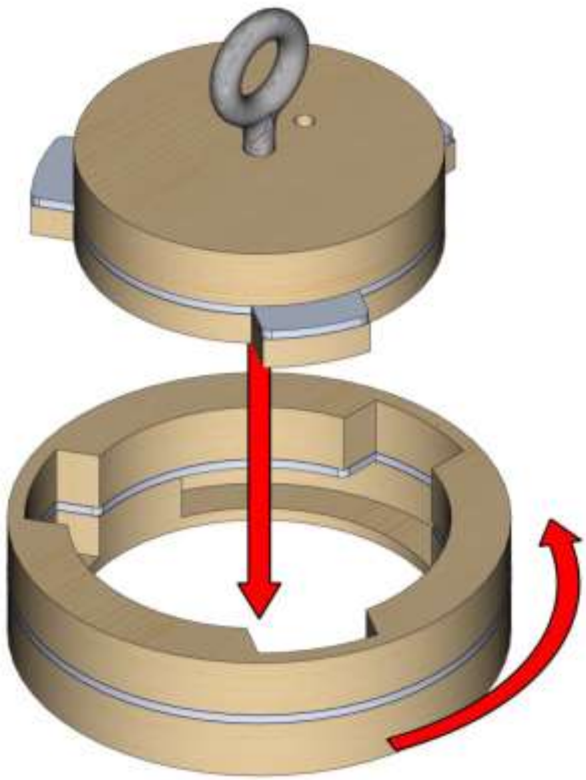

Figure 21: Locking Mechanism Assembly Step 4

PPE Required	Mask
Instructions	• Check all components fit and rotate as desired. • If either translation or rotation is difficult, sand down relevant areas until rotation and translation is easier to achieve. Sand areas where epoxy is visible first.

Avionics Sled

ITEM NO.	PART NUMBER	QTY.
1	Avionics Sled	1
2	RRC3	1
3	SL100	1
4	9V Battery Case Holder	2
5	9V Battery	2
6	4-40 Heat Set Insert	8
7	4-40 Phillips Head Screw	8

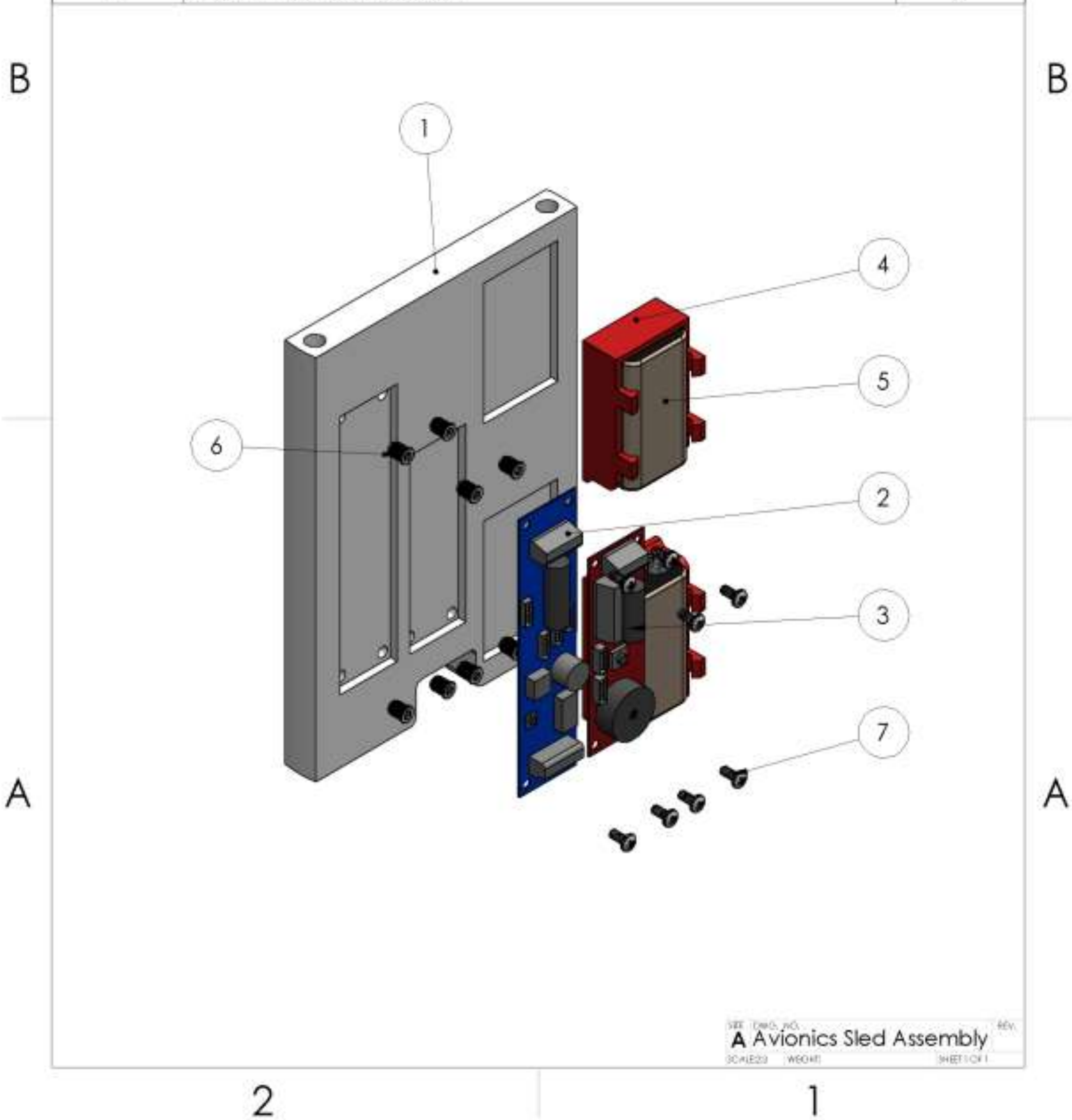

Figure 22:Avionics Sled Exploded View

All plastic components of the avionics bay are 3D printed with ABS plastic meanwhile all metal components are bought from a hardware store. Avionics are discussed their respective sections and are all off-the store parts, including the 9V batteries, housed in the red plastic holders.

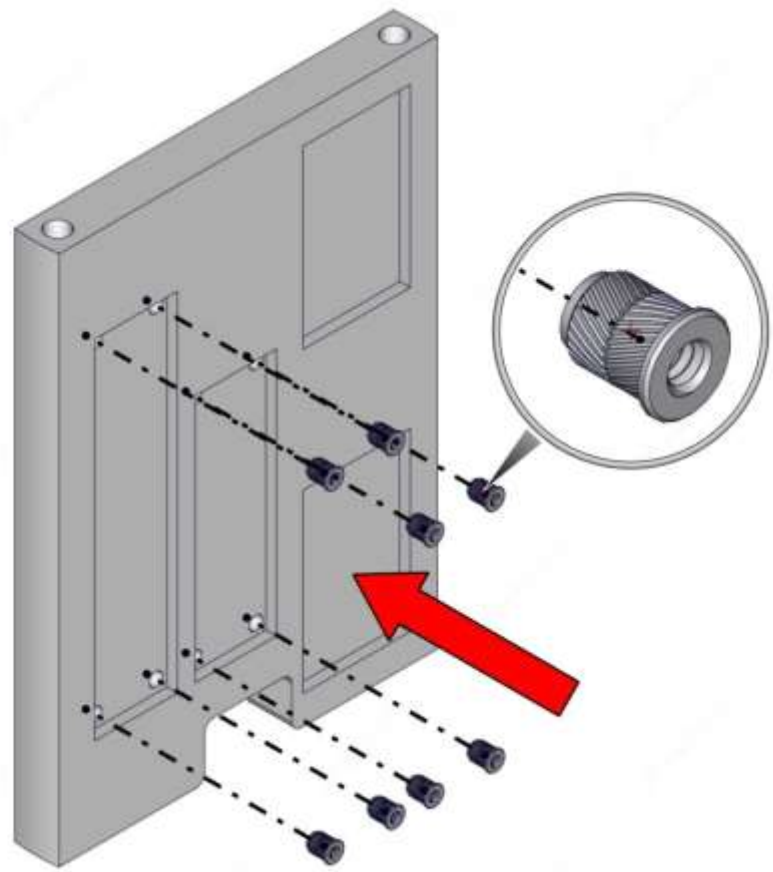

Figure 23: Avionics Sled Assembly Step 1

PPE Required	Safety Goggles, Mask
Instructions	• Use hot soldering iron to melt edges of plastic where the heat set inserts will be inserted. • Place heat set inserts into the heated holes of the avionics sled. • Ensure inserts are flush with the avionics sled (if not, reprint the avionics sled and restart process).

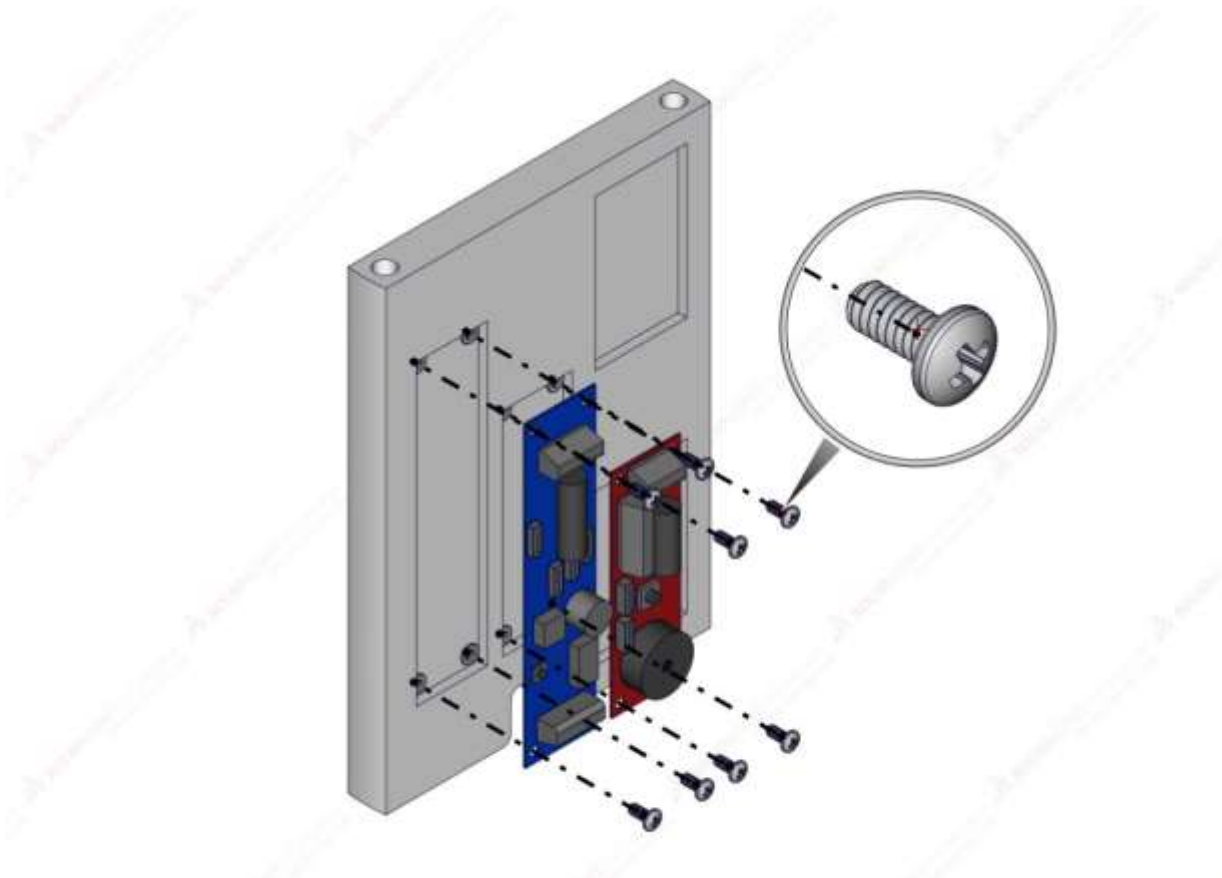

Figure 24: Avionics Sled Assembly Step 2

PPE Required	None
Instructions	• Use screws to attach altimeters to the avionics sled by threading the screw through the altimeter and then the corresponding guided insert. • Ensure screw is tightened so altimeter will not move during flight.

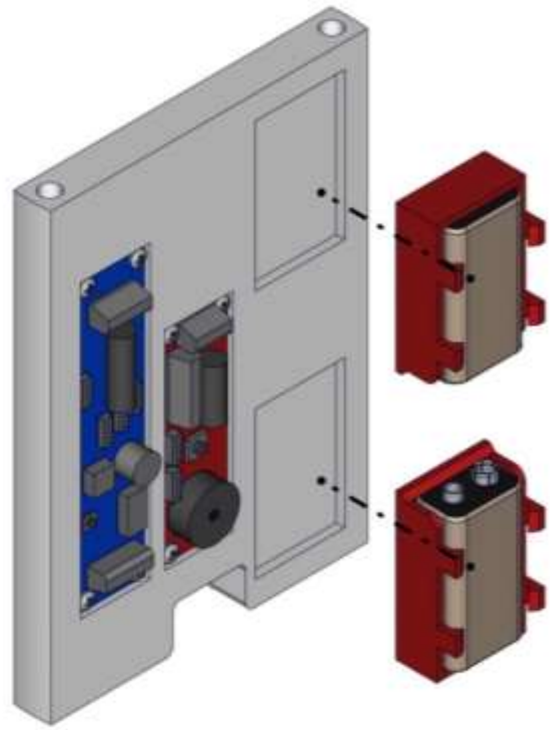

Figure 25: Avionics Sled Assembly Step 3

PPE Required	Mask, Gloves
Instructions	• Use epoxy to adhere back of battery retainers to the appropriate slot on the avionics sled. • Allow epoxy to set for at least 24 hours.

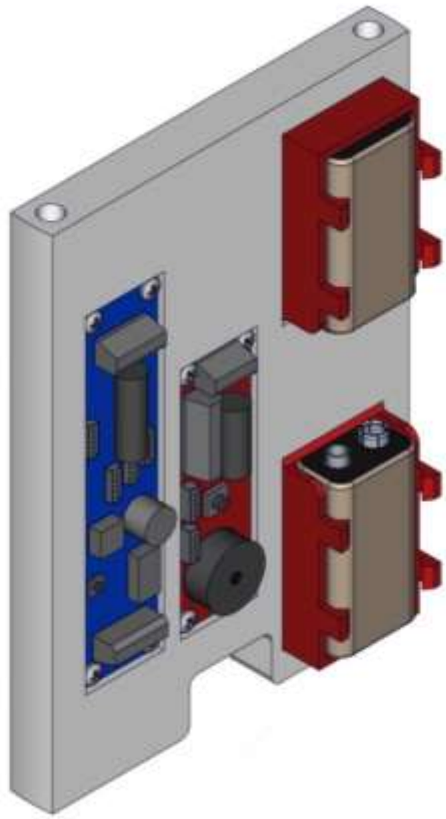

Figure 26: Avionics Sled Assembly Step 4

PPE Required	None
Instructions	• Ensure all components are secured properly into place by trying to jiggle each with respect to the sled. • If avionics are loose, tighten screws, and if battery holders are loose add more epoxy.

Ebay within Upper Body Tube

ITEM NO.	PART NUMBER	QTY.
1	Inner Ring Locking Mechanism	1
2	Outer Ring Locking Mechanism	1
3	Avionics Sled	1
4	3/8"-16 Steel Locknut	6
5	Upper Body Tube	1
6	Turn Key Switch	2
7	Wood Screw	7
8	3/8"-16 Steel Threaded Rod	2
9	Aluminum Reinforcement	1
10	Wooden Bulkhead	1
11	3/8"-16 Galvanized Steel Eyebolt	2

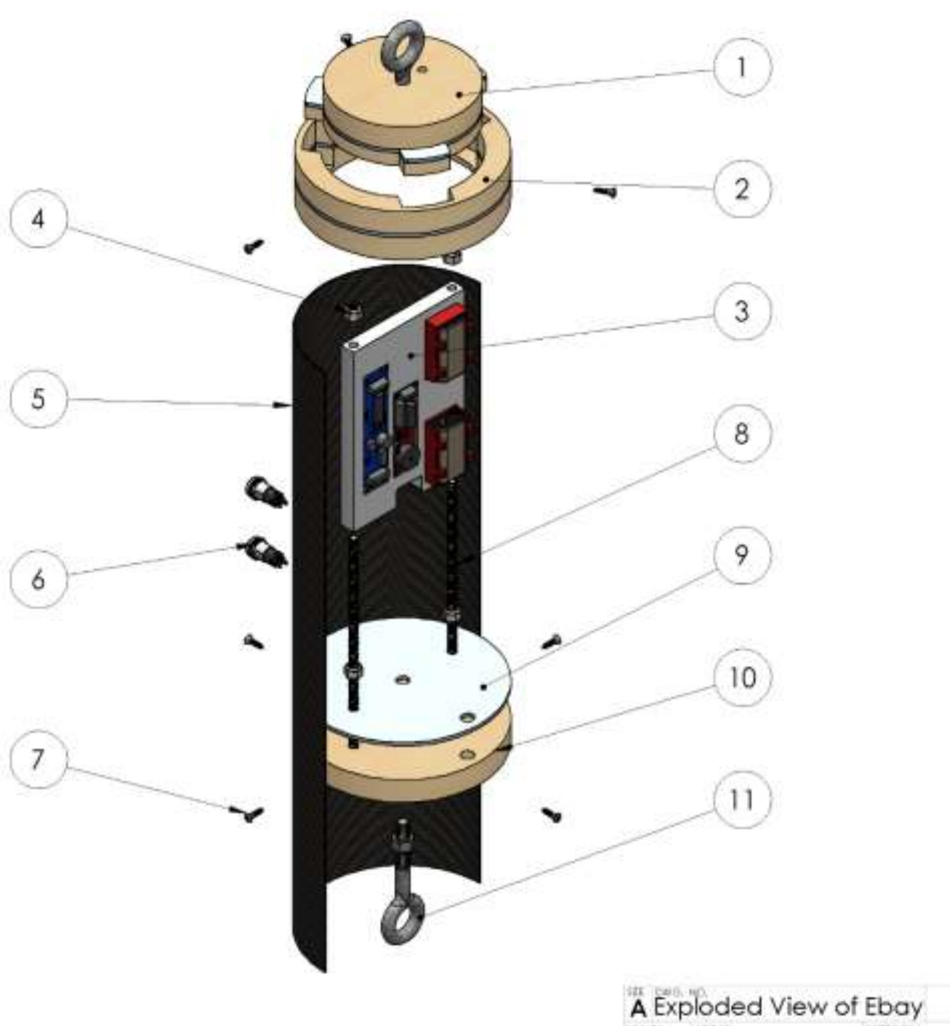

Figure 27: Exploded View of Ebay within Upper Body Tube

Avionics sled and locking mechanism assembly procedures have been outlined above. All other wood components are CNC'ed to size and metal disks are cut from a sheet of metal using a water jet cutter. Other hardware is bought commercially and utilized.

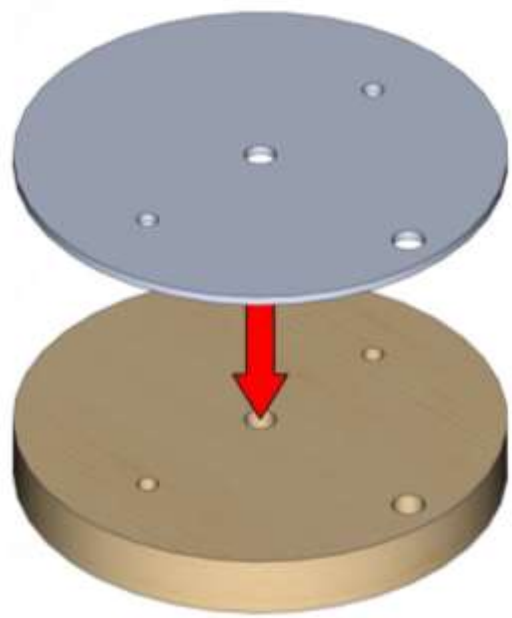

Figure 28: Ebay Assembly Step 1

PPE Required	Mask, Gloves
Instructions	• Use epoxy to glue metal disk to wooden bulkhead. • Ensure all holes line up while gluing. • Brace the two components together using clamps to ensure a secure interface. • Allow a cure time of at least 24 hours. • If any excess epoxy exists on the sides of the disks or in the holes, sand it down with sandpaper or DA sander until no excess epoxy exists.

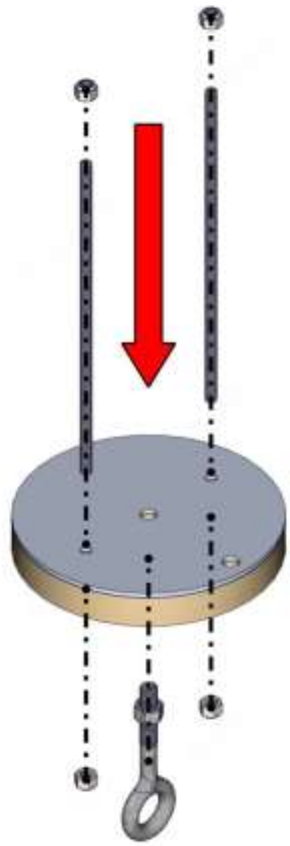

Figure 29: Ebay Assembly Step 2

PPE Required	Mask, Gloves
Instructions	• Push threaded rods through outer holes of the bulkhead until about half an inch of the rod sticks out of the other end. • Screw nuts onto either end of each threaded rod to secure the rod in place. • On the opposite side of the bulkhead, screw in the eyebolt until the shoulder is pushed against the bulkhead. • Screw nut onto opposite end of the eyebolt to secure it in place. • Use epoxy to reinforce each nut interface by covering each nut with epoxy. • Allow a cure time of at least 24 hours.

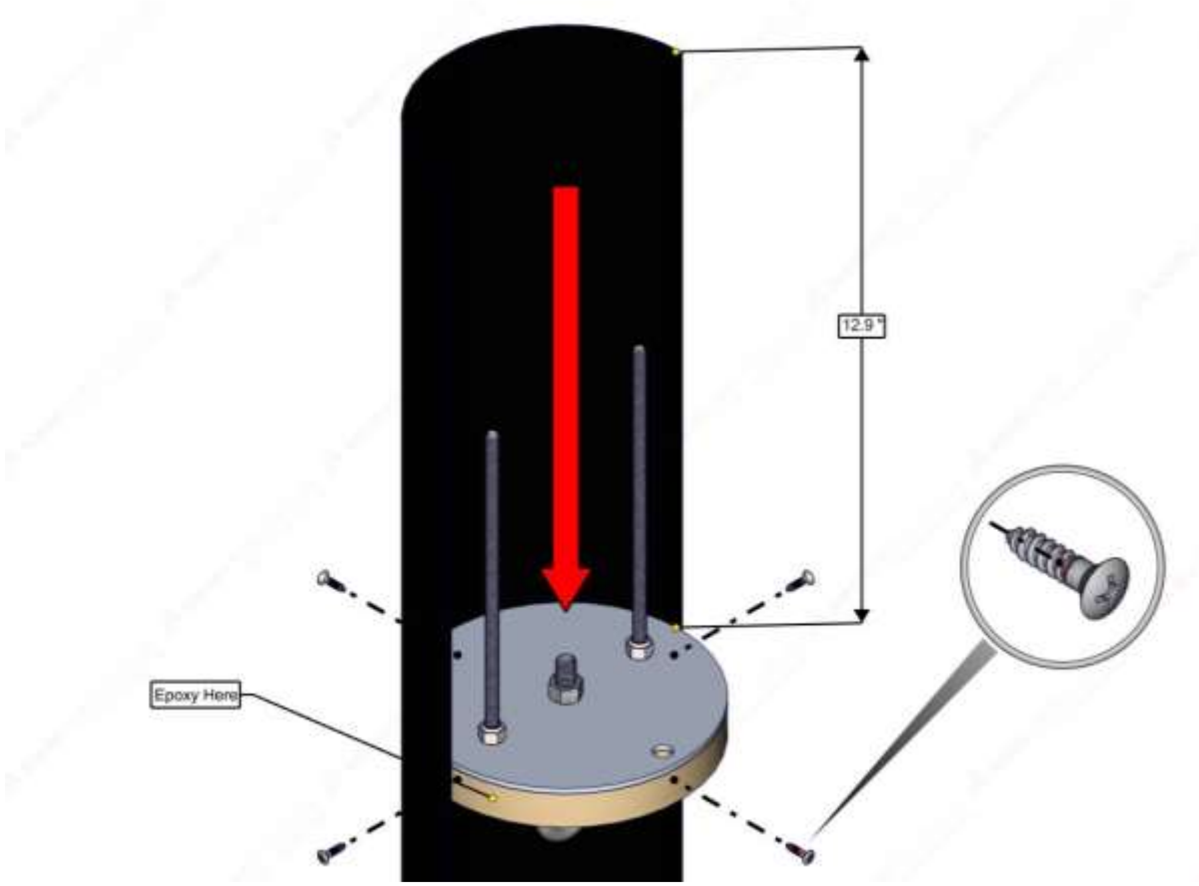

Figure 30: Ebay Assembly Step 3

PPE Required	Mask, Gloves, Lab Coat, Goggles
Instructions	• Place a line of epoxy around the inside of the body tube 12.9" from the edge. • Slide the bulkhead 12.9" in, eyebolt side down so it goes over the line of epoxy. • Allow cure time of 24 hours. • Use drill to insert 4 equally spaced screws into the bulkhead.

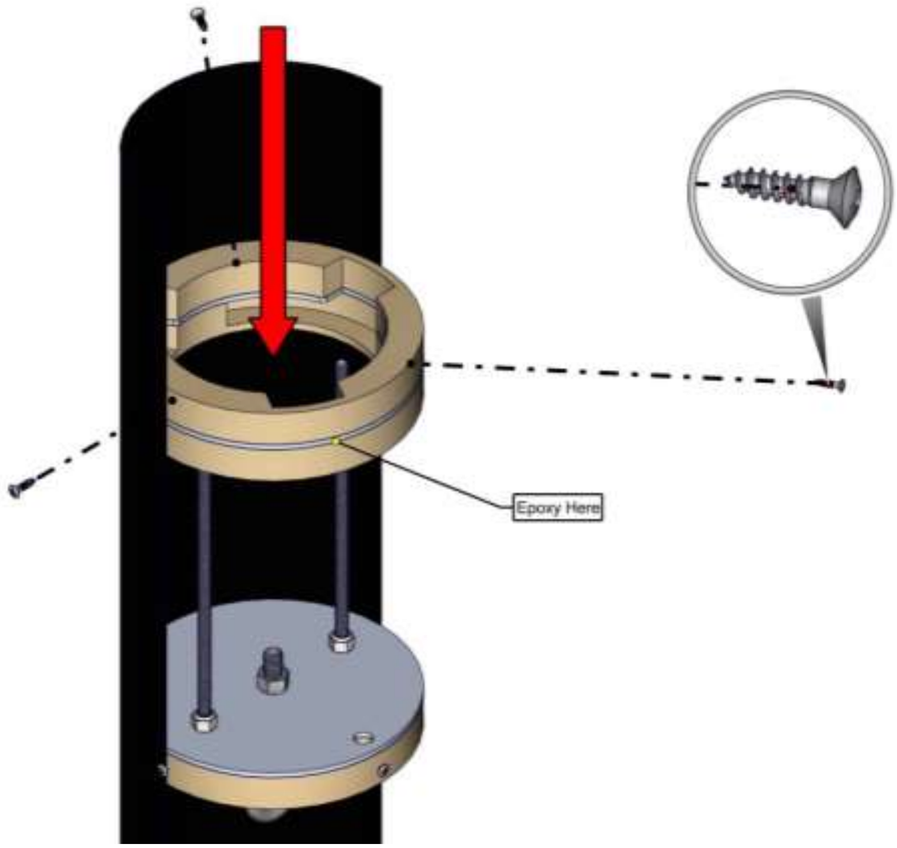

Figure 31: Ebay Assembly Step 4

PPE Required	Mask
Instructions	• Place a line of epoxy around the inside of the body tube just above where the threaded rods end. • Slide the locking mechanism to be just over this line, with the accessible side facing up so the middle section can be inserted. • Allow cure time of 24 hours. • Use drill to insert 4 equally spaced screws into the locking mechanism.

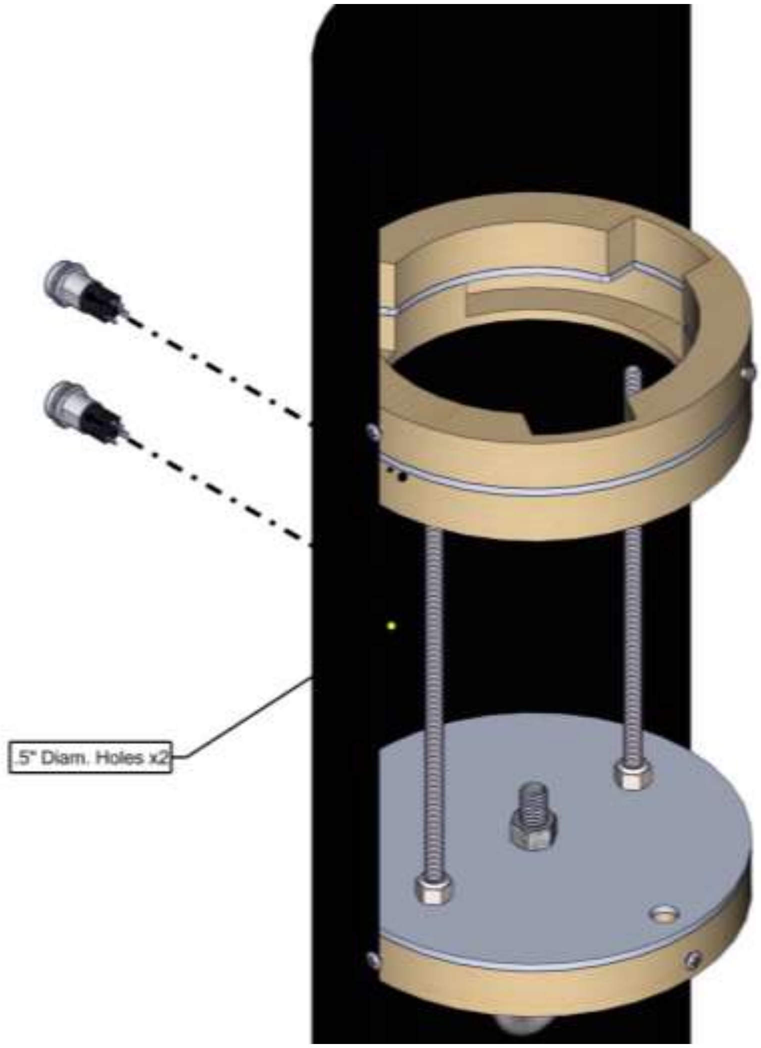

Figure 32: Ebay Assembly Step 5

PPE Required	Mask, Goggles, Lab Coat
Instructions	• Drill two .5” diameter holes into the body tube between the bulkhead and locking mechanism as shown. • Insert turnkey switches with wires already soldered on into designated holes and use included screws to temporarily secure the switches in place. • Add epoxy around the switches on both the inner and outer face of the body tube to ensure security. • Allow cure time of at least 24 hours.

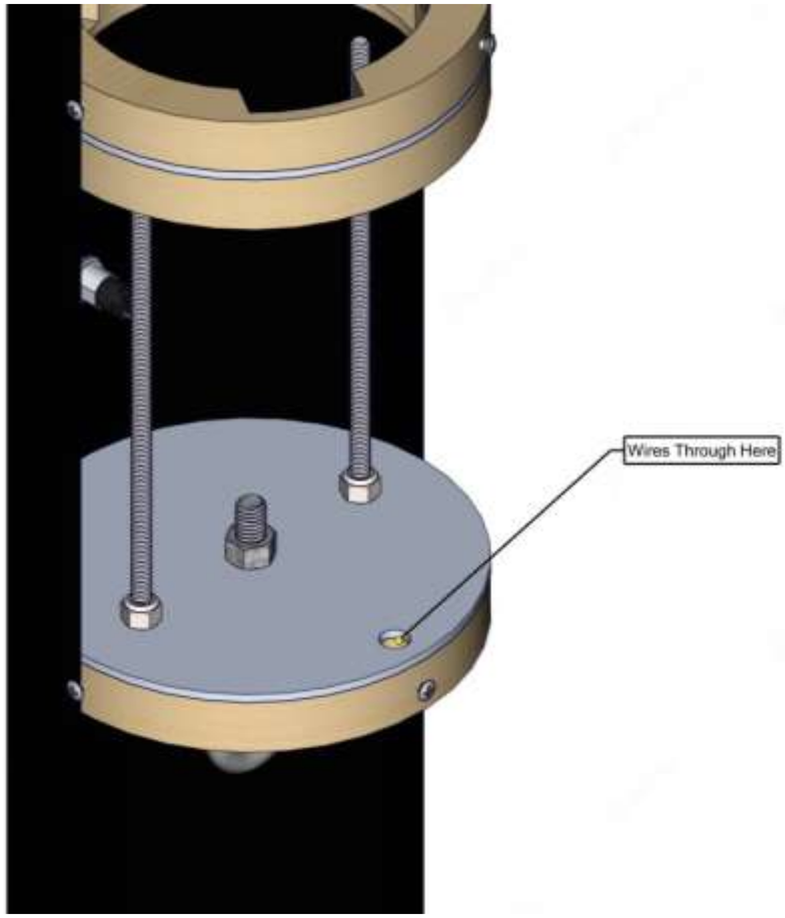

Figure 33: Ebay Assembly Step 6

PPE Required	Mask, Gloves
Instructions	• Thread wiring that will control parachute deployment through the hole shown above. Ensure wires extend beyond the other side of the upper body tube for easier wiring to ebay electronics from outside the launch vehicle. • Seal hole using epoxy. • Allow for a cure time of at least 24 hours.

Figure 34: Ebay Assembly Step 7

PPE Required	None
Instructions	• Make all necessary wire connections for electrical components found in the avionics sled. • Place avionics sled into the body tube by aligning the holes in the sled to the threaded rods. • Push sled to the end of the rods so it is in contact with the bulkhead assembly. • Screw nuts onto each threaded rod until each is snug against the avionics sled. This should ensure the sled cannot move during flight.

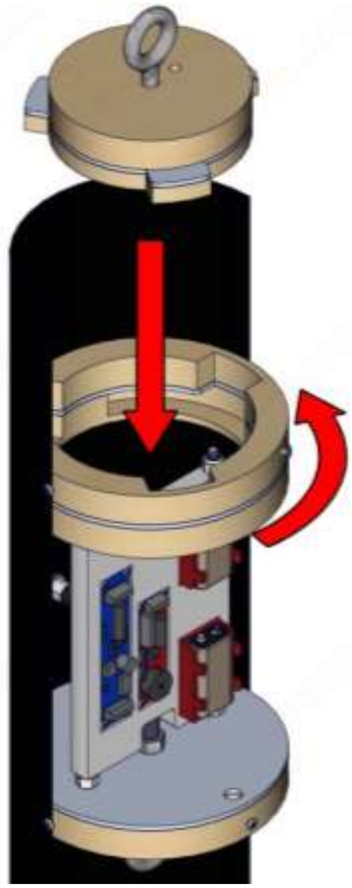

Figure 35: Ebay Assembly Step 8

PPE Required	None
Instructions	• Place center component of the locking mechanism into the assembly and twist to secure. • If preparing for flight, place duct tape over the locking mechanism to provide an air-tight seal.

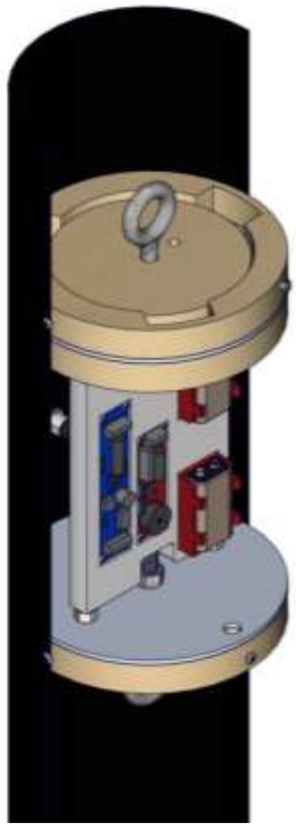

Figure 36: Ebay Assembly Step 9

PPE Required	None
Instructions	• Ensure all components are properly secured by trying to jiggle them with respect to the body tube. • Assembly is complete. • Shock cords will be attached to both eyebolts on the Ebay. The eyebolt on top will connect to the drogue parachute near the nosecone. The bottom eyebolt will be connected to the eyebolt attached to the payload through a shock cord.

3.1.6. Final Rocket Design

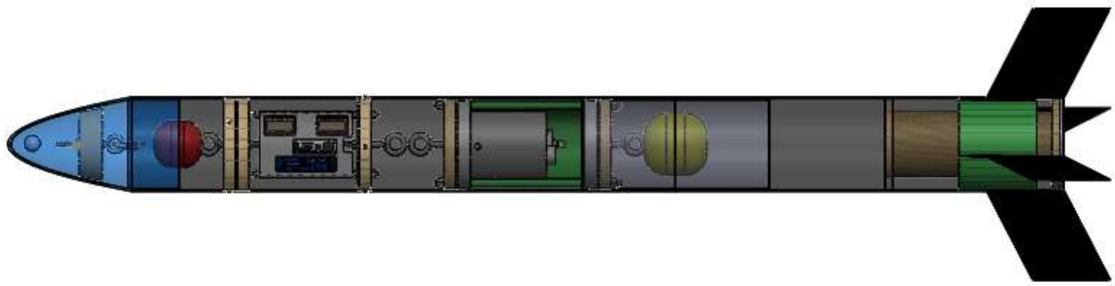

Figure 37: Final Rocket Design

All the necessary final schematics, diagrams, and measurements can be found in section 3.1.3.1 where we go in detail over our current design and the measurements of each component.

3.2. Recovery Subsystem

3.2.1. Design Robustness

To follow is a detailed description of structural and electrical components, along with testing plans and completed simulations to verify robustness.

3.2.1.1. 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.

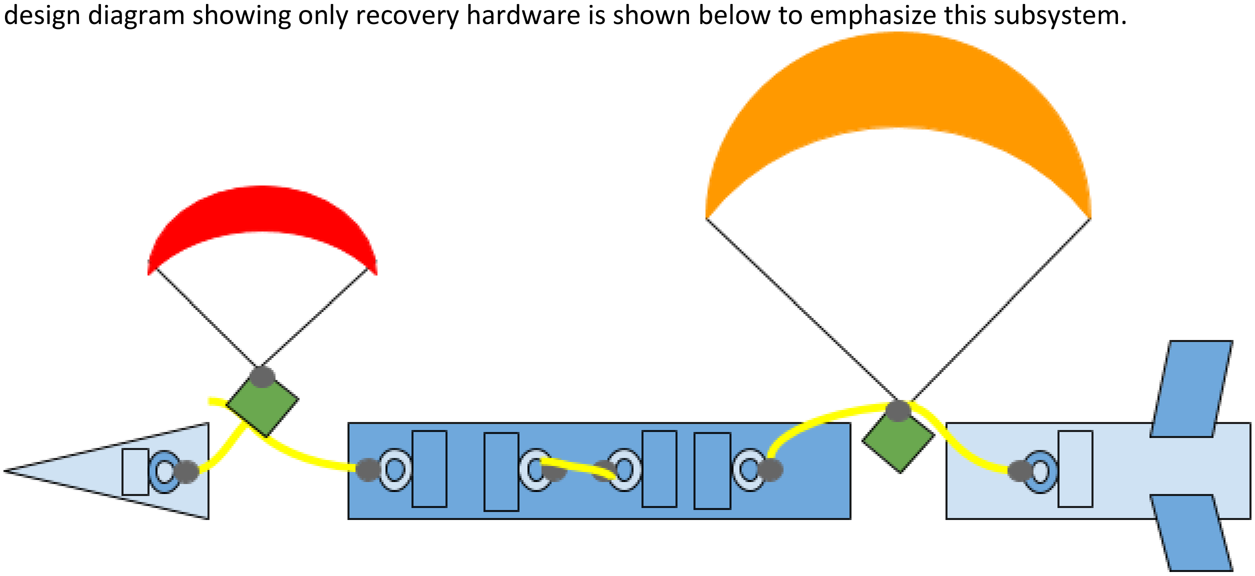

Figure 38: Recovery System Structural Overview

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.

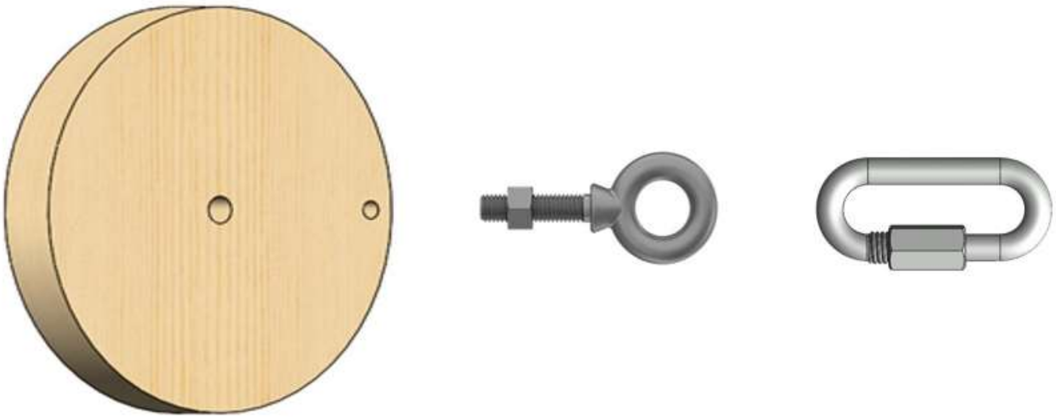

Figure 39: Structural Attachment Hardware

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 and 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 6: Nosecone Bulkhead 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	78 lbf of shear force

Constants:	• Bulkhead 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

Table 6: Nosecone Bulkhead Structural Integrity (Virtual)

	○ Mass Density: 0.0156 lb./in^3 ○ Yield Strength (shear): 899 psi
Step-by-Step Execution:	1. Fix outer edges of bulkhead. 2. Place shear force of 78 lbs. on the hole that will be containing eyebolt. 3. Evaluate Results.
Relevant Safety Concerns:	None.
Status/Results:	Planned
Justification:	Nosecone bulkhead failure could cause detachment of nosecone from recovery hardware, posing a hazard to personnel.
Possible Necessary Changes:	If failed, a thicker nosecone bulkhead must be implemented.

Status/Results: (if completed):

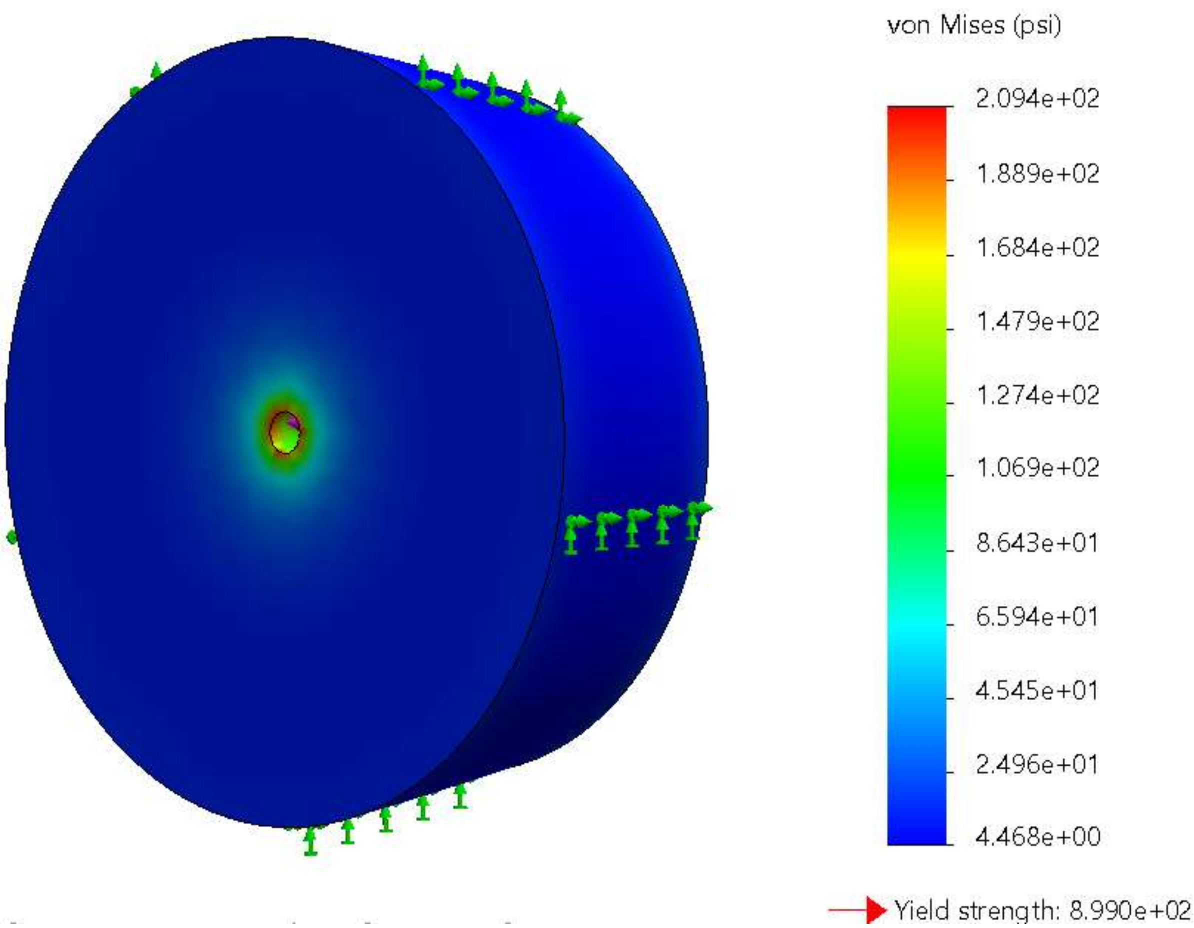

Figure 40: Nosecone Bulkhead Testing Results

Table 7: 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:	• 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 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.

$$Area\ of\ Interface = \pi * D * t\_bulkhead$$

$$Stress = \frac{Shear\ Force}{Area\ of\ Interface}$$

With known variables this becomes the following.

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

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

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

Table 8: 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:	4. Fix the surface of the bulkhead and aluminum sheet in contact with the .375" nuts. 5. Place an axial force of 81.20 lbf on the hole that will be containing the eyebolt. 6. 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):

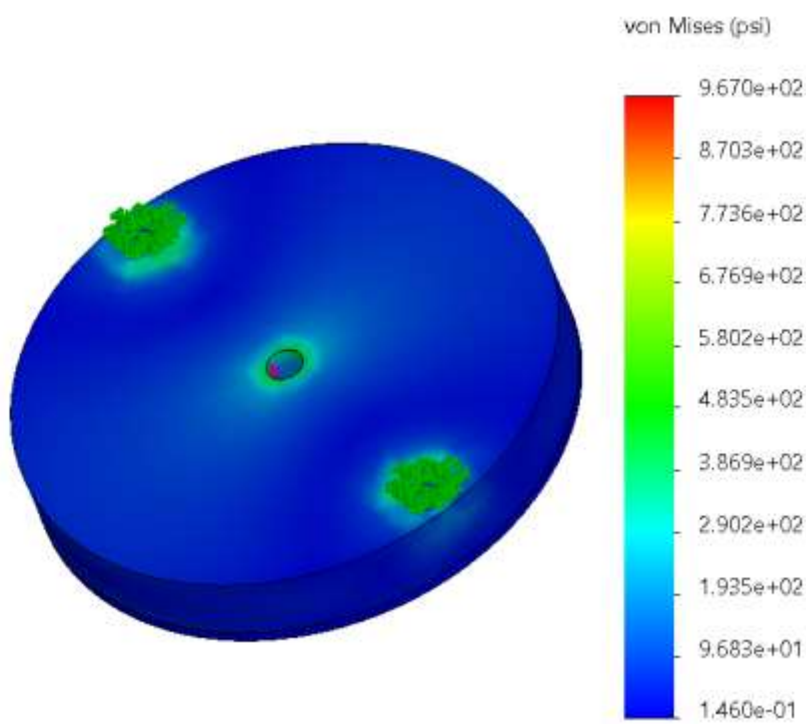

Figure 41: Retention System Testing Results

Table 9: 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.

$$Area\ of\ Interface = \pi * D * t\_bulkhead$$

$$Stress = \frac{Shear\ Force}{Area\ of\ Interface}$$

With known variables this becomes the following.

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

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

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

Table 10: 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.

Table 10: Centering Ring Structural Integrity (Virtual)

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):

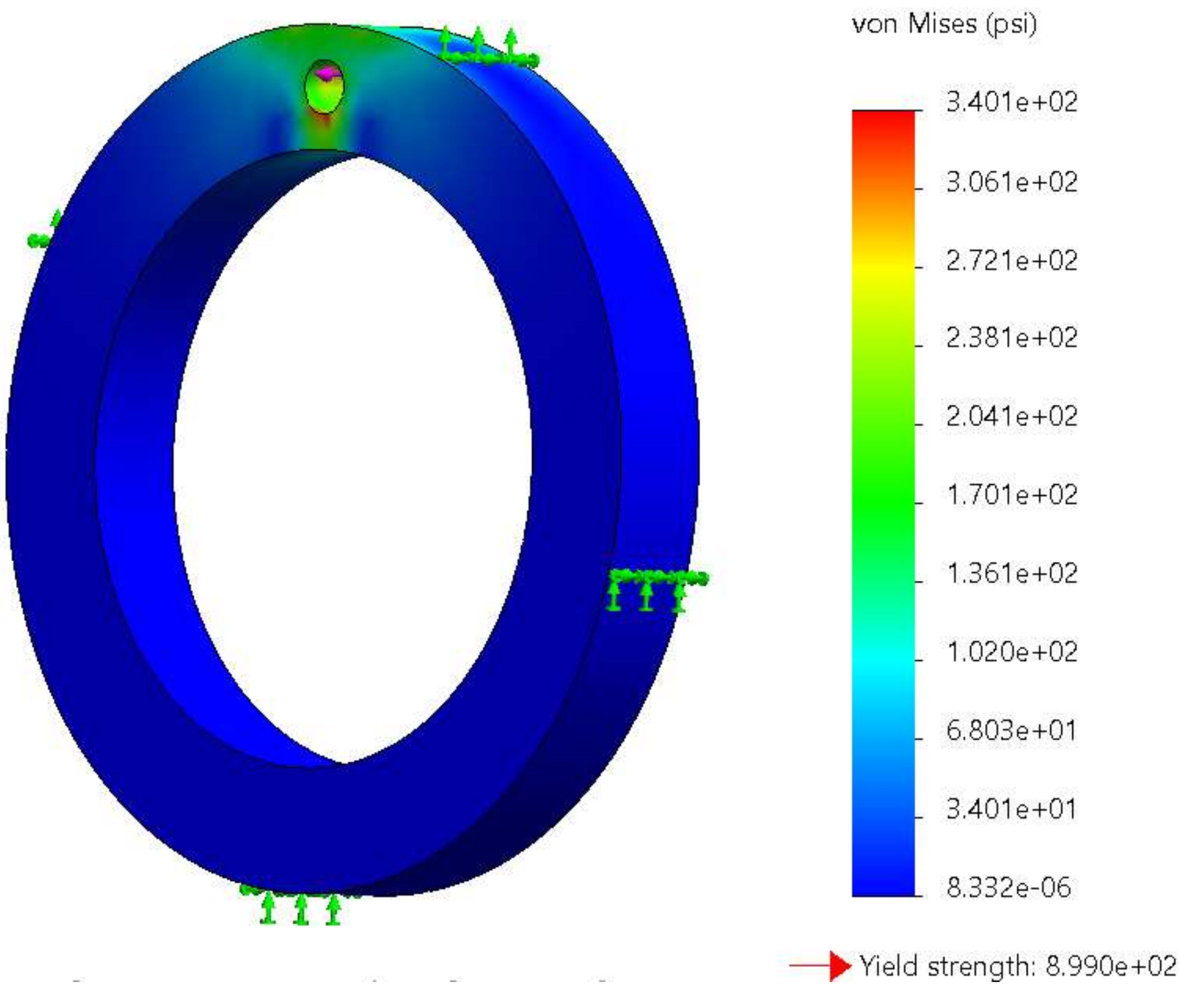

Figure 42: Centering Ring Testing Results

Table 11: 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:	• Contact area between the two components.
	  ○ Can be found by finding the surface area of the centering ring.
	• Epoxy shear strength
	  ○ To be acquired from the manufacturer

Step-by-Step Execution:	1. Divide the total force by the total contact area. 2. Compare to the strength of the epoxy used.

Table 11: Centering Ring Interface Testing

	3. 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.

$$Area\ of\ Interface = \pi * D * t\_bulkhead$$

$$Stress = \frac{Shear\ Force}{Area\ of\ Interface}$$

With known variables this becomes the following.

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

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

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

Table 12: 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:	• 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:	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):

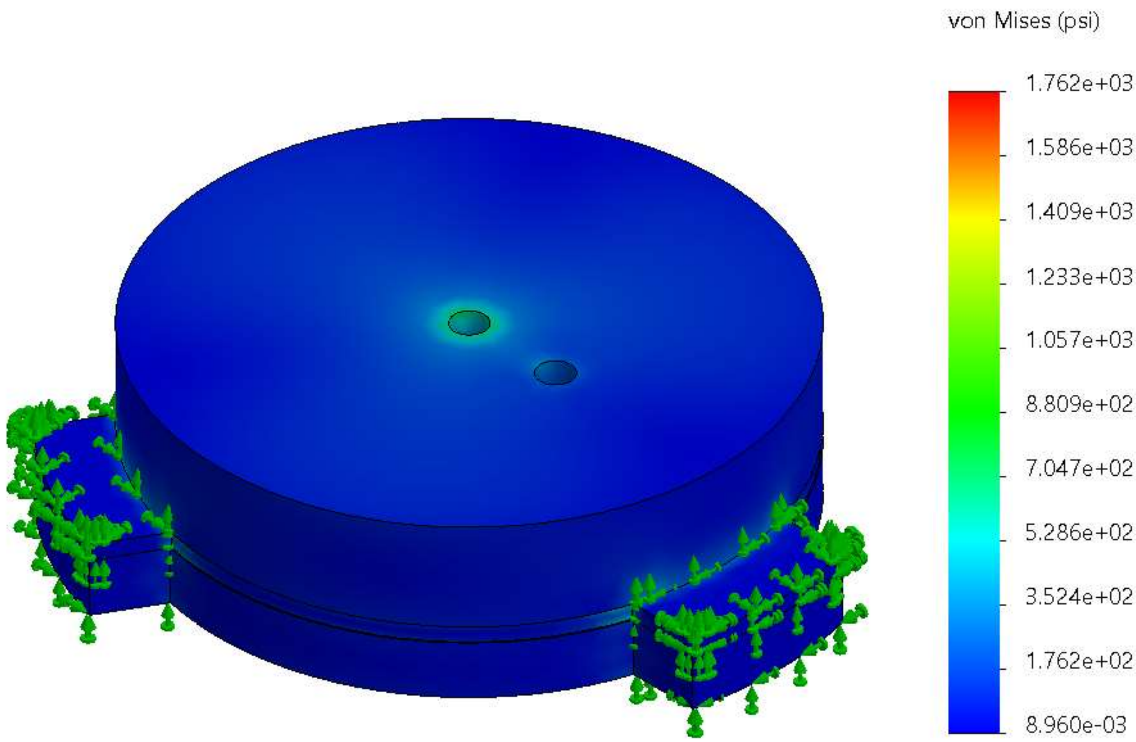

Figure 43: Inner Locking Mechanism Stress Results

Table 13: 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

Table 13: Outer Locking Mechanism Testing

	• 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:	1. Fix the interface of the aluminum reinforcement slot and the pine bulkhead slot that make up the outer locking mechanism. 2. Place a normal force of 74.79 lbf on the interface that will be in direct contact with the inner tabs. 3. 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):

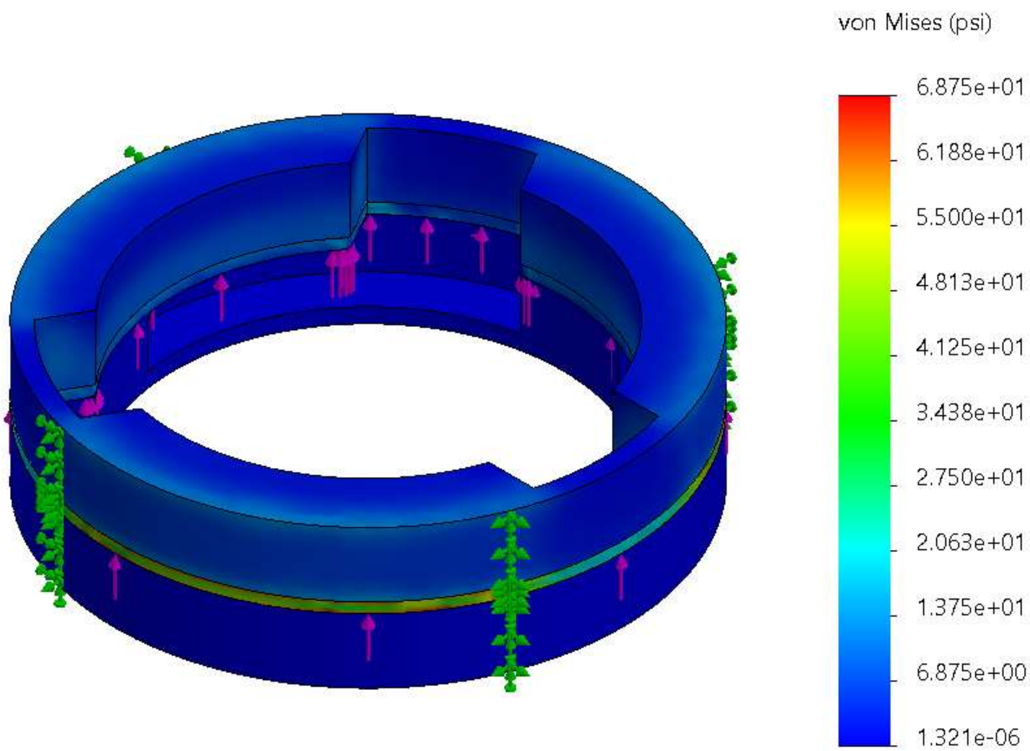

Figure 44: Outer Locking Mechanism Stress Analysis

Table 14: 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:	1. Epoxy the locking mechanism to a scrap piece of body tube and wait 1 full day for the epoxy to cure. 2. Locate a bridge that is safe to drop heavy objects from. Ensure the test area is free of bystanders. 3. Place the locking mechanism against the guardrail of the bridge, ensuring the locking mechanism is unable to move after the weight has been dropped. 4. Tether a ~18.7 lb. weight to the locking mechanism's eyebolt using a shock cord and quicklink through the guardrail of the bridge.

Table 14: Locking Mechanism Test

	5. Drop the weight. 6. 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 15: 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:	• Contact area between the two components.
	  ○ Can be found by finding the surface area of the locking mechanism.
	• Epoxy shear strength
	  ○ To be acquired from the manufacturer

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 vehicle may detach from recovery hardware, posing a safety concern.

Table 15: Locking Mechanism Interface Testing

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.

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

With known variables this becomes the following.

$$30.54\ [in] = \pi * 6\ [in] * 1.62\ [in]$$
$$2.55\ psi = \frac{78\ [lbf]}{30.54\ [in]}$$

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

3.2.1.2. Electrical Elements

Altimeters

In order to deploy the recovery parachute system, two commercially available altimeters will be used. This is for redundancy purposes to promote safety within the system, taking both the launch vehicle and spectators into consideration. Both altimeters feature dual deployment to deploy the main parachute at apogee and drogue parachute at 700 ft AGL. The selected altimeters are the StratoLogger SL 100 Altimeter and the RRC3 Sports Altimeter. Two different brand altimeters are used to further promote redundancy. This is because the two altimeters have different pressure sensors, which leads to a better accuracy average rather than using one or two of the same altimeters. Both altimeters will be individually powered by standard 9V alkaline batteries as they are less flammable than LiPo batteries. 9V batteries have a capacity of 500 mAh, which means the RRC3 Sports Altimeter will have an operational time of about 83.33 hours with a power consumption of 6 mA, and the StratoLogger SL 100 Altimeter will have an operational time of about 333.33 hours with a power consumption of 1.5 mA. Batteries are connected to the altimeters via individual turnkey switches outside the body of the launch vehicle for easier powering of avionics electronics.

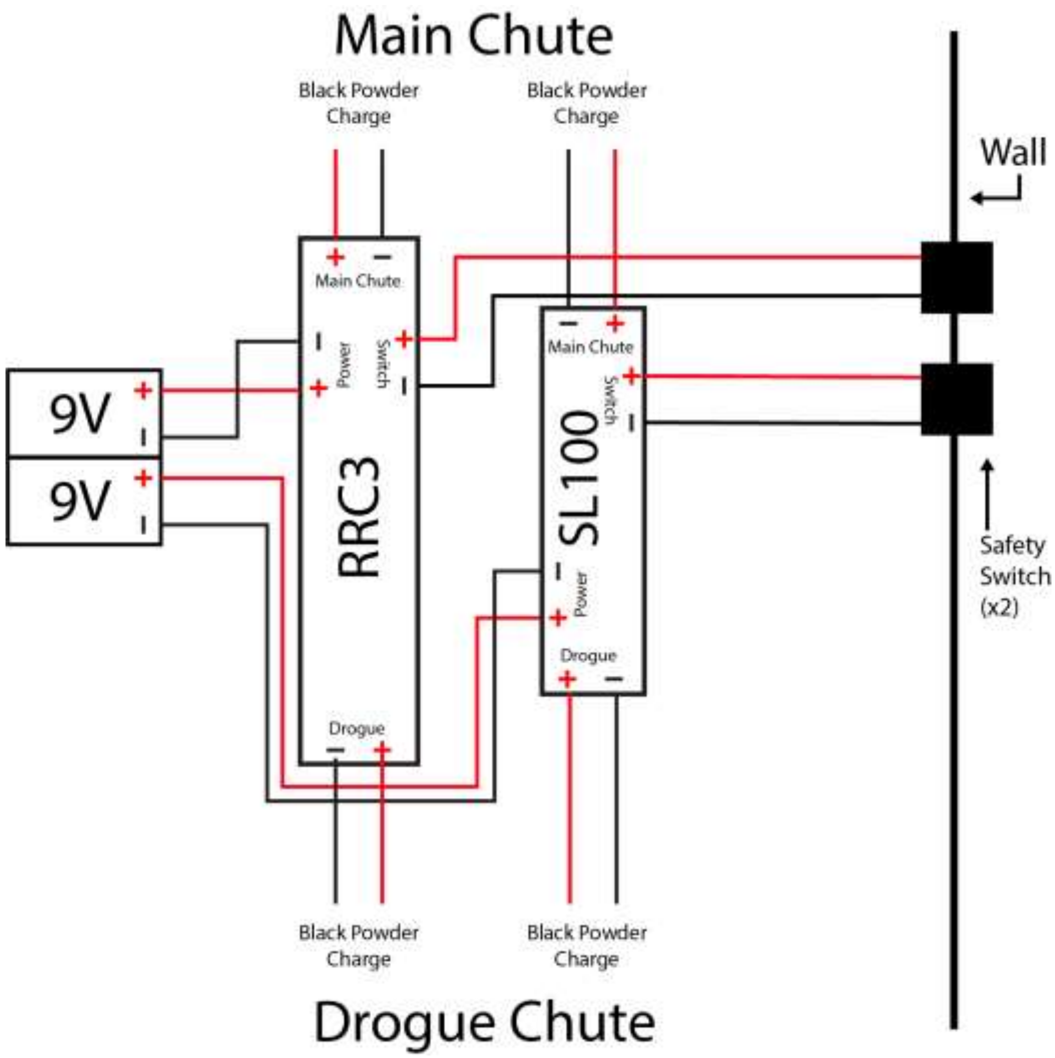

Figure 45: Avionics Bay Wiring Schematic

3.2.1.3. Redundancy Features

In order to introduce redundancy into the design of the recovery subsystem, two altimeters are being used to activate the black powder charges in order to release the main and the drogue chutes. The main altimeter is the RRC3 and the redundant altimeter in place is the StratoLogger. Each altimeter will be separately connected to their own individual black powder charges, and they will be offset from each other. The main altimeter will be 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 will be 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. Not only that, but each altimeter will be powered individually by the battery, and they each will be connected to turn switches. This is to ensure that if something goes wrong with one of the altimeters, for instance it stops working or for some reason its black powder charges are not activated, there will be another altimeter that will be able to activate its black powder charges and release the chutes.

3.2.1.4. Parachute Sizes and Descent Rates

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.

Table 16: 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	81
Main	7	8	0.97	Rocketman Enterprise	19.5

3.2.1.5. Drawings and Schematics

Locking Mechanism

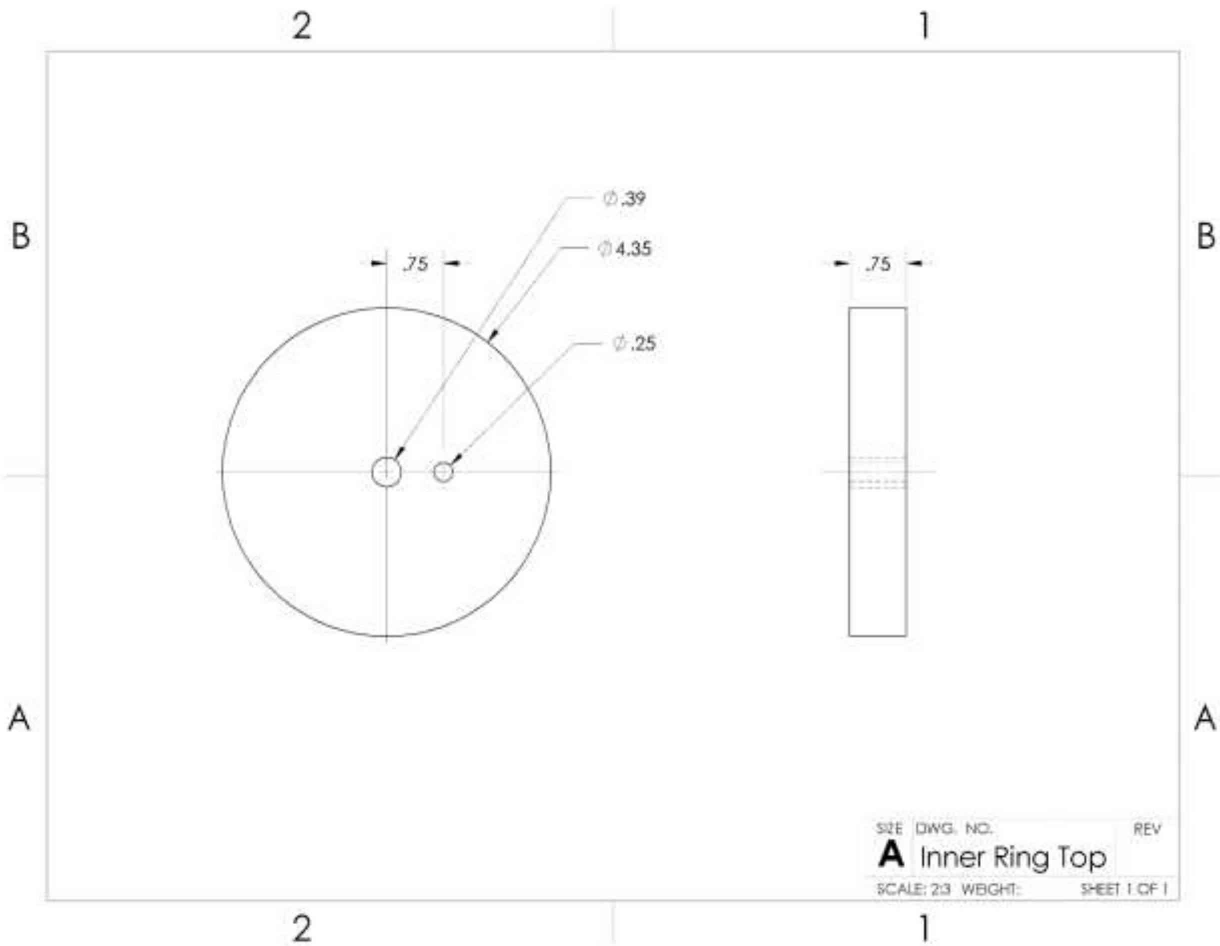

Figure 46: Locking Mechanism Inner Ring Top Drawing

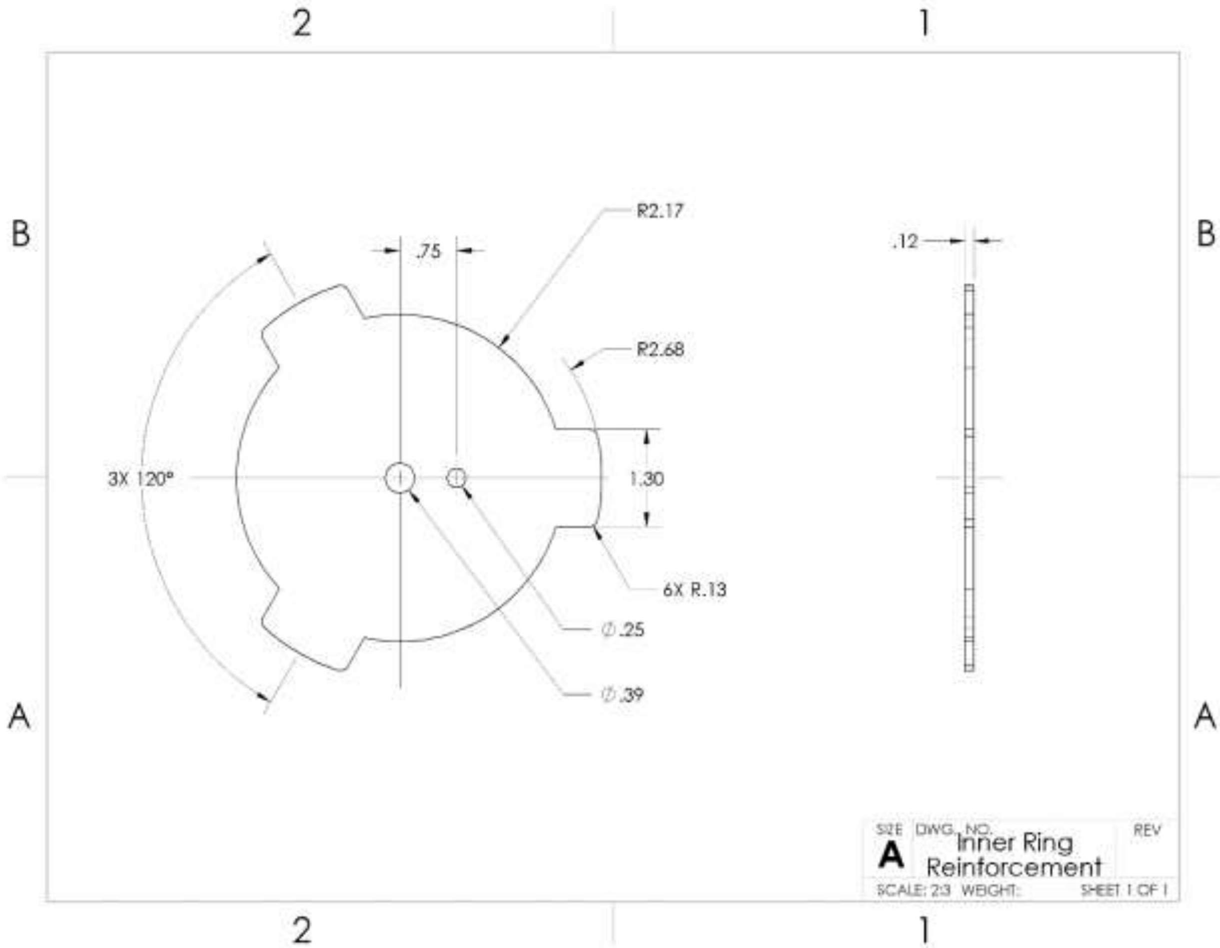

Figure 47: Locking Mechanism Inner Ring Reinforcement Drawing

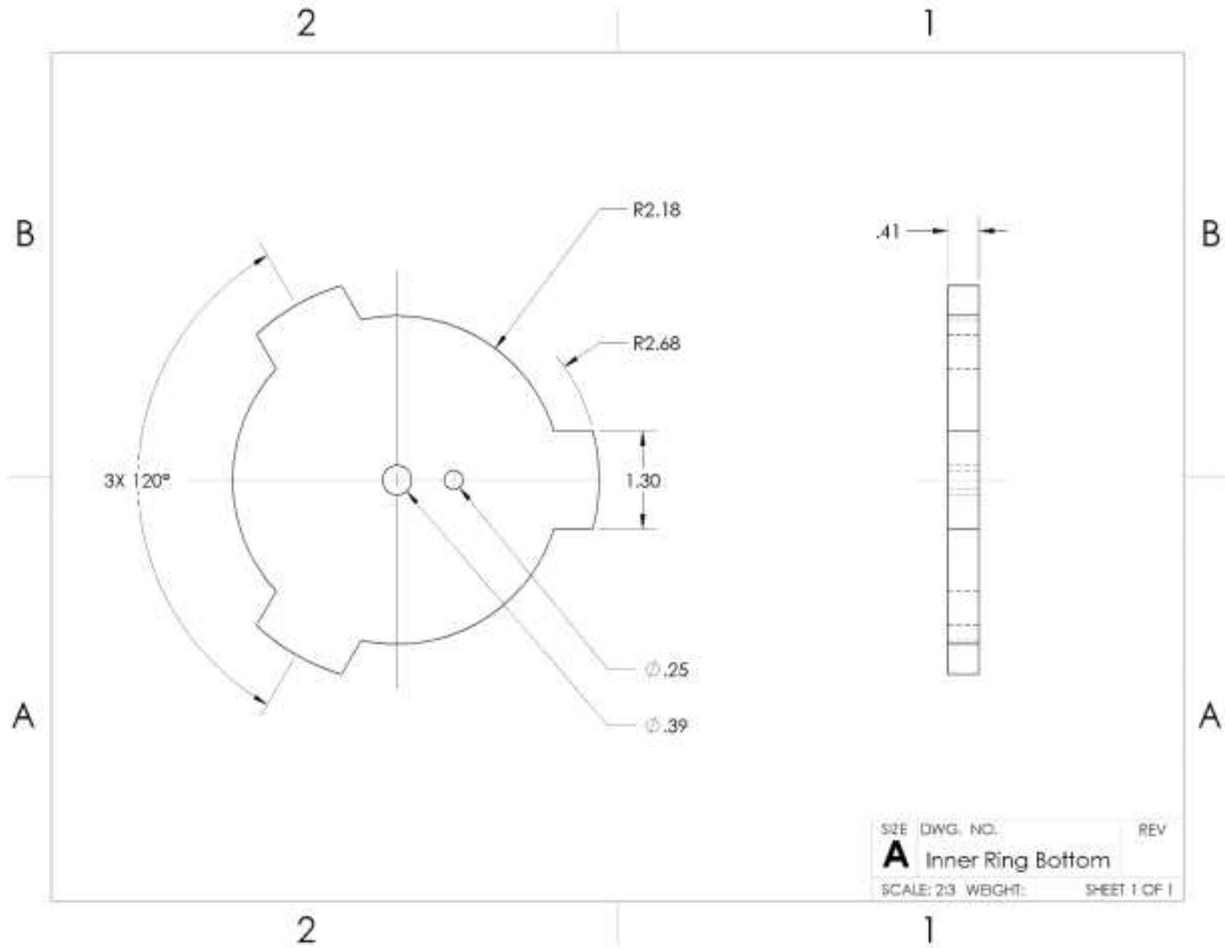

Figure 48: Locking Mechanism Inner Ring Bottom Drawing

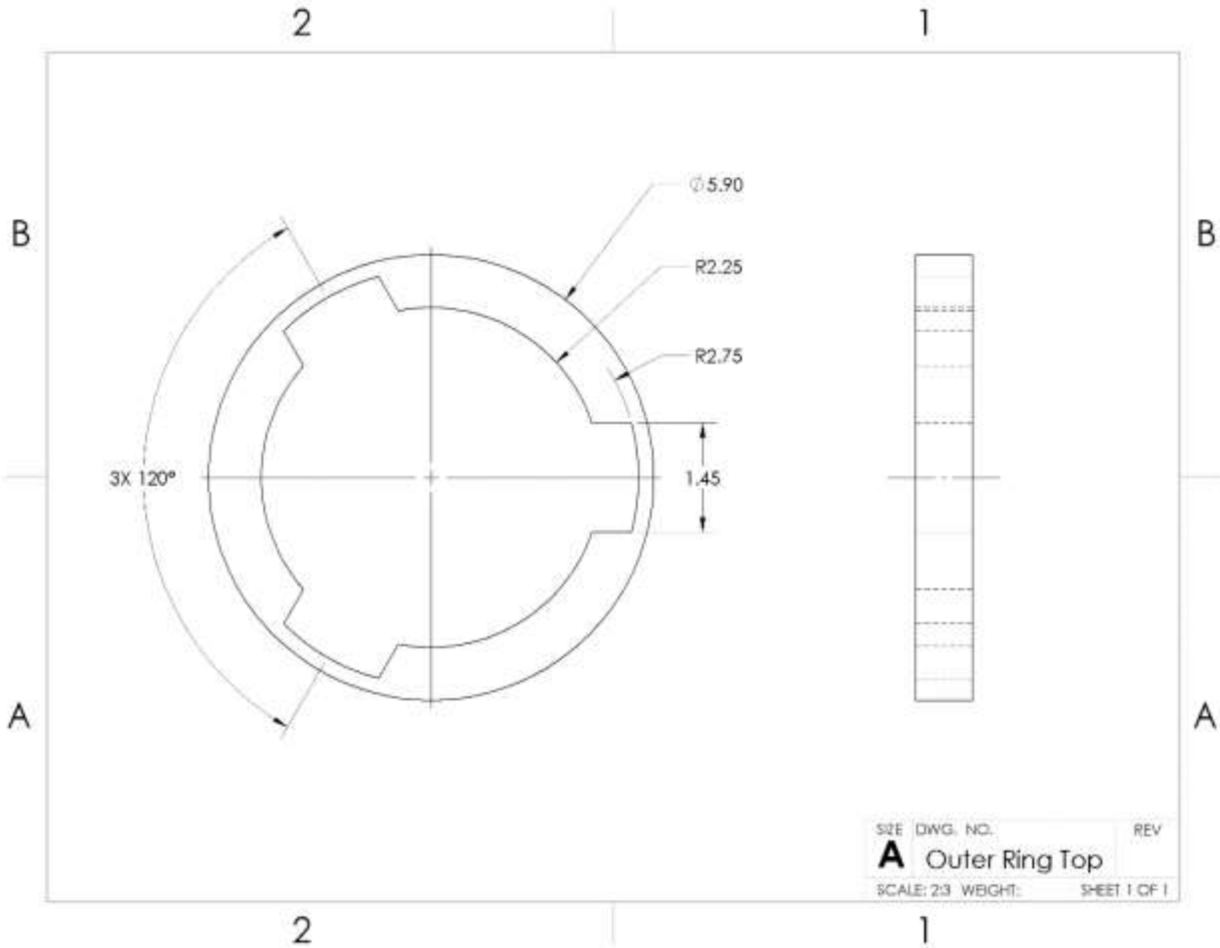

Figure 49: Locking Mechanism Outer Ring Top Drawing

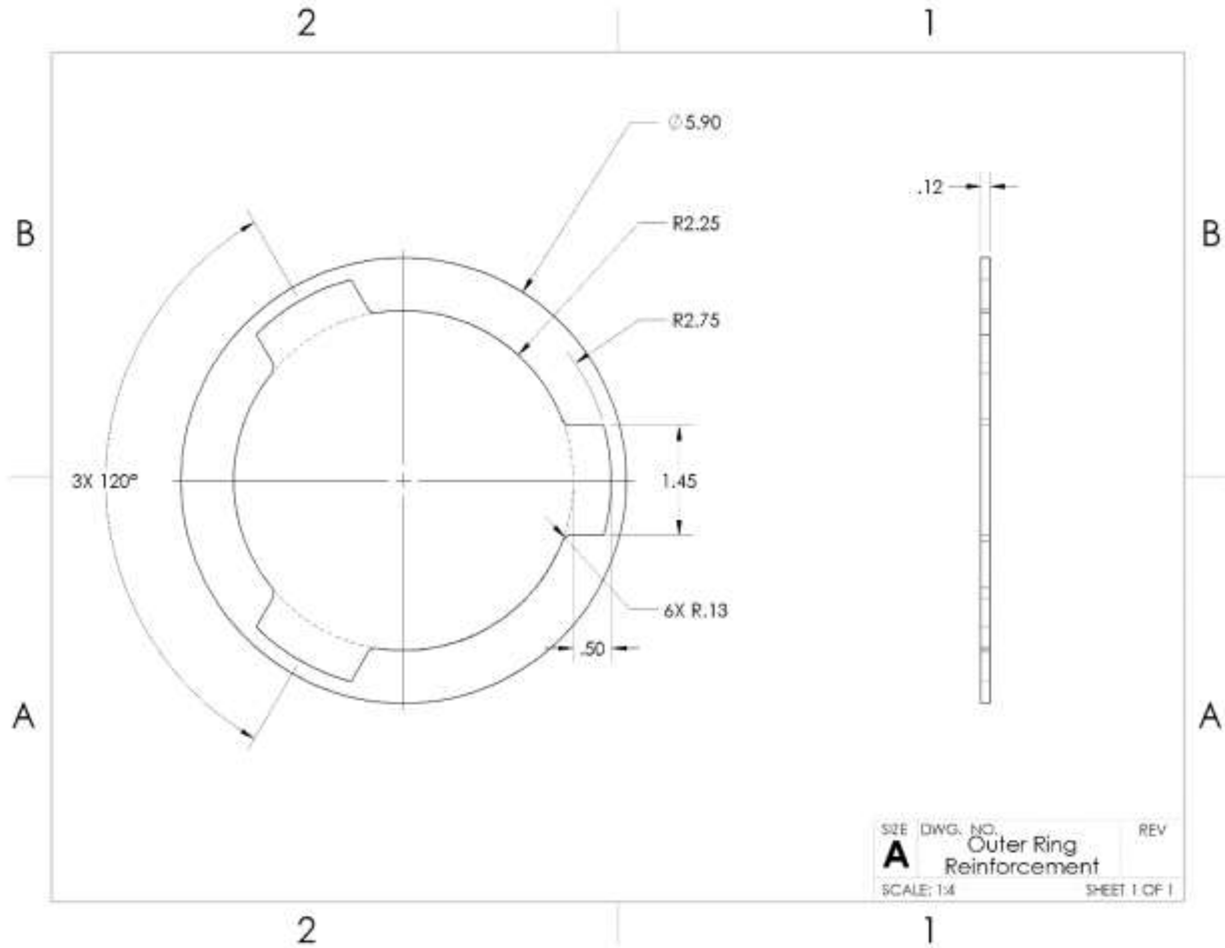

Figure 50: Locking Mechanism Outer Ring Reinforcement Drawing

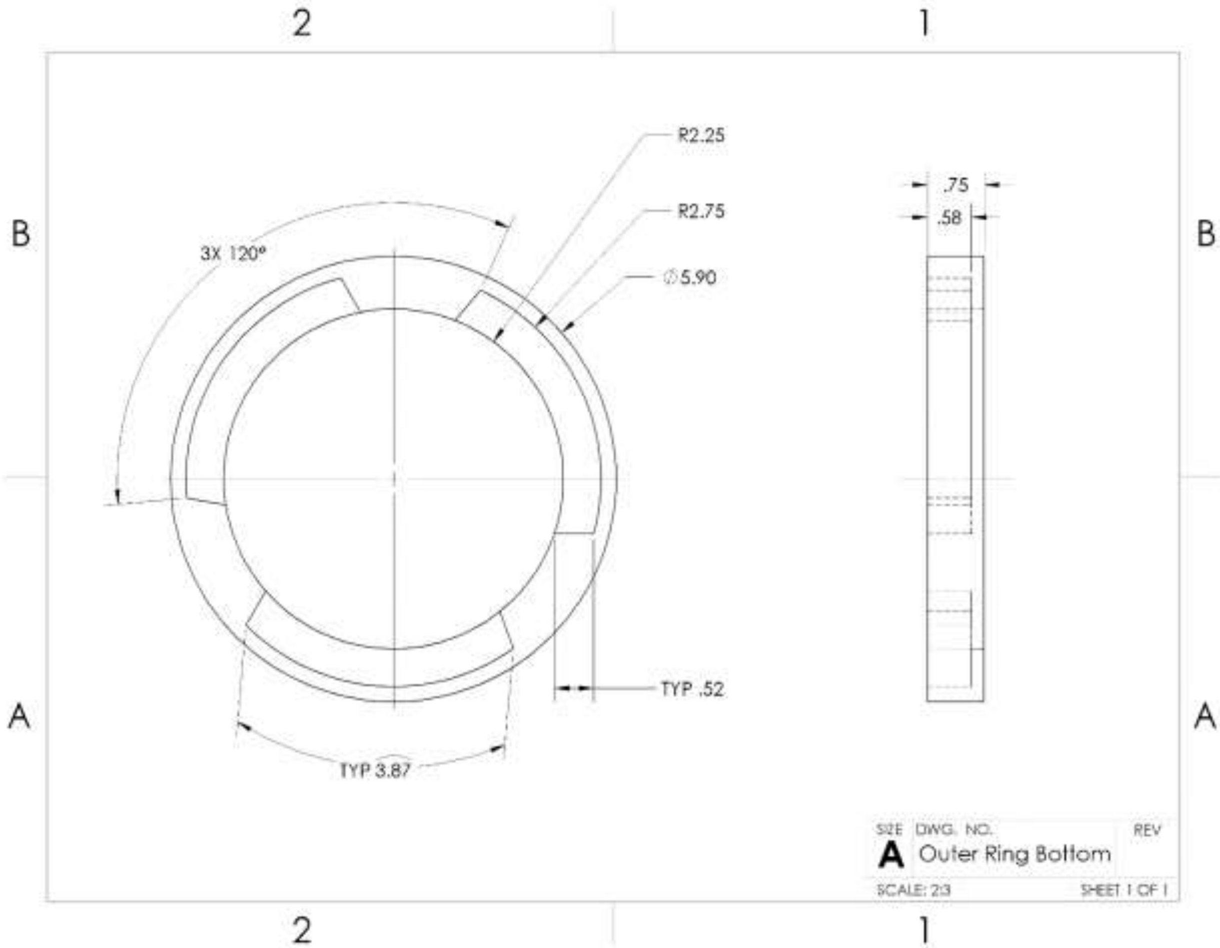

Figure 51: Locking Mechanism Outer Ring Bottom Drawing

3.2.1.6. Rocket-Locating Transmitters

The rocket will be located using the Tiny Telematics Tracker GPS. It operates at a frequency of 9090 MHz and has a wattage of 180 mW of power. It has an operational range of 9 miles. It works via Bluetooth connection to an Android device.

3.2.2. Recovery System Sensitivity

The recovery electronics will be purchased shielded, although the sensors are still exposed to barometric pressure and setting off the black powder charges will be done electrically by a switch set off by the electronics inside the rocket. Moreover, the electronic components produce magnetic fields, such as the GPS and video transmitter, will be a sufficient distance away from each other so as to not interfere with each other, in addition to shielding provided by the bulkheads.

3.3. Mission Performance Predictions

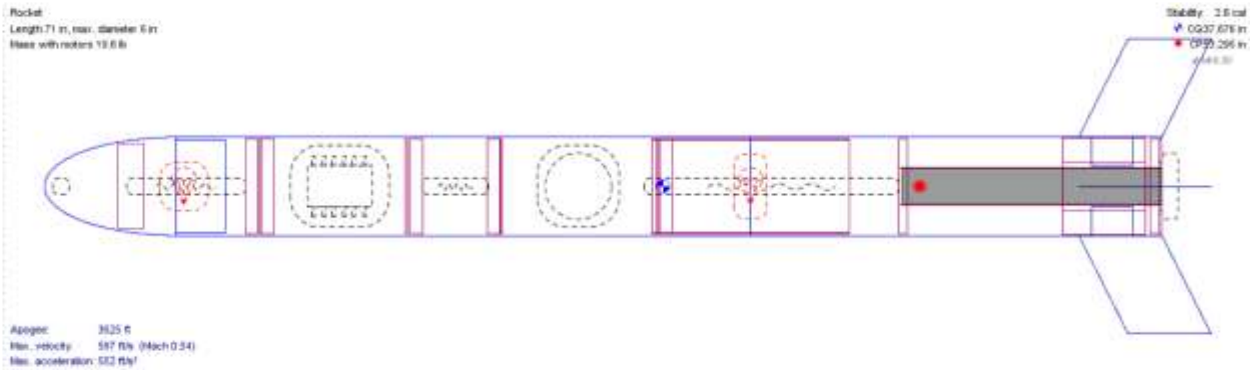

Figure 52: OpenRocket Model

Provided above in Figure 52 is the ongoing OpenRocket model of the full-scale rocket vehicle with payload and loaded motor.

To determine whether the rocket vehicle is robust enough, virtual, and experimental testing must be applied, as discussed in Section 3.2.1.1.

For component weights, refer to Section 3.1.3.1.

3.3.1. Flight 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 3525ft AGL using an average of 10mph for windspeed and an 8-foot launch rod. The velocity of the vehicle at main parachute deployment is simulated to be 80.5 ft/s while the velocity at drogue parachute deployment is 2.5 ft/s. Probable additional loss in apogee height through other factors such as launch rail friction may be accounted for.

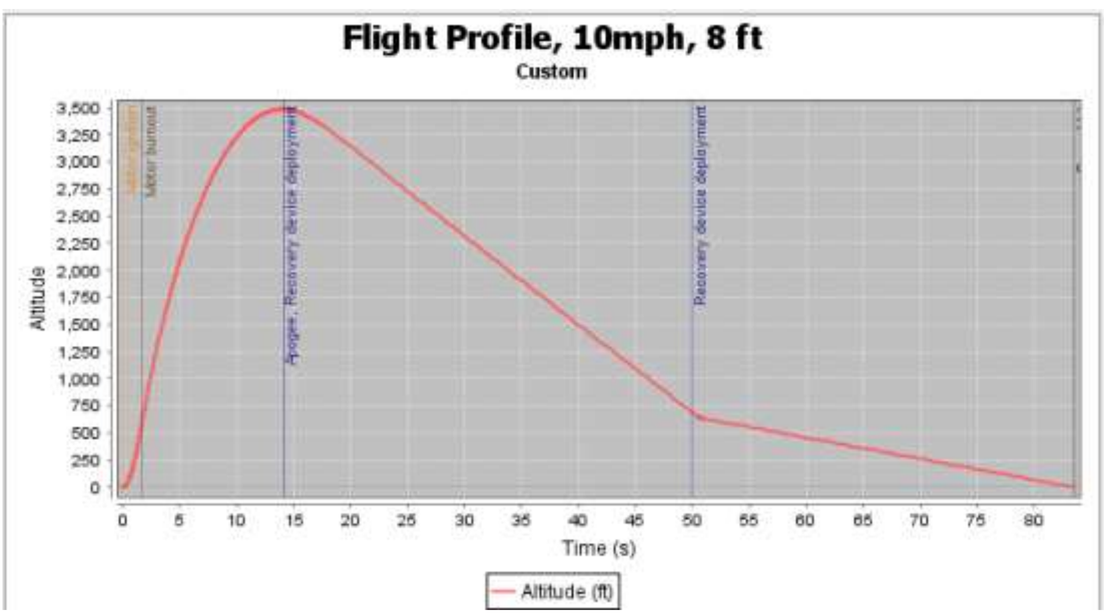

Figure 53: Flight Profile, 10mph Winds

3.3.1.1. Motor Configurations

The motor selected for the final version of the vehicle remained consistent with the leading design from the CDR. Below are both the motor data and the thrust curve for the Aerotech K-1103X motor.

Table 17: Final Design Motor – K1103X-14 Motor Data

Motor Diameter	2.13in	**Motor Length**	15.8in
Average Thrust	1099 N	**Max Thrust**	1620 N
Burn Time	1.65s	**Total Motor Mass**	3.2 lbs.
Total Impulse	1810Ns	**Propellant Mass**	1.8 lbs.
Thrust to Weight	13.17	**Post-burn Mass**	1.4 lbs.

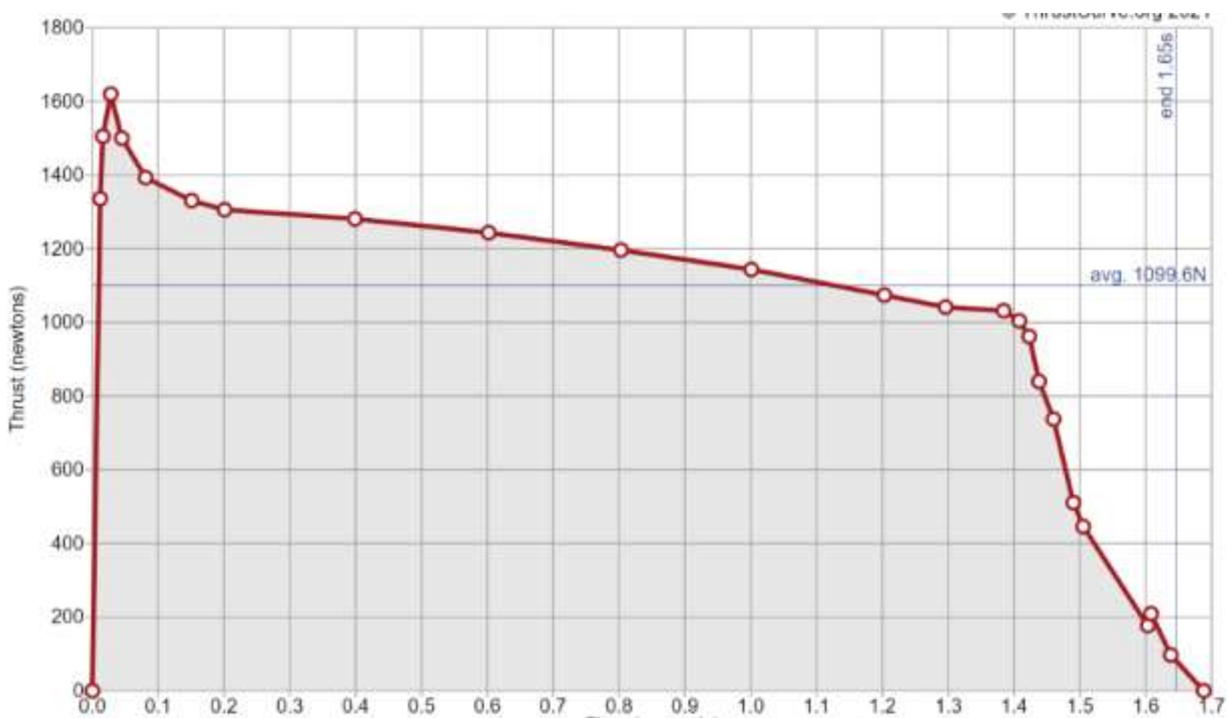

Figure 54:Motor Thrust Curve – K1103X-14

3.3.1.2. Design Robustness

To verify that the vehicle is robust enough to withstand the expected loads, refer to Section 3.2.1.1.

3.3.2. Stability

The CG and CP locations are as follows:

- CG: **37.676 in.** from the tip of the nose cone.
- CP: **53.295 in.** from the tip of the nose cone.

Together, with a 6 in. diameter body tube, the resulting stability is anticipated to be **2.6.**

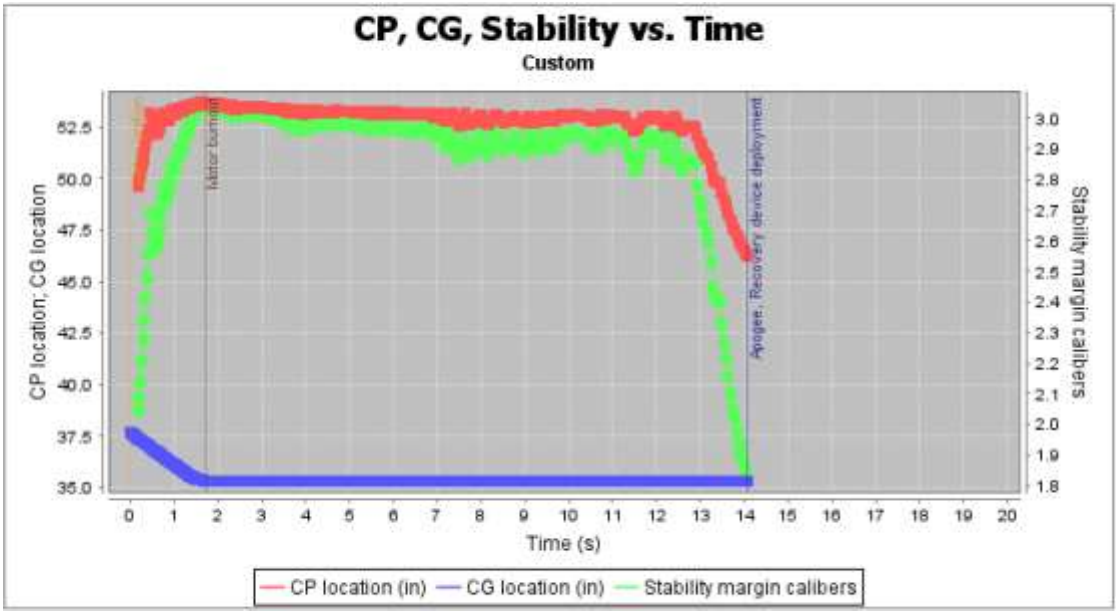

Figure 55: Stability, CP, CG vs. Time

3.3.3. 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.

$$v_{descent} = 19.4\frac{ft}{s}(for\ a\ post - burn\ mass\ of\ 17.77\ lb)$$

*m1= (2.272lbf)/(32.2 ft/s^2) -> KE1 = 0.5*m1*vdescent^2 => KE1 = 13.278 ft-lbf.*
*m2= (9.54lbf)/(32.2 ft/s^2) -> KE2 = 0.5*m2*vdescent^2 => KE2 = 55.753 ft-lbf.*
*m3= (4.544 lbf)/(32.2 ft/s^2) -> KE3 = 0.5*m3*vdescent^2 => KE3 = 26.556 ft-lbf*

3.3.4. Expected Descent Time

For a predicted apogee of app. 4200 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 = 19.4 ft/s, vdrogue, descent = 80.5 ft/s (for a post-burn mass of lb.)

$$apogee = 3525\ ft\ AGL,\ hmain\text{-}deploy = 700\ ft\ AGL$$

$$Descent\ Time= (hapogee-hmain\text{-}deploy)/vdrogue + hmain\text{-}deploy/vmain$$
$$Descent\ Time= 71.176\ s$$

3.3.5. Drift

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

Table 18: Drift Relation to Wind Speed

Wind Speed	0 mph	5 mph	10 mph	15 mph	20 mph
Horizontal Drift	0 ft.	505.244ft.	1007.623 ft.	1504.8 ft.	2009.311 ft.

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

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

Table 19: Drift relation to Wind Speed Trials

Wind Speed	0 mph	5 mph	10 mph	15 mph	20 mph
Horizontal Drift (1)	0 ft.	506.7 ft	1015.8 ft.	1520 ft.	2024.6 ft.
Horizontal Drift (2)	0 ft.	513.3 ft	1029 ft.	1540 ft.	2051 ft.
Horizontal Drift (3)	0 ft.	506 ft	1014.3 ft.	1518 ft.	2023.8 ft.
Horizontal Drift (4)	0 ft.	502 ft	1007 ft.	1507 ft.	2009 ft.

3.3.6. Differences Between 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 3.3.5, 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. RockSim simulations were also done in section 5 when comparing to the Mock-Demonstration Flight data.

3.3.7. Calculation Preciseness Validation

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 being a very reliable source. The team has also decided to utilize both RockSim and OpenRocket and compare the simulations between the two programs.

3.3.8. Variant Method

The team used both RockSim and OpenRocket to verify that the original results are accurate. The OpenRocket simulations can be found in Section 3.3 while the RockSim simulation can be found in Section 5.

3.3.9. Variance Between 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 3530 feet while RockSim gives about 4100 feet. The team ultimately decided to use OpenRocket to predict the target apogee but going forward, the team will utilize both programs in predicting the target apogee as well as calculations.

3.3.10. Preciseness Analysis

This has been talked about in Sections 3.3.5 and 3.3.6. 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.

4. Payload Criteria

4.1 Payload Design and Testing

4.1.1. Changes since CDR

An additional component to the retention mechanism was implemented to shield the payload during its volatile deployment. This shield is tethered to the retention system's eyebolt and prevents the payload from scraping the inside of the body tube during deployment. Without this component, the surface of the payload itself will interact with the inner body tube of the launch vehicle. This component mitigates potential damage to the payload during deployment. The addition of the shield to the retention system required modifications to the circular base component to have a designated slot for the shield to fit in.

4.1.2. Unique Features

4.1.2.1. Structural Elements

Payload Assembly

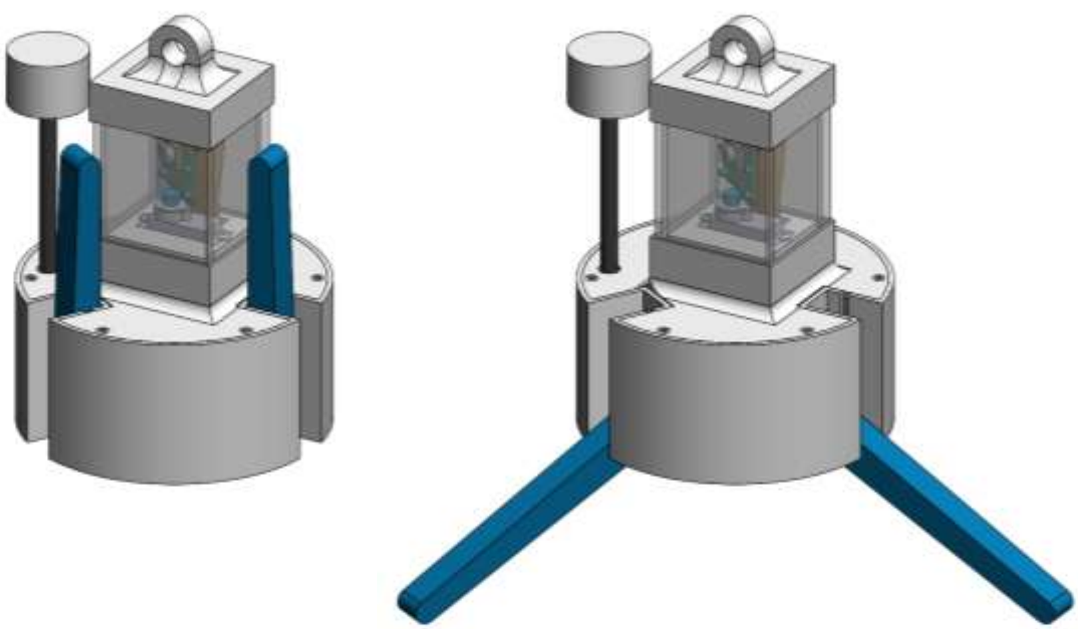

Figure 56: Packed Payload (left) and Unpacked Payload (right)

The payload assembly is a 6.1” tall by 4.4” diameter 3-legged lander that houses electronics necessary for completing the mission within its body. Each leg is individually controlled by a singular servo motor. While within the launch vehicle, the payload's legs are packed in an upright configuration to minimize the effective volume of the payload. During descent, the legs will be actuated to be parallel with the base of the payload to effectively increase the surface area of the payload for landing. Once a landing event is detected, the payload will orient itself within 5° of vertical by rotating the legs and obtaining feedback from a gyroscope/accelerometer module. A central column perches the camera for a greater field of view of the landing site. The camera is mounted on a continuous servo motor to rotate the camera 360°. In order to center the camera within the payload and provide the camera with a clear view of the landing site for taking pictures, acrylic sheets are used. The main cover is attached to the base of the payload using six pairs of M2.5 screws and M2.5 threaded heat set inserts which are implemented in the base component for a strong and detachable interface. The use of screws and heat set inserts allows the team to easily access and troubleshoot electronics within the payload. Electronics within the payload are harnessed using pairs of M2.5 screws and threaded heat set inserts or are compartmentalized within the base component of the payload. Further details of the entire payload assembly are provided in section **Error! Reference source not found.**.

Payload Central Column

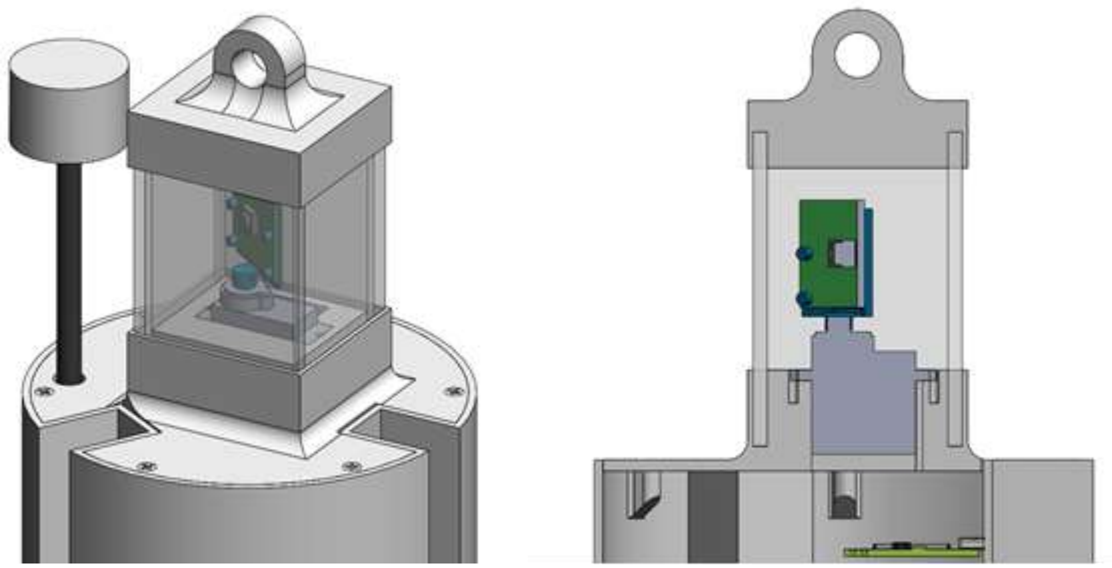

Figure 57: Payload Central Column (left) and Cross-Section of Central Column (right)

One of the concerning design aspects is the payload central column and its use of acrylic sheets. Both the camera and parachute need to be centered to properly carry out their intended tasks. The camera needs to be centered to create a properly centered panoramic image of the landing site. The parachute must be attached to a single central point on the payload to prevent the parachute shroud lines from tangling with the camera or the antenna. If a rotational motion caused by wind or chaotic behavior of the payload during its deployment phase induces a torsional force on the shock cords of the parachute, the shroud lines will gravitate towards the center of the payload. Using an acrylic sheet central column design allows the camera to take 360° picture of the landing site and prevent the parachute from tangling with the camera. The top cap features a thick 0.4” inner diameter ABS plastic ring to attach the shock cord of the payload’s parachute to the payload. This design raises safety issues as the brittle acrylic sheets and ABS top cap ring are load-bearing components. Fracture of these components during parachute deployment result in an untethered payload. Testing for these critical components are provided in section 4.1.3. Flight Reliability Confidence.

Retention System

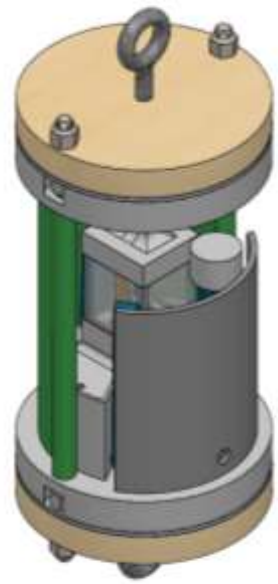

Figure 58: Retention System with Payload

The retention system used involves a cage like mechanism that houses the payload from within. The retention system is tethered to the launch vehicle’s main parachute shock cord using two 3/8” galvanized steel eyebolts and is deployed during the vehicle’s main parachute’s deployment at 700 ft AGL. The bottom of the retention system is tethered to the launch vehicle’s bulkhead and the other side is tethered to the main parachute using separate shock cords. The 30” length shock cord between the retention system and the launch vehicle’s bulkhead allows the payload to exit the 16” long body tube and jettison the payload without colliding with the launch vehicle. An added shield component is packed upright within the launch vehicle to prevent the payload from colliding and damaging itself with the inner wall of the upper body tube during deployment. The shield is tethered to the bottom-most eyebolt as show in the figure above to prevent the component from detaching from the launch vehicle.

The cage features a 5.7” diameter by 10.74” tall cylindrical cage, excluding the added length of the eyebolts shown in the figure above. The volume available for the payload is a 4.46” diameter by 7.35” length space. The retention system uses .75” thick pine bulkheads reinforced with .12” thick sheets of aluminum at the ends of the cage to endure forces experienced by the 3/8”-16 eyebolt attached to the launch vehicle’s main parachute. The bulkhead and the reinforcement sheet fastened to each other with 3/8”-16 locknuts that interface with 1ft long 3/8”-16 threaded rods that run across the retention system. Additional 3D printed circular components create a flat surface on which the payload can rest on and prevent the payload’s parachute from entangling with the retention system. A green semicircular enclosure prevents the payload and its parachute from deploying on sides opposite of each other during its ejection. The following figure helps visualize the structure and assembly process of the retention system.

The use of a retention method that deploys using the launch vehicle’s main parachute shock cord is a concerning design aspect. The retention system interferes with the normal operation of the launch vehicle’s main parachute shock cord as it introduces potential failure modes such as additional knots that can untie, failure of the wood and aluminum bulkhead section during parachute deployment, failure of the threaded rods during parachute deployment, and potential for the retention system to get stuck within the launch vehicle which affects how the main parachute functions. While these issues raise safety concerns, conclusive physical testing must be conducted to determine the validity of the design. Virtual testing of load bearing components is provided in section 4.1.3. Flight Reliability Confidence. Aluminum reinforcement sheets have been placed to increase the maximum stress of the bulkhead components to prevent failure. Thick 3/8" steel threaded rods have been selected to endure the impulse experienced by the main parachute deployment. The outer diameter of the retention system is 5.7", which is enough clearance within a 6" body tube for the retention system to slide within the body tube. The retention system selected also simplifies the manufacturing process and electrical complexity as all components have simple geometries and require no additional batteries or electronics to operate. The retention method also shields the payload from the ejection charge from the deployment of the main parachute.

4.1.2.2. Electrical Elements

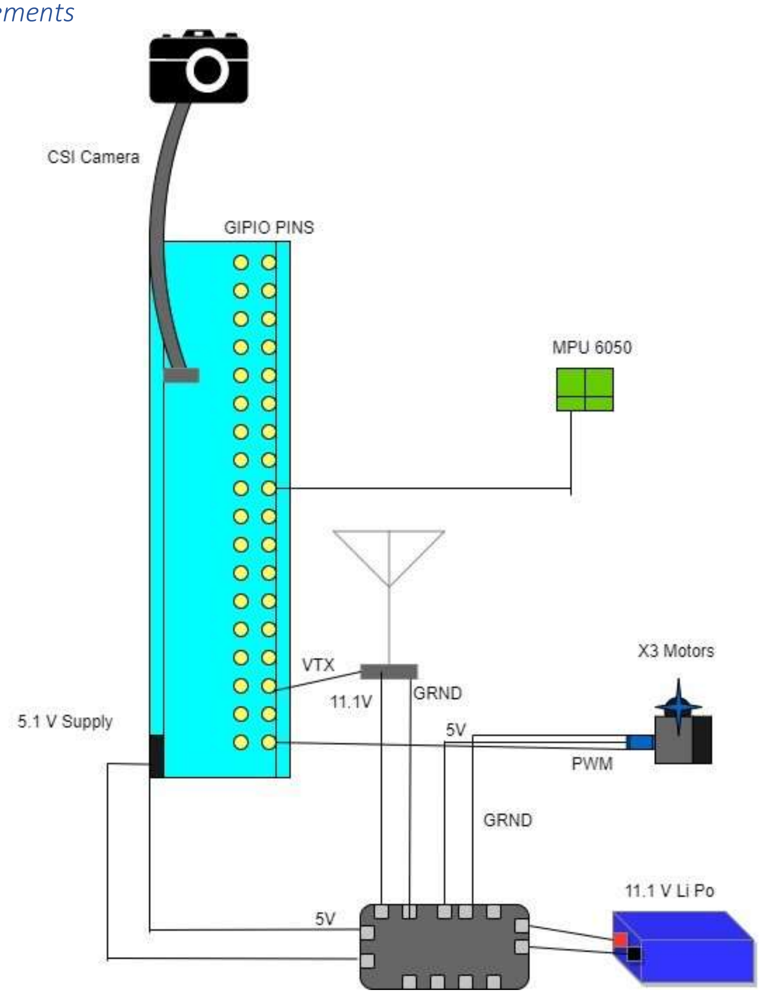

Figure 59: Payload Circuit Schematic

The payload will use a Raspberry Pi Zero as the microcontroller that will power and control the rest of the electrical components within the payload. The payload will implement an Arducam for Raspberry Pi Camera Module in order to take the necessary pictures of the landing site. It will achieve this by using a FS90R continuous rotation micro servo in order to turn the camera a full 360-degree rotation. Not only that, but upon landing, the microcontroller will actuate three FEETECH FS0403-FB Sub-Micro Servos with Position Feedback of up to 120 degrees to control the legs of the payload, by using the Adafruit MPU-

6050 Accel and Gyro Sensor in order to help position the payload level with the ground with accuracy and precision. It will all be powered using a Tattu 11.1V 850mAh LiPo battery and a FPVDrone Matek PDB-XT60 Power Distribution Board in order to regulate the power and voltage that is used with the battery. Lastly, the payload will use a Furious FPV 2.4 GHz Transmitter in order to encode the resulting images to be able to be transmitted back to HQ via a TrueRC Singularity 2.4GHz Antenna that is right hand circular polarized.

4.1.3. Flight Reliability Confidence

Reliability of the payload to perform its intended tasks is verified by testing individual critical components. Tests are outlined in this section for components that the team has deemed as potential safety hazards, or their successful behavior is questionable. Structural and electrical components of the payload are tested to ensure a successful payload mission.

Table 20: Retention System Testing (Virtual)

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:	7. Fix the surface of the bulkhead and aluminum sheet in contact with the .375" nuts. 8. Place an axial force of 81.20 lbf on the hole that will be containing the eyebolt. 9. 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.

Status/Results: (if completed):

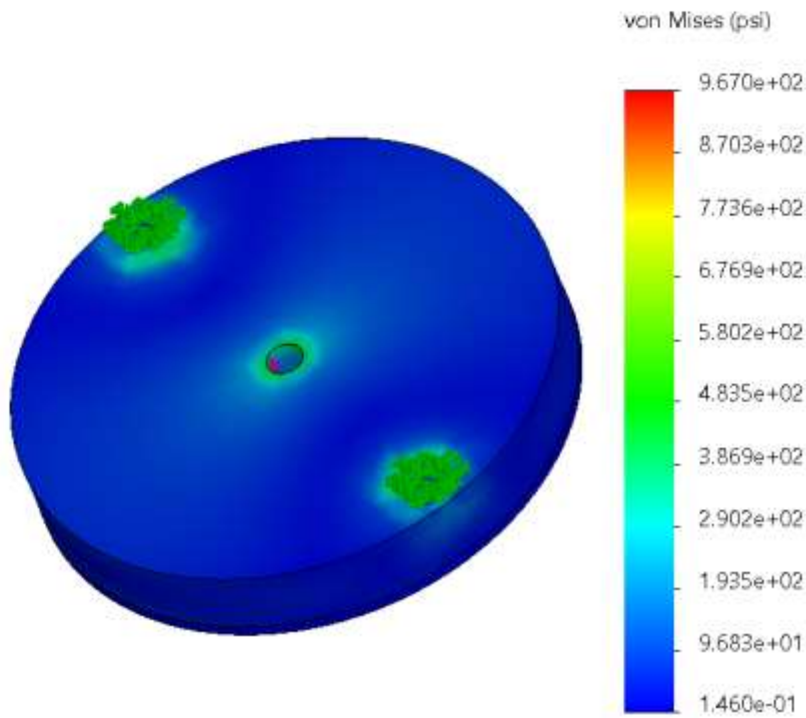

Figure 60: Retention System Stress Results

Table 21: Retention System Threaded Rods Testing (Virtual)

Objective:	Analyze stress concentrations experienced by the individual 3/8" threaded rods
Success Criteria:	The maximum force felt by the steel alloy rods during launch does not exceed the expected yield strength.
Variables:	Force: 81.20 lbf total of axial force; 40.6 lbf on each of the two rods.
Constants:	• Two 3/8-inch steel alloy rods geometry
Step-by-Step Execution:	1. Fix both the top and bottom faces of the rod. 2. Place an axial force of 40.6 lbf on the interface of the rod that is in contact with the hole. 3. Evaluate Results
Relevant Safety Concerns:	None.
Status:	Complete.
Justification:	The two rods serve as an interface that holds the retention system together and experiences a force due to parachute deployment during launch. By examining the behavior of this retention system component, 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 the two alloy steel rods that are included in the retention assembly.

Status/Results: (if completed):

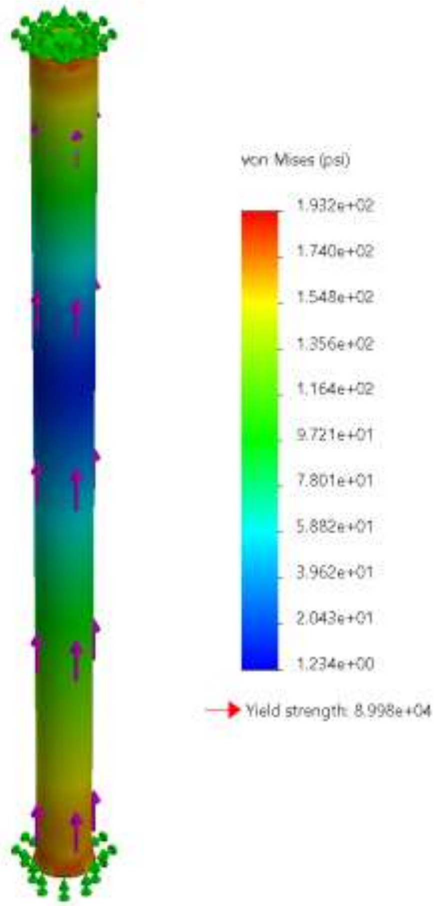

Figure 61: Rods in Retention System Stress Results

Table 22: Payload Top Cap Testing (Virtual)

Objective:	Analyze the stress experienced by the plastic ring (ABS) from parachute deployment at the attachment point.
Success Criteria:	The maximum force felt by the plastic ring (ABS) during parachute deployment does not exceed the expected yield strength.
Variables:	Force: 3.62 lbf of axial force
Constants:	• Plastic top cap (ABS) geometry ○ Elastic Modulus: 290075 psi ○ Poisson's Ration: 0.394 ○ Mass Density: 0.0368 lb./in^3 ○ Yield Strength: 7000 psi
Step-by-Step Execution:	1. Fix the surface of the plastic top cap that is between the interface of the cap and the acrylic sheets. 2. Place an axial force of 3.62 lbf on the ring that will be an attachment point for the parachute during deployment. 3. Evaluate Results
Relevant Safety Concerns:	None.
Status:	Complete.

Table 22: Payload Top Cap Testing (Virtual)

Justification:	The plastic ring (ABS) of the top cap serves as the first interface between the payload and force due to parachute deployment 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 ABS that makes up the top cap of the payload.

Status/Results: (if completed):

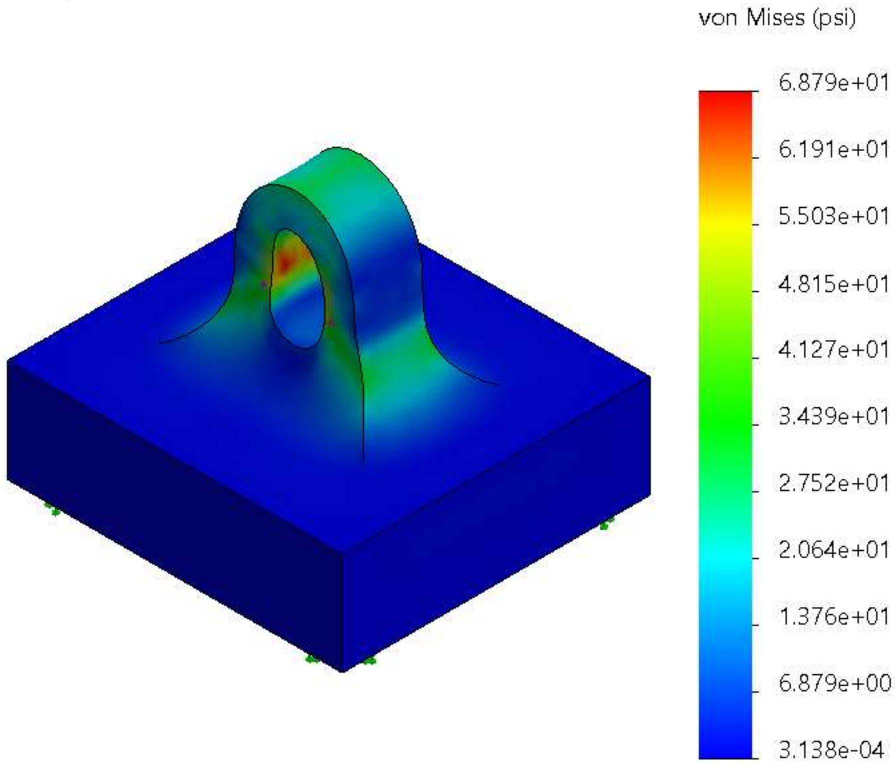

Figure 62: Payload Top Cap Stress Analysis

Table 23: Retention System Test

Objective:	Test and verify the validity of the retention system used to deploy the payload.
Success Criteria:	No physical cracks, warping, or any other deformities are observed
Variables:	Force: 81.20 lbf of axial force (Safety factor of 4) Pine bulkhead grain pattern (random)
Constants:	• Aluminum reinforcement sheet and pine bulkhead geometry • Aluminum material properties
Step-by-Step Execution:	1. Tether a ~20.3 lb. weight to one side of the retention system using a shock cord and relevant eyebolts.

Table 23: Retention System Test

	2. Tether the launch vehicle's main parachute to the other eyebolt of the retention system. 3. Locate a bridge that is safe to drop heavy objects from. Ensure the test area is free of bystanders. 4. Drop the weight, retention system, and parachute. 5. Evaluate retention system
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 payload's bulkhead sections and threaded rods have been verified to pass with a safety factor of 4, physical testing is necessary as this assembly deals with the launch vehicle's main 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

Status/Results: (if completed):

Table 24: Wireless Transmission Range Test

Objective:	Test and Verify the range of the transmitter within a specified area
Success Criteria:	Transmission of image happens within a half mile radius of the transmitter
Variables	Location of receiver from Transmitter
Constants:	• Power Output of the transmitter (200 mW) • Geometry of payload (deployed and leveled) • Altitude, pressure, clear environment
Step-by-Step Execution:	1. Initiate remote image transfer to ground station. 2. Take image and note quality. 3. Move to various location within half mile radius of transmitter. 4. Take more points (Approximately 30)
Relevant Safety Concerns:	None.
Status/Results:	Planned
Justification:	Mission success depends on transmission working within the specified range

Table 24: Wireless Transmission Range Test

Possible Necessary Changes:	If failed, a different antenna topology must be chosen

Status/Results: (if completed): Planned

4.1.4. Construction Plans and Procedures

4.1.4.1. Payload Assembly Construction

ITEM NO.	PART NAME	QTY.
1	Base	1
2	Leg	3
3	Main Cover	1
4	Top Cap	1
5	Camera Holder	1
6	Antenna	1
7	M2.5 Threaded Heat Set Inserts	11
8	Acrylic Sheets	4
10	M2.5 x 8 Phillips Flat Head Screws	6

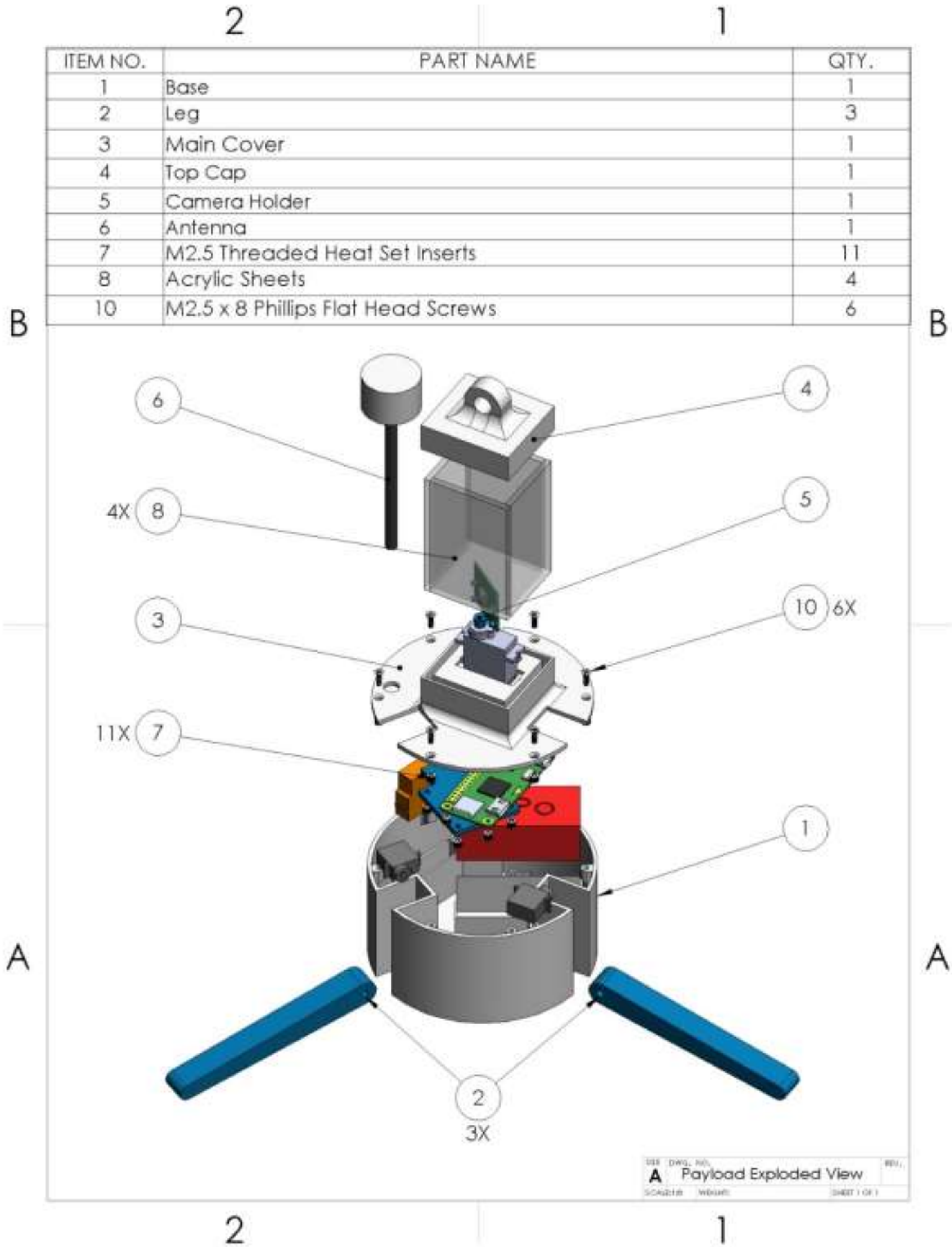

Figure 63: Exploded View of Payload

All custom sized components are 3D printed using PLA plastic except for the 'Top Cap' as indicated in the figure above. Acrylic sheets are cut from 1/8" thick acrylic sheets using a waterjet. Proper caution and PPE must be taken while manufacturing the acrylic sheets as outlined by the machine shop guidelines. Electronics and hardware are purchased as COTs parts. The following images illustrate the assembly process.

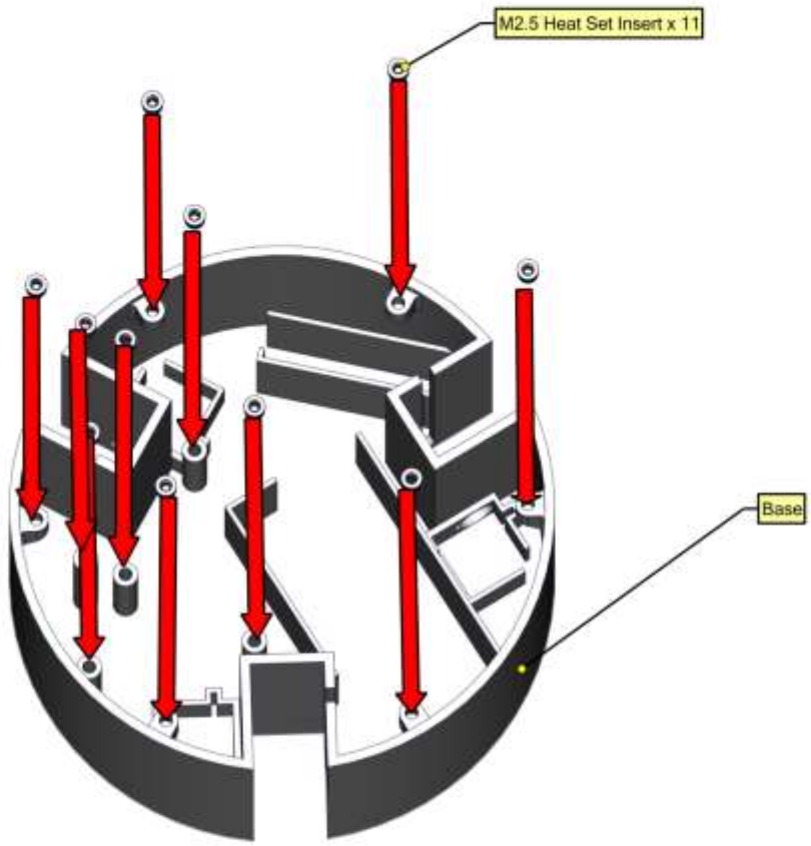

Figure 64: Payload Assembly Step 1

PPE Required	Safety Goggles, Mask, Fan
Instructions	• Ensure a fan is sucking air blowing air away from the person to prevent inhaling fumes. • Use hot soldering iron to heat the heat set inserts. • Place heat set inserts designated holes of the 3D printed PLA payload base. • Ensure inserts are flush with the payload base (if not, reprint the payload base and restart process). • It is beneficial to practice these steps on scrap pieces of PLA plastic

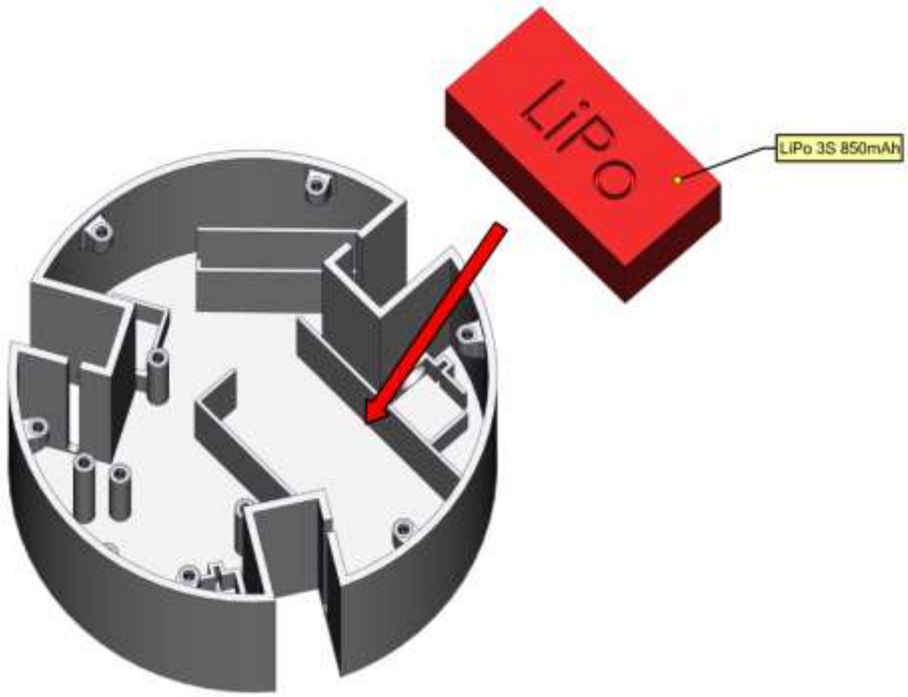

Figure 65: Payload Assembly Step 2

PPE Required	N/A
Instructions	• Place the LiPo Battery into the corresponding compartment within the 3D printed Payload Base. • Secure the LiPo Battery in its compartment using duct tape to secure its position.

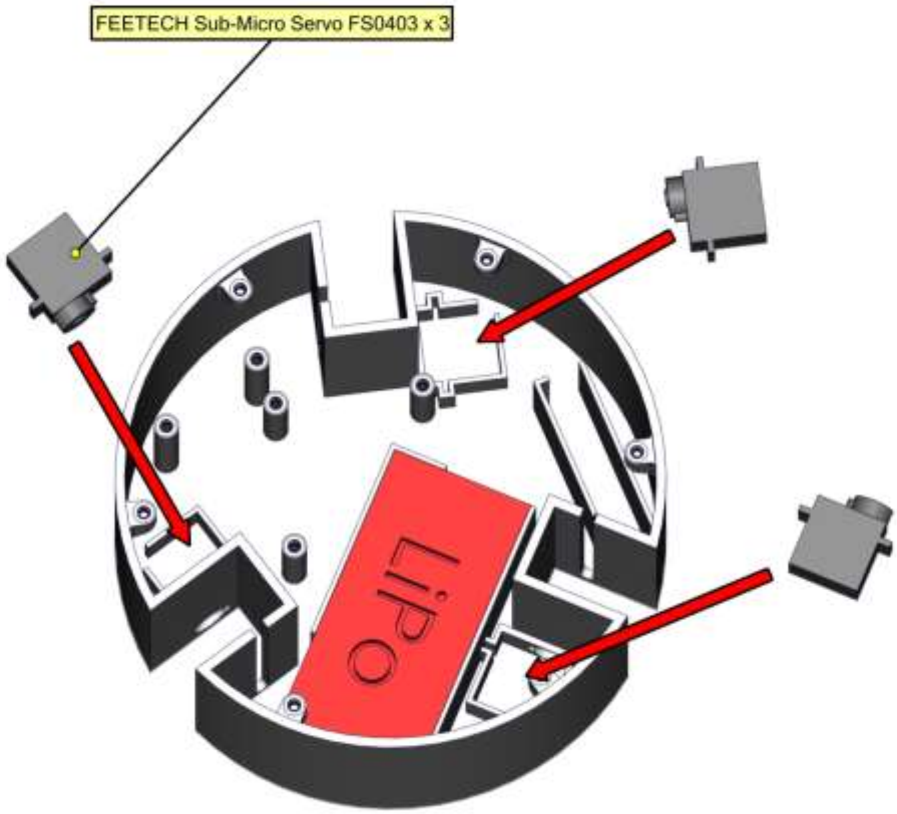

Figure 66: Payload Assembly Step 3

PPE Required	N/A
Instructions	• Place the each of the 3 Sub-Micro Servo motors in each of their corresponding compartments.

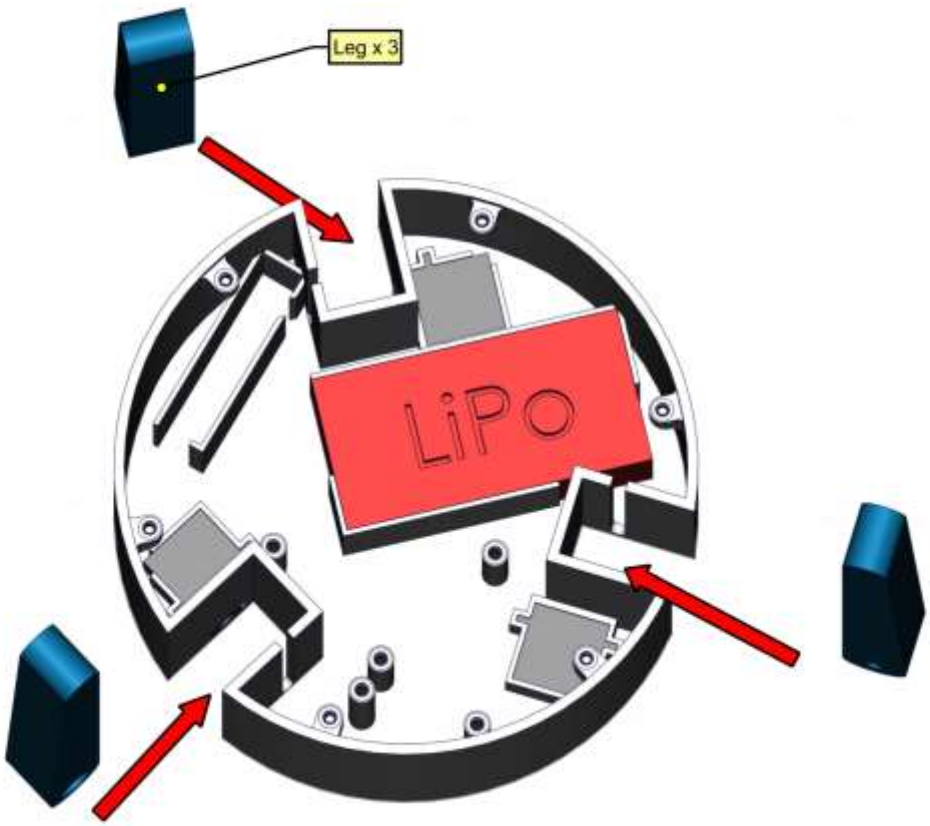

Figure 67: Payload Assembly Step 4

PPE Required	N/A
Instructions	• Place the each of the 3D printed PLA Payload legs in each of their corresponding compartments. • Ensure that the holes on each leg is aligned with the Sub-Micro Motor that will operate each leg.

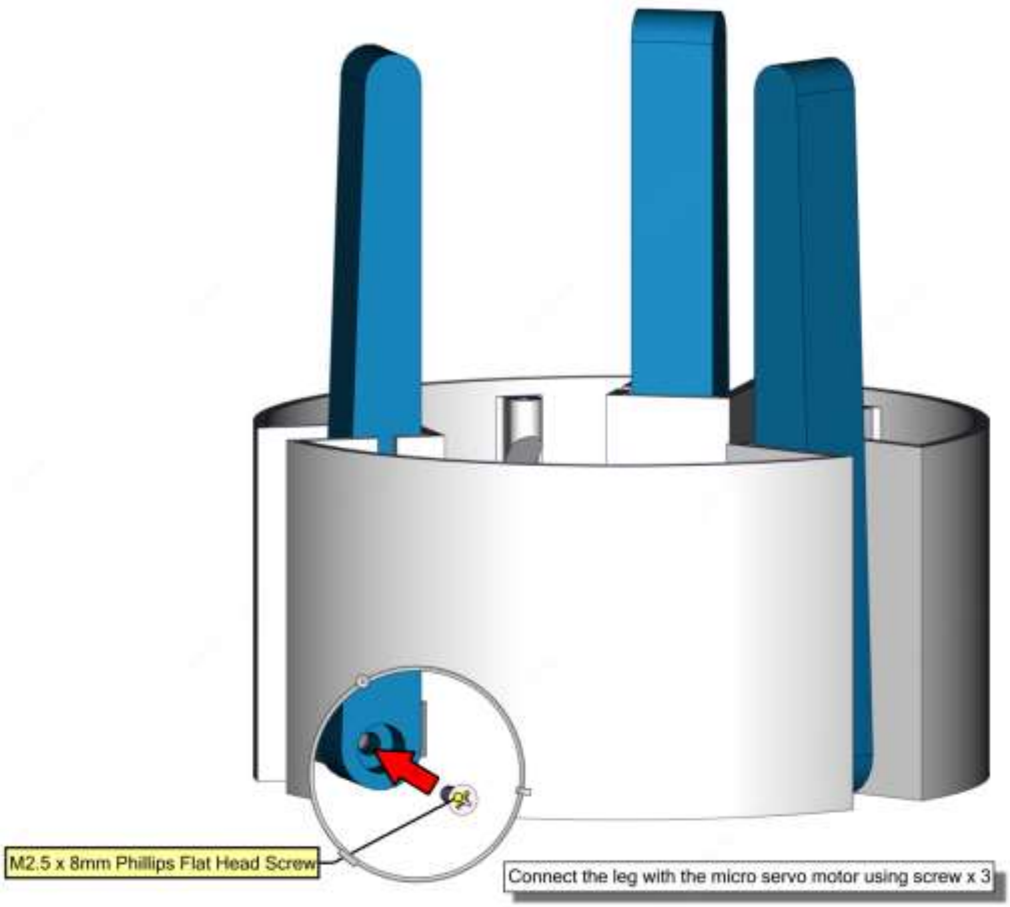

Figure 68: Payload Assembly Step 5

PPE Required	N/A
Instructions	• Use Phillips Flat Head Screws (3 x's) to attach Payload legs to the Sub-Micro motors by threading the screw through each leg and into the corresponding hole that leads to the motor. • Ensure that the screws allow for full operating ability of the movement of each leg.

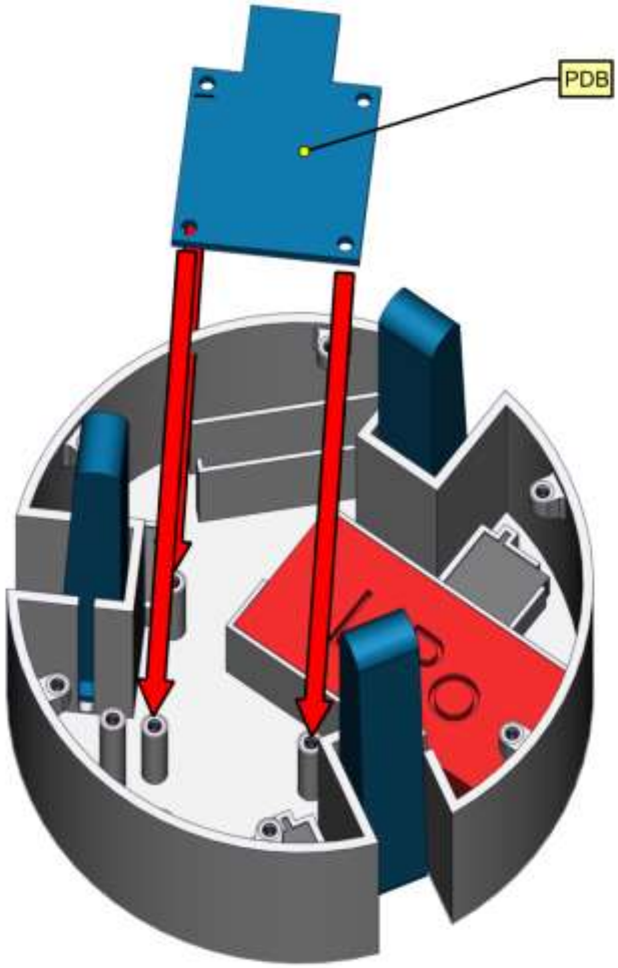

Figure 69: Payload Assembly Step 7

PPE Required	N/A
Instructions	• Solder and wire components that are connected to the PDB. • Place the PDB on top of the 3 posts and manually support until position is as needed. • Ensure that the holes for the PDB is aligned with the 3 posts that will host the board in the appropriate area for maximization of space

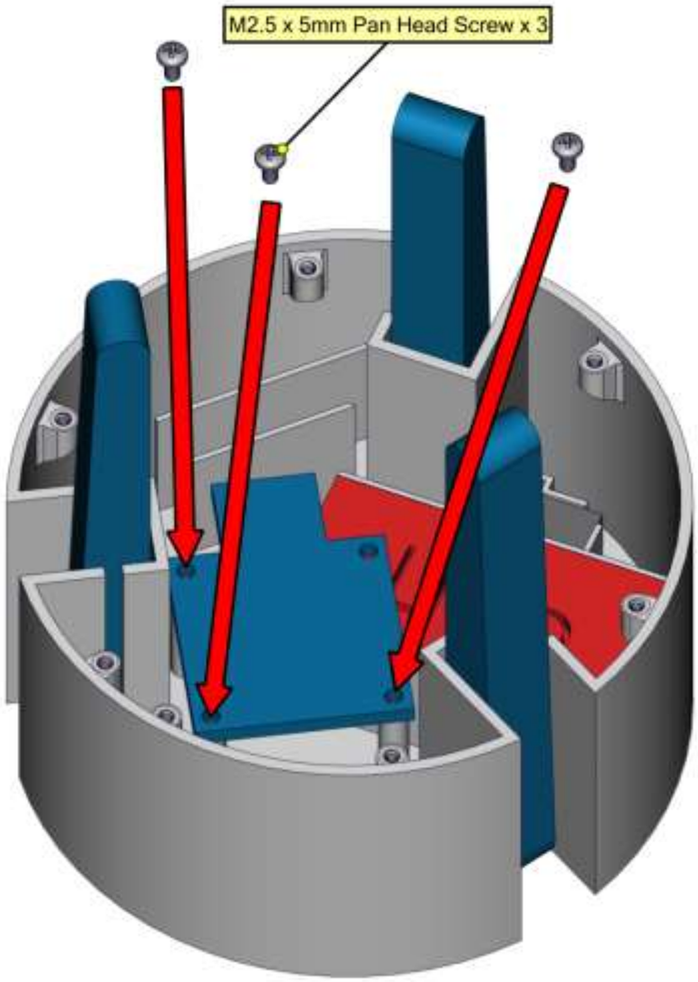

Figure 70: Payload Assembly Step 8

PPE Required	N/A
Instructions	• Use Phillips Pan Head Screws (3 x's) to attach PDB to the corresponding posts by threading the screw through each slot and into the appropriate hole with the corresponding guided insert. • Ensure that the screws are tightened so the PDB stays secure

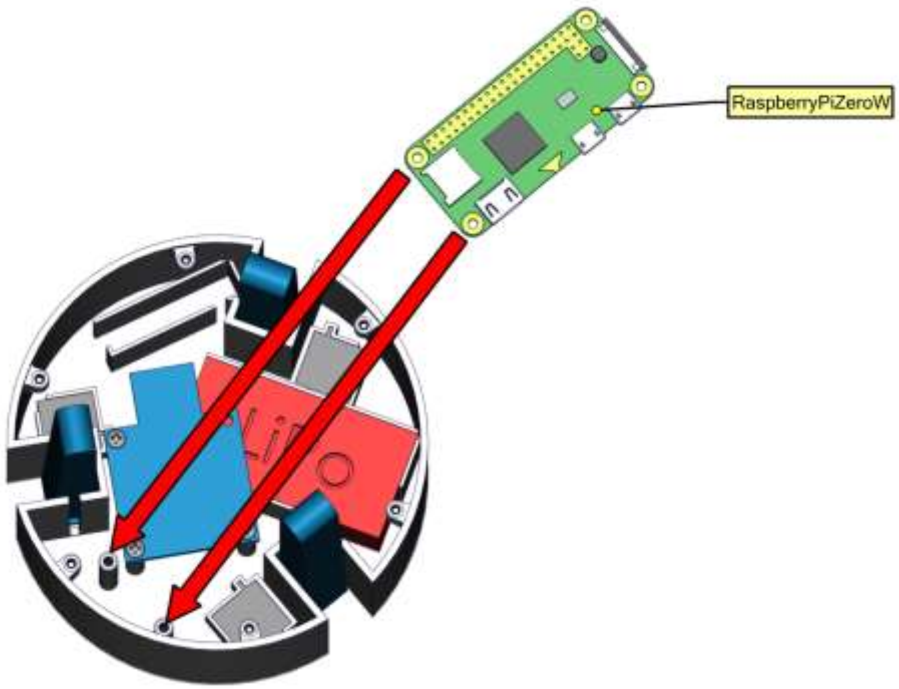

Figure 71: Payload Assembly Step 9

PPE Required	N/A
Instructions	• Place the RaspberryPi microcontroller on top of the 2 posts and manually support until position is as needed. • Ensure that the holes for the microcontroller are aligned with the 2 posts that will host the board in the appropriate area for maximization of space

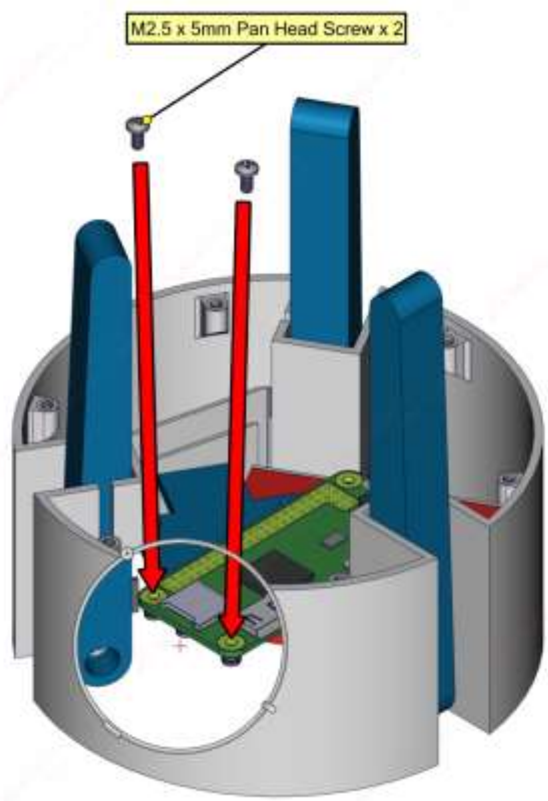

Figure 72: Payload Assembly Step 10

PPE Required	N/A
Instructions	• Use Phillips Pan Head Screws (2 x's) to attach RaspberryPi microcontroller to the corresponding posts by threading the screw through each slot and into the appropriate hole with the corresponding guided insert. • Ensure that the screws are tightened so the microcontroller stays secure

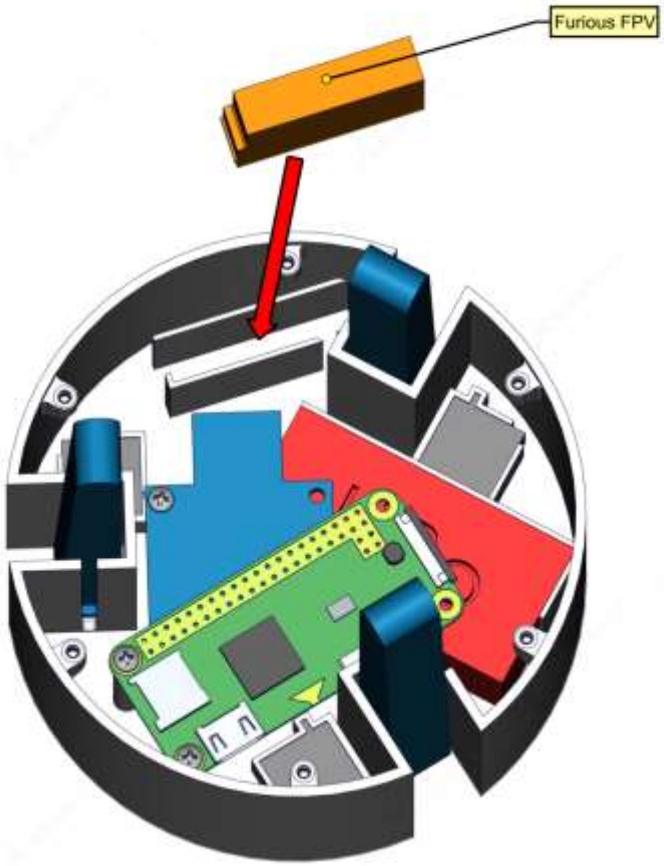

Figure 73: Payload Assembly Step 11

PPE Required	N/A
Instructions	• Solder and wire all connections made to the Furious FPV transmitter. • Place the transmitter into the corresponding compartment within the 3D printed Payload Base. • Secure the transmitter in its compartment using duct tape to secure its position.

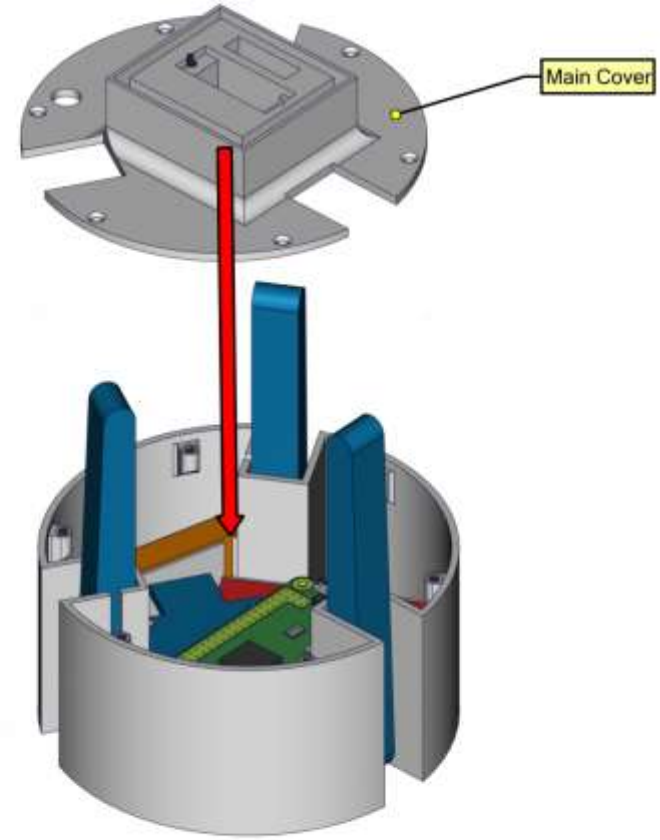

Figure 74: Payload Assembly Step 12

PPE Required	N/A
Instructions	• Place the main cover over the base and align with the 3D printed Payload Base and the corresponding holes to secure base.

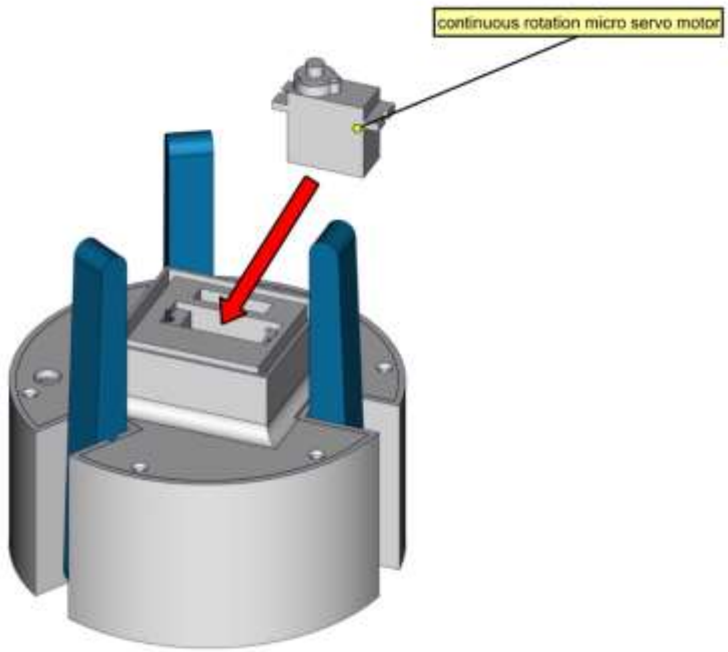

Figure 75: Payload Assembly Step 13

PPE Required	N/A
Instructions	• Place the Continuous Rotating Micro Servo motor in its corresponding compartment within the 3D printed main cap. • Wire the servo motor to the RaspberryPi microcontroller.

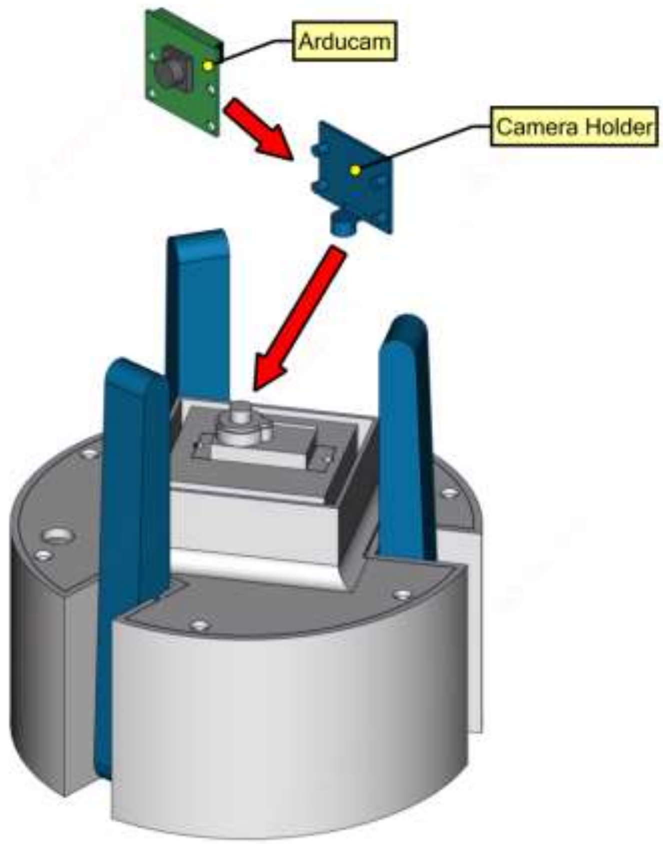

Figure 76: Payload Assembly Step 14

PPE Required	N/A
Instructions	• Place the Arducam onto the 3D printed PLA camera holder. • Secure the Arducam using tape from behind the camera holder for ease of removing and prototyping. • With the assembled Arducam and camera holder, place on the continuous rotating motor for 360-degree view.

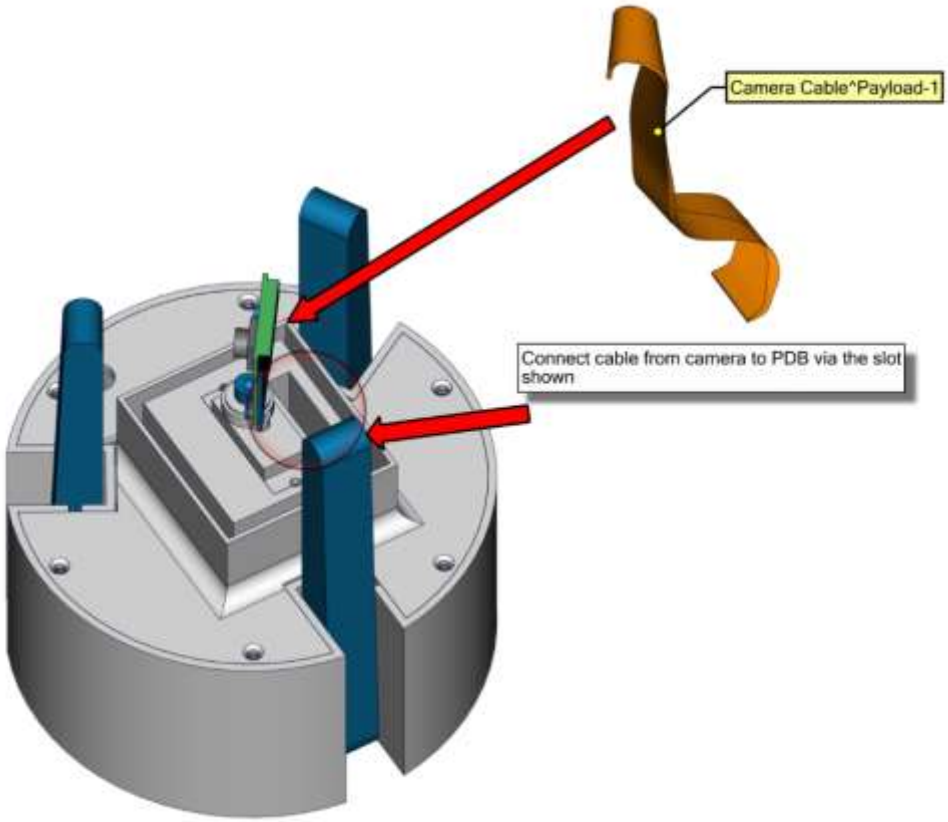

Figure 77: Payload Assembly Step 15

PPE Required	N/A
Instructions	• Attach the camera cable to the RaspberryPi microcontroller and assembled Arducam and camera holder.

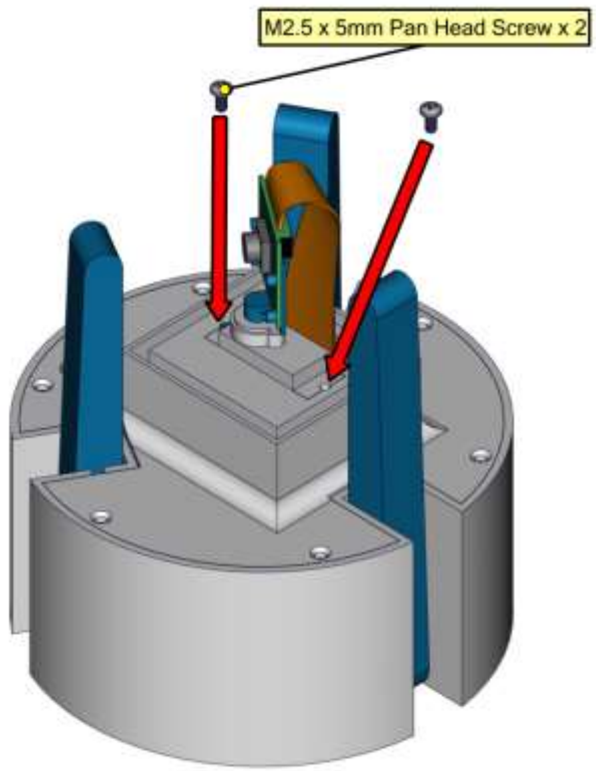

Figure 78: Payload Assembly Step 16

PPE Required	N/A
Instructions	• Use Phillips Pan Head Screws (2 x's) to attach the camera and rotating motor to the corresponding compartment in the main cover by threading the screw through the slot and into the appropriate holes. • Ensure that the screws are tightened so the camera stays secure

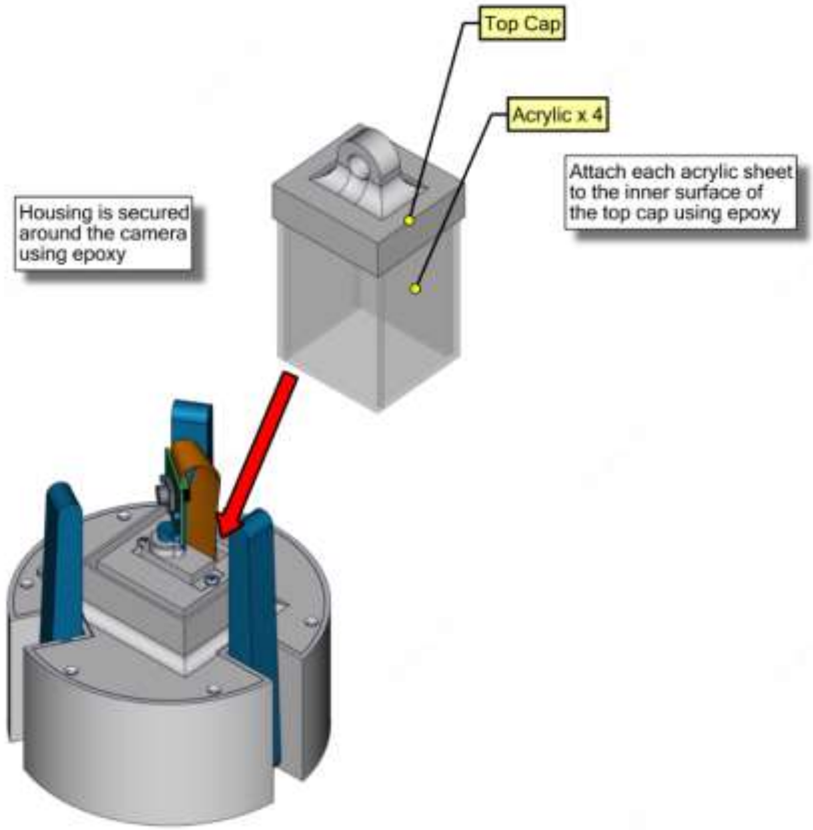

Figure 79: Payload Assembly Step 17

PPE Required	Mask, Gloves, Safety Goggles
Instructions	• Use epoxy to attach each acrylic sheet with the top cap. • Ensure all acrylic sheets are flush in the slots around the underside of the top cap and no epoxy obstructs the vision of the camera. • Cure the epoxy for 24 hours, making sure the epoxied components are oriented such that subtle deformations over 24 hours do not propagate. • If any excess epoxy exists on the sides of the disks or in the holes, sand it down with sandpaper or DA sander until no excess epoxy exists. • Repeat steps to secure the camera housing over the camera with epoxy to ensure that it is safely secured.

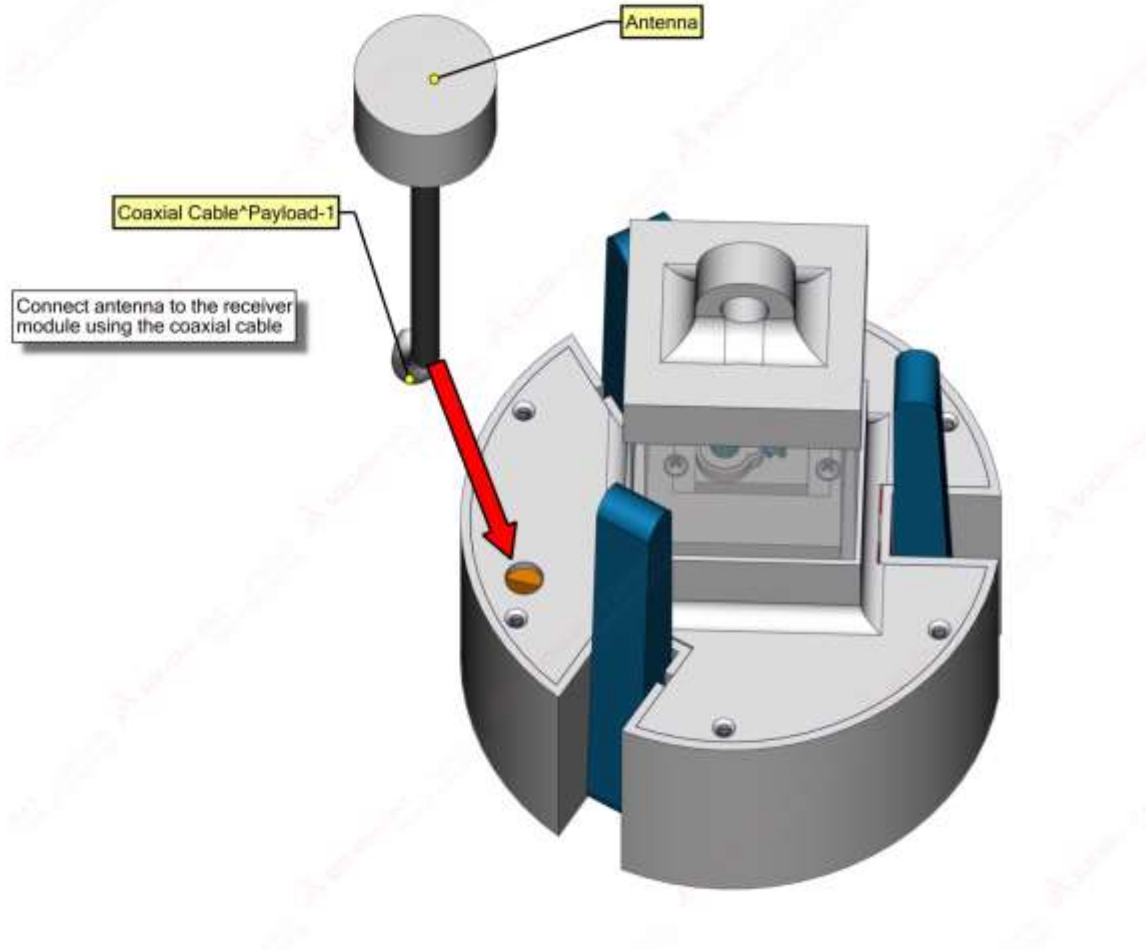

Figure 80: Payload Assembly Step 18

PPE Required	N/A
Instructions	• Attach antenna to coaxial cable through the designated hole. • Fasten screws to attach the entire payload together. • Attach quicklink to the top cap and harness parachute to quicklink. • Fold and pack parachute to fit within the retention system.

4.1.4.2. Retention System Construction

ITEM NO.	PART NUMBER	QTY.
1	3/8" Steel Locknut	8
2	Aluminum Reinforcement	2
3	Wooden Bulkhead	2
4	3/8" Steel Threaded Rod	2
5	3/8" Galvanized Steel Eyebolt	2
6	Eyebolt Cover	2
7	Semicircle Enclosure	1
8	Payload Cover	1

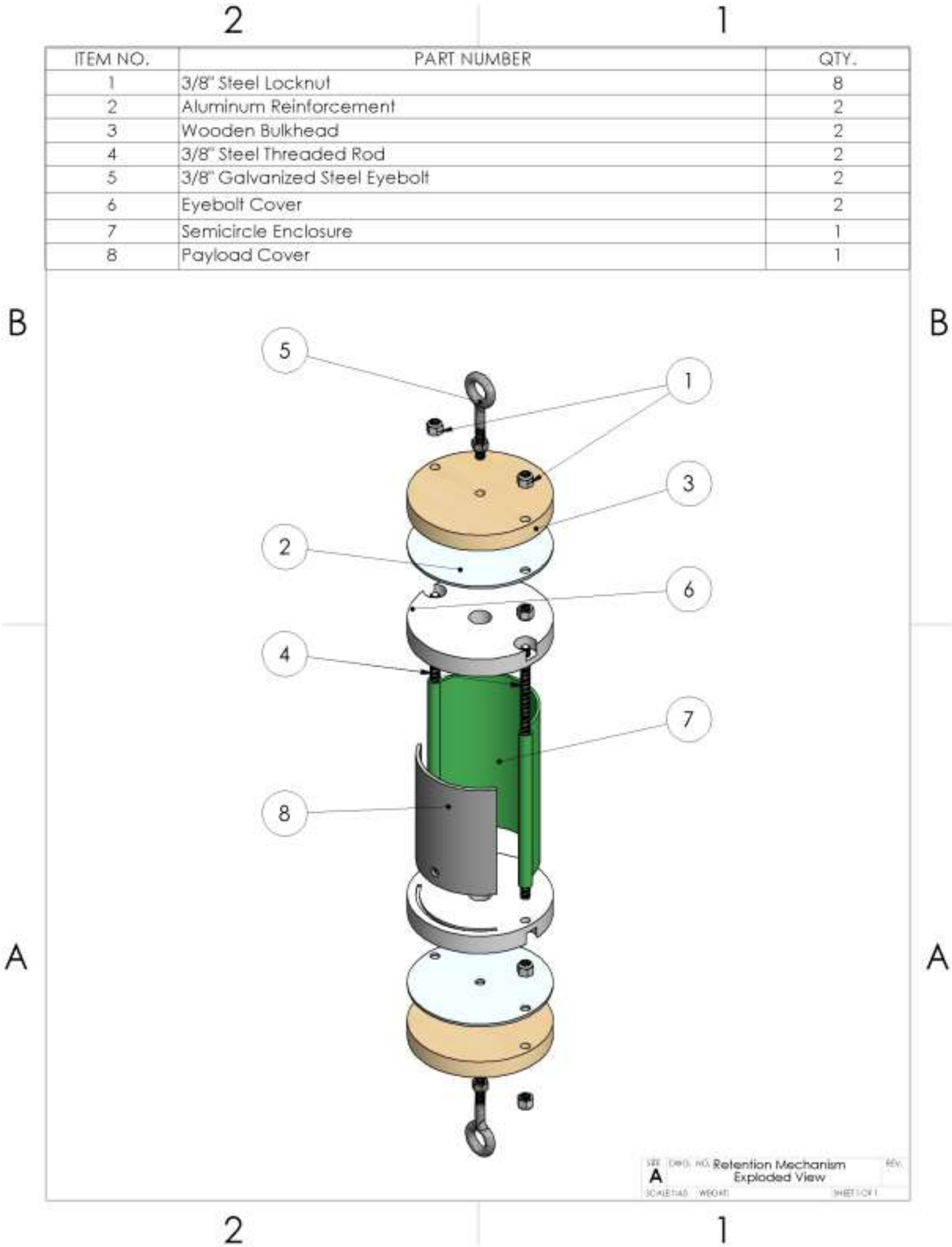

Figure 81: Exploded View of Retention System

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. Custom geometry components are 3D printed using PLA plastic. Instructions on how to assemble the retention system are outlined below.

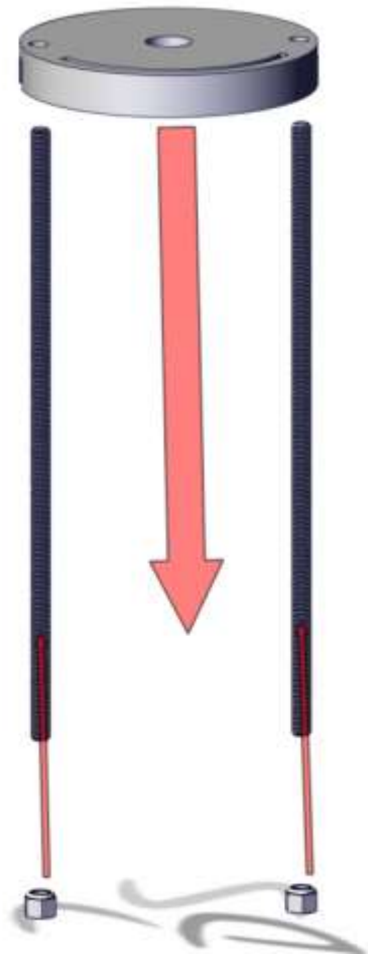

Figure 82: Retention System Assembly Step 1

PPE Required	N/A
Instructions	• Tighten one 3/8in nut onto each steel rod, going up 2.4 inches from the base of the rod. • With the slit facing upward to long end of the rod, insert the eyebolt cover from the top of the two rods to sit on each locknut.

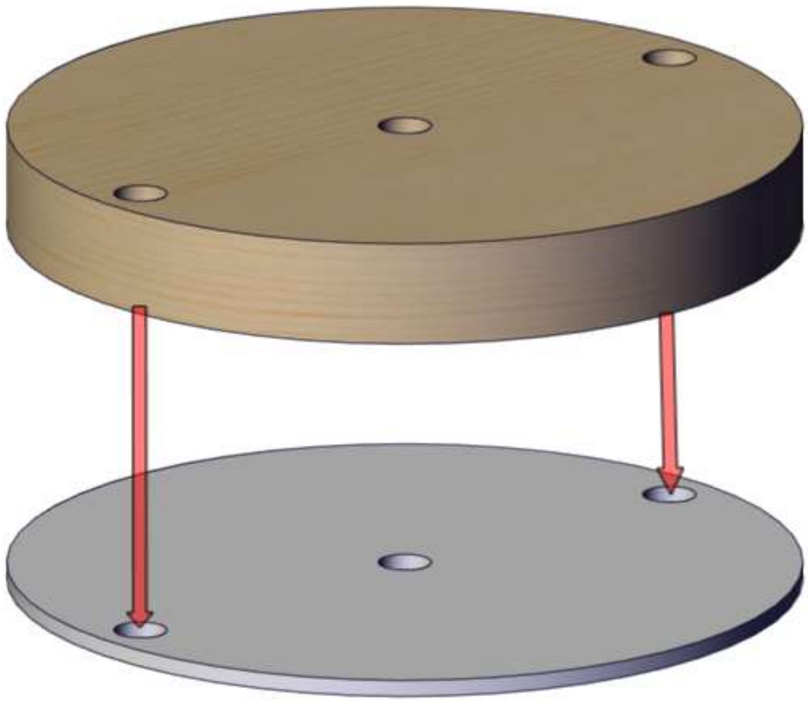

Figure 83: Retention System Assembly Step 2

PPE Required	Latex gloves and protective eyewear
Instructions	• Apply 1:1 epoxy to the surfaces indicated above using a clean wooden popsicle stick. • Stick components together and align properly. • Use multiple clamps to stick parts together. • Wipe off any excess epoxy and let dry for 24 hours with clamps. • Sand off any other imperfections. • Repeat the steps indicated above to create two exact iterations of the same component.

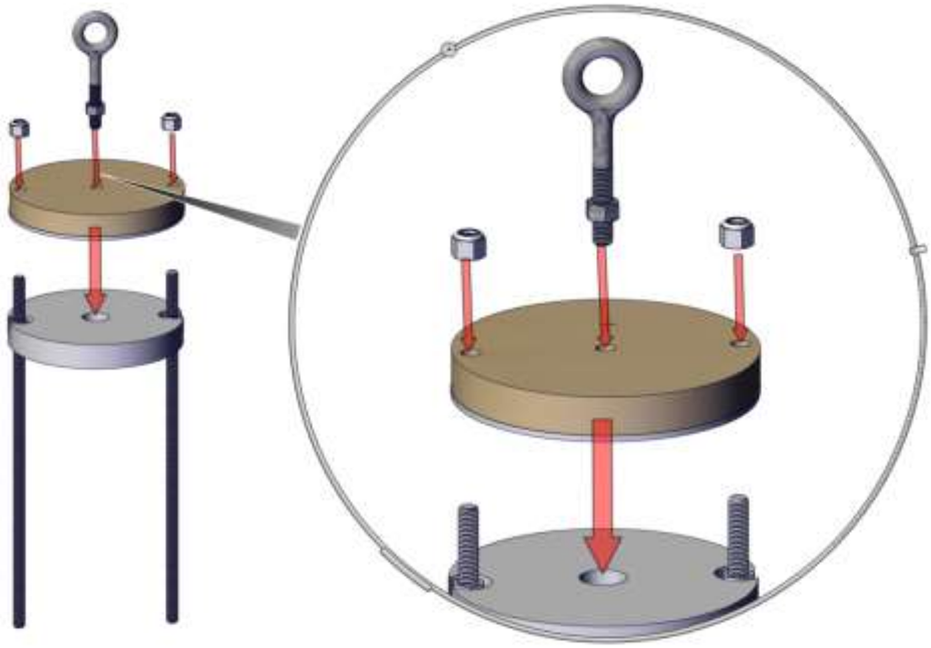

Figure 84: Retention System Assembly Step 3

PPE Required	Latex gloves and protective eyewear
Instructions	• Screw indicated locknuts firmly, one on each rod. • Through the center hole, apply epoxy using a wooden popsicle stick and insert the eyebolt. • Screw the eyebolt screw and let epoxy dry for 24 hours.

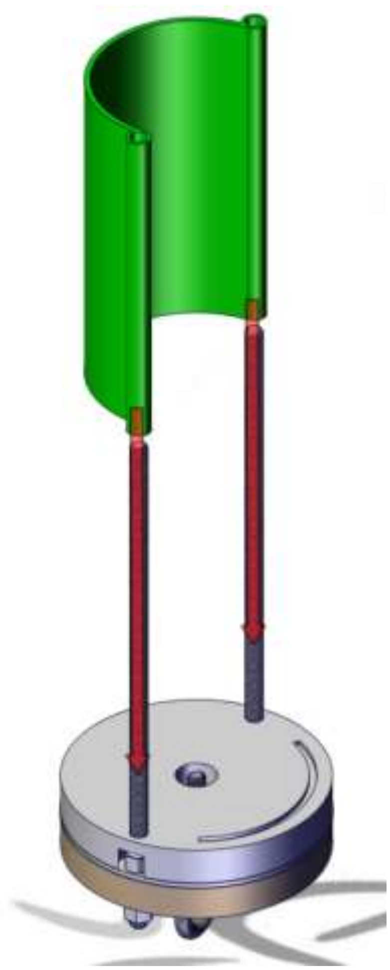

Figure 85: Retention System Assembly Step 4

PPE Required	Latex gloves and protective eyewear
Instructions	• Slide the semicircle enclosure with the circle opening towards the side with the slit on the eyebolt cover. • Apply epoxy at the base where the semicircle enclosure meets the eyebolt cover. • Wipe off excess epoxy and let cure for 24 hours.

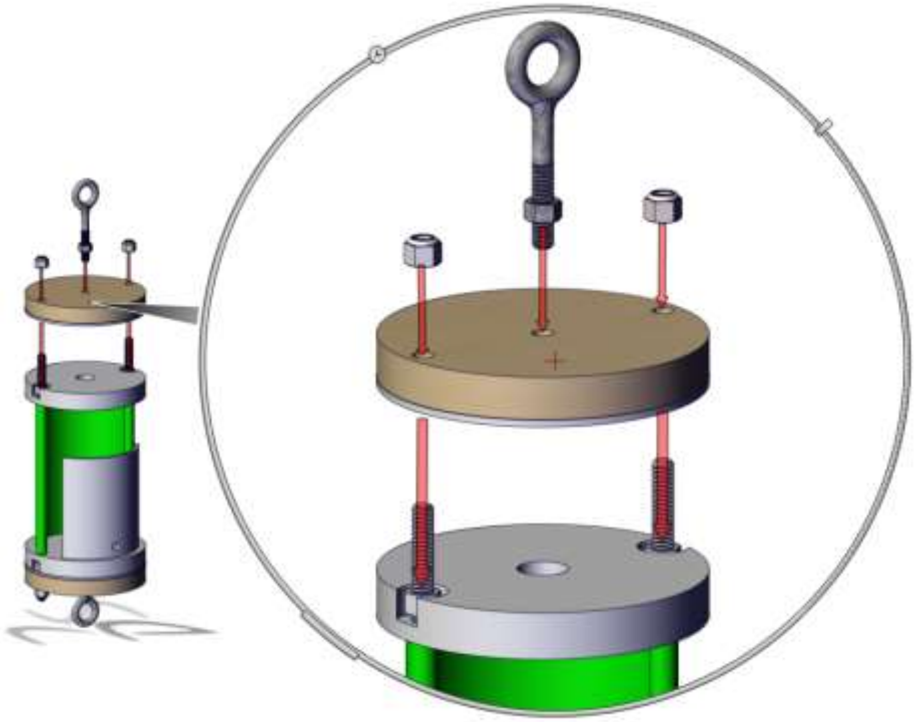

Figure 86: Retention System Assembly Step 5

PPE Required	Latex gloves and protective eyewear
Instructions	• Repeat step 3 to create a mirror of the same components.

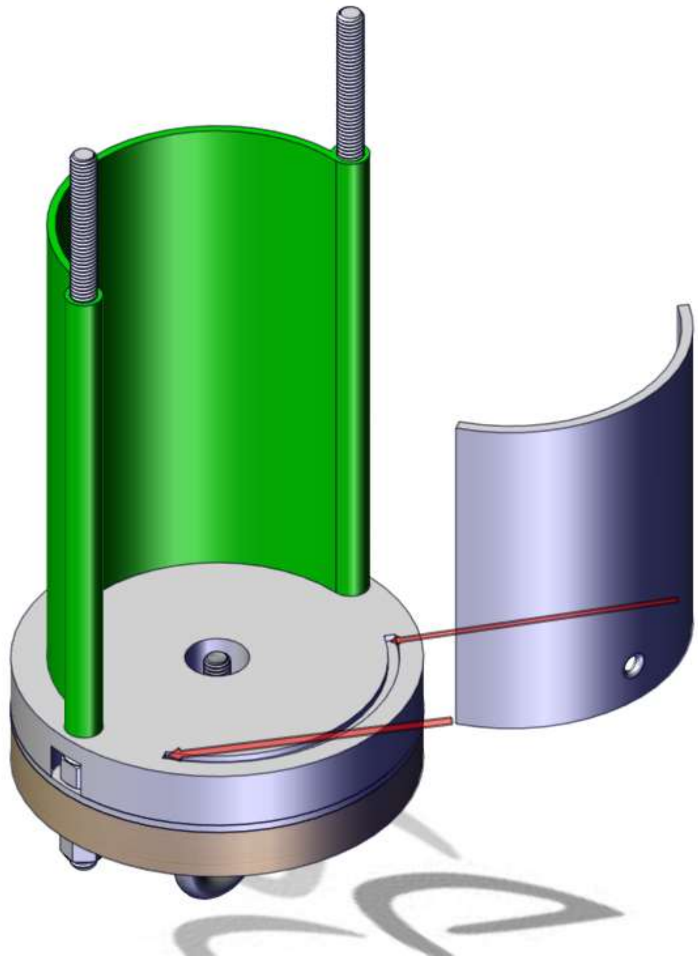

Figure 87: Retention System Assembly Step 6

PPE Required	N/A
Instructions	• Place the packed payload within designated area with the base of the payload on the base shown above. • Using a sturdy string, tie the payload cover piece shown above to the bottommost eyebolt of the retention system. • Place the cover within the designated slit. The payload cover is intended to remove easily so the connection between the slit and the cover is flimsy. The slit merely serves as a visual reference point of where to place the cover.

4.1.5. Final Payload Design

For the sake of brevity, the purpose and dimensions of individual components that make up the entire payload and its retention system will not be discussed in detail. Dimensions of most components are the same as stated in CDR except for some minor changes to accommodate for screws and other assembling processes in the main body of the payload assembly itself.

4.1.5.1. Payload Assembly

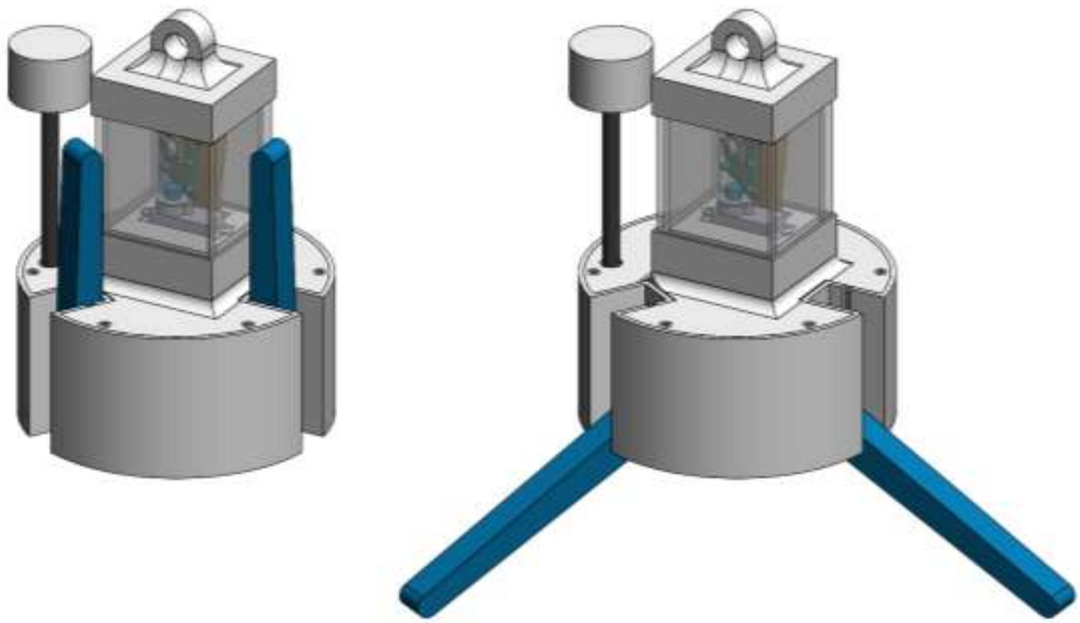

Figure 88: Packed Payload (left) and Unpacked Payload (right)

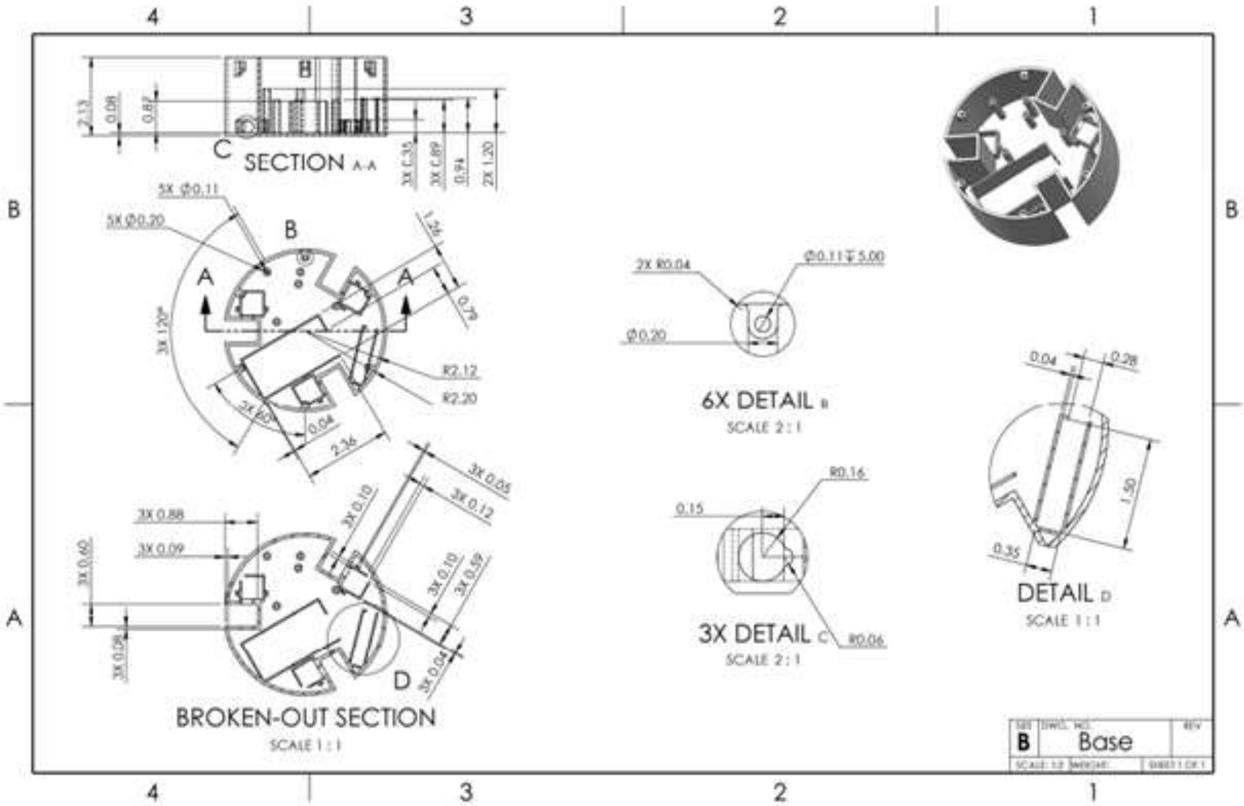

Figure 89: Drawing of Payload Base

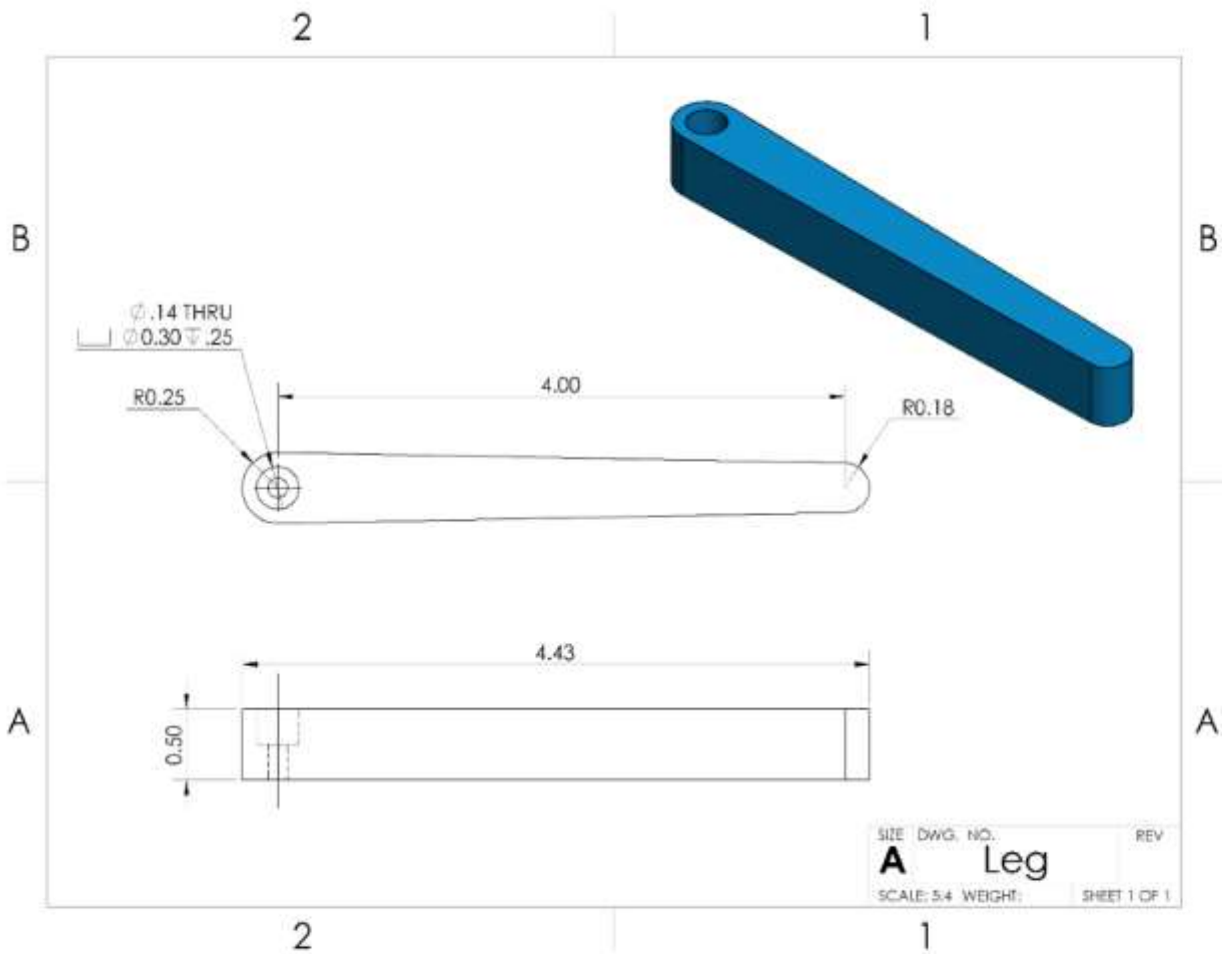

Figure 90: Drawing of Payload Leg

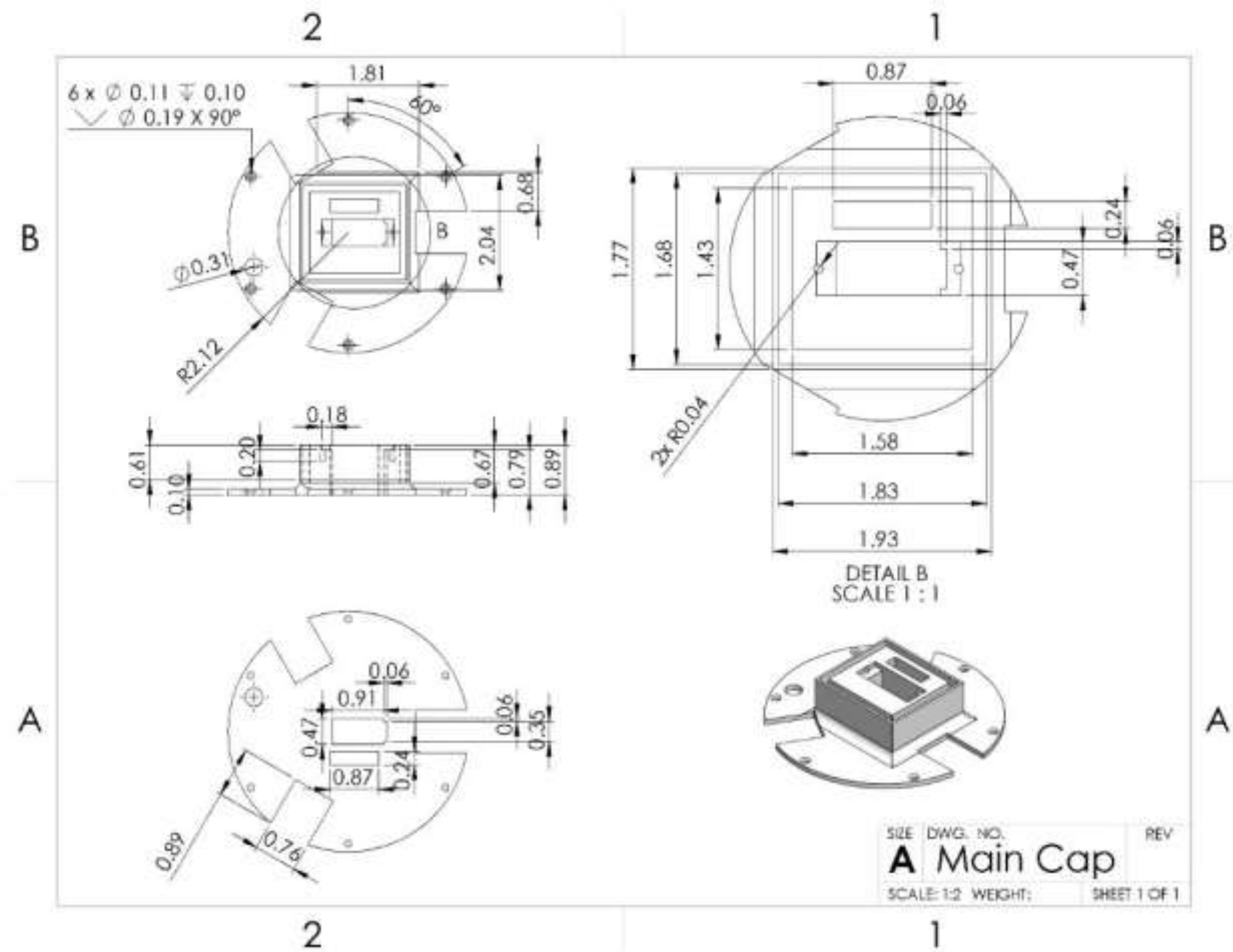

Figure 91: Drawing of Main Cap

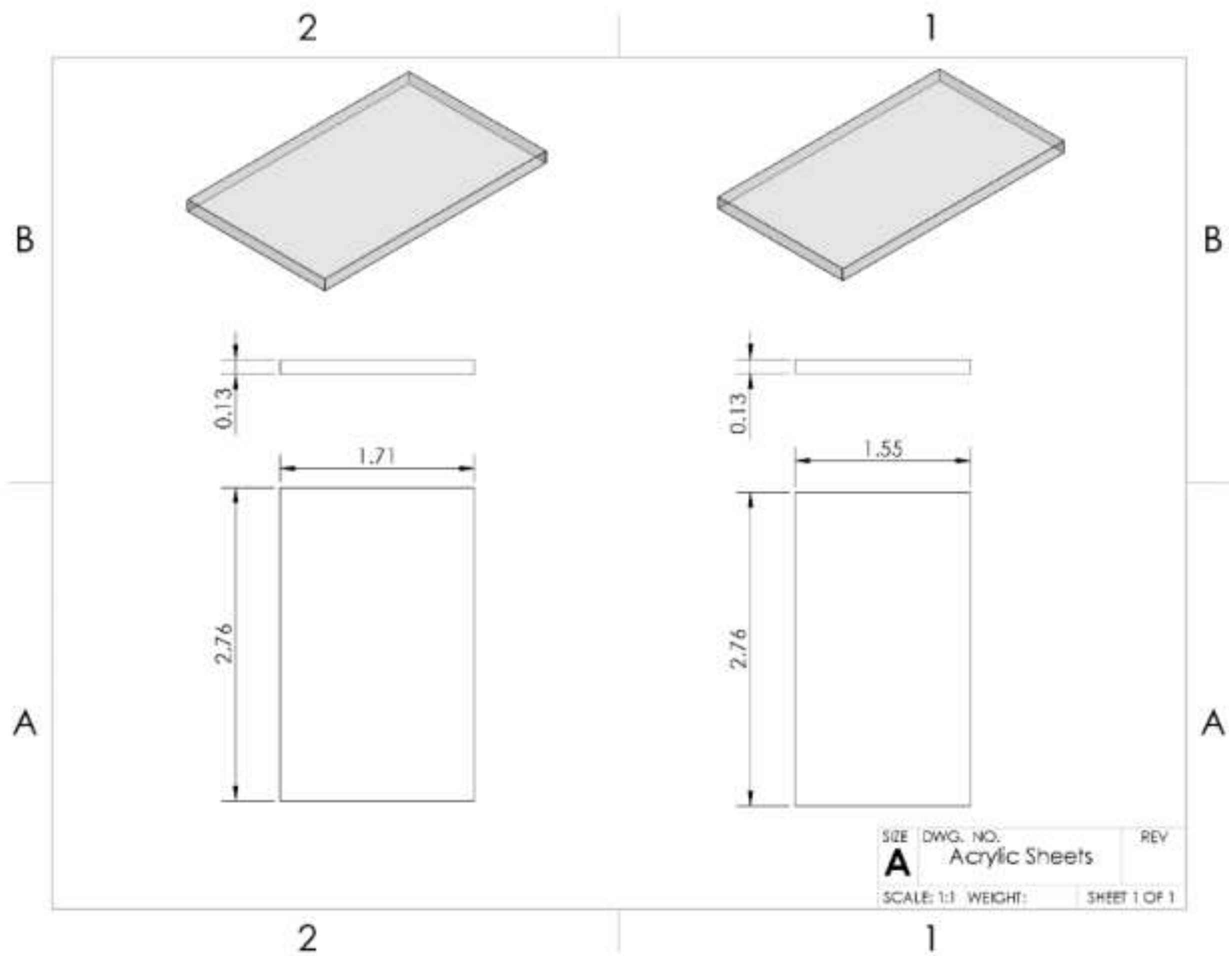

Figure 92: Drawing of Acrylic Sheets

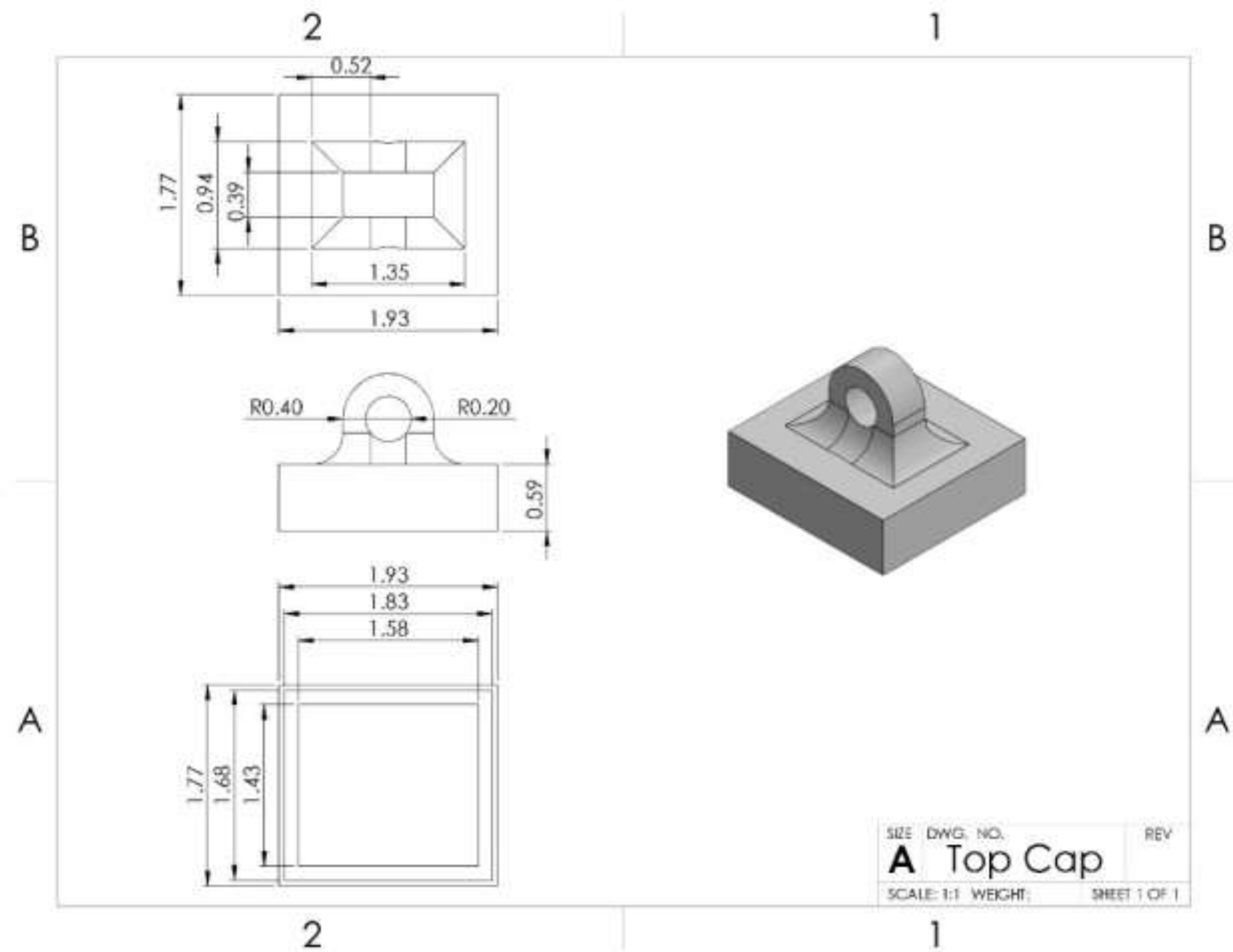

Figure 93: Drawing of Top Cap

5.1.5.2 Retention System

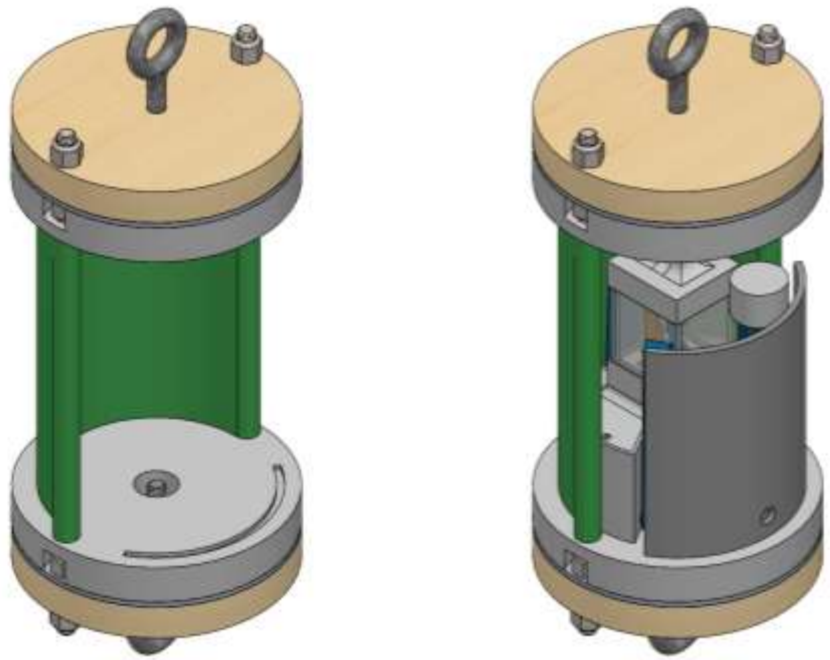

Figure 94: Retention System without Cover (left) and with Cover (right)

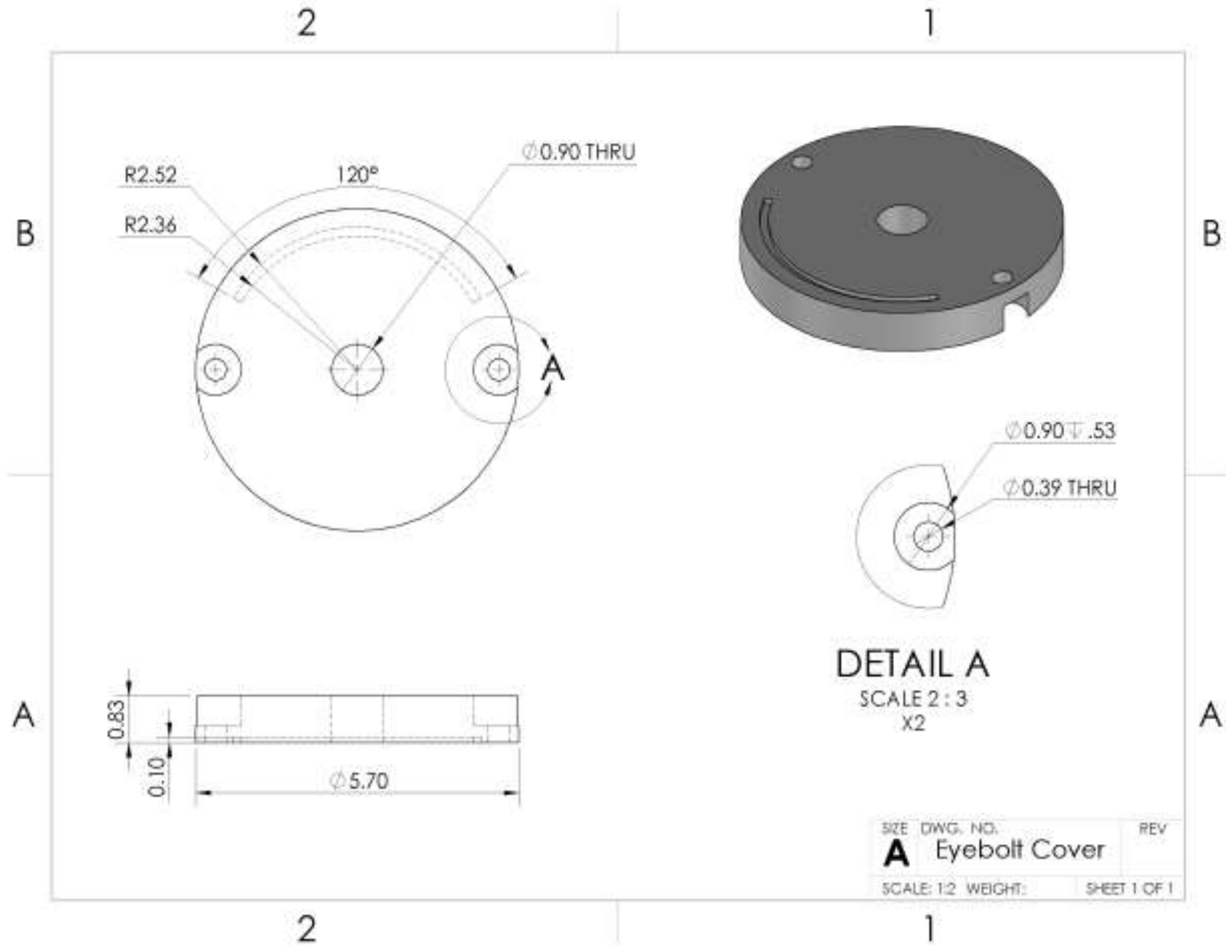

Figure 95: Drawing of Eyebolt Cover

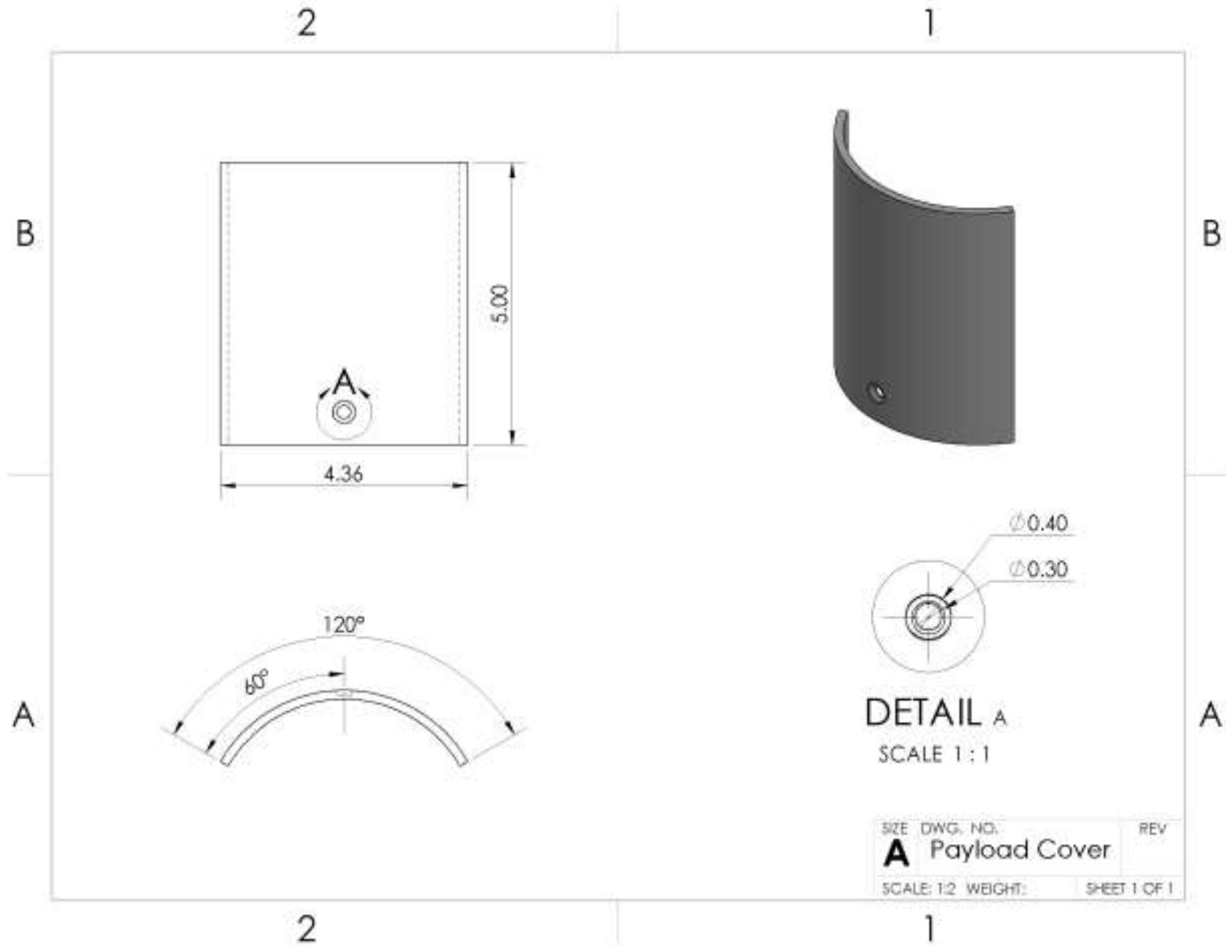

Figure 96: Drawing of Payload Cover

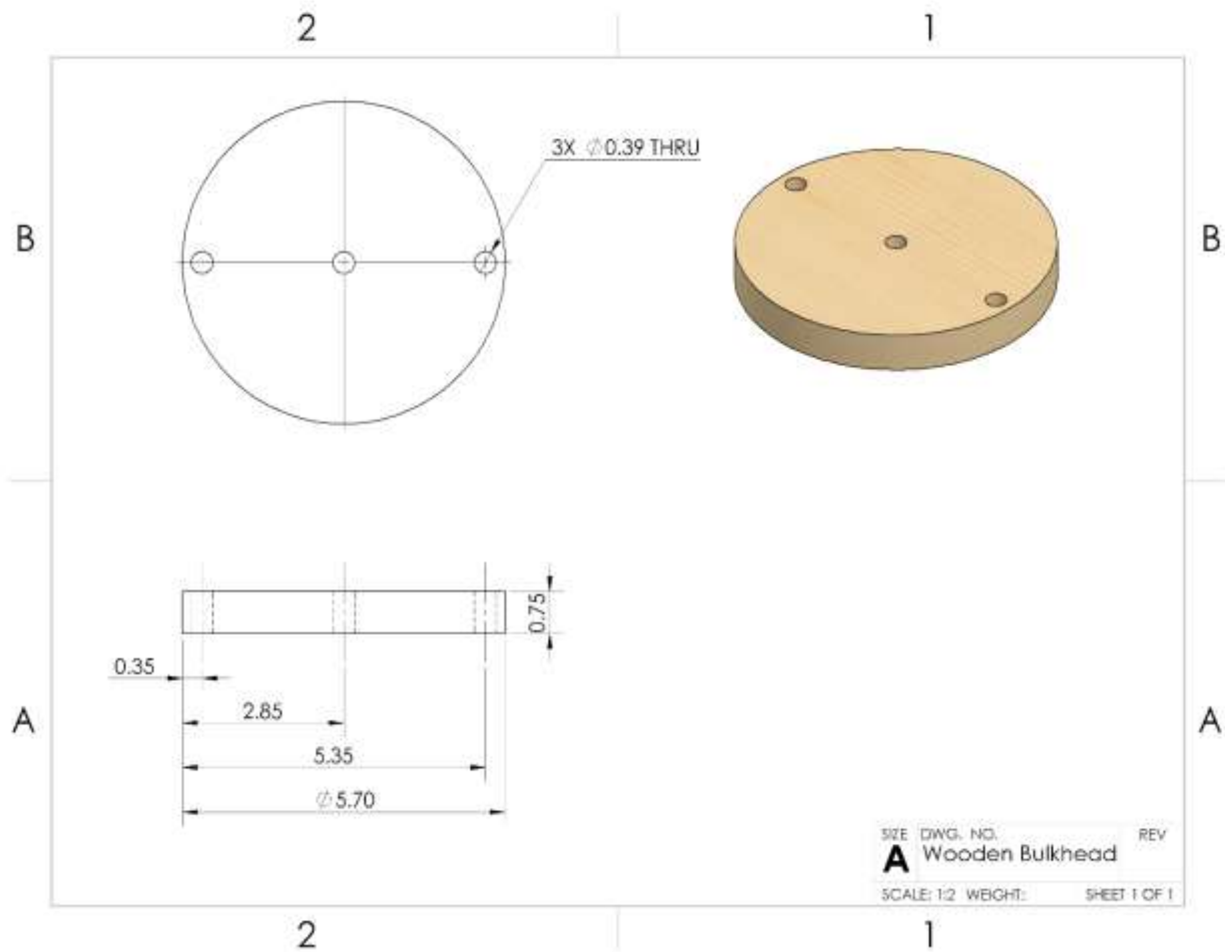

Figure 97: Drawing of Retention System Wooden Bulkhead

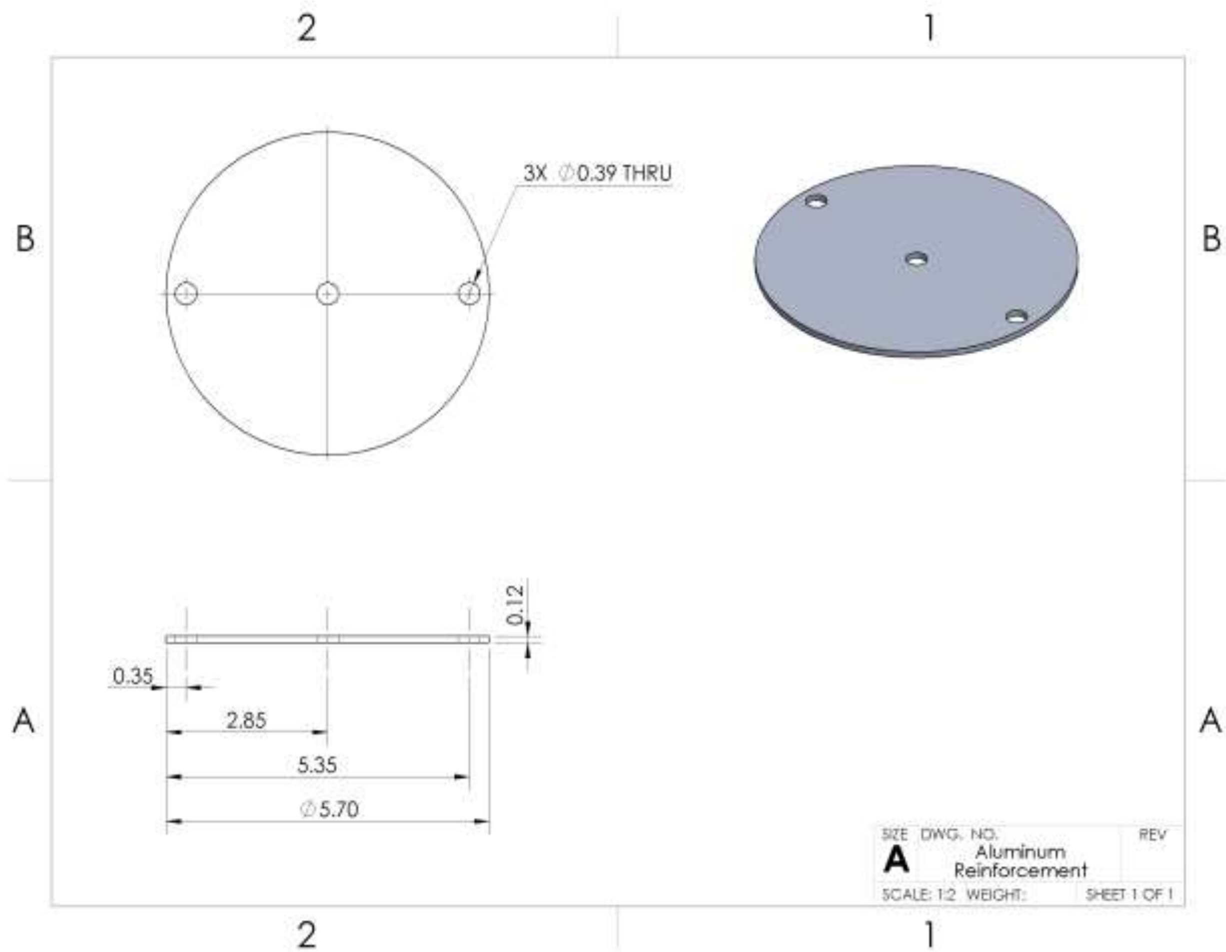

Figure 98: Drawing of Retention System Aluminum Reinforcement

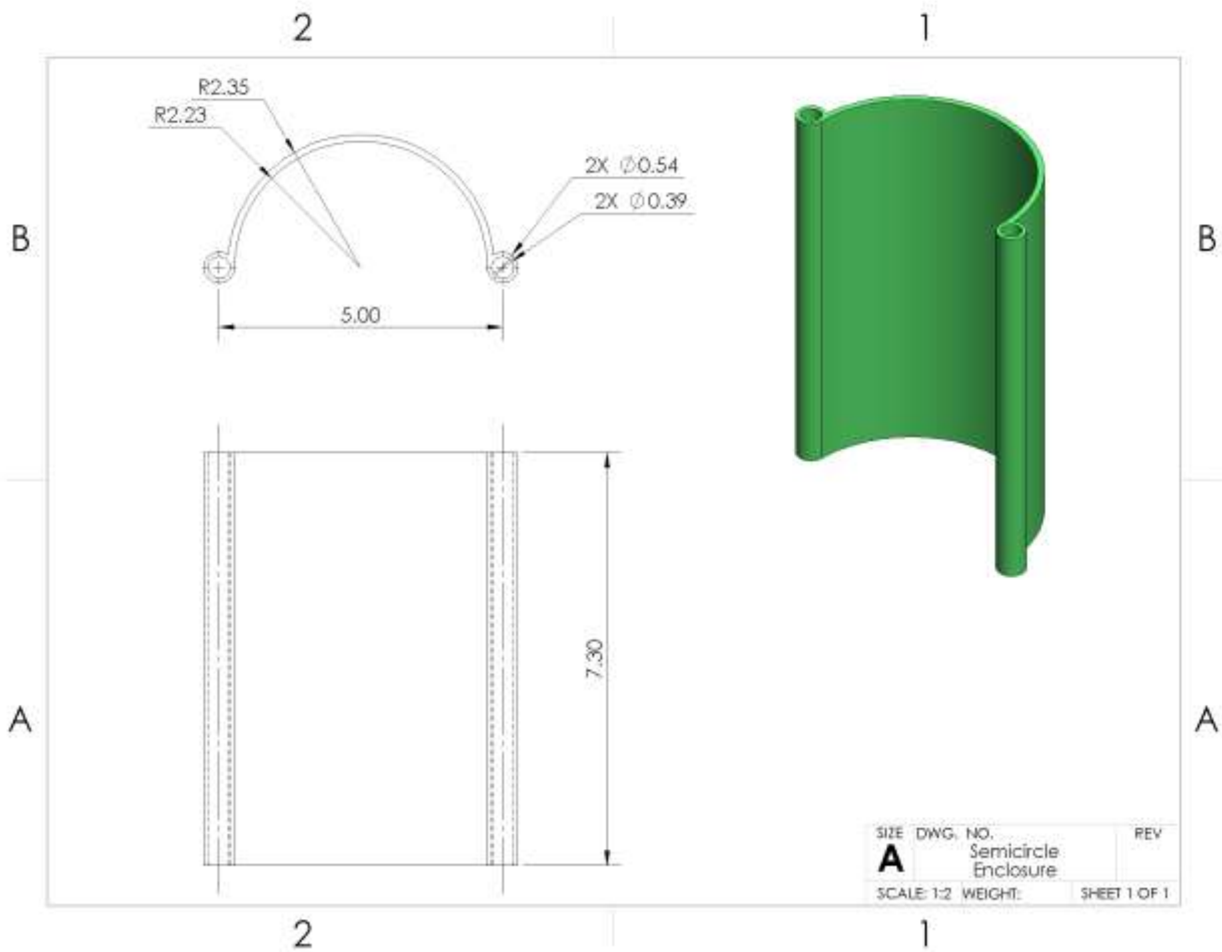

Figure 99: Drawing of Semicircular Enclosure

5. Mock-Demonstration Flight Assessment

5.1. Launch Conditions Summary

Mock-Demonstration Flight profile data along with Launch Conditions were provided by the NASA panel and will analyzed in this section. The table below summarizes the launch conditions that were set for the Mock-Demonstration Flight profile data.

Table 25: Launch Conditions of Mock-Demonstration Flight Profile data

Altitude (AGL) (ft)	500
Temperature (°F)	55
Barometric Pressure (mmHg)	760
Wind Speed (mph)	5 (constant speed)
Thermals	0
Launch Rail Length (inches)	144
Launch Angle (°)	5

Using this Mock-Demonstration Flight data, another predicted flight will be conducted and compared with this data in section 5.8 Simulated Flight Model.

5.2. Motor Flown

The motor flown, as declared at the CDR milestone, is the AeroTech K1103X-14 motor. The motor thrust curve along with the motor statistics have been provided in section 3.3.1.1.

5.3. Ballast Flown

The ballast flown is 1.25 lbs. which has been increased from the value given in the CDR (0.75 lbs.). Flying with 1.25 lbs. of ballast still satisfies the requirement of vehicle ballast not exceeding 10% of the total unballasted weight of the rocket as it would sit on the pad. Unballasted, the rocket has an approximate weight of 18.3 lbs., so the requirement is satisfied.

5.4. Official Target Altitude

The official target altitude is 3600 feet.

5.5. Mock-Demonstration Flight Apogee

The Mock-Demonstration Flight apogee is 4525.25 feet as determined from the data.

5.6. Mock-Altimeter Flight Profile

The graphs of altitude, velocity, and acceleration versus time have been given below based on the mock-altimeter flight profile and performance data.

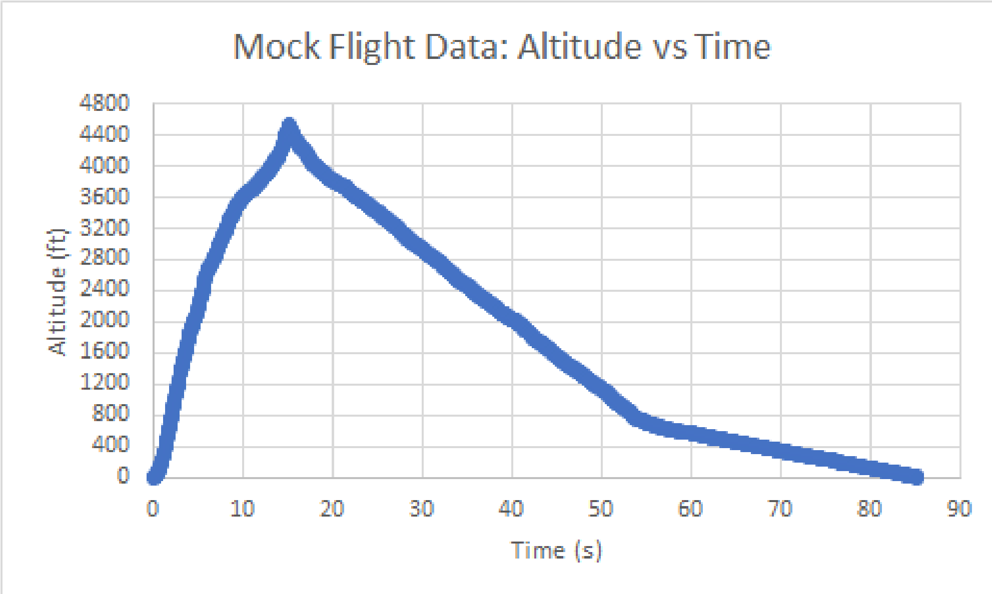

Figure 100: Altitude vs Time of Mock Flight Data

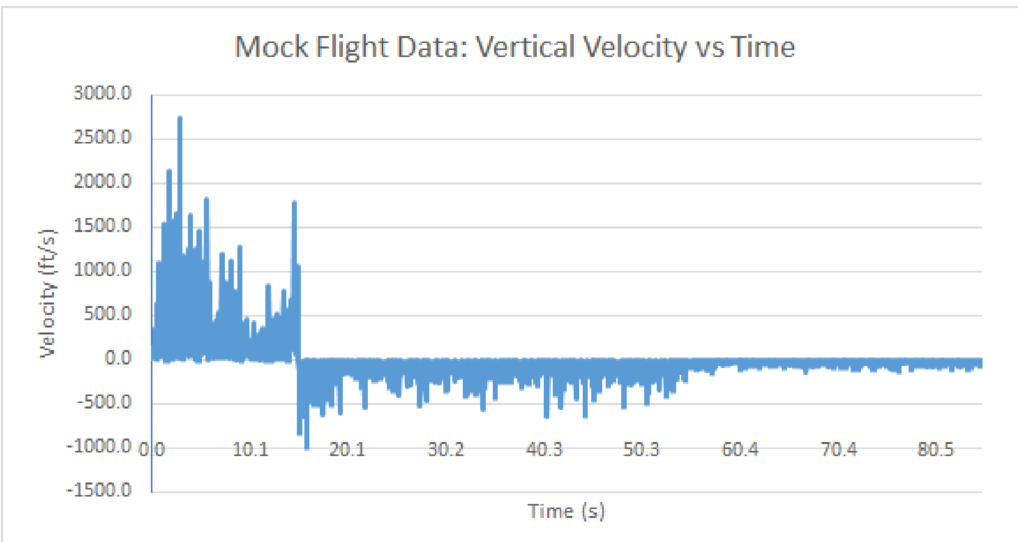

Figure 101: Vertical Velocity vs Time of Mock Flight Data

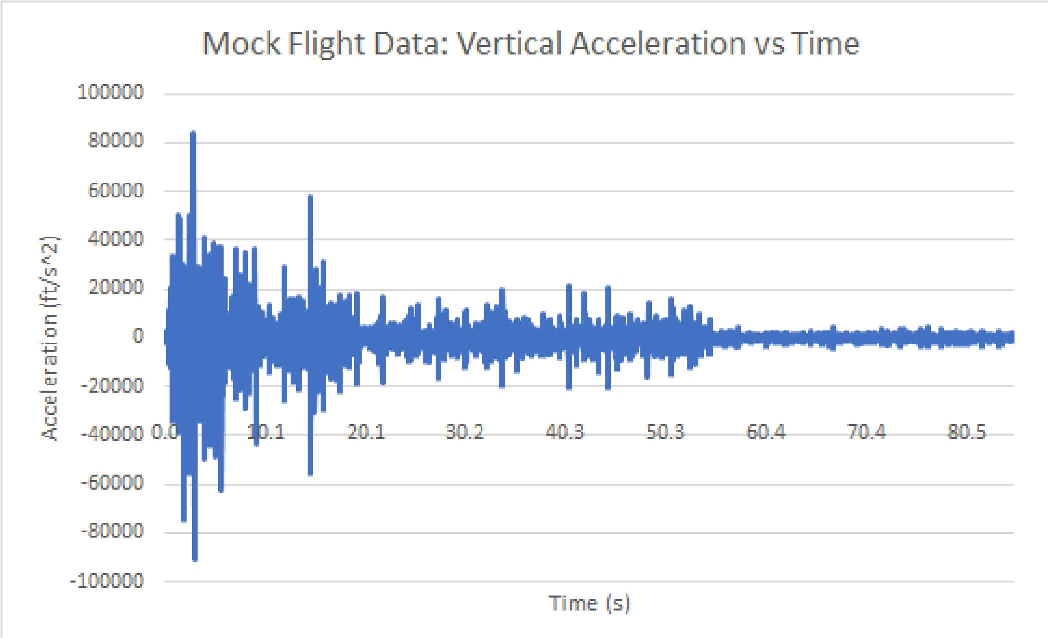

Figure 102: Vertical Acceleration vs Time of Mock Flight Data

All graphs were taken from the results of the mock-demonstration fight data and plotted using Excel. Vertical velocity was found by subtracting two data points of altitude divided by the elapsed time. This same process was conducted for vertical acceleration. Some values of velocity and acceleration were very high because the time interval between the two data points was so small.

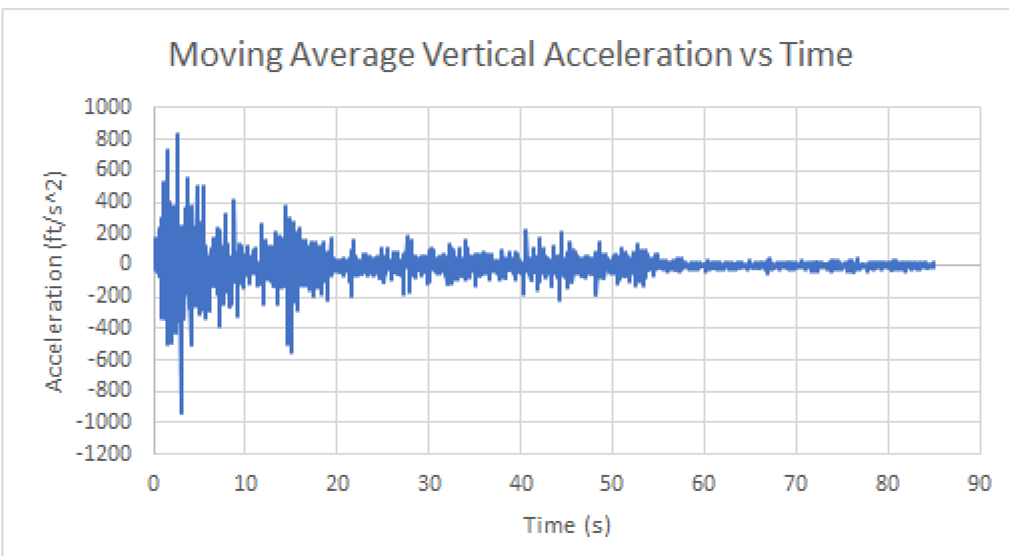

Figure 103: Moving Average of Vertical Acceleration vs Time of Mock Flight Data

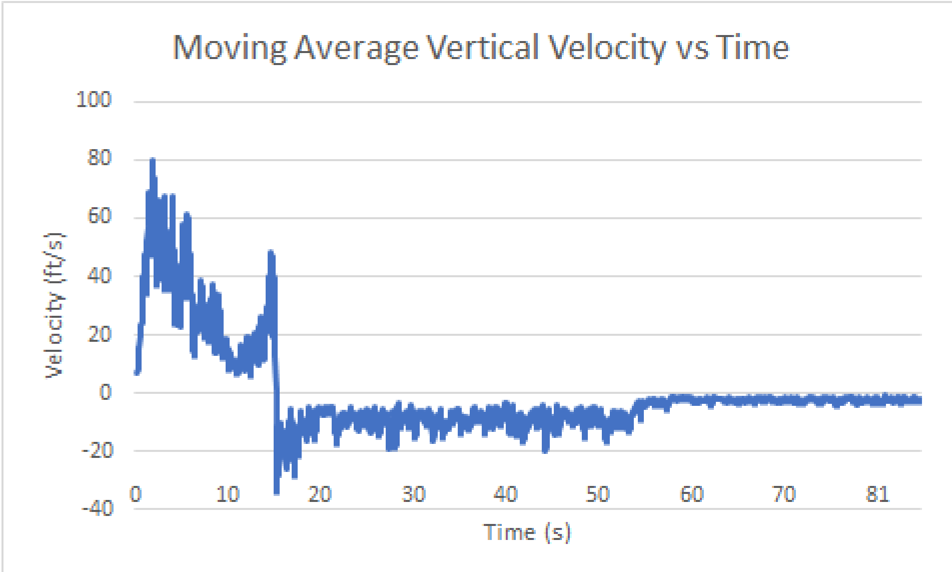

Figure 104: Moving Average of Vertical Velocity vs Time of Mock Flight Data

Due to the very large vertical velocity and acceleration values, a moving average of each was conducted to better represent the data with a larger time interval. As seen in the two figures above, the vertical velocity and acceleration values are much more reasonable due to the larger time interval. These graphs are much more consistent with data from both RockSim and OpenRocket.

5.7. Mock-Demonstration Flight Analysis

Graphs of altitude, vertical velocity, and vertical acceleration versus time were created above. Discussions of these graphs can be found in the section below in Section 5.8 Simulated Flight Model.

Table 26: Mock-Demonstration Flight data Analysis

Maximum Altitude (ft)	4525.25
Maximum Velocity (ft/s)	79.9 (from moving average)
Maximum Acceleration (ft/s^2)	8 (from moving average)
Total Flight Time (s)	85.24
Time to Apogee (s)	15.1
Descent Time (s)	70.14
Descent Rate Under Drogue Parachute (ft/s)	96.2 (average)
Descent Rate Under Main Parachute (ft/s)	22.4 (average)

Table 27: Mock-Demonstration Kinetic Energy

	Nose Cone	Upper Body Tube	Lower Body Tube
Landing Kinetic Energy	17.69 ft-lbf	74.3 ft-lbf	35.37 ft-lb

Table 27: Mock-Demonstration Drift

Wind Speed	0 mph	5 mph	10 mph	15 mph	20 mph

Horizontal Drift	0 ft.	512 ft.	1031 ft.	1543 ft.	2055 ft.

From the mock data, this analysis was conducted, and it still is relatively consistent with the mission predictions in section 3.3. Because of the very large vertical velocity and acceleration values, it was difficult to find an accurate value for the descent rates, so an average was taken to make it as accurate as possible.

5.8. Simulated Flight Model

Using RockSim, the simulated flight model was updated to match the launch day conditions provided by the NASA panel. Below are the graphs of altitude, vertical velocity, and vertical acceleration versus time.

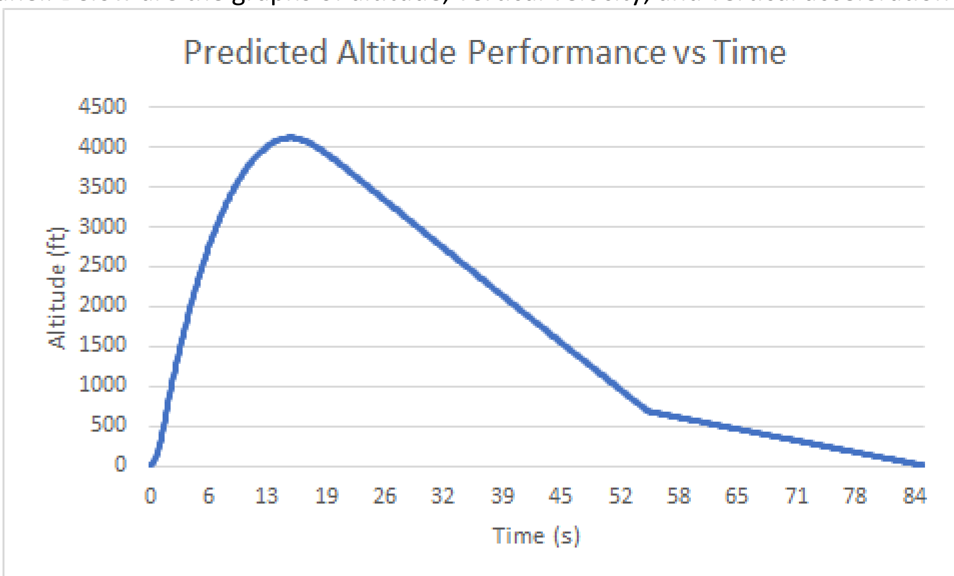

Figure 105: Predicted Altitude Performance with RockSim

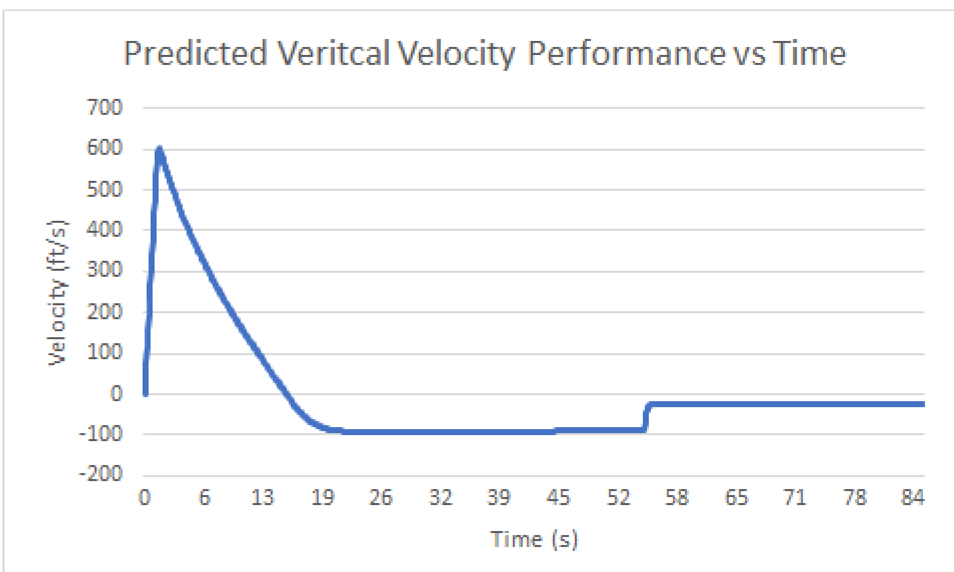

Figure 106: Predicted Vertical Velocity Performance with RockSim

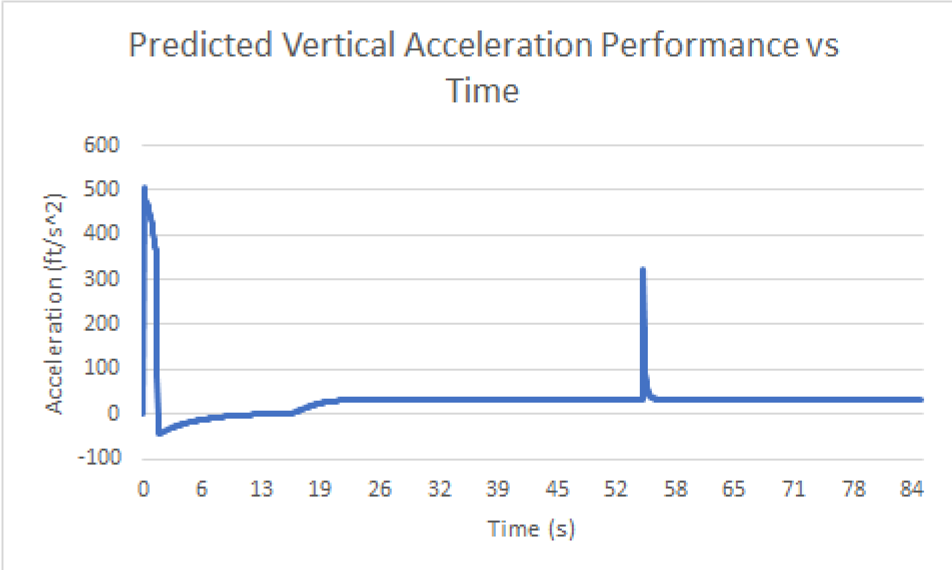

Figure 107: Predicted Vertical Velocity Performance with RockSim

The overall altitude profile for the predicted flight performance compared to the Mock-Demonstration Flight data is very similar. They both share a very similar flight time along with similar time stamps of when apogee and touchdown are reached. The biggest difference between the predicted flight performance and the Mock-Demonstration Flight data is that the apogee value is different by 400 feet. The apogee from the Mock- Demonstration Flight data is about 4525 feet while the apogee from the predicted flight performance from RockSim is about 4100 feet.

In terms of the velocity profiles, the graph from the predicted flight performance has much cleaner data points than the Mock-Demonstration Flight data. As a result, there is a lot of noise in the vertical velocity graph in the mock data. It should also be noted that the actual values of vertical velocity from the predicted performance do not really match the values from the mock data, likely due to the large time steps exported from RockSim (about 1000 data points with time stamps of 0.09 s) for the predicted flight performance while the mock data has much smaller time steps (about 3000 data points with time stamps of 0.03 s). Because of the smaller time steps, the vertical velocity values are much larger in the mock data than in the predicted flight performance values, even with a moving average of 10. However, even with these differences, both graphs follow the same trends. Both data sets have their highest velocities during ascent with a sharp decrease in vertical velocity once apogee is reached. They also both share constant velocities as free fall occurs and the rocket reaches terminal velocity. Lastly, these data sets share very small velocities once the main parachute is deployed.

For the acceleration profiles, the data from the predicted flight performance has much cleaner data as seen in the figure above than the Mock-Demonstration Flight data. There is a lot of noise that can be seen in the vertical acceleration graph of the mock data. It should be noted that the actual values of vertical acceleration from the predicted performance do not match the values from the mock data at all, likely due to the large time steps from RockSim for the predicted flight performance while the mock data has much smaller time steps. Because of the much smaller time steps, the vertical acceleration values are much larger in the mock data. To address this, the team took a moving average of 10 which can be seen above in section 5.6. The values of vertical acceleration for both data sets are somewhat similar when using the moving average values rather than the raw data itself of the mock data. Even with these large differences, the data sets still follow the same trends. Both data sets have a very high acceleration during ascent, followed by a very small acceleration and a small rise in acceleration as the main parachute is deployed.

5.9. Drag Coefficient Estimate

The drag coefficient of the full-scale rocket using the Mock-Demonstration Flight data was found by changing the drag coefficient until the apogee from RockSim was nearly the same as the apogee from the mock data. As a result, the drag coefficient was determined to be 0.24 with an apogee of 4503 feet while the apogee from the mock data was 4525 feet.

6. Safety and Procedures

6.1. Safety and Environment

Student Safety Officer

UCLA's Student Launch Safety Officer has adjusted and enhanced her responsibilities for the duration of the project's timeline. She will work in conjunction with subteam leads, group leads, and team mentors to ensure adequate understanding of safety information and quality communication throughout the project's timeline.

Close inspection of our tentative project timeline, member and vehicle construction has been done and many hazards that have been observed and/or 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.

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 28: 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 29: 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	Elimination and loss of equipment. Irreparable damage and possible	Immense effect on project lifetime and results on complete halt and/or	Irreparable and immense physical damage to the surroundings. Violates

	serious repercussions.	dissipation of location.	termination of project.	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, equipment, or facilities.	May result in temporary but notable pause in project timeline and redesign of methods.	Possibly reversible but noteworthy damage. Subject to review based 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 30: 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.

Personnel Hazard Assessment

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.

Table 31: Personnel Hazard Assessment

Risk	Cause	Effect	BM	Mitigation Strategy	PM	Verification
Cuts/ lacerations	Improper use of machines/ equipment	Injury & potential medical attention needed	1B	All team members performing potentially hazardous operations will be properly trained. Buddy system implementation for hazardous operations. Always ensure you are working diligently in the lab space and be conscientious of others around you.	1C	Consultation of shop safety guidelines. Immediate attention from team leads and Safety Officer to proceed accordingly.
Exposure to chemicals/ allergens	Improper handling of chemicals and known allergens	Chemical burns, Epidermal contamination; Cross contamination; Medical attention	3B	Latex gloves will be worn when handling chemicals & known allergens. Proper lab etiquette will be enforced.	3C	PPE enforcement of latex, chemically resistant gloves
Black powder explosion	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 in a ventilated, spacious area 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 with proper PPE and certified to handle. Only small amounts are to be handled.

Inhalation of chemical fumes	Improper use/lack of PPE; mishandling of chemicals	Difficulty breathing; potential organ damage	3A	P100 rated respirator masks and filters and goggles will always be worn when working with volatile chemicals & will be handled in well-ventilated rooms, under a fume-hood when possible.	3C	Required consultation of MSDS prior to use; Respirators and relevant PPE when working with chemical fumes.
Chemical contact with eyes	Improper handling of chemicals	Temporary to Moderately sustained blindness; burning sensation	1B	Proper eye protection will be worn at all times when handling chemicals. Always ensure chemicals are kept away from face and ensure proper lab etiquette is always enforced.	3B	Required consultation of MSDS; Eye protection PPE is to be used.
Spilled or contact with epoxy resin and/or hardener	Epoxying without informing team members; mistakenly tipping bottles	Epidermal injury, medical attention depending on severity and body contact	3B	Team members will be trained on how to use epoxy and supervised until they are capable. All team members should be informed when working in areas where epoxy is being adhered and worked.	3C	Required consultation of MSDS; An experienced team member will either be performing the epoxy work or supervising it.
Open paint fume inhalation	Improper use of chemicals; lack of PPE	Discomfort; damage to lungs; nausea	1C	P100 rated respirator masks and filters and goggles will be worn at all times when working with paint in conjunction with proper PPE requirements in well-ventilated areas.	3C	Every respirator checked for filter cleanliness. Shop safety guidelines are adhered to regarding appropriate fuming location.
Electric shock	Equipment malfunction; electrical	Electrical component failure; black	2A	All wires should be checked for damaged cording	3B	Medical attention should be

	power build-up; damaged wires	powder explosion; epidermal injury; limb loss		before plugging. Refrain from water usage around electronics. Handlers of sensitive equipment will ground themselves to discharge static buildup.		sought. Depending on the location of shock, equipment may cause fire. Fire extinguisher and lab safety kits on hand.
Prolonged exposure to loud machinery without ear protection	Operation of or enveloping of large machinery	Disorientation; hearing loss; light-headedness	1B	Hearing protection will be worn when handling large machinery or being around equipment that emits consistent, loud sound.	3C	PPE enforcement of earmuffs and/or ear plugs ONLY when working around or with loud machinery.
Injury from falling tools/equipment or materials	Incorrect storage or placement; Stock not secured or fastened	Varied injury: depending on height, may require medical attention	2B	All members will wear closed-toed shoes and long pants before being allowed to enter the lab space. All storage will be fastened and secured before leaving the lab space.	3B	Required shop safety guidelines, proper storage, and clean-up. PPE requires clothing covering the full body.
Falls/ stumbling	Loose cords; wires running across floor; horseplay through lab area	Moderate to severe, varying injury	2B	All lab equipment will be placed in its designated storage area when not in use and be used solely where assigned spaces are available. No crowding. Cords are kept at minimal distance from wall plugs and tucked away from walking pathways.	3C	Consultation of shop safety guidelines & proper lab etiquette enforced.
Inhalation of Lead Fumes	Using lead-based solder	Lead known to cause physical and mental health	2A	If lead based solder is used, it will be done in an environment with a	3C	PPE enforcement of P100 respirators.

		problems when ingested or inhaled; difficulty breathing		fan to diffuse the fumes away from the user, under fume hoods, while user wears a respirator mask.		
Shop Fire	Chemical cross contaminati on	Moderate to Fatal injuries or death; irreparable damage to equipment and lab space	2A	Always label and store chemicals separately. Always be aware of one's surroundings and be diligent when working in a lab environment; fire extinguishers kept in shop.	2B	All lab coats are fire resistant. Fire protocol and exit route is included in all lab safety certified courses.
Shop Fire	Incorrect / improper wiring	Potential for serious injury or death; irreparable damage to equipment and lab space	2B	High power circuitry completed with safety officer present; 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.
Shop Fire	Equipment overheating; explosion	Potential for serious injury or death; irreparable damage to equipment and lab space	2A	Avoid overheating with proper ventilation and usage of equipment; fire extinguishers kept in shop.	2B	All lab coats are fire resistant. Fire protocol and exit route is included in all lab safety certified courses.
Caught in a machining equipment	Loose clothing; overhanging jewelry; hair draped over face	Potential for serious injury or death	2B	Those performing machining operations will never wear loose fitting clothing or jewelry. All long hair must be tied back.	3B	Reiteration and consultation of shop safety guidelines. Appropriate clothing worn during workdays.
Physical contact with heat sources	Soldering iron; Contact with Machining tools	Varied degree burns	3B	Lab coats are always on hand and are required when working with all heat- producing tools.	3C	PPE requirement of lab coats; all heat producing tools be turned off when not in use.

Safety Officer Unavailable	No identifiable person ensuring adequate safety procedures are followed	Possible increased likelihood or other risks	2B	All students participating will be briefed on safety operations prior.	3C	Safety officer will designate a competent club member as acting Safety Officer in their absence

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.

Written Safety Statements

In addition, further steps would be taken to strictly comply with all NAR Safety Codes, federal and state laws, and UCLA Machine Shop Safety regulations, as will be seen in extension to the hazard analysis.

Federal Aviation Regulations 14 CFR

In accordance with Federal Aviation Regulations 14 CFR, Subchapter F, Part 101, Subpart C: the team will ensure that the rocket is launched and adhered to the general operating limitations. The team will operate the rocket in a manner that is launched, unmanned, on a suborbital trajectory in US territory and does not create a hazard to any persons or property. All team members shall be made aware of this regulation and must agree to comply.

Code of Federal Regulation 27 Part 55

In relation to the handling and use of low explosives (Ammonium Perchlorate Rocket Motors, APCP), Code of Federal Regulation 27 Part 55: Commerce in Explosives, the rocket only uses the motor provided by the competition at the launch site so storing and handling low explosives will not be necessary. All team members shall be made aware of this regulation and must agree to comply.

NFPA 1127

In accordance with fire prevention, set by the NFPA 1127 Code for High Powered Motors, the team will bring both a first aid kit to the launch site and a fire suppression device. Members will follow all guidelines as set by the code. In the event of a misfire, no one from the team will approach the rocket until the safety interlock has been engaged, 60 seconds have elapsed, and the safety officer has given permission for one person to approach and inspect. Team members are to wear proper PPE and have read corresponding MSDS. All team members shall be made aware of this regulation and must agree to comply.

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 32: Environmental Hazard Assessment

Environmental Hazard Risk Assessment: On Environment						
Risk	**Cause**	**Effect**	**BM**	**Mitigation Strategy**	**PM**	**Verification**
Chemical contamination of groundwater	Leakage of battery fluid or excess fuel post landing in natural body of water.	Electrical components leak toxic chemicals into & contaminate the water & wildlife.	3A	Electrical components provided extra separation from environment within body tube; rocket recovered quickly to minimize exposure time; launch site chosen away from bodies of water.	3C	Consultation of launch operations procedure before and after launch. Launch is no-go if body of water within 2500 feet of launch pad.
Injury to wildlife	Animal contact with launch pad/vehicle mount; vehicle impact during flight or landing	Animal injury/death	3A	Mitigation is attempted by establishing launch away from any area near known wildlife grounds.	3B	Ensure complete inspection to launch operations procedure & constant visual of launch pad throughout launch.
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.
Vehicle strikes people or structures outside	Excessive wind; improper timing of main	Vehicle drifts outside planned launch area	3A	Large launch field chosen in case of early parachute deployment	3C	Simulation testing to predict drift under non-

planned launch area	parachute deployment					ideal conditions; launch operations procedures followed in choosing launch field
Launch pad fire	The launch vehicle harms the environment around it with the flame of the motor ignition	Heat source damage of surrounding land beneath the launch area and detrimental outcomes to plant and animal life	3A	Ensure launch area is clear of underbrush or plant vegetation; launch aborted in extremely dry conditions.	3C	Fire extinguisher is on hand & taken to launch site. Consultation of launch operations procedure during launch.
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.
Shorting wires and explosions; apogee not reached	Rainfall	Hindrance from arrival at apogee and defer the vehicle course. Soggy land may prove impossible for payload to deploy. Possible shorting of wires and electric shock	3A	Depending on individual circumstances, we may decide that it is best for our vehicle not to fly to safely ensure the wellbeing of the launch day attendees.	3C	Team members and leads would consult the RSO and establish ways to proceed
Excess weather-rocking	Large wind speeds	Increase drift & unexpected vehicle	2A	Ensure launch vehicle has an	2C	Enhanced analysis of vehicle design

		trajectory; vertical stability complication		ample margin of stability.		choice of fins and mass distribution.
Unsafe landing zone; elevated drift	High wind speeds	Increase drift from the launch pad, resulting in unrecoverable vehicle or land in an area posing additional safety concerns.	3B	If the wind is 20 mph, it is possible that the launch will be cancelled. Do not launch in wind speeds larger than 20mph.	3C	Monitor wind levels and await approval from the RSO.
Excessive launch rail friction	Misalignment of rail buttons; high temperatures or exposure to sunlight, low humidity	Unexpected vehicle trajectory	3B	Ensure rail buttons are aligned properly; coat rail in Vaseline	3C	Vehicle design ensures alignment of rail buttons
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
Damage to rocket body	Nearby obstacles/debris in field	Increased vehicle damage due to dragging across field from large horizontal velocity	3A	Launch occurs in field clear of destructive obstacles	3C	Certify robustness of external components; design analysis of external vehicle profile
Parachute destruction	Excessive wind	Increased vehicle damage due to large horizontal velocity; high drift from pad exceeding size of launch field	3A	If the wind is above 20 mph, it is possible that the launch will be cancelled. Do not launch in wind speeds larger than 20mph.	3C	Monitor wind levels and await approval from the RSO.

Table 33: Vehicle Launch and Risk Assessment

Vehicle Launch Failure Modes and Risk Assessment						
Risk	**Cause**	**Effect**	**BM**	**Mitigation Strategy**	**PM**	**Verification**
Launch pad/ rail failure	Issues concerning the stability of launch pad/ rail	Leads to unpredictable rocket trajectory	3A	Inspect launch pad and rail prior to ensure minimum level of stability.	3C	Ensure that all personnel are at a minimum distance from the launch site as established by NAR.
Malfunction in electronics	System failure	May result in failure to deploy/ collect data/ operate as intended	2B	Vigorous testing of separate functions within each part. Electronics Operation Checklist thoroughly completed.	3B	Electronics Operation Checklist thoroughly completed.
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

Damage from transportation/ handling	Improper protection during transportation/ handling	Unusable components; incapable of safe launch; potential damage to/loss of rocket	1B	Proper storage overseen by safety advisor and student safety officer, especially for motor handling	2B	Adhere to safety protocol
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 indicated altitude of deployment	Structural failure. Failure in electronics, premature activation of black powder	Rocket does not reach apogee and may follow ballistic path	2B	Increased redundancy incorporated into the system. Increased amount of shear pins or creating a more robust coupler.	3C	Consultation of Operation and Pre-Launch Checklist.
Motor retention failure	A drogue chute applies a force great enough to push out 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. 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 .
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.
GPS tracking malfunction	General malfunction; battery depletion; erroneous code	Unable to locate the launch vehicle in extreme cases	3B	Ensure all batteries fully charged and checked using the voltmeter. GPS rigorously tested prior to launch.	3C	Consult Operations and Pre-Launch Checklist.
Low battery of avionics electronics power supplies	Old, untested batteries used in avionics bay assembly	Failure to power flight altimeters throughout flight; failure to fire drogue and/or main ejection charges	3A	Ensure all batteries fully charged and checked using the voltmeter prior to assembly	3C	Pre-launch checklist assures battery testing and replacement if necessary
Rocket comes loose from launch pad	Rail buttons not securely mounted to rocket; extreme wind; team error in aligning rocket	Rocket breaks free during initial phase of launch; potential damage to rocket,	2A	Rail buttons used on rocket for secure attachment; careful precision of alignment while guiding rocket on launch rail	3A	Design analysis to align rail buttons

	while attaching to pad	payload, bystanders, and property				
Altimeter failure	Circuitry failure due to improper wiring; loss of or insufficient power to operate altimeters and fire ejection charges	Failure to ignite drogue and/or main ejection charges; deploy parachutes at undesired altitudes or lack of deployment altogether; damage to/loss of rocket	2A	Individual power supply module for each redundant altimeter; fully ground-based altimeter testing before each flight	3A	Pre-launch checklist assures proper circuitry

6.2. Launch Operations Procedures

Launch operation procedures span from the day before launch to post-flight inspection. A series of tables have been created to show the tasks necessary for successfully and safety completing the launch as well as the potential risks associated with each step. A sample table has been provided below for ease of reading further tables.

Table 34: Sample Procedures Checklist

Initial	Completed Substeps	Task
		Task to be completed along with success criteria
		PPE REQUIRED: List of required equipment
		Steps 1 to troubleshoot problem if success criteria are not met
		Step 2
		Step 3
		Success criteria for troubleshooting to be deemed successful.
	Warning: Possible repercussions if task is skipped.	

If task is already completed then the first blue box under the “Completed Substeps” should be checked off, otherwise each yellow box following it must be checked. The initial box must be completed by required personnel listed at the beginning of each section as a final check that each step has been completed. More complex components of the vehicle will have preparation steps the day before launch as well as launch day which will be displayed.

5.1.1.1. Packing Checklist

Purpose: To be followed while packing transportation vehicles the night before or morning of launch day to ensure all materials are transported to launch site.

Structural Components

- Nose cone
    - Should contain nosecone bulkhead and eyebolt.
- Upper body tube
    - Should contain ejection assembly, static portion of locking mechanism (to be talked about in payload component section)
- Removable portion of locking mechanism
    - E-bay (discussed in electronic components)
    - Eyebolt
- Lower body tube
    - Should contain centering rings (one with eyebolt), coupler, phenolic tube, fins, aluminum plate, static portion of motor retainer.
- Removable portion of motor retainer
- 4 quicklinks
- 1 main parachute
- 1 drogue parachute
- 3 shock cords
- 3 fire cloths
- 20 shear pins
- Motor
    - Motor casing

Structural Equipment

- Toolbox
- Corded Dremel
- Battery-Powered Dremel (fully charged)
- Corded Drill
- Drill Bit Set
- Painters Tape
- Gorilla Tape
- Rip-Stop Parachute Tape
- 2-Tube Epoxy
- Scissors
- Tape Measure
- Caliber
- Large Scale
- Small Scale
- Powdered Graphite
- Sandpaper

Electrical Components

- Electronics Bay

  - Avionics sled with 4-40 heat set inserts.
  - 8X 4-40 screws
  - Two altimeters (RRC3 and SL100)
  - 2X 9V Batteries (ensure full voltage with voltmeter)

Electrical Equipment

- Wire Strippers
- Wire cutters
- Extra Wiring
  - 18AWG wire box
  - Jumper cable assortment
- Voltmeter
- Laptop with the following software
  - OBS Studio
  - mDACS
  - PerfectFlite DataCap
  - MATLAB
- Portable soldering iron
- Normal soldering iron
- Solder
- Heat shrink tubing.
- Electrical tape

Payload Components

- Payload
  - Main Body with 11 M2.5 threaded heat set inserts.
  - 11X M2.5 Phillips flat head screws
  - Main Cover
  - 4X Acrylic Sheets
  - Top Cap
  - Legs
  - Parachute
  - Shock Cord
- Retention System
  - 2X Wood bulkhead with aluminum reinforcement and galvanized eyebolt
  - 8X 3/8" Locknuts
  - Semicircle Enclosure
  - 2X Eyebolt Cover
  - 2X Quicklinks
- Payload Electronics
  - 3S 1200mAh LiPo battery
  - 2.4 GHz Video receiver
  - RCHP Antennas
  - SMA to MMCX adapters
  - SMA female to SMA-RF female adapters
  - USB SMI Grabber
  - AV to component cables
  - Power Distribution Board
  - Raspberry Pi Zero W/ Headers

- ArduCam for Pi
- Jumper Cables
- MPU 6050 Gyroscope+ accelerometer
- SD Card

Payload Equipment

- Screwdriver set.
- Angled pliers
- Quick-dry epoxy
- Tape
- Battery charger unit

6.2.1. Recovery Preparation

Table 35: Recovery Pre-launch Preparation

Initial	Completed Substeps	Task
		Parachutes, firecloths, and quicklinks should already be secured to shock cord. If not, refer to recovery section for assembly instructions. The following in yellow will be listed as a checklist for recovery preparedness. If any steps are not completed, complete them now.
		Main shock cord should have quick links tied onto each end with a knot and half- hitch, each knot taped over with gorilla tape for reinforcement.
		Main shock cord should have quicklink tied 2/3rds of the way down for the main parachute.
		Main shock cord should have firecloths threaded onto the cord between the two closer quicklinks.
		Drogue shock cord should have quick links tied onto each end with knot and half-hitch, each knot taped over with gorilla tape for reinforcement.
		Drogue shock cord should have quicklink tied 2/3rds of the way down for drogue chute.
		Drogue shock cord should have firecloths threaded onto the cord between the two closer quicklinks.
		Main shock cord should have quicklink closer to middle quicklink fastened to eyebolt within the nosecone.
		Main quicklink on the opposite side of the shock cord should be fastened to quicklink extending from the REA.
		Drogue shock cord should have quicklink closer to middle quicklink fastened to locking mechanism eyebolt.
		Drogue quicklink on the opposite side of the shock cord should be fastened to quicklink extending from lower body tube centering ring.
	Warning: Failure to complete could result in failure of recovery hardware.	
		Parachute shroud lines should be detangled.
		Lay parachute flat on ground with shroud lines on top of it.
		Detangle all shroud lines.

Table 35: Recovery Pre-launch Preparation

Initial	Completed Substeps	Task
		If needed, repeat for other parachute. Step is completed when both parachutes have detangled shroud lines.
	Warning: Failure to complete could result in altered coefficient of friction or delayed deployment of parachutes.	
		Main parachute should be attached to quicklink in the middle of the main shock cord and drogue parachute should be attached to quicklink in the middle of the drogue shock cord.
		Locate the quicklink that the parachute in question must be connected to.
		Thread centers of all shroud lines of that parachute through open quicklink.
		Close quicklink.
		Repeat for other parachute if necessary. Step is completed when both parachutes are properly threaded.
	Warning: Failure to complete could result in detachment of parachutes from vehicle.	
		Both parachutes should be properly folded.
		Detangle parachute shroud lines.
		Repeatedly fold parachute in half to create triangle.
		Fold shroud lines into center of triangle.
		Fold triangle over itself to create a 6-inch cylinder
		Repeat for other parachute if necessary. Step is completed which both parachutes are properly folded.
	Warning: Failure to complete could result in altered coefficient of drag of parachutes.	
		Shock cords should be taped to ensure lowered shock upon deployment.
		The following must be done to each segment between quicklinks.
		Start at one side of the segment.
		Fan-fold 9inch folds of the shock cord, starting with 3 folds.
		Tape two loops of masking tape around the center of the fan-fold.
		Repeat with an incrementing number of folds for the remainder of the segment.
		Repeat with each segment of the recovery system (4 segments total).
		Mark as done when all sections are properly taped.
	Warning: Failure to complete could cause violent shock, causing load-bearing interface failure.	
		Black powder should be loaded into canisters.
		PPE Required: Safety goggles.
		Personnel Required: Team Mentor

Table 35: Recovery Pre-launch Preparation

Initial	Completed Substeps	Task
		Team mentor will measure out needed black powder amounts and load into canisters.
		Team mentor will place ignitor into canister and gorilla tape over the canister to seal it.
		Team mentor will repeat this for each canister (4 total).
	Warning: Failure to complete will result in deployment failure.	
		Ignitors must be connected to altimeter wiring.
		PPE Required: Safety Goggles
		Main canisters and wiring will be marked with black tape. If not marked, alert electronics lead or project manager to conduct wiring matching.
		Match wiring for main and backup charges to corresponding canisters.
		Rub wiring together to ensure no charge going through wiring.
		Connect one wire to each side of the igniter or corresponding main or backup charges.
		Repeat for all wiring for nosecone and lower body tube charges.
		Mark as completed when all ignitors are connected to corresponding altimeter wiring.
	Warning: failure to complete will result in deployment failure.	
		Payload must be completed packed.
		Pause in build process until payload team has finished packing process.
		Mark as completed once payloads lead and project manager has approved.
	Warning: failure to complete will result in deployment failure.	
		Packed parachute facing the ejection charge must be wrapped in fire cloth.
		PPE Required: Safety Goggles
		Portion of the main parachute facing the tip of the nosecone should be wrapped in firecloth to completely cover the exposed cross section.
		Portion of the drogue parachute facing the locking mechanism should be wrapped in firecloth to completely cover the exposed cross section.
		Mark as completed once both parachutes are properly wrapped.
	Warning: Failure to complete will result in parachute destruction.	
		Main parachute should be packed, and nosecone shoulder placed into the upper body tube.
		PPE Required: Safety Goggles
		Put parachute into the nosecone with the fire-cloth covered portion going in first.
		Fold remaining shock cords loosely and place into the nosecone shoulder and upper body tube atop the REA.

Table 35: Recovery Pre-launch Preparation

Initial	Completed Substeps	Task
		Put nosecone shoulder within upper body tube next to the REA ensuring full insertion by checking that none of the shoulder is visible. If a portion of it is still visible, alert structures lead or project manager.
		Mark as completed when nosecone is completely inserted and containing the main parachute.
	Warning: failure to complete will result in deployment failure.	
		Drogue parachute should be packed, and lower body tube and upper body tube connected.
		PPE Required: Safety Goggles
		Put parachute into the upper body tube with the fire-cloth covered portion going first towards the locking mechanism.
		Fold remaining shock cords loosely and place into the upper body tube after the parachute.
		Place upper body tube onto the coupler, connecting it to the lower body tube. Ensure full insertion by checking that none of the coupler is visible. If portion of it is still visible, alert structures lead or project manager
		Mark as completed when upper body tube is completely inserted to lower body tube and containing drogue parachute.
	Warning: failure to complete will result in deployment failure.	
		Insert all shear pins (3 in coupler interface and 3 in nosecone interface).
		PPE Required: Safety Goggles
		Alignment point should be marked at all parent component interfaces. This was checked in the Pre-Packing section.
		Align the alignment points and locate shear pin holes (both marked in silver sharpie).
		Screw one shear pin into each hole.
		Mark as completed when all shear pins are screwed in.
	Warning: failure to complete will result in deployment failure.	
Recovery System is Ready for Launch. Proceed to Launch Pad Procedure.		

6.2.2. Payload Preparation

Table 36: Payloads Pre-launch Preparation

Initial	Completed Substeps	Task
		Interface between legs and servo motor should be tight and not loose
		PPE Required: Gloves

Table 36: Payloads Pre-launch Preparation

Initial	Completed Substeps	Task
		Extend payload leg out and move up and down to feel any resistance from the servo motor
		If no resistance is detected, a loose connection has been identified
		Use a screwdriver to screw any loose screws until tight
		Add a dab of crazy glue or quick-set glue to prevent screw from moving
	Warning: Failure to complete can result in payload unable to orient itself	
		Ensure all threaded het set inserts are sufficiently imbedded in the main body component of the payload
		Screw all screws into each threaded heat insert
		Pull on the partially screwed screw and observe for any loose or unexpected behavior from the threaded heat set inserts
		If a heat insert is loose, remove heat set insert and place new one using a soldering iron. If main body component is broken or damaged such that the heat set insert is not able to be pressed, reprint another body piece.
	Warning: Failure to complete could result in damage to the payload and pose a safety hazard during the parachute deployment phase of the payload	
		Verify acrylic sheets in central column of payload are fully secured to main cover and top cap
		PPE Required: Gloves
		Verify epoxy has been placed within the indentations of each 3D printed part where the acrylic sheets will be placed. If no epoxy has been placed, use quick-set epoxy, and cover relevant surfaces with epoxy. Wait an hour and a half for the epoxy to cure
		Give the top cap a hard tug and verify all components are still fully epoxied together. Ensure no deformities have occurred.
		If epoxied surfaces have slipped, insufficient time was allotted for the epoxy to dry. Remove epoxy, line with epoxy, and wait again.
	Warning: Failure to complete will result in damage to the payload and pose a safety hazard during the parachute deployment phase of the payload	
		Verify shock cord and parachute are packed and tethered to the top cap of the payload structure
		If not, attach the shock cord to the payload using a square knot
		Attach the shock cord to the shroud lines using another knot
		Pack the parachute into a tight configuration
		Place payload and parachute system within retention system and ensure the payload can easily exit the retention system via gravity

Table 36: Payloads Pre-launch Preparation

Initial	Completed Substeps	Task
		If not, remove parachute and pack into a tighter configuration and repeat the steps
	Warning: Failure to complete will result in a payload that will freefall with no parachute or not jettison out of the retention assembly	
		Verify Continuity of all electronics on the payload
		If not use multimeter to find open circuits
		Replace component and use multimeter to check nominal readings
	Warning: Failure to complete will result in nonfunctional payload.	

6.2.3. Electronics Preparation

Required Personnel: Project Manager and Electronics Lead
To Be Completed: Upon launch site arrival

Table 37: Electronics Pre-launch Preparation

Initial	Completed Substeps	Task
		Four wires should be coming out of the bulkhead, and four out of the locking mechanism, all securely connected to the altimeter for the purposes of setting off ejection charges.
		If any wires are missing, alert electronics lead and locate missing wire.
		Inspect altimeters to find which wire is missing. An empty pin on the altimeter denotes which wire is missing
		Cut new piece of wire and slide the wire through the designated wiring hole and connect to the altimeter
		All drogue chute wires should go through the locking mechanism and all main chute wires should go through the payload bulkhead
		Mark as completed when there are a total of 8 wires protruding from the electronics bay but still within the upper body tube. 4 wires should be protruding from each side.
	Warning: Failure to complete can result in recovery deployment failure.	
		Interface between ejection charge wiring and bulkheads surrounding electronics bay should be airtight by means of an epoxy seal.
		PPE Required: Gloves
		Put quick-setting epoxy onto the interface to completely cover it.
		Allow a 1- hour cure time, 1.5 hours if the temperature is below 60-degree Fahrenheit.
		Repeat for another interface if it is not deemed airtight.

Table 37: Electronics Pre-launch Preparation

Initial	Completed Substeps	Task
		Mark as completed once all interfaces have been deemed completely sealed.
	Warning: Failure to complete could result in damage of altimeters from ejection charges, causing main parachute deployment failure and hardware destruction.	
		Main ejection charge wiring should be marked differently than the backup charge wiring by means of black tape.
		Open mDACS software (for RRC3, which is the main altimeter) and connect the altimeters to the laptop being used.
		Twist ends of two LEDs together, ensuring the positive terminal of one is twisted with the negative terminal of another
		Connect each end of the LED circuit to two random wires and set off an "ejection charge" for the wiring that is being tested (either main or drogue chute) in the software.
		If one LED lights up with the charge, the two wires connected to the LEDs will be marked with black tape as the main charge wiring. If there is no light, try a different combination of wires and continue until two wires allows for an LED to light up.
		No further testing is required since the other set of wires is for the backup altimeter.
	Warning: Failure to complete will result for failure of ejection charges ignition.	
		All black powder charges should be connected to specified wiring.
		MUST HAVE TEAM MENTOR PRESENT
		Specify amounts of black powder required for main and backup deployment of both main and drogue chute deployment. For this reference, the flysheet.
		Follow mentor instruction to install black powder or have mentor install charges. Do not attempt to install without mentor
	Warning: Failure to complete will result in failure of recovery hardware deployment.	
		GPS module and GPS battery are securely placed within the nosecone.
		Use gorilla tape to attach transmitter module of GPS to the inner wall of the nosecone. Make sure GPS module is as close as possible to the tip of the nosecone.
		Connect LiPo battery to transmitter module on the rocket and test connectivity with receiver using the included application.
		Move entire as-built rocket with GPS to check connectivity and see if locating ability is working as intended.
		Remove one wire connection from the GPS transmitter and place LiPo battery within 3D printed enclosure to protect the battery from ejection charges.

Table 37: Electronics Pre-launch Preparation

Initial	Completed Substeps	Task
		Use Gorilla tape to attach battery and battery holder to the inner wall of the nosecone.
	Warning: Failure to complete could result in falling debris during launch, combustion of LiPo battery, and the inability to locate the rocket after launch.	

6.2.4. Rocket Preparation

Required Personnel: Project Manager and Structures Lead
To Be Completed: Day before launch & upon launch site arrival

Table 38: Rocket Pre-Launch Preparation

Initial	Completed Substeps	Task
		Visual Inspection of the external face of the nosecone for small cracks, dents, or chips. Check as completed if no such imperfection is detected. Else, complete the following.
		PPE REQUIRED: Gloves
		Apply two-tube epoxy to the imperfection and smooth to be flush with the rest of the nosecone. (This epoxy used for fast cure time.)
		Wait 1 hour for full cure at room temperature. (Wait 1.5 hours if the temperature is below 60 degrees F.)
		After allowed cure time, ensure epoxy is dry to touch.
		Sand seal until the epoxy is flush with the rest of the component.
		Reinspect component for imperfections. If no further imperfections, requirement is fully completed.
	Warning: Failure to complete could result in failure of nosecone.	
		Visual Inspection of the external faces of the upper body tube, coupler, fins, and lower body tube for visible cracks or chips. If no imperfections detected, mark as completed.
		Wait 1 hour for full cure at room temperature. (Wait 1.5 hours if the temperature is below 60 degrees F.)
		Wait 1 hour for full cure at room temperature. (Wait 1.5 hours if the temperature is below 60 degrees F.)
		After allowed cure time, ensure epoxy is dry to touch.
		Sand seal until the epoxy is flush with the rest of the component.
		Reinspect component for imperfections. If no further imperfections, requirement is fully completed.
	Warning: Failure to complete could result in failure of body.	

Table 38: Rocket Pre-Launch Preparation

Initial	Completed Substeps	Task
		Visual Inspection of fin-lower body tube contact point for gap in epoxy application. If no gaps at any point in interface on any fin, mark as completed.
		PPE REQUIRED: Gloves
		Apply two-tube epoxy to the gap and smooth to be flush with the rest of the epoxy interface. (This epoxy used for fast cure time.)
		Wait 1 hour for full cure at room temperature. (Wait 1.5 hours if the temperature is below 60 degrees F.)
		After allowed cure time, ensure epoxy is dry to touch.
		Sand seal until the recently applied epoxy is flush with previously applied epoxy.
		Reinspect interface for imperfections. If no further imperfections, requirement is fully completed.
	Warning: Failure to complete could result in fin detachment from the launch vehicle during flight or on landing.	
		Visual Inspection of the internal interface between nosecone and nosecone bulkhead, internal interface between nosecone bulkhead and eyebolt attached to it, external interface between coupler and lower body tube, internal interface between centering ring closest to the shoulder and the lower body tube, and internal interface between that centering ring and the eyebolt attached to it for gap in epoxy application. If no gaps at any point in either interface, mark as completed.
		PPE REQUIRED: Gloves
		Apply two-tube epoxy to the gap and smooth to be flush with the rest of the nosecone. (This epoxy used for fast cure time.)
		Wait 1 hour for full cure at room temperature. (Wait 1.5 hours if the temperature is below 60 degrees F.)
		After allowed cure time, ensure epoxy is dry to touch.
		Sand seal until the recently applied epoxy is flush with previously applied epoxy.
		Reinspect interfaces for imperfections. If no further imperfections, requirement is fully completed.
	Warning: Failure to complete could result in recovery hardware failure.	
		Physical Inspection to ensure friction fitting between nosecone and upper body tube when all recovery hardware and payload components are packed inside. Friction fitting defined as components will not immediately separate due to the force of gravity but will separate with some small applied impulse force. To test: pack all recovery and payload components within upper body tube and nosecone, connect components using shoulder, turn assembly so the nosecone is closest to the ground (NOSE CONE MUST NOT FALL OUT) then apply small downward impulse to the assembly (NOSE CONE SHOULD FALL OUT, RELEASING RECOVERY HARDWARE). If both actions in capital above occur, requirement is fully completed.

Table 38: Rocket Pre-Launch Preparation

Initial	Completed Substeps	Task
		If friction fitting is not met, classify it as one of the bolded cases below and follow the subsequent steps.
		If Nosecone doesn't fit in body tube:
		PPE Required: Respirator and Safety Goggles
		Sand outer face of nosecone shoulder until friction fitting defined above is met.
		Return back to definition of friction fitting above, preform the test, and classify the passing or failing of the requirement.
		If Nosecone falls out of body tube with force of gravity alone.
		Apply painters' tape to shoulder of the nosecone in a fashion where there is an even layer covering the entire shoulder. Continue adding even layers until friction fitting defined above is met.
		Return back to definition of friction fitting above, preform the test, and classify the passing or failing of the requirement.
	Warning: Failure to complete could result in pre-deployment or failure to deploy recovery hardware.	
		Physical Inspection to ensure friction fitting between upper and lower body tube when all recovery hardware and payload components are packed inside. Friction fitting defined as components will not immediately separate due to the force of gravity but will separate with some small applied impulse force. To test: pack all recovery and payload components within upper and lower body tube, connect components using coupler, turn assembly so the upper body tube is closest to the ground (UPPER BODY TUBE MUST NOT FALL OUT) then apply small downward impulse to the assembly (UPPER BODY TUBE SHOULD FALL OUT, RELEASING RECOVERY HARDWARE). If both actions in capital above occur, requirement is fully completed. If friction fitting is not met, classify it as one of the bolded cases below and follow the subsequent steps.
		If upper body tube doesn't fit in body tube:
		PPE Required: Respirator and Safety Goggles
		Sand outer face of coupler until friction fitting defined above is met.
		Return back to definition of friction fitting above, preform the test, and classify the passing or failing of the requirement.
		If Nosecone falls out of body tube with force of gravity alone.
		Apply painters' tape to the coupler in a fashion where there is an even layer covering the entire coupler. Continue adding even layers until friction fitting defined above is met.
		Return back to definition of friction fitting above, preform the test, and classify the passing or failing of the requirement.

Table 38: Rocket Pre-Launch Preparation

Initial	Completed Substeps	Task
	Warning: Failure to complete could result in pre-deployment or failure to deploy recovery hardware.	
		Visual Inspection to ensure main parachute and drogue parachute have no holes or rips within the fabric (including next to the shroud line interfaces). If no imperfections are detected, requirement is fully completed
		Lay the damaged parachute on the ground fully unfolded so it forms an unwrinkled circle on the ground.
		Apply Rip-Stop Parachute tape to both sides of any rips or holes in parachutes in a way where no wrinkles in the parachute are caused when lying flat.
		Reinspect both parachutes for rips and holes. If no others are found, requirement is met.
	Warning: Failure to complete will result in a change in the expected coefficient of drag, causing faster descent time and larger Kinetic Energy at landing or failure of parachute at full deployment.	
		Visual Inspection of all shock cords and shroud lines used in recovery subsystem for tears. If no visible tears, requirement is fully completed.
		Discontinue use, use replacement of this component. Inspect new component and other component, if no further tears are found on any components, requirement is passed.
	Warning: Failure to complete will result in a change in the expected coefficient of drag, causing faster descent time and larger Kinetic Energy at landing or failure of parachute at full deployment.	
		Visual Inspection of main parachute and drogue parachute for knot containing all shroud lines about 2" from end of shroud lines to prevent tangling of shroud lines.
		Lay unknotted parachute flat on the ground with shroud lines untangled on top of the parachute fabric.
		Pinch centers of each shroud line and lift off the ground.
		Tie one overhand knot containing all shroud lines about 2" from the pinched point.
		Tighten knot as much as possible.
		Repeat for another parachute if needed. Otherwise, requirement is completed.
	Warning: Failure to complete can result in recovery deployment failure.	
		Visual Inspection of main parachute's shroud lines tied to the middle of the shock cord. If knot is tied and tight, this requirement is met.
		Thread shock cord through the loop made with the ends of the main parachute's shroud lines between the middle of the lines and the knot containing all lines made prior.
		Continue to thread until the main parachute is at the approximate midpoint of the shock cord.
		Tie an overhand knot in the shock corn where it interfaces the shroud line loop, therefore containing the loop within the knot.

Table 38: Rocket Pre-Launch Preparation

Initial	Completed Substeps	Task
		Tighten the knot.
		If shroud line loop cannot move relevant to the interface with the shock cord, requirement is met.
	Warning: Failure to complete can result in recovery deployment failure.	
		Visual Inspection of drogue parachute's shroud lines tied to the middle of the shock cord. If knot is tied and tight, this requirement is met.
		Thread shock cord through the loop made with the ends of the drogue parachute's shroud lines between the middle of the lines and the knot containing all lines made prior.
		Continue to thread until the drogue parachute is at the approximate midpoint of the shock cord.
		Tie an overhand knot in the shock corn where it interfaces the shroud line loop, therefore containing the loop within the knot.
		Tighten the knot.
		If shroud line loop cannot move relevant to the interface with the shock cord, requirement is met.
	Warning: Failure to complete can result in recovery deployment failure.	
		Shear pin holes should be drilled and marked with one alignment marking per interface.
		PPE Required: Safety Goggles
		Draw two arrows pointing to each other in silver sharpie, one on each parent component facing each other on either side of the interface.
		Drill 3 holes with drill bit equally spaced around the upper body tube about 2" from the interface.
		Draw circles around each hole with a silver sharpie.
		Mark as completed when all holes are drilled and marked (6 total).
	Warning: Failure to complete can result in recovery deployment failure.	

6.2.5. Motor Preparation

Required Personnel: Team Mentor

To Be Completed: Day before launch

Motor is to be prepared under direct supervision and action of the Team Mentor. Team understands this and will not attempt to independently handle or prepare the motor for launch.

6.2.6. Setup on Launch Pad

Required Personnel: Team Mentor

To Be Completed: At Launch

Table 39: Setup on Launch Pad

Initial	Completed Substeps	Task
		Rocket secured on the guide rail
		Tilt rail out of the upright position
		Slide rocket, nose side up onto the guide rails, ensuring that rail guides are in full contact with the rail at all points.
		Tilt rail back into upright position
		Success criteria met when rocket is vertical on launch pad
	Warning: Personnel hazard as well as failed launch possible if step is incorrectly competed	
		Activate altimeter switches.
		Turn one turnkey switch at a time and wait for the activation beep sequence from the altimeter.
		Repeat with each turnkey.
		Success criteria met when all switches have been turned on.
	Warning: Recovery hardware deployment may fail if incorrectly completed	
		Igniter installed
		See section 5.1.1.8.
	Warning: Personnel hazard as well as failed launch possible if step is incorrectly competed.	

6.2.7. Igniter Installation

Required Personnel: Team Mentor

To Be Completed: At Launch

Table 40: Igniter Installation

Initial	Completed Substeps	Task

Table 40: Igniter Installation

Initial	Completed Substeps	Task
		Igniter successfully installed
		PPE Required: Safety Goggles
		Separate two ends of the igniter carefully so as to not rip the contact point.
		Take two alligator clips from the ignition system that will connect to igniter and brush them against one another, checking for sparks. If sparks occur alert team mentor. If not proceed.
		Clamp each side of the ignitor with an alligator clip and wrap the ends of the ignitor around the clip so a secure contact is made.
		Slide ignitor into the open end of the motor within the rocket as far as it'll go (about a foot)
		Tape external wiring to the side of the rocket loosely so that ignitor does not fall out of motor prematurely.
		Success criteria met when ignitor is fully inserted into the motor and does not fall out by itself.
	Warning: Failure to ignite if step is done incorrectly.	

6.2.8. Launch Procedure

Required Personnel: Team Mentor
To Be Completed: At Launch

Table 41: Launch Procedure

Initial	Completed Substeps	Task
		Team and viewers in watch area and aware of launch.
		All team members and surrounding people should proceed to designated watch area determined by the launch site.
		Launch is announced by Range Safety Officer to alert al personnel.
		Countdown is initiated and rocket is launched using a dual key turn signal connected to igniter.
		Success criteria met when rocket is launched.
	Warning: Personnel hazard if steps are not followed.	

6.2.9. Troubleshooting

To Be Completed: If launch attempt occurs but rocket does not ignite.

Table 42: Troubleshooting

Initial	Completed Substeps	Task
		All personnel have waited one minute before approaching rocket.
		Once igniter ignition is attempted, everyone must wait at least 1 minute or until the all clear from the RSO before approaching the vehicle.
		Success criteria met when cool down period has passed.
	Warning: Personnel hazard if steps are not followed.	
		Ignitor is removed and examined.
		Remove ignitor from ignition system and examine if it has been damaged in any way, seek Team Mentor for advice.
		If deemed safe, insert new ignitor and attempt to launch again.
		Success criteria met when ignitor has been replaced safely.
	Warning: Personnel hazard if steps are not followed.	

6.2.10. Post-Flight Inspection

Required Personnel: Project Manager, Structures Lead, and Electronics Lead
To Be Completed: Post-successful launch

Table 43: Post Flight Inspection

Initial	Completed Substeps	Task
		Upon approach to the vehicle, altimeters should be making high-pitched whining sound. This is a location feature that also signals that the component is still being powered and was powered during the duration of the flight.
		Personnel Required: Electronics Lead
		If no whining is occurring, electronics lead will disarm altimeters and inspect component using the appropriate software
	Warning: Failure to complete could result in future altimeter failure.	
		Vehicle should be disassembled on the ground with the following components visibly separated from each other and connected by shock cord: lower body tube, drogue parachute, upper body tube, main parachute, nose cone.
		PPE Required: Safety Goggles
		If components are not disassembled, this be a product of either ejection charges not going off or not enough black powder being used.

Table 43: Post Flight Inspection

Initial	Completed Substeps	Task
		Vehicle should be taken back to team mentor with no members walking or standing in the trajectory of the vehicle's components in the case that ejection charges go off unexpectedly.
		Mentor will examine black powder charges and safely disconnect black powder from any ignition source.
	Warning: Failure to complete could result in serious injury from spontaneous combustion leading to burns.	
		Parachutes should not have new tears or holes sustained during flight.
		If damage was sustained by the parachute during flight, it is most likely a sign of insufficient fire cloth sizing
		If another flight is planned, a bigger fire cloth must be utilized in place of fire cloth on that shock cord.
	Warning: Failure to complete could result in damage to recovery hardware.	
		Altimeter data must be transferred from vehicle avionics to a laptop with appropriate reading software.
		Personnel Required: Electronics Lead
		Electronics lead should remove locking mechanism and disconnect any cords that are no longer necessary.
		Electronics lead will properly connect altimeters to a computer with appropriate software able to read altimeter data and save for further examination.
		Step will be marked done with data from both altimeters have been overviewed and the data saved onto the altimeter or computer for further examination.
	Warning: Failure to complete could result in no flight data.	

7. Project Plan

7.1. Requirements Compliance

7.1.1. Handbook Requirements Compliance

Table 44: USLI Handbook Requirements Compliance

Requirement	Method of Verification	Verification Plan	Status
1.1. Students on the team will do 100% of the project, including design, construction, written reports, presentations, and flight preparation with the exception of assembling the motors and handling black powder or any variant of ejection charges, or preparing and installing electric matches (to be done by the team's mentor). Teams will submit new work. Excessive use of past work will merit penalties.	Demonstration	Team has been and plans to continue to continue work needed for competition, excluding tasks requiring a mentor.	In Progress
1.2. The team will provide and maintain a project plan to include, but not limited to the following items: project milestones, budget and community support, checklists, personnel assignments, STEM engagement events, and risks and mitigations.	Demonstration	Finance lead maintains general project plan with milestones, budget, and STEM engagement with assistance from the Project Manager. Individual subteam leads maintain personnel assignments and checklists relevant to their team. Safety Officer maintains risks, mitigations, and checklists throughout project.	In Progress
1.3. Foreign National (FN) team members must be identified by the Preliminary Design Review (PDR) and may or may not have access to certain activities during launch week due to security restrictions. In addition, FN's may be separated from their team during certain activities on site at Marshall Space Flight Center.	Demonstration	Foreign National members will be identified by PDR submission.	Complete
1.4. The team must identify all team members attending launch week activities by the Critical Design Review (CDR). Team members will include:	Demonstration	Team is confirmed in Design Competition – travel to launch week will not occur.	Completed
1.4.1. Students actively engaged in the project throughout the entire year.			

Table 44: USLI Handbook Requirements Compliance

Requirement	Method of Verification	Verification Plan	Status
1.4.2. One mentor (see requirement 1.13).			
1.4.3. No more than two adult educators.			
1.5. The team will engage a minimum of 200 participants in educational, hands-on science, technology, engineering, and mathematics (STEM) activities. These activities can be conducted in-person or virtually. To satisfy this requirement, all events must occur between project acceptance and the FRR due date. The STEM Engagement Activity Report must be submitted via email within two weeks of the completion of each event. A template of the STEM Engagement Activity Report can be found on pages 36-38.	Demonstration	Bearospace at UCLA will partner with SOLES, NSBE, and AISES at UCLA to aid their STEM outreach efforts.	Completed
1.6. The team will establish a social media presence to inform the public about team activities	Demonstration	A multi-platform media presence has been established and is updated by the social media coordinator.	Completed
1.7. Teams will email all deliverables to the NASA project management team by the deadline specified in the handbook for each milestone. If a deliverable is too large to attach to an email, inclusion of a link to download the file will be sufficient. Late submissions of milestone documents will be accepted up to 72 hours after the submission deadline. Late submissions will incur an overall penalty. No milestone documents will be accepted beyond the 72-hour window. Teams that fail to submit milestone documents will be eliminated from the project.	Demonstration	All deliverables will be emailed on time to correct personnel.	In Progress
1.8. All deliverables must be in PDF format.	Demonstration	All deliverables will be in PDF format.	In Progress
1.9. In every report, teams will provide a table of contents including major sections and their respective sub-sections.	Demonstration	Table of Contents will be included in all reports	In Progress
1.10. In every report, the team will include the page number at the bottom of the page.	Demonstration	Page Number will be on every page of every report.	In Progress
1.11. The team will provide any computer equipment necessary to perform a video	Demonstration	Equipment necessary for virtual presentations will be	In Progress

Table 44: USLI Handbook Requirements Compliance

Requirement	Method of Verification	Verification Plan	Status
teleconference with the review panel. This includes, but is not limited to, a computer system, video camera, speaker telephone, and a sufficient Internet connection. Cellular phones should be used for speakerphone capability only as a last resort.		acquired before presentation date and properly tested prior to presentation.	
1.12. All teams attending Launch Week will be required to use the launch pads provided by Student Launch's launch services provider. No custom pads will be permitted at the NASA Launch Complex. At launch, 8-foot 1010 rails and 12-foot 1515 rails will be provided. The launch rails will be canted 5 to 10 degrees away from the crowd on Launch Day. The exact cant will depend on Launch Day wind conditions.	Demonstration	Launch vehicle will be designed to be compatible with available launch rods and will be utilized at launch. No custom pad will be used. Rail cannot be considered in flight simulations.	No Longer Needed
1.13. Each team must identify a "mentor." A mentor is defined as an adult who is included as a team member, who will be supporting the team (or multiple teams) throughout the project year and may or may not be affiliated with the school, institution, or organization. The mentor must maintain a current certification, and be in good standing, through the National Association of Rocketry (NAR) or Tripoli Rocketry Association (TRA) for the motor impulse of the launch vehicle and must have flown and successfully recovered (using electronic, staged recovery) a minimum of 2 flights in this or a higher impulse class, prior to PDR. The mentor is designated as the individual owner of the rocket for liability purposes and must travel with the team to Launch Week. One travel stipend will be provided per mentor regardless of the number of teams he or she supports. The stipend will only be provided if the team passes FRR and the team and mentor attend launch week in April.	Demonstration	A qualified mentor has been identified	Completed
1.14 Teams will track and report the number of hours spent working on each milestone.	Demonstration	Hours will be tracked and reported by all members of the team.	In Progress

Table 44: USLI Handbook Requirements Compliance

Requirement	Method of Verification	Verification Plan	Status
2.1. The vehicle will deliver the payload to an apogee altitude between 3,500 and 5,500 feet above ground level (AGL). Teams flying below 3,000 feet or above 6,000 feet on Launch Day will receive zero altitude points towards their overall project score and will not be eligible for the Altitude Award.	Analysis, Test, Demonstration	OpenRocket will be utilized to design a launch vehicle that can comply with this requirement. Test launch will be utilized to confirm simulation expectations. Both these actions should prepare the vehicle to meet this requirement on launch day.	No Longer Needed
2.2. Teams shall identify their target altitude goal at the PDR milestone. The declared target altitude will be used to determine the team's altitude score.	Analysis, Demonstration	OpenRocket and RockSim will be utilized to predict and declare a target altitude. This altitude will be submitted with the PDR.	Complete
2.3. The vehicle will carry one commercially available, barometric altimeter for recording the official altitude used in determining the Altitude Award winner. The Altitude Award will be given to the team with the smallest difference between their measured apogee and their official target altitude on Launch Day. This altimeter may also be used for deployment purposes (see Requirement 3.4)	Inspection	The vehicle will contain two different commercially available altimeters for redundancy.	Completed
2.4. The launch vehicle will be designed to be recoverable and reusable. Reusable is defined as being able to launch again on the same day without repairs or modifications.	Inspection	Launch vehicle was designed to be reusable meaning it is designed to be able to withstand flight forces.	Complete
2.5. The launch vehicle will have a maximum of four (4) independent sections. An independent section is defined as a section that is either tethered to the main vehicle or is recovered separately from the main vehicle using its own parachute.	Analysis, Inspection	Launch vehicle was designed to have 3 independent sections tethered together.	Complete
2.5.1. Coupler/airframe shoulders which are located at in-flight separation points will be at least 1 body diameter in length.	Analysis, Inspection	Shoulders will be 1 body diameter in length.	Complete
2.5.2. Nosecone shoulders which are located at in-flight separation points will be at least ½ body diameter in length.	Analysis, Inspection	Nosecone shoulders will be at least ½ body diameter in length.	Complete

Table 44: USLI Handbook Requirements Compliance

Requirement	Method of Verification	Verification Plan	Status
2.6. The launch vehicle will be capable of being prepared for flight at the launch site within 2 hours of the time the Federal Aviation Administration flight waiver opens.	Demonstration	Vehicle and launch procedure are designed to meet this requirement.	Complete
2.7. The launch vehicle and payload will be capable of remaining in launch-ready configuration on the pad for a minimum of 2 hours without losing the functionality of any critical on-board components, although the capability to withstand longer delays is highly encouraged.	Analysis, Test, Demonstration	Electronics will be selected so they can last a minimum 4-hour lifetime. This will be tested at some point before launch. Materials of the launch vehicle will be chosen to remain in launch-ready configuration.	Complete
2.8. The launch vehicle will be capable of being launched by a standard 12-volt direct current firing system. The firing system will be provided by the NASA-designated launch services provider.	Demonstration	Motor will be compatible with this ignition system.	Complete
2.9. The launch vehicle will require no external circuitry or special ground support equipment to initiate launch (other than what is provided by the launch services provider).	Demonstration	Vehicle will not be designed to need ground systems beyond what is provided.	Complete
2.10. The launch vehicle will use a commercially available solid motor propulsion system using ammonium perchlorate composite propellant (APCP) which is approved and certified by the National Association of Rocketry (NAR), Tripoli Rocketry Association (TRA), and/or the Canadian Association of Rocketry (CAR).	Analysis, Inspection	Vehicle will be designed to utilize a motor within these specifications and motor will be declared at CDR. Valid motor choice will be confirmed with the NAR/TRA mentor.	Complete
2.10.1. Final motor choices will be declared by the Critical Design Review (CDR) milestone.	Demonstration	Motor has been declared at CDR.	Complete
2.10.2. Any motor change after CDR must be approved by the NASA Range Safety Officer (RSO). Changes for the sole purpose of altitude adjustment will not be approved. A penalty against the team's overall score will be incurred when a motor change is made after the CDR milestone, regardless of the reason.	Inspection	Motor change post-CDR will be approved by NAS RSO if needed.	No Longer Needed
2.11. The launch vehicle will be limited to a single stage.	Demonstration	Vehicle will be designed to be single stage.	Complete

Table 44: USLI Handbook Requirements Compliance

Requirement	Method of Verification	Verification Plan	Status
2.12. The total impulse provided by a College or University launch vehicle will not exceed 5,120 Newton-seconds (L-class). The total impulse provided by a High School or Middle School launch vehicle will not exceed 2,560 Newton-seconds (K-class).	Analysis, Demonstration	Motor choice will be L-class impulse or lower.	Complete
2.13. Pressure vessels on the vehicle will be approved by the RSO and will meet the following criteria: 2.13.1. The minimum factor of safety (Burst or Ultimate pressure versus Max Expected Operating Pressure) will be 4:1 with supporting design documentation included in all milestone reviews. 2.13.2. Each pressure vessel will include a pressure relief valve that sees the full pressure of the tank and can withstand the maximum pressure and flow rate of the tank. 2.13.3. The full pedigree of the tank will be described, including the application for which the tank was designed and the history of the tank. This will include the number of pressure cycles put on the tank, the dates of pressurization/depressurization, and the name of the person or entity administering each pressure event.	Demonstration	Team will not utilize pressure vessels.	Complete
2.14. The launch vehicle will have a minimum static stability margin of 2.0 at the point of rail exit. Rail exit is defined at the point where the forward rail button loses contact with the rail.	Analysis, Test	Vehicle has been designed to have a static stability margin above 2.0 at rail exit point. This has been confirmed using simulation software at many different conditions.	Complete
2.15. Any structural protuberance on the rocket will be located aft of the burnout center of gravity. Camera housings will be exempted, provided the team can show that the housing(s) causes minimal aerodynamic effect on the rocket's stability.	Analysis, Inspection	No structural protuberance on the rocket has been placed aft the burnout center of gravity, as confirmed by OpenRocket.	Complete
2.16. The launch vehicle will accelerate to a minimum velocity of 52 fps at rail exit.	Analysis, Test	Vehicle has been designed to have a rail exit velocity above 52 fps. This has been	Complete

Table 44: USLI Handbook Requirements Compliance

Requirement	Method of Verification	Verification Plan	Status
		confirmed using simulation software.	
2.17. All teams will successfully launch and recover a subscale model of their rocket prior to CDR. The subscale flight may be conducted at any time between proposal award and the CDR submission deadline. Subscale flight data will be reported at the CDR milestone. Subscales are not required to be high power rockets.	Demonstration	Team will not be constructing subscale model as part of design competition	No Longer Needed
2.17.1. The subscale model should resemble and perform as similarly as possible to the full-scale model; however, the full-scale will not be used as the subscale model.			
2.17.2. The subscale model will carry an altimeter capable of recording the model's apogee altitude.			
2.17.3. The subscale rocket must be a newly constructed rocket, designed and built specifically for this year's project.			
2.17.4. Proof of a successful flight shall be supplied in the CDR report. Altimeter data output may be used to meet this requirement.			
2.18. All teams will complete demonstration flights as outlined below.	-	-	-
2.18.1. Vehicle Demonstration Flight - All teams will successfully launch and recover their full-scale rocket prior to FRR in its final flight configuration. The rocket flown must be the same rocket to be flown on launch day. The purpose of the Vehicle Demonstration Flight is to validate the launch vehicle's stability, structural integrity, recovery systems, and the team's ability to prepare the launch vehicle for flight. A successful flight is defined as a launch in which all hardware is functioning properly (i.e., drogue chute at apogee, main chute at the intended lower altitude, functioning tracking devices, etc.). The following criteria must be met during the full-scale demonstration flight:	Demonstration	Team will not be conducting Demonstration Flight due to competing in Design Competition.	No Longer Needed

Table 44: USLI Handbook Requirements Compliance

Requirement	Method of Verification	Verification Plan	Status
2.18.1.1. The vehicle and recovery system will have functioned as designed.			
2.18.1.2. The full-scale rocket must be a newly constructed rocket, designed and built specifically for this year's project.			
2.18.1.3. The payload does not have to be flown during the full-scale Vehicle Demonstration Flight. The following requirements still apply:			
2.18.1.3.1. If the payload is not flown, mass simulators will be used to simulate the payload mass.			
2.18.1.3.2. The mass simulators will be in the same approximate location on the rocket as the missing payload mass.			
2.18.1.4. If the payload changes the external surfaces of the rocket (such as with camera housings or external probes) or manages the total energy of the vehicle, those systems will be active during the full-scale Vehicle Demonstration Flight.			
2.18.1.5. Teams shall fly the launch day motor for the Vehicle Demonstration Flight. The team may request a waiver for the use of an alternative motor in advance if the home launch field cannot support the full impulse of the launch day motor or in other extenuating circumstances.			
2.18.1.6. The vehicle must be flown in its fully ballasted configuration during the full-scale test flight. Fully ballasted refers to the maximum amount of ballast that will be flown during the launch day flight. Additional ballast may not be added without a re-flight of the full-scale launch vehicle.			
2.18.1.7. After successfully completing the full-scale demonstration flight, the launch vehicle or any of its components will not be modified without the concurrence of the NASA Range Safety Officer (RSO).			

Table 44: USLI Handbook Requirements Compliance

Requirement	Method of Verification	Verification Plan	Status
2.18.1.8. Proof of a successful flight shall be supplied in the FRR report. Altimeter data output is required to meet this requirement.			
2.18.1.9. Vehicle Demonstration flights must be completed by the FRR submission deadline. No exceptions will be made. If the Student Launch office determines that a Vehicle Demonstration Re-flight is necessary, then an extension may be granted. THIS EXTENSION IS ONLY VALID FOR RE-FLIGHTS, NOT FIRST TIME FLIGHTS. Teams completing a required re-flight must submit an FRR Addendum by the FRR Addendum deadline.			
2.18.2. Payload Demonstration Flight - All teams will successfully launch and recover their full-scale rocket containing the completed payload prior to the Payload Demonstration Flight deadline. The rocket flown must be the same rocket to be flown on launch day. The purpose of the Payload Demonstration Flight is to prove the launch vehicle's ability to safely retain the constructed payload during flight and to show that all aspects of the payload perform as designed. A successful flight is defined as a launch in which the rocket experiences stable ascent and the payload is fully retained until it is deployed (if applicable) as designed. The following criteria must be met during the Payload Demonstration Flight: 2.18.2.1. The payload must be fully retained until the intended point of deployment (if applicable), all retention mechanisms must function as designed, and the retention mechanism must not sustain damage requiring repair. 2.18.2.2. The payload flown must be the final, active version. 2.18.2.3. If the above criteria are met during the original Vehicle Demonstration Flight, occurring prior to the FRR deadline and the information is included in the FRR package, the additional flight and FRR Addendum are not required.	Demonstration	Team will not be conducting Payload Demonstration Flight due to competing in Design Competition.	No Longer Needed

Table 44: USLI Handbook Requirements Compliance

Requirement	Method of Verification	Verification Plan	Status
2.18.2.4. Payload Demonstration Flights must be completed by the FRR Addendum deadline. NO EXTENSIONS WILL BE GRANTED.			
2.19. An FRR Addendum will be required for any team completing a Payload Demonstration Flight or NASA required Vehicle Demonstration Re-flight after the submission of the FRR Report.	Demonstration	Requirements not applicable due to no flights being conducted.	No Longer Needed
2.19.1. Teams required to complete a Vehicle Demonstration Re-Flight and failing to submit the FRR Addendum by the deadline will not be permitted to fly a final competition launch.			
2.19.2. Teams who successfully complete a Vehicle Demonstration Flight but fail to qualify the payload by satisfactorily completing the Payload Demonstration Flight requirement will not be permitted to fly a final competition launch.			
2.19.3. Teams who complete a Payload Demonstration Flight which is not fully successful may petition the NASA RSO for permission to fly the payload at launch week. Permission will not be granted if the RSO or the Review Panel have any safety concerns.			
2.20. The team's name and Launch Day contact information shall be in or on the rocket airframe as well as in or on any section of the vehicle that separates during flight and is not tethered to the main airframe. This information shall be included in a manner that allows the information to be retrieved without the need to open or separate the vehicle.			
2.21. All Lithium Polymer batteries will be sufficiently protected from impact with the ground and will be brightly colored, clearly marked as a fire hazard, and easily distinguishable from other payload hardware.	Demonstration	Vehicle and payload designed so Lithium Polymer batteries will be harbored within bright red 3D printed plastic enclosures to be distinguished as a fire hazard. They will also be sealed from any explosive sources.	Complete

Table 44: USLI Handbook Requirements Compliance

Requirement	Method of Verification	Verification Plan	Status
2.22. Vehicle Prohibitions	-	-	-
2.22.1. The launch vehicle will not utilize forward firing motors.	Analysis, Inspection	Vehicle will not be designed to utilize forward canards.	Complete
2.22.2. The launch vehicle will not utilize motors that expel titanium sponges (Sparky, Skid mark, MetalStorm, etc.)	Demonstration	Launch vehicle will be designed to only use approved motors.	Complete
2.22.3. The launch vehicle will not utilize hybrid motors.			
2.22.4. The launch vehicle will not utilize a cluster of motors.			
2.22.5. The launch vehicle will not utilize friction fitting for motors.	Demonstration	Motors will not utilize friction fitting and confirmed by mentor	Complete
2.22.6. The launch vehicle will not exceed Mach 1 at any point during flight.	Analysis, Test	Simulation software is used during design of the vehicle to ensure maximum speeds is well below Mach 1. Vehicle demonstration will prove this.	Complete
2.22.7. Vehicle ballast will not exceed 10% of the total unballasted weight of the rocket as it would sit on the pad (i.e., a rocket with an unballasted weight of 40 lbs. on the pad may contain a maximum of 4 lbs. of ballast).	Analysis, Inspection	Rocket will not carry more than the maximum amount of ballast as determined by its measured pre-launch weight.	Complete
2.22.8. Transmissions from onboard transmitters, which are active at any point prior to landing, will not exceed 250 mW of power (per transmitter).	Analysis, Inspection	All transmitters have been selected with a power rating less than 250 mW.	Complete
2.22.9 Transmitters will not create excessive interference. Teams will utilize unique frequencies, handshake/passcode systems, or other means to mitigate interference caused to or received from other teams.	Test, Demonstration	All transmitters will communicate to the team using frequency hopping to prevent interference with other teams.	Complete
2.22.10. Excessive and/or dense metal will not be utilized in the construction of the vehicle. Use of lightweight metal will be permitted but limited to the amount necessary to ensure structural integrity of the airframe under the expected operating stresses.	Analysis, Inspection	No heavy metal will be included in design of the vehicle. Only a small amount of aluminum, a lightweight metal, is used for the bottom of the vehicle for strength purposes.	Complete

Table 44: USLI Handbook Requirements Compliance

Requirement	Method of Verification	Verification Plan	Status
3.1. The full-scale launch vehicle will stage the deployment of its recovery devices, where a drogue parachute is deployed at apogee, and a main parachute is deployed at a lower altitude. Tumble or streamer recovery from apogee to main parachute deployment is also permissible, provided that kinetic energy during drogue stage descent is reasonable, as deemed by the RSO.	Analysis, Demonstration	Vehicle will be designed to utilize dual deployment, with drogue deployment occurring at apogee and main deployment occurring at some lower altitude as determined by deployment speed and descension time. This will be demonstrated at launch and full-scale verification flight.	Complete
3.1.1. The main parachute shall be deployed no lower than 500 feet.	Analysis, Demonstration	Vehicle will be designed to deploy main parachute above 500 ft gal. Redundant altimeters will be used to ensure this.	Complete
3.1.2. The apogee event may contain a delay of no more than 2 seconds.	Analysis, Demonstration	Vehicle will be designed to have to delay at apogee to fulfill this requirement. Redundant altimeters will be used to ensure this.	Complete
3.1.3. Motor ejection is not a permissible form of primary or secondary deployment.	Analysis, Demonstration	Vehicle will not deploy motor at any point during or post flight. Motor retainer will ensure this.	Complete
3.2. Each team will perform a successful ground ejection test for all electronically initiated recovery events prior to the initial flights of the subscale and full-scale vehicles.	Demonstration	No longer needed in Design Competition.	No Longer Needed
3.3. Each independent section of the launch vehicle will have a maximum kinetic energy of 75 ft-lbf at landing.	Analysis, Test, Demonstration	OpenRocket will be utilized to analyze weights of individual tethered sections as well as landing speed to ensure completion of this. Main parachute deployment can be altered to alter speed and kinetic energy at landing.	Complete
3.4. The recovery system will contain redundant, commercially available altimeters. The term “altimeters” includes both simple altimeters and more sophisticated flight computers.	Inspection	Two commercial altimeters have been selected. The Missile Works RRC3 and StratoLogger SL100	Complete

Table 44: USLI Handbook Requirements Compliance

Requirement	Method of Verification	Verification Plan	Status
3.5. Each altimeter will have a dedicated power supply, and all recovery electronics will be powered by commercially available batteries.	Demonstration	Each altimeter will be individually powered using 9V alkaline batteries	Complete
3.6. Each altimeter will be armed by a dedicated mechanical arming switch that is accessible from the exterior of the rocket airframe when the rocket is in the launch configuration on the launch pad.	Test, Inspection	Two small mechanical pushbuttons will be used as arming switches. The pushbuttons will be able to withstand the necessary current and voltage needed to power the altimeters.	Complete
3.7. Each arming switch will be capable of being locked in the ON position for launch (i.e., cannot be disarmed due to flight forces).	Test, Inspection	Pushbuttons will be selected such that when pressed (turned on), the button is no longer protruding from the body of the launch vehicle.	Complete
3.8. The recovery system electrical circuits will be completely independent of any payload electrical circuits.	Demonstration	All recovery components will be housed in the avionics of the launch vehicle. This is separated from payload electronics using pine wood bulkheads.	Complete
3.9. Removable shear pins will be used for both the main parachute compartment and the drogue parachute compartment.	Demonstration	Shear pin placement will be placed in pre-launch procedures to ensure completion.	Complete
3.10. The recovery area will be limited to a 2,500 ft. radius from the launch pads.	Analysis, Test, Demonstration	Simulation software will be utilized with varying wind conditions to ensure recovery area complies with this restriction. Full scale demonstration will verify simulation.	Complete
3.11. Descent time will be limited to 90 seconds (apogee to touch down). The jettisoned payload (planetary lander) is not subject to this constraint.	Analysis, Test, Demonstration	Simulation software will be utilized to ensure this. Main parachute deployment time can be altered to comply if needed.	Complete
3.12. An electronic tracking device will be installed in the launch vehicle and will transmit the position of the tethered vehicle or any independent section to a ground receiver.	Test, Demonstration	The Missile Works Tiny Telematics Tracker system will be used to transmit the launch	Complete

Table 44: USLI Handbook Requirements Compliance

Requirement	Method of Verification	Verification Plan	Status
		vehicle's location from at least a mile radius to the team.	
3.12.1. Any rocket section or payload component, which lands untethered to the launch vehicle, will contain an active electronic tracking device	Inspection, Demonstration	All rocket components and payload will land tethered with a main tracking device.	Complete
3.12.2. The electronic tracking device(s) will be fully functional during the official flight on Launch Day.	Testing, Inspection	GPS systems designed to be fully functional.	Complete
3.13. The recovery system electronics will not be adversely affected by any other on-board electronic devices during flight (from launch until landing).	Demonstration	All electronics within the avionics bay will not interfere or make use of any connections designated for recovery system electronics.	Complete
3.13.1. The recovery system altimeters will be physically located in a separate compartment within the vehicle from any other radio frequency transmitting device and/or magnetic wave producing device.	Demonstration	An avionics bay within the launch vehicle will separate radio telecommunication electronics from recovery system electronics. Other low-powered electronics will be housed within the avionics bay. Bulkheads will be used to shield the avionics bay from the rest of the vehicle.	Complete
3.13.2. The recovery system electronics will be shielded from all onboard transmitting devices to avoid inadvertent excitation of the recovery system electronics.	Test, Demonstration	Recovery system electronics will be housed within the avionics bay which separates all electronics from onboard transmitting devices.	Complete
3.13.3. The recovery system electronics will be shielded from all onboard devices which may generate magnetic waves (such as generators, solenoid valves, and Tesla coils) to avoid inadvertent excitation of the recovery system.	Demonstration	Besides wires carrying current between low-amperage electronic devices, no magnetic-field producing devices will be used, so no additional shielding is required.	Complete
3.13.4. The recovery system electronics will be shielded from any other onboard devices which may adversely affect the proper operation of the recovery system electronics.	Demonstration	Recovery electronics will be adequately shielded within the avionics bay and will be tested for functionality.	Complete

Table 44: USLI Handbook Requirements Compliance

Requirement	Method of Verification	Verification Plan	Status
4.1. High School/Middle School Division – Teams may design their own science or engineering experiment or may choose to complete the College/University Division mission. Data from the science or engineering experiment will be collected, analyzed, and reported by the team following the scientific method.	-	-	-
4.2. College/University Division – Teams will design a planetary landing system to be launched in a high-power rocket. The lander system will be capable of being jettisoned from the rocket during descent, landing in an upright configuration or autonomously up righting after landing. The system will self-level within a five-degree tolerance from vertical. After autonomously up righting and self-leveling, it will take a 360-degree panoramic photo of the landing site and transmit the photo to the team. The method(s)/design(s) utilized to complete the payload mission will be at the teams' discretion and will be permitted so long as the designs are deemed safe, obey FAA and legal requirements, and adhere to the intent of the challenge.	Demonstration	Payload subteam will develop original design to fulfill challenge. Safety officer will analyze any safety or legal concerns. These will be reviewed by NASA RSO.	Complete
4.3. Primary Landing System Mission Requirements	-	-	-
4.3.1. The landing system will be completely jettisoned from the rocket at an altitude between 500 and 1,000 ft. AGL. The landing system will not be subject to the maximum descent time requirement (Requirement 3.11) but must land within the external borders of the launch field. The landing system will not be tethered to the launch vehicle upon landing.	Analysis, Demonstration	Payload is designed to be jettisoned from rocket at main parachute deployment at 700ft AGL	Complete
4.3.2. The landing system will land in an upright orientation or will be capable of reorienting itself to an upright configuration after landing. Any system designed to reorient the lander must be completely autonomous.	Demonstration	Payload is designed to be capable of reorienting itself to upright configuration using 3 legs	Complete

Table 44: USLI Handbook Requirements Compliance

Requirement	Method of Verification	Verification Plan	Status
4.3.3. The landing system will self-level to within a five-degree tolerance from vertical.	Analysis, Test	Payload designed with motors and feedback loop to accomplish mission objective.	Complete
4.3.3.1. Any system designed to level the lander must be completely autonomous.	Demonstration	Leveling system is autonomous.	Complete
4.3.3.2. The landing system must record the initial angle after landing, relative to vertical, as well as the final angle, after reorientation and self-leveling. This data should be reported in the Post Launch Assessment Report (PLAR).	Demonstration	Landing system designed to be programmed to record all data needed. Lander uses a gyroscope/accelerometer to record angle	Complete
4.3.4. Upon completion or reorientation and self-levelling, the lander will produce a 360-degree panoramic image of the landing site and transmit it to the team.	Analysis, Demonstration	Lander uses a camera and a servo motor to rotate camera 360 degrees. Images are transmitted and compiled automatically at the team base	Complete
4.3.4.1. The hardware receiving the image must be located within the team's assigned prep area or the designated viewing area.	Test, Demonstration	Transmission hardware designed around this requirement.	Complete
4.3.4.2. Only transmitters that were onboard the vehicle during launch will be permitted to operate outside of the viewing or prep areas.	Analysis, Demonstration	Not relevant in Design Competition.	Complete
4.3.4.3. Onboard payload transmitters are limited to 250mW of RF power while onboard the launch vehicle but may operate at a higher RF power after landing on the planetary surface. Transmitters operating at higher power must be approved by NASA during the design process.	Analysis	Payload transmitters will not exceed 250mW of power	Complete
4.3.4.4. The image should be included in your PLAR.	Analysis	Not needed for design competition.	No Longer Needed
4.4. General Payload Requirements	-	-	-
4.4.1. Black Powder and/or similar energetics are only permitted for deployment of in-flight recovery systems. Energetics will not be permitted for any surface operations.	Inspection	Black powder only deploys the parachute. Payload retention system is tethered to shock cord of parachute to expose the payload outside the body tube. Gravity fully jettisons the payload.	Complete

Table 44: USLI Handbook Requirements Compliance

Requirement	Method of Verification	Verification Plan	Status
4.4.2. Teams must abide by all FAA and NAR rules and regulations.	Inspection	Safety officer will ensure all FAA and NAR rules are followed.	In Progress
4.4.3. Any experiment element that is jettisoned, except for planetary lander experiments, during the recovery phase will receive real-time RSO permission prior to initiating the jettison event.	Inspection	Team does not plan on incorporating an additional experimental element other than the planetary lander.	Not Needed
4.4.4. Unmanned aircraft system (UAS) payloads, if designed to be deployed during descent, will be tethered to the vehicle with a remotely controlled release mechanism until the RSO has given permission to release the UAS.	Demonstration	UAS was not selected as part of the payload	Not Needed
4.4.5. Teams flying UASs will abide by all applicable FAA regulations, including the FAA's Special Rule for Model Aircraft (Public Law 112-95 Section 336; see https://www.faa.gov/uas/faqs).			
4.4.6. Any UAS weighing more than .55 lbs. will be registered with the FAA and the registration number marked on the vehicle			
5.1. Each team will use a launch and safety checklist. The final checklists will be included in the FRR report and used during the Launch Readiness Review (LRR) and any Launch Day operations.	Demonstration	Safety officer works with subteam leads to create a launch and safety checklist used for all launches. This checklist will be included in the FRR.	Completed
5.2. Each team must identify a student safety officer who will be responsible for all items in section 5.3.	Demonstration	A student safety officer has been named and listed in all reports.	Completed
5.3. The role and responsibilities of the safety officer will include, but are not limited to:	Inspection	Student safety officer works alongside all subteam leads during every part of the design and manufacturing process. Safety officer is present during all manufacturing, testing, and launches to ensure proper safety protocol is followed. If safety officer cannot be	-
5.3.1. Monitor team activities with an emphasis on safety during:			-
5.3.1.1. Design of vehicle and payload			Completed
5.3.1.2. Construction of vehicle and payload components			Not Needed
5.3.1.3. Assembly of vehicle and payload			Not Needed

Table 44: USLI Handbook Requirements Compliance

Requirement	Method of Verification	Verification Plan	Status
5.3.1.4. Ground testing of vehicle and payload		present, another lead will be briefed by them on possible safety concerns and mitigations. Safety officer also completes safety portions of all reports to demonstrate adequate understanding of all safety risks and mitigations.	Not Needed
5.3.1.5. Subscale launch test(s)			Not Needed
5.3.1.6. Full-scale launch test(s)			Not Needed
5.3.1.7. Launch day			Not Needed
5.3.1.8. Recovery activities			Not Needed
5.3.1.9. STEM Engagement Activities			Completed
5.3.2. Implement procedures developed by the team for construction, assembly, launch, and recovery activities.	Demonstration	In person activities not conducted as part of design competition.	No Longer Needed
5.3.3. Manage and maintain current revisions of the team's hazard analyses, failure modes analyses, procedures, and MSDS/chemical inventory data.	Demonstration	These tasks are part of the safety officer's description and will be demonstrated on all reports. MSDS sheets are also always readily available in the lab where all members have access to them.	In Progress
5.3.4. Assist in the writing and development of the team's hazard analyses, failure modes analyses, and procedures.	Demonstration	Safety officer is responsible for completing these portions of the reports. They have meetings with and work closely with subteam leads to ensure these sections are adequately in depth.	In Progress
5.4. During test flights, teams will abide by the rules and guidance of the local rocketry club's RSO. The allowance of certain vehicle configurations and/or payloads at the NASA Student Launch does not give explicit or implicit authority for teams to fly those vehicle configurations and/or payloads at other club launches. Teams should communicate their intentions to the local club's President or Prefect and RSO before attending any NAR or TRA launch.	Demonstration	No test flights planned	No Longer Needed
5.5. Teams will abide by all rules set forth by the FAA.	Demonstration	Safety officer has reviewed FAA rules and ensured vehicle complies with all restrictions.	In progress

Table 44: USLI Handbook Requirements Compliance

Requirement	Method of Verification	Verification Plan	Status
6.1 NASA Launch Complex	-	-	-
6.1.1. Teams must complete and pass the Launch Readiness Review conducted during Launch Week.	Demonstration	Team will not be traveling to NASA Launch Complex	No Longer Needed
6.1.2. The team mentor must be present and oversee rocket preparation and launch activities.			
6.1.3. The scoring altimeter must be presented to the NASA scoring official upon recovery.			
6.1.4. Teams may launch only once. Any launch attempt resulting in the rocket exiting the launch pad, regardless of the success of the flight, will be considered a launch. Additional flights beyond the initial launch, will not be scored and will not be considered for awards.			
6.2 Commercial Spaceport Launch Site	-	-	-
6.2.1. The launch must occur at a NAR or TRA sanctioned and insured club launch. Exceptions may be approved for launch clubs who are not affiliated with NAR or TRA but provide their own insurance, such as the Friends of Amateur Rocketry. Approval for such exceptions must be granted by NASA prior to the launch.	Demonstration	Team is not launching from Home Site	No Longer Needed
6.2.2. Teams must submit their rocket and payload to the launch site Range Safety Officer (RSO) prior to flying the rocket. The RSO will inspect the rocket and payload for flightworthiness and determine if the project is approved for flight. The local RSO will have final authority on whether the team's rocket and payload may be flown.			
6.2.3. The team mentor must be present and oversee rocket preparation and launch activities.			
6.2.4. BOTH the team mentor and the Launch Control Officer shall observe the flight and report any off-nominal events during ascent or recovery on the Launch Certification and Observations Report.			

Table 44: USLI Handbook Requirements Compliance

Requirement	Method of Verification	Verification Plan	Status
6.2.5. The scoring altimeter must be presented to BOTH the team's mentor and the Range Safety Officer.			
6.2.6. The mentor, the Range Safety Officer, and the Launch Control Officer must ALL complete the applicable section for the Launch Certification and Observations Report. The Launch Certification and Observations Report document will be provided by NASA upon completion of the FRR milestone and must be returned to NASA by the team mentor upon completion of the launch.			
6.2.7. The Range Safety Officer and Launch Control Officer certifying the team's flight shall be impartial observers and must not be affiliated with the team, individual team members, or the team's academic institution.			
6.2.8. teams may launch only once. Any launch attempt resulting in the rocket exiting the launch pad, regardless of the success of the flight, will be considered a launch. Additional flights beyond the initial launch will not be scored and will not be considered for awards.			

7.1.2. Team Derived Requirements Compliance

Table 45: Team Requirements

Number	Team Requirement	Reason for Enforcement	Method of Verification	Verification Plan	Status
1. General Requirements					
1.1	Team leads will plan and carry out a member retention strategy that is successful in recruiting at least 10 members who continue the project into the next year.	Project must be sustainable from year to year. Being an underrepresented minority team can limit interest from prospective participants. At least 10 experienced members should always be on the team to ensure quality	Demonstration	Team has carried out several recruitment events and several retention meetings.	Incomplete

Table 45: Team Requirements

Number	Team Requirement	Reason for Enforcement	Method of Verification	Verification Plan	Status
		and correct work is representing our school.			
1.2	Industry relations must be established and at least $5,000 must be received in donations to the team from corporate sponsors.	While the team in the past has sustained itself on grants through UCLA, this funding source is not consistent in amount granted or in timely delivery; it is also usually meant for newly established organizations. As the team continues to expand, constant funding sources must be established as well as connections to industry which our members may find useful for the purposes of career development.	Demonstration	Team has found individual sponsors along with sponsors of the parent organization, AISES	Complete
1.3	Virtual social events will be planned and carried out by team leads to encourage membership and team bonding throughout the year.	New member communication with team leads is often lacking due to the level of technicality of the team. Social events where new recruits and leads were both present would help increase communication and retention.	Demonstration	Team has and continues to hold socials for new and returning members	Complete / Continued
1.4	Online presence must be established.	The position of "webmaster" was created, and a team of three people applied and were selected to create a website to present the team and the projects we have worked on. Leads	Demonstration	Webmaster continued to code website	In Progress

Table 45: Team Requirements

Number	Team Requirement	Reason for Enforcement	Method of Verification	Verification Plan	Status
		meet with the webmasters to check the progress of the website as well as offer formatting tips.			
2. Vehicle Requirements					
2.1	Upper and lower body tubes will be a cumulative sum of 5' in length.	Our team plans on purchasing a body tube, where a 6" diameter and 5' length body tube costs roughly $600. By limiting the purchase to just one of these, our team is saving a considerable amount of funds.	Demonstration	Design will be restrained by this.	Completed
2.3	Fins must have a rectangular leading edge.	Fins are generally cut out of flat sheets of material into a shape determined by the stability of the vehicle. By defining them as rectangular, it eliminates any error that may come through trying to reshape the leading edge into an airfoil or some other shape. Furthermore, the material chosen often creates volatile particulates during cutting and this would minimize any health threats to team members.	Demonstration	Design will be constrained to include fins within rectangular leading edge.	Completed
2.5	There will be no structural protuberance on the outer frame of the rocket excluding fins and launch lugs.	It is very hard to accurately measure drag on a complex object. By confining any possible protuberances such as wiring or cameras to within the rocket, the drag estimate will be	Demonstration	No structural protuberance will be placed in the design of the vehicle	Completed

Table 45: Team Requirements

Number	Team Requirement	Reason for Enforcement	Method of Verification	Verification Plan	Status
		more precise. Also, the subscale model will give more insight to the actual model results since scaling factors of constant objects will not have to be accounted for.			
2.6	There will be no vessel harbored in the vehicle for the specific purpose of containing a gas or liquid with pressure significantly above ambient pressure.	Equipment needed to accurately record pressure within the vessel would be costly. Also, failure of the vessel in any way could result in significant damage to the launch vehicle which could cause failure of the recovery system during flight or derailment of the vehicle from the original launch path.	Demonstration	Vehicle will not include any pressures vessels.	Complete
3. Recovery System Requirements					
3.1	No recovery hardware or parachutes will be planned to deploy if the vehicle is traveling faster than 85 ft/s	Parachutes deploying at too high of a speed could result in failure of the retainment hardware or parachute material itself. Delay in altimeters for any reason can cause a complete failure of deployment if the vehicle is descending at too fast a rate.	Analysis	OpenRocket will be utilized to find vehicle speed at recovery deployment. Parachutes and deployment times will be altered to meet this condition.	Complete
3.2	Parachutes will have high-visibility coloring for easy visual tracking.	In the case of GPS failure for any reason, visual tracking is the only method of estimating the landing site of the vehicle. By utilizing high-visibility parachutes, visual tracking will be easier regardless of weather conditions.	Demonstration	Only high visibility parachutes will be planned for purchased	Complete

Table 45: Team Requirements

Number	Team Requirement	Reason for Enforcement	Method of Verification	Verification Plan	Status
3.3	Recovery hardware and load-bearing interfaces will be able to take loads expected during flight with a safety margin of 4 for physical testing.	When failure testing, it is better to be conservative in estimating to ensure failure will not occur. A 1.5 safety margin will be added to loading calculations to ensure that no element of the recovery hardware will fail upon deployment. This includes both hardware and any interfaces including screw links, nuts, and any epoxied surfaces.	Demonstration	Requirement will be utilized for final testing in FRR	Complete
3.4	All static interfaces must be reinforced with epoxy or screws.	Reinforcing interfaces with epoxy or screws when possible allows for greater load-bearing capabilities so they will be less likely to fail during deployment.	Demonstration	Epoxy planned for use on all static interfaces	Complete
3.5	Altimeter redundancy must be used using two altimeters from two different brands.	Using altimeters from different manufacturers decreases the chance that both will fail due to the same reason if there is a problem during flight. Using different altimeters will verify the accuracy of data acquired by comparing them to each other.	Demonstration	Different branded altimeters will be planned for use.	Complete
4. Payload Experiment Requirements					
4.1	Payload will use a parachute during its descent.	Using a UAV as the desired descent method will prove too difficult and time consuming. This is exacerbated by the fact that the team is working remotely so	Observation	Payload has been designed around this requirement. Payload features a parachute to slow its descent	Complete

Table 45: Team Requirements

Number	Team Requirement	Reason for Enforcement	Method of Verification	Verification Plan	Status
		communication is hindered.			
4.2	Payload will use no more than 4 cameras to complete mission objective.	Using more than 4 cameras is unnecessary since most compact cameras have a viewing angle of 120 degrees. Increasing the number of cameras also means more pins are needed to wire all cameras. Preferably, only one camera would be used and rotated to take pictures.	Observation	Payload features a central camera that will rotate to obtain a 360-degree view of landing site	Complete
4.3	Payload will release parachute upon landing.	Releasing the parachute after landing prevents the parachute from interfering with the levelling stage of the payload.	Demonstration	Requirement has been omitted due to the increased complexity this requirement would pose. Releasing parachute has a minute effect on the payload’s picture taking operation	Omitted
4.4	Payload will use no more than 6 motors for levelling	Using more than 6 motors for levelling is unnecessary since each motor requires multiple pins to wire. Using less motors achieves electrical simplicity and allows for more space for computing electronics to be placed within the payload.	Observation	Payload will only use 3 motors to rotate 3 legs for levelling the payload.	Complete

7.2. Budgeting and Funding Summary

7.2.1. Budget

Table 46: Budget

Grand Total					$12,873
	Expense	Vendor	Projected Units	Projected Unit Price	Projected Total Price
Structures	**Totals:**				**$2,278**
	Contingency			10%	$207
	Body Tube	Public Missiles	1	$450	$450
	Rocket Kit	Apogee Components	1	$265	$265
	Subscale Motor	Apogee Components	1	$72	$72
	L-910 C-Star Motors	Cesaroni Technologies	3	$268	$804
	Coupler	Public Missiles	1	$94	$94
	Fiber Glass 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
Electrical / Payload	**Totals:**				**$462**
	Contingency			10%	$42
	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

Table 46: Budget

	2.4GHz SMA Antenna (RHCP)	Amazon	2	$30	$60
Recovery	**Totals:**				**$226**
	Contingency			10%	$21
	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:**				**$336**
	Contingency			10%	$31
	Particle Mask filters		3	$16	$48
	Particle Mask		3	$55	$165
	Gloves (100 pack)	Fisher Scientific	3	$31	$92
Travel	**Totals:**				**$9,570**
	Contingency			10%	$870
	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

7.2.2. Funding Plan

In the previous academic year, UCLA Bearospace had successfully obtained upwards of $2000 dollars in multiple UCLA grants for use in purchasing materials and travel expenses. This upcoming year, funding plan will be twofold: continuing to pursue grants and donations from UCLA organizations and entities, as well as pursuing donations from corporate sponsors.

Firstly, team managers will apply to grants which the team has won in the past. Last year, the UCLA Engineering Alumni Association (EAA) awarded UCLA Bearospace roughly $1200 for purchasing rocket materials. In addition, UCLA Student Organizations, Leadership and Engagement (SOLE) office released the UCLA Leadership Development Fund recently, a grant for covering travel expenses to conferences that promote student leadership development, to which the team successfully applied and won $1875 for travel expenses. Managers plan on applying to this grant again with AISES at UCLA's help. Aside from these two, team managers plan on exploring more opportunities by partnering more closely with UCLA SOLE representatives that have an extensive and positive contributive relationship with AISES at UCLA.

Secondly, the team will pursue corporate donations for UCLA Bearospace. At AISES at UCLA's Industry Advisory Board (IAB) meeting this summer, UCLA Bearospace representatives had the opportunity to meet corporate representatives from Lockheed Martin, Boeing, Northrop Grumman, and others. After this event, we were contacted by Aerospace Corporation to meet and form a funding opportunity during the fiscal year. Team managers were able to create a comprehensive fundraising plan and budget to provide prospective companies in hopes of obtaining corporate donations, and in so doing, establish the beginnings of a working relationship between UCLA Bearospace and corporate sponsors that will continue to provide funding for UCLA Bearospace into the future.

Once obtained, these funds are distributed throughout the various sub teams that build our rocket in order to purchase materials, licenses, and any other necessary components. Our team typically purchases materials through purchase orders logistics and material management department of our university, and we purchase our materials through vendors that have been pre-approved by our university. For materials that are unavailable through purchases orders, the team will use traditional retailers to acquire parts.