Bearospace at UCLA
(LoL)
Leveling on Land
2020 - 2021 NASA Student Launch
Critical Design Review (CDR)

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1. Summary of CDR Report

1.1 Team Summary

Team Name:	Bearospace at UCLA
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Number of Hours Spent on CDR:	120 Hrs

1.2 Launch Vehicle Summary

Target Altitude (ft.):	3600 feet
Final Motor Choice:	AeroTech K1103X-14
Size:	Length: 68 in; Diameter: 6 in
Mass:	19.1 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 feet

1.3 Payload Summary

Payload Title: Levelling 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 PDR

2.1 Changes to Vehicle Criteria

The rocket design has not changed much since the PDR. The more notable changes are the following:

1. The ballast mass located in the nosecone has changed from 1.81 lbs to 0.75 lbs
2. As a result of the ballast change, the static stability has changed from 2.55 to 2.30
3. The mass of the rocket has changed from 18.7 lbs to 19.1 lbs after a more accurate mass of the payload and avionics bay has been determined. Additional bulkheads and the locking mechanism for the avionics bay have been included in the OpenRocket file which altered the total mass of the rocket. This will be explained further in the recovery subsystem section.
4. The bulkhead thickness in the upper body tube has also been altered to 0.75” and reinforced with a 0.12” aluminum sheet to better withstand the impulse and shock from the parachute deployments.
5. The locations of the avionics bay and payload have been switched in which the payload is now near the separation point between the upper and lower body tubes and the avionics bay is near the separation point between the nosecone and the upper body tube. This location switch was done since the team wanted to have the payload deployed simultaneously with the main parachute by attaching them together through shock cords/quicklinks/eyebolts

In terms of action items from the PDR, no direct changes were made to the vehicle to address these action items since they were not needed. Instead, calculations and simulations were need to address the action items from the PDR such as recalculating parachute dimensions, kinetic energies, descent velocities, and airframe bending analysis.

2.2 Changes to Payload Criteria

The payload has drastically changed since the PDR. Changes have been made to reflect the action items outlined after the preliminary design stage. The payload now features a 3-legged lander that levels the payload as a opposed to a payload that uses its base to level a camera. The payload now includes a central column with acrylic sheets to provide the singular camera with a panoramic view of the landing site. The retention and deployment system for the payload has also changed. The selected method in the PDR used flaps to allow the payload to jettison from the launch vehicle using gravity, however, this did not insure the payload itself would actually leave the launch vehicle. The retention and deployment system now resembles a cage that is exposed to the exterior of the launch vehicle by attaching itself to the shock cord of the main parachute. This allows the payload to jettison from the cage after the deployment of the main parachute.

2.3 Changes to Project Plan

Since PDR, the team has transitioned to the Design Competition of USLI this year. The project plan was updated so as to remove any time acquiring materials, build times, and launch days. Instead, the design phase was extended through submission of the CDR and a redesign phase starting once the PMVR details are released was added. Timeline will be updated further as more details regarding the FRR and PMVR are released. Budget and funding sources are still presented however rocket materials will not be purchased due to the nature of the design competition.

3. Vehicle Criteria

3.1. Design and Verification of Launch Vehicle

3.1.1. Mission Statement

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

3.1.2. Mission Success Criteria

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

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

3.1.3. PDR Alternative Selection

In the PDR, three alternate designs were presented, all with slightly different designs to help fulfill the mission criteria for this year's competition. The designs mainly differed in fin design as well as motor choice. The alternate designs are presented below:

<u>Alternate Design 1:</u> AeroTech K715G-P

Alternate Design 1 uses a larger sized motor with a thin diameter that allows for large fin tabs to better secure the fins. This design still allows for flexibility in the placement of the payload and avionics bay despite the motor's larger length. One of the downsides of this design is that the motor barely the lower limit of the apogee window by having a 3567 ft. The sizing of the fins is major factor of not selecting this design as the final design; they are relatively large compared to Alternate Design 2 which would thus increase the cost of production and not be feasible to manufacture. The fins have a height of 7 inches with a sweep angle of 45 degrees and a root and tip chord length of 5 inches.

<u>Alternate Design 2:</u> AeroTech K1103X-14

Alternate Design 2 uses a similar sized motor from the first design although it lowers the stability a bit more than design 1. The advantage of this motor is that it provides a higher apogee than design 1 which gives the team more flexibility for any design changes that have come up. One flaw of this design was that the bulkheads were thin compared to design 3 but this no longer a flaw as the thickness of the bulkheads have been redesigned to be thicker and reinforced with aluminum sheets. The main reason this design is the leading design is because it provides a reasonable fin sizing. The fin design has a tip and root chord length of 5 inches with a 6 inch height and a sweep length of 63.43 degrees. The fin tabs are also long enough (3 inches) to be secured within the fin securing mechanism which gives them an advantage over the fin design in alternate design 3. This fin design also gives the team the best chance to avoid fin flutter which will be proven in the fin section.

Alternate Design 3: AeroTech K1999N-P

Alternate Design 3 uses the smallest motor of all three designs which gives it the most felxibility in spacing but it limits the height of the fin tabs due to the increased thickness of the motor. This compromises the security of the fins since they won't be fully secured in the fin securing mechanism. The main advantage of this design is that it provides an apogee directly in the middle of the apogee window. The main drawback of this design is the fin design. These fins have a high of 8 inches with a sweep angle of 45 degrees and a tip and root chord length of 6 inches, making them the largest fins of all the designs. This fin design is unrealistic to manufacture and makes them susceptible to fin flutter during flight.

The leading design is Alternate Design 2 with the AeroTech K1103X-14, primarily due to its reasonable fin size. The reasonable fin size makes manufacturing them feasible and lowers costs which is the focus of our rocket vehicle. The fins are small enough to ensure structural integrity during flight and are only reinforced with the large fin tabs. This motor, while larger in length than the motor in design 3, provides sufficient space for adjustments to the payload and avionics bay spacing. The team has already made adjustments to this spacing and this design has proven its flexibility in spacing. Although the predicted apogee barely reaches the lower window of the requirement, it still fulfills the requirement regardless.

3.1.4. Design Overview

Overview

Figure 1: 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 to 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

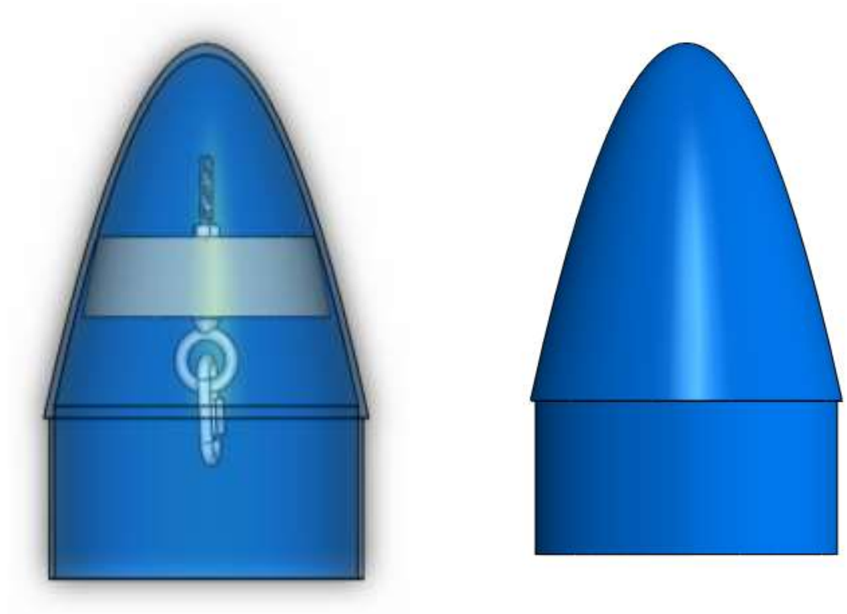

Figure 2: Nose Cone Overview

Estimated Rocket Vehicle Section Weight: 2.00 lb

The nose cone vehicle section is composed of five 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

Table 1: Nose Cone Section Components

Component	Material	Dimensions
Nose Cone	ABS Plastic	Cone Length: 7 in. Cone Thickness: 0.07 in.

Table 1: Nose Cone Section Components

Component	Material	Dimensions
		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 as the material is used in the 3D printers available, and allows a greater capability of conforming the structural design to team design parameters.	Ogive shape and length are given by the need for a desirable stability and apogee; an ogive nose cone of this length resulted in both a stability and apogee that was adequate with a margin for potential weight gain.
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,

Table 1: Nose Cone Section Components

Component	Material	Dimensions
		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 strength, a necessary consideration for the loading forces present during the main parachute'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 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.

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.

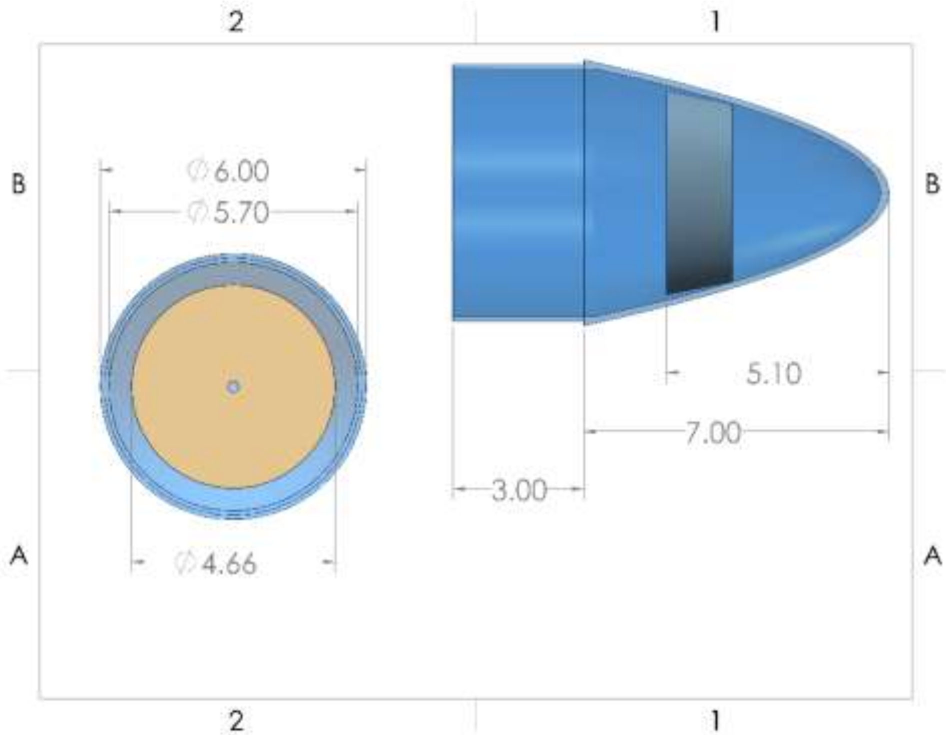

Figure 3: Nose Cone Drawing

Upper Body Tube

Figure 4: 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 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 shops.	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
	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 during the main parachute's	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
	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 tubes, as it is both stronger and lighter in	The body tube at at minimum must be long enough to house half the

Table 3: Lower Body Tube Section Components

Part	Material	Dimensions
	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.	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: 0.75 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 assemly's deployment.	The diameter of the eyebolt must be wide enough such that a quicklink can be fed through the eye and secured, serving as the attachment point of the drogue parachute assembly. Additionally, the length of the eyebolt's shank must be long enough to pass through the entirety of the centering ring, and still have enough length left to fasten a nut to the eyebolt, securing the eyebolt against the centering ring and thus the lower body tube parent component.

Table 3: Lower Body Tube Section Components

Part	Material	Dimensions
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 apogee capability at the same weight. As such, carbon fiber was selected over fiberglass.	The sizing of the trapezoidal fins is directly a result of trying to influence the stability of the rocket in flight while ensuring a generally streamlined aerodynamic shape for good airflow.

Table 3: Lower Body Tube Section Components

Part	Material	Dimensions
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.

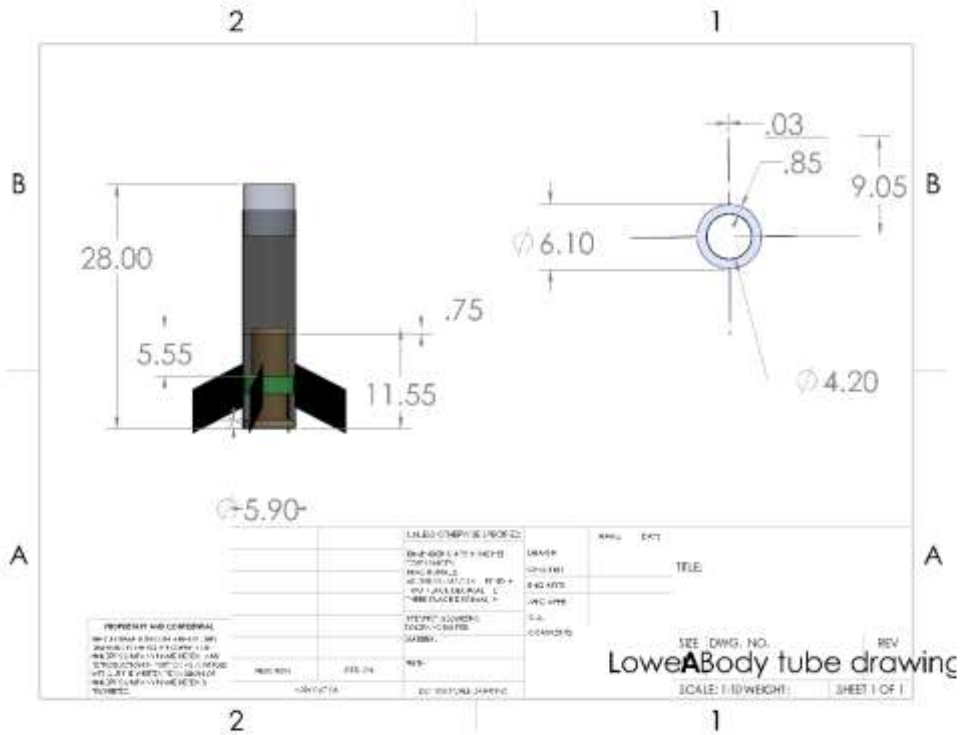

Figure 5: Lower Body Tube Drawing

One component that was specifically focused on was the FSM. Between the PDR and CDR, 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.

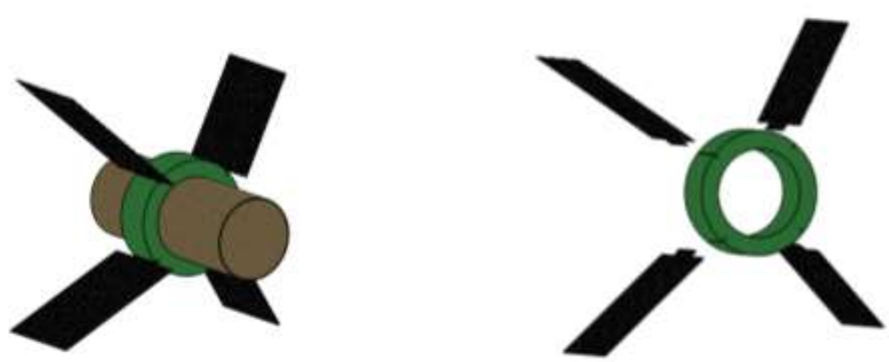

Figure 6: FSM Overview

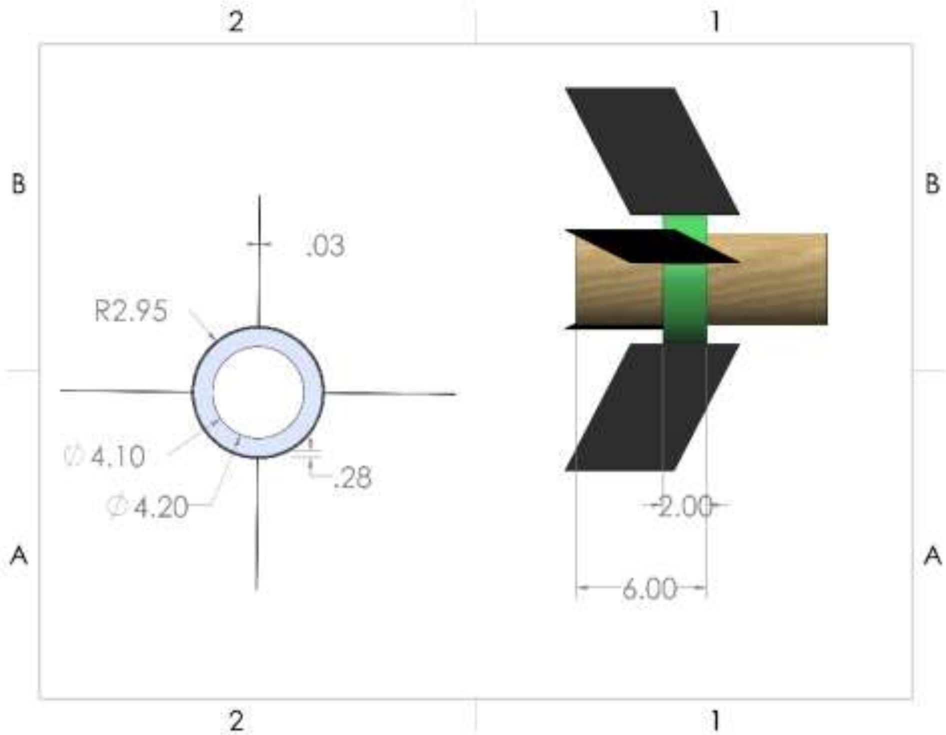

Figure 7: FSM Drawing

3.1.5. Manufacturing Readiness

All designs for structural components of the rocket vehicle are complete and ready to manufacture. For methodologies with steps that involve carbon fiber, fiberglass, epoxy, cutting, epoxying, etc. proper PPE will be maintained for those steps for handling hazardous and potentially hazardous materials and processes. The process of manufacturing each component and assembling each rocket vehicle section is provided below.

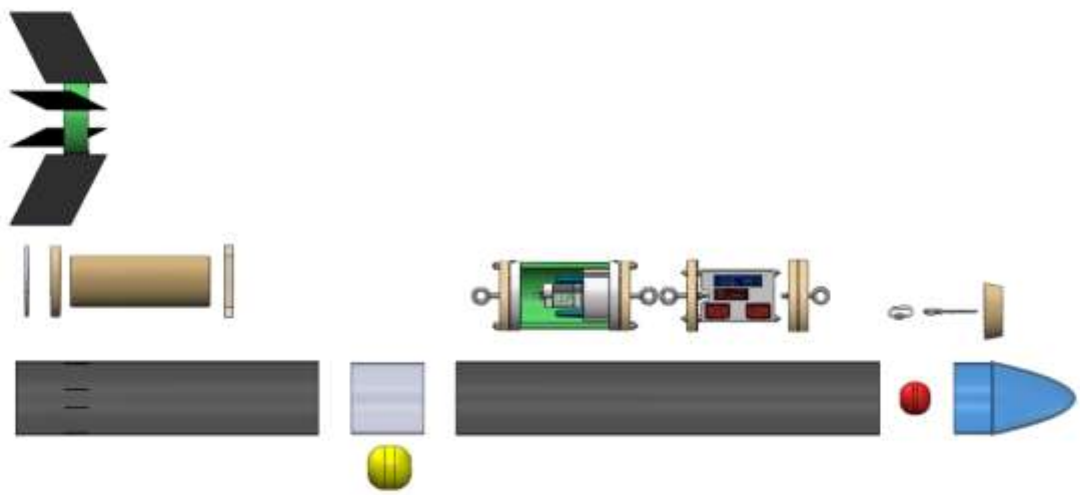

Figure 8: Launch Vehicle Exploded View

Nose Cone

Manufacturing Methodology for Nose Cone

1. The nose cone's 3D model is uploaded to a 3D printer, and printed out as three approximately 8 in. parts.
2. The three parts are then epoxied together while ensuring the interior and exterior edges are flush to prevent protruding edges that can interfere with aerodynamic performance or main parachute assembly deployment.
3. Let cure for 24 hours.
4. Visually inspect nose cone for structural protrusions. If it cannot be appropriately reduced by means of sanding, restart with new nose cone.
5. Test fit nose cone into 38 in. body tube. If it does not fit snugly, lightly sand shoulder until it does. If it is too loose, restart with new nose cone.

Body Tubes

Figure 9: Launch Vehicle Parent Components

Figure 10: Coupler Assembly

Manufacturing Methodology for Body Tube Parent Components

1. Receive shipment of 60 in. carbon fiber body tube and shipment of 12 in. coupler.
2. Having donned PPE, cut body tube 38 in. down from the top, resulting in a 38 in. part and a 22 in. part using a Dremel hand saw for cutting and a vacuum for sucking up carbon fiber sawdust.
3. Ensure coupler can be snugly inserted halfway into the 22 in. body tube. If it cannot, lightly sand exterior of coupler with medium grain sandpaper until it does.
4. Coat half of coupler with epoxy and slide that half into the 22 in. body tube. As it hardens, wipe away any excess epoxy left on the coupler or body tube surface.
5. Let cure for 24 hours.
6. At the opposite end of the 22 in. body tube from the couper, cut with a Dremel hand saw the slots through which the trapezoidal fins will be inserted.

Bulkheads and Centering Rings

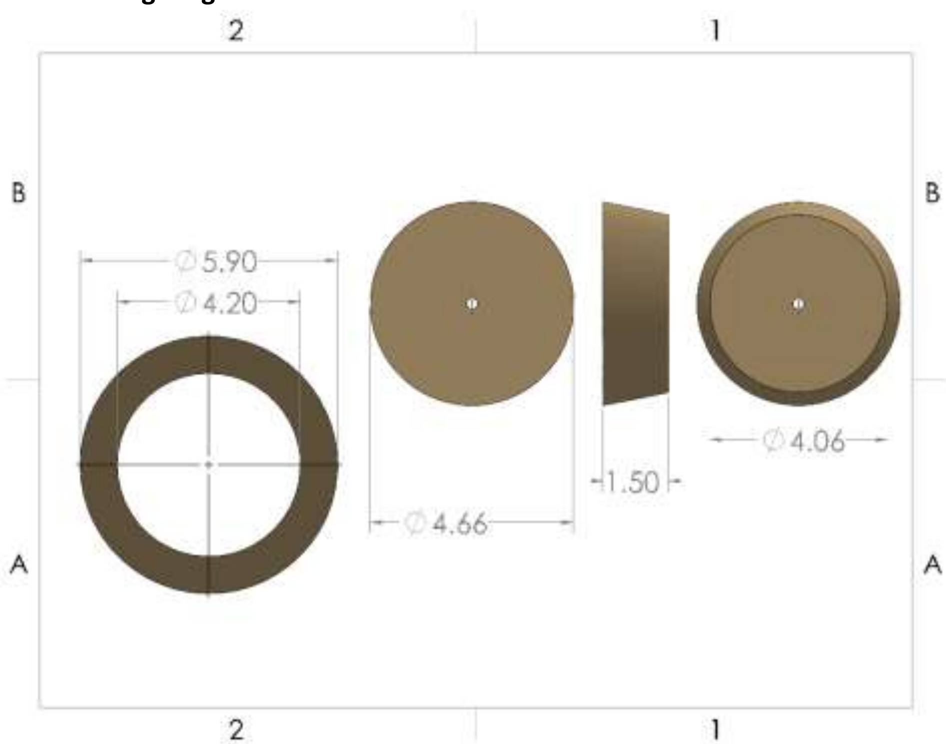

Figure 11: Bulkhead and Centering Ring Drawings

Manufacturing Methodology for Bulkhead (Nose Cone)

1. Take wood stock of either 0.125 in. or 0.25 in. thickness and prepare 2D drawings on CorelDraw for use on 2D laser cutters, altering the diameter to be 0.125 in. larger than the anticipated bulkhead diameter at that part of the nose cone.
2. Laser cut bulkhead layers.
3. Epoxy bulkhead layers together, securing them together with clamps to ensure structural integrity and wiping away excess epoxy.
4. Let cure 24 hours.
5. Using a mix of Dremel hand sanders, grinders, and sandpaper, sand away sloping sides until it is smooth and comparatively flush to the interior wall of the nose cone.

Manufacturing Methodology for Bulkhead (Body Tube)

1. Take wood stock of either 0.125 in. or 0.25 in. thickness and prepare 2D drawings on CorelDraw for use on 2D laser cutters.
2. Laser cut bulkhead layers, which when put together add up to desired thickness.
3. Test fit layers into the body tube, lightly sanding if too large or recutting larger layers if too small.
4. Epoxy bulkhead layers together, securing them together with clamps to ensure structural integrity and wiping away excess epoxy.
5. Let cure 24 hours.

Manufacturing Methodology for Centering Rings

1. Take wood stock of either 0.125 in. or 0.25 in. thickness and prepare 2D drawings on CorelDraw for use on 2D laser cutters.
2. Laser cut centering ring layers, which when put together add up to desired thickness.
3. Test fit layers into the body tube and on the phenolic tube, lightly sanding if outer diameter is too large and/or inner diameter is too small, or recutting larger layers of outer diameter is too small and/or if inner diameter is too large.
4. Epoxy centering ring layers together, securing them together with clamps to ensure structural integrity and wiping away excess epoxy.
5. Let cure 24 hours.

Manufacturing Methodology for Aluminum Ring

1. Take aluminum stock of desired thickness and prepare 2D CAD model for uploading to a water-jet cutter.
2. Water-jet cut the aluminum ring.
3. Test fit aluminum ring on the body tube and phenolic tube, lightly sanding if outer diameter is too large and/or inner diameter is too small, or recutting larger layers if outer diameter is too small and/or if inner diameter is too large.
4. Epoxy centering ring layers together, securing them together with clamps to ensure structural integrity and wiping away excess epoxy.

5. Let cure 24 hours.

Fin and FSM

Manufacturing Methodology for Trapezoidal Fins
1. Take carbon fiber stock and demarcate lines along which the stock will be cut.
2. Using Dremel hand saw and a vacuum, cut out trapezoidal fins while vacuuming the carbon fiber sawdust.
3. Lightly sand edges of fins to reduce chances of splinters and smoothen sharp and/or rough cuts.

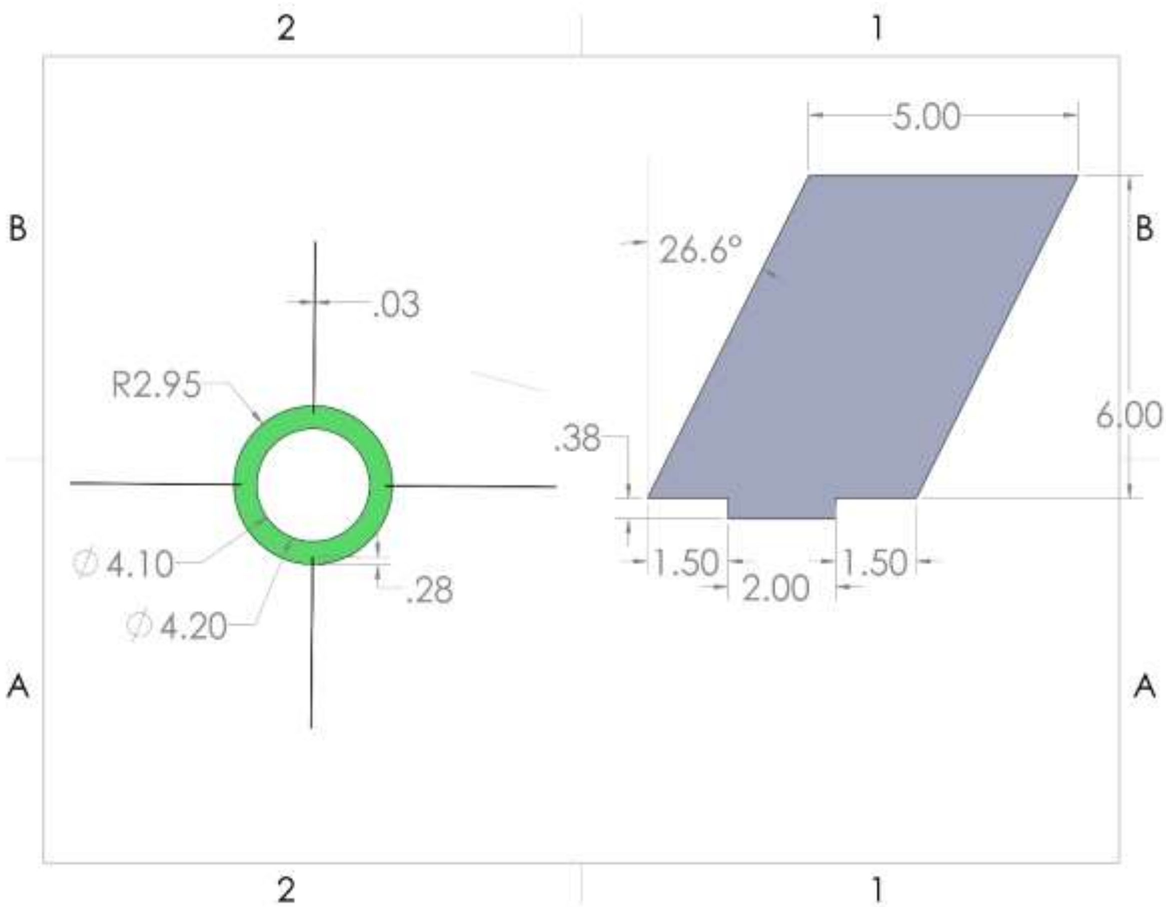

Figure 12: FSM and Fin Drawings

Manufacturing Methodology for FSM
1. The FSM's 3D model is uploaded to a 3D printer, and printed out as one whole piece
2. Visually inspect nose cone for structural protrusions. If it cannot be appropriately reduced by means of sanding, restart with new FSM.
3. Test fit FSM into 22 in. body tube. If it does not fit, lightly sand edges until it does.

4. Test fit FSM onto phenolic tube. If it is too small or too large, reprint a new FSM with a different size.
5. Test fit trapezoidal fins into FSM slots. If slots are too large or too small, reprint a new FSM with appropriately sized slots.

Nose Cone Vehicle Section Assembly

1. Screw hole through center of nose cone bulkhead for eyebolt.
2. Thread eyebolt through, lightly coat protruding end with epoxy and thread the nut onto the eyebolt, wiping away excess epoxy.
3. Let cure for 24 hours.
4. Demarcate position of bulkhead within nose cone, and coat interior wall of nose cone that will be making contact with the bulkhead with epoxy.
5. Put bulkhead into demarcated position and secure it there.
6. Let cure for 24 hours. If need be, additional epoxy can be added once bulkhead is placed to ensure attachment to nose cone parent component.
7. Secure quicklink to eyebolt.

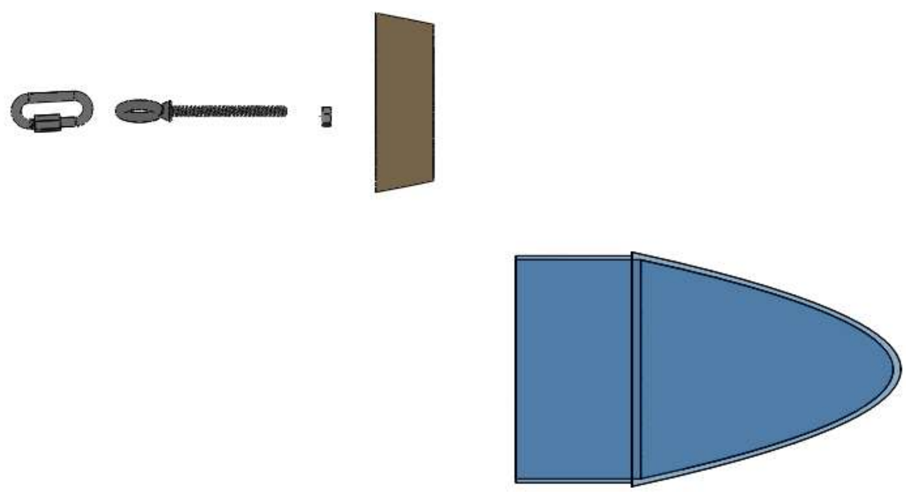

Figure 13: Nose Cone Assembly

Upper Body Tube Vehicle Section Assembly

Refer to Section 4.2.1.

Lower Body Tube Vehicle Section Assembly

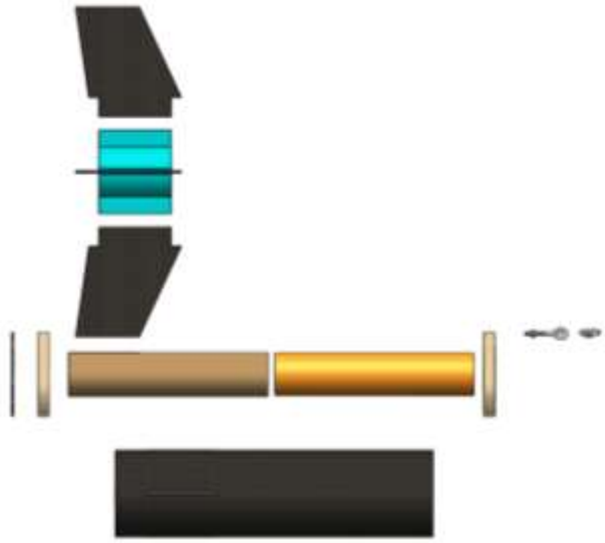

Figure 14: Upper Body Tube Assembly

1. Screw hole through center of forward centering ring for eyebolt.
2. Thread eyebolt through, lightly coat protruding end with epoxy and thread the nut onto the eyebolt, wiping away excess epoxy.
3. Let cure for 24 hours.
4. Epoxy forward centering ring onto forward end of phenolic tube, the FSM 2.4 in. away from the rear end of the phenolic tube, rear centering ring onto the rear end 0.13 in. away from rear end, and aluminum centering ring onto rear centering ring (ensure exterior surface of aluminum ring is flush with end of phenolic tube.
5. Let cure for 24 hours.
6. Coat with epoxy the interior body tube wall where the forward centering ring will be in contact, slide the phenolic tube assembly past the forward centering ring, and coat with epoxy the interior body tube wall where the rear centering ring and aluminum ring will be in contact.

Figure 15: Motor Stabilizing Assembly

7. Slide phenolic tube assembly into position, ensuring the FSM slots are lined up with the fin slots cut into the body tube (the fins can be inserted for this purpose).
8. Let cure for 24 hours (an upright condition on a level surface is recommended).
9. Coat fin tabs with epoxy and insert into the body tube and FSM slots one at a time, securing each one with tape or by other means. Wipe away excess epoxy.
10. Let cure for 24 hours.

3.1.6. Design Integrity

Material selection is discussed in design overview section. Material and vehicle component testing are covered in section 6.1

3.1.7. Design Justification

Justification for material selection, dimensioning, and other design aspects are discussed in design overview and manufacturing readiness sections.

3.2. Recovery Subsystem

The recovery subsystem is responsible for ensuring the completion of three major events, deployment of drogue chute at apogee, deployment of the main chute at 700 ft AGL, and touchdown.

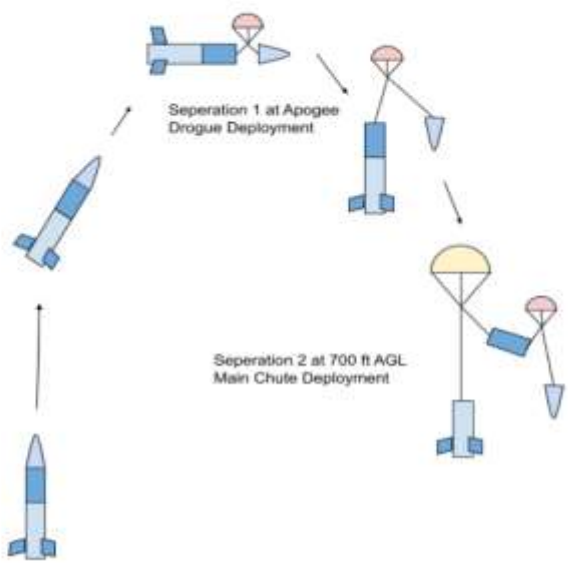

Figure 16: Recovery System Event Diagram

3.2.1. PDR Alternative Selection

Within the recovery subsystem, alternates had to be considered in parachute sizing, hardware choices, materials, and electrical components.

The team also considered an entirely different recovery system with the use of a chute release. This device uses an altimeter to release the parachute at a predetermined altitude. The chute release does not use pyro charges in its deployment method, instead it uses the motor’s ejection charge to eject the parachutes. After consideration, the team decided to not include this in our design, as it would be overly expensive and would lead to technical difficulties.

Parachutes

After further calculations, the main parachute is determined to be 7 feet in diameter with a weight of 8 oz and 0.97 for the drag coefficient. The drogue parachute is determined to be 2 feet in diameter with a weight of 0.6 oz and 0.75 for the drag coefficient. Both parachutes are made from nylon and will be purchased from different vendors. These parachute diameters were determined by using the kinetic energy equation and solving for the descent velocity of the upper body tube. The max kinetic energy from the handbook (75 ft-lbf) was used in the calculation to find the max descent velocity which turned out to be 22.5 ft/s. After finding the max descent velocity, parachute sizes were estimated until a ground hit velocity less than the max descent velocity was determined through simulations on OpenRocket. A ground hit velocity of 19.4 ft/s was found with these parachute sizes and drag coefficients. Once this was found, the kinetic energy values for the nosecone, upper and lower body tubes were determined. The kinetic energy for the nosecone, upper body tube, and the lower body tube were respectively determined to be 11.69 lbf-ft, 55.69 lbf-ft, and 27.8 lbf-ft by using the kinetic energy equation with the ground hit velocity determined through OpenRocket and the corresponding masses of the nosecone, the upper body tube, and the lower body tube.

Additionally, descent times were recalculated to fix past errors and can be seen in Section 3.3.4.

Bulkheads

Figure 17: Bulkheads

The bulkheads are the major load bearing aspect of the recovery system along with the adhesive that secures the bulkheads to the airframe. When considering the material for the bulkheads, the most important aspects of the materials are material weight, strength, and cost. The materials that were considered for the bulkheads were carbon fiber and pine wood. To determine material for the bulkheads, both the manufacturing process and the material properties were considered. As seen by previous uses, pine is less prone to release of particulates when cut to specific dimensions. Carbon fiber may hold some advantages with an estimated strength to weight ratio of 2457 kN*m/kg while oak (similar to pine) has a strength to weight ratio of 87 kN*m/kg. The rigidity of carbon fiber is about 20 times stronger than pine.

The team then looked at securement strategies. Bulkheads could be epoxied in or screwed in with screws from the outside of the vehicle. Epoxy offers more assurance of its strength; however accurate application is very difficult and incorrect application could tamper with the payload or other sensitive components.

Resins have worked in the past for our team, so the team decided to stick with resins, specifically epoxy. Regarding resins, most of the components of the rocket were treated with epoxy but before deciding on the resin, properties between polyester resin and epoxy resin were compared. The following table details the properties of both resins and its hardness.

Table 4: Resin Properties

Resin Type:	Viscosity (cpl)	Density (g/cm3) (20 ºC)	Gelling time (min.)	Elongation at break (%)	Hardness (Barkol)
Epoxy	156	1.2	110-130	1.0	66
Polyester	450	1.6	8	2.3	45

The pine wood applied with the epoxy resin has an overall lower density than the one where polyester was the resin. The epoxy and polyester resin had the overall similar effects on the strength of the pine. In addition, the epoxy resin provided a greater hardness and minimal elongation occurs during failure. The minimal elongation is preferred, specifically for the locking mechanism as it will hold a pull of force for a longer period of time and should resist strain applied

Bolt Types

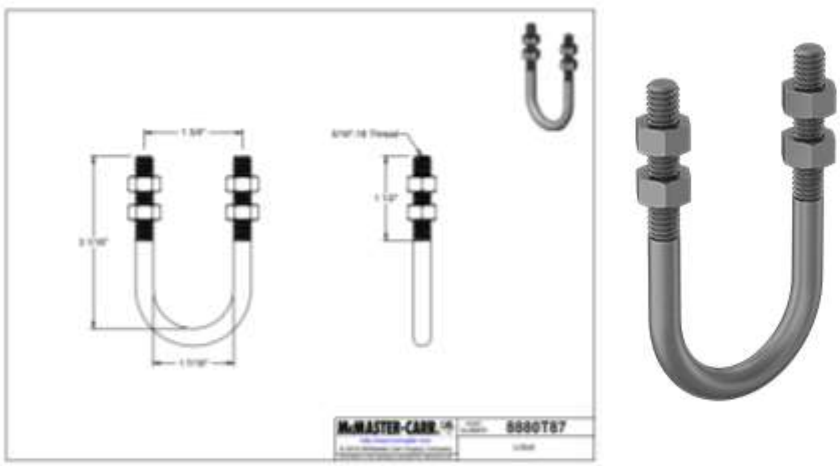

Figure 18: U-Bolts

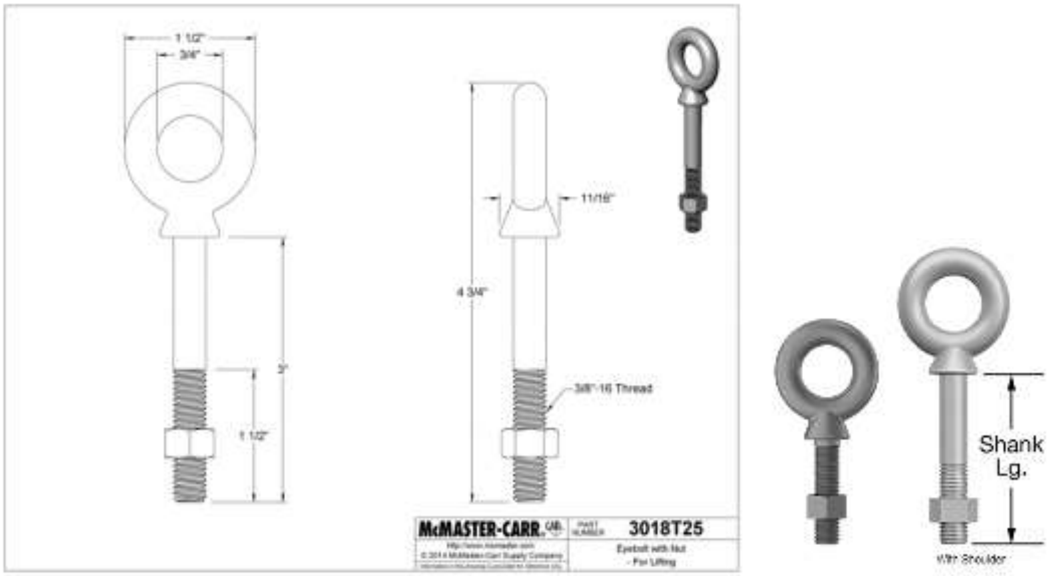

Figure 19: Eyebolts

When analyzing load-bearing bolts, two aspects must be considered: number of interface points (as defined by the number of threaded legs) and the load bearing capabilities of the structure. While a u-bolt would provide double the interface with the bulkhead, decreasing the chances of it being ripped out on recovery system deployment, it is not very strong. This particular u-bolt can only hold 600 lbs of force with no factor of safety. Eyebolts only have one interface with the bulkhead so they are more likely to be ripped out the vehicle. Other than this, its vertical capacity is 1,200 lbs, far exceeding the force that will be seen by the vehicle during flight. The team opted for a larger eyebolt than last year's design to increase the vertical capacity load since the team had the space in the vehicle to opt for a large eyebolt.

Locking Mechanism Design

The goal of the locking mechanism is to shield critical safety electronics in the avionics bay from hazardous forces during flight while providing easy access to the avionics bay. The locking mechanism simplifies the way electronics are implemented into the launch vehicle.

A concept for this involves a male screw cap that interlocks with a female threaded bulkhead ring. The following image better visualizes this concept.

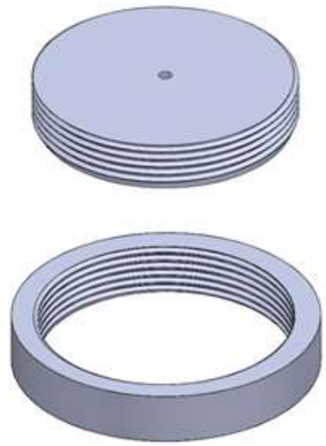

Figure 20: Threaded Locking Mechanism

Using mating male and female threads as a securing mechanism enable the electronics within the avionics to be easily positioned into the launch vehicle. This also allows the thickness of the locking mechanism to be varied depending on the space within the launch vehicle. However, for both male and female threads to screw on properly without forcing the two pieces together, the parts must be machined with a high degree of precision. Due to the complex geometries of the parts, material options are limited. To achieve the desired precision, the parts would have to be 3D printed using an SLA 3D printer. Traditional FDM printers have a bigger print bed and faster print speeds, but their precision is limited to the nozzle diameter. An FDM printer must be used, but their limited build size may not permit these large parts to be printed.

Another alternative involves a simple slide-and-lock mechanism. This system involves an inner ring which slides into place vertically and then rotates axially to lock into place. The following image illustrates the design.

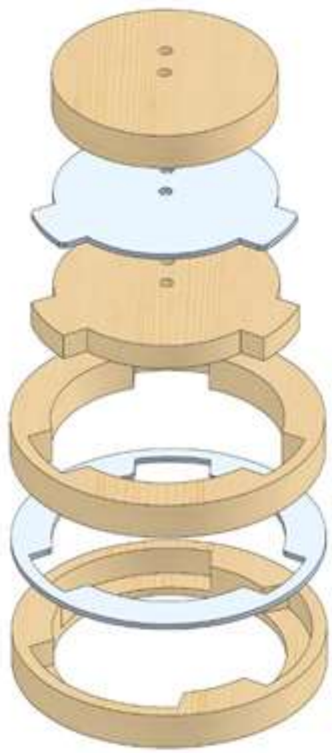

Figure 21: Slide-and-Lock Locking Mechanism

Because the geometry of the assembly is simple, component manufacturing is also simplified. This simple, yet robust design permits a greater variety of materials to be used. Primarily, wood and metals can be CNC'd to specification. A double layered wooden locking mechanism with reinforcing aluminum sheets can be implemented.

Since the inner ring is locked into position through friction fitting, there is a possibility of the locking mechanism rotating out of the locked position and sliding out. The chances of this happening are low, but it must be considered when tolerancing for manufacturing. Another issue is that the tabs must be sufficiently long to withstand forces from black powder charges and parachute deployment. By increasing tab length, the usable circular area for the avionics sled decreases. This design can cause unexpected complications within the avionics system if space is decreased. The avionics system is easier to wire and maneuver if more space is allotted for the avionics system.

3.2.2. Hardware

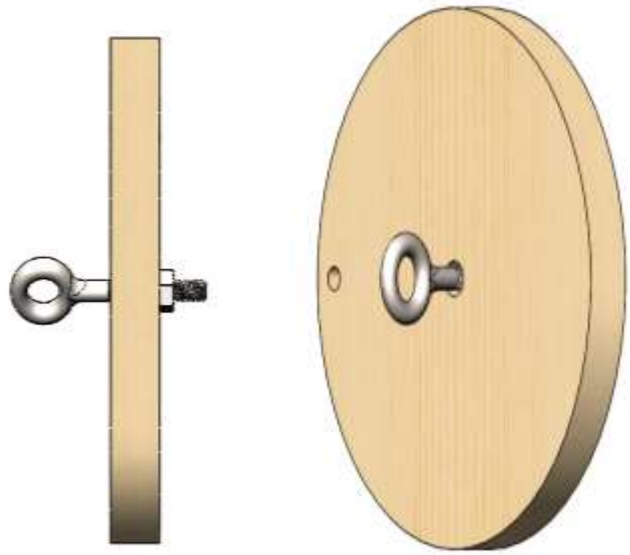

Figure 22: Pine Bulkhead

Since pine bulkheads are easier to manufacture, pine will be selected over carbon fiber. Further virtual testing will allow our team to ensure that this material can withstand the forces of launch.

Connecting to the eyebolts is a quicklink which allows for the attachment of the parachute to the shock cords which are directly attached to the eyebolt.

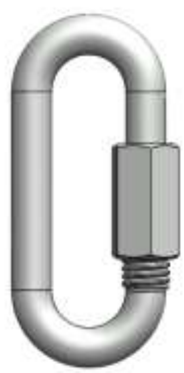

Figure 23: Quicklink

While there weren't any alternatives to this piece of hardware, alternatives will only be considered if testing demonstrates that this mechanism will fail under given launch conditions. The quicklink above is made of stainless steel and has a capacity of 1,400 lbs, which exceeds the actual forces expected during flight. Shock cords are then used to connect quicklinks together between the shroud lines of the parachute. Shock cords are designed to withstand the forces of deployment and are made of tear resistant nylon. There is no current alternative to this component. Fire cloths are attached to the end of parachute shroud lines so that packed components within the rocket pre-launch can ensure to not be damaged by black powder charges during recovery events. Since these are effective in mitigating charge damage, there is no current alternative to them. To ensure early deployment isn't a possibility, shear pins are used to keep the nose cone shoulder and coupler in place. Since these have repeatedly been successful in past launches, there is no considered alternative to them. An assembled display of recovery hardware can be seen below.

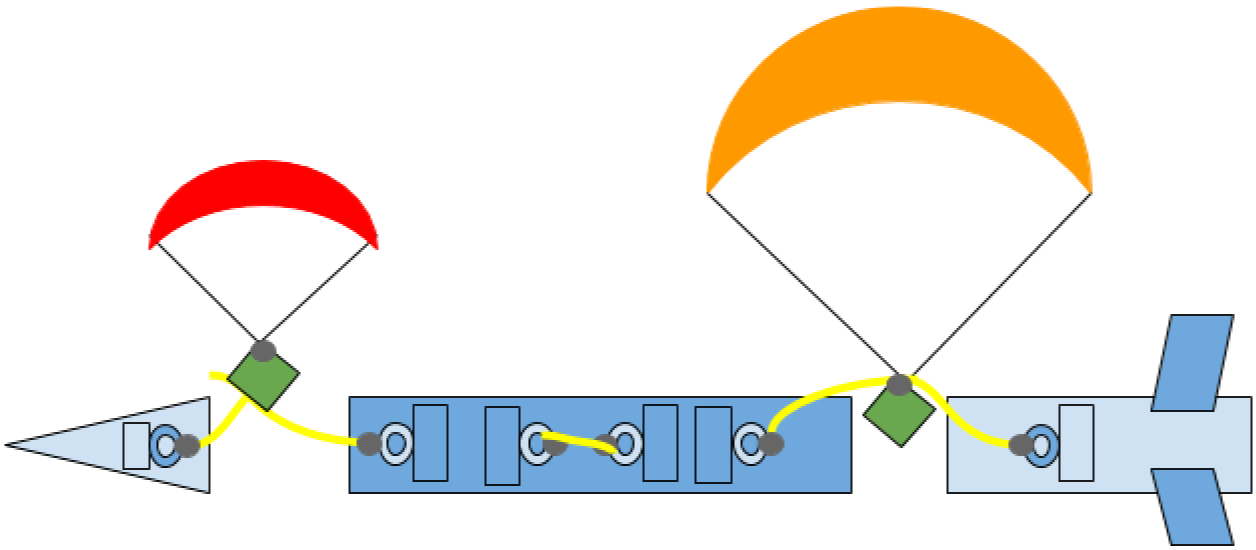

Figure 24: Recovery system with hardware

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.

3.2.2.1 Avionics Bay and Locking Mechanism

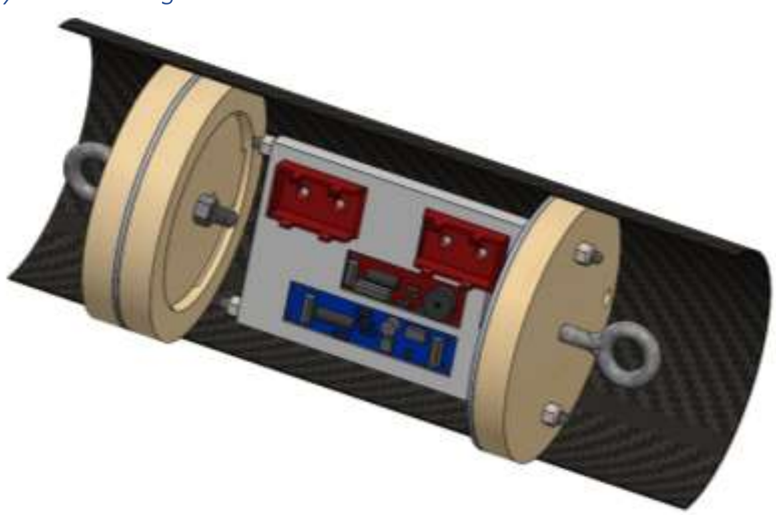

Figure 25: Avionics Bay

In order to shield and fasten onboard electronics, provide easy access to the avionics bay, and safely tether the drogue parachute to the launch vehicle, an avionics bay comprising of a locking mechanism and an avionics sled that slides and fastens onto threaded rods. The avionics bay has a usable internal volume that is ~6” in diameter and 7.5” in length. This avionics bay configuration has the benefit of being able to slide the avionics sled and all its wired components into a set of 1/4"-20 threaded rods. Once positioned, the avionics sled is fastened using 1/4"-20 locknuts and wires outside the avionics bay are positioned within the avionics bay. The threaded rods are attached to a load bearing bulkhead that faces the payload using 1/4"-20 locknuts. Because of the avionic sled’s minute mass, the assembly does not impose a concerning load to the structural bulkhead. The following figure helps illustrate the assembly process of the avionics bay.

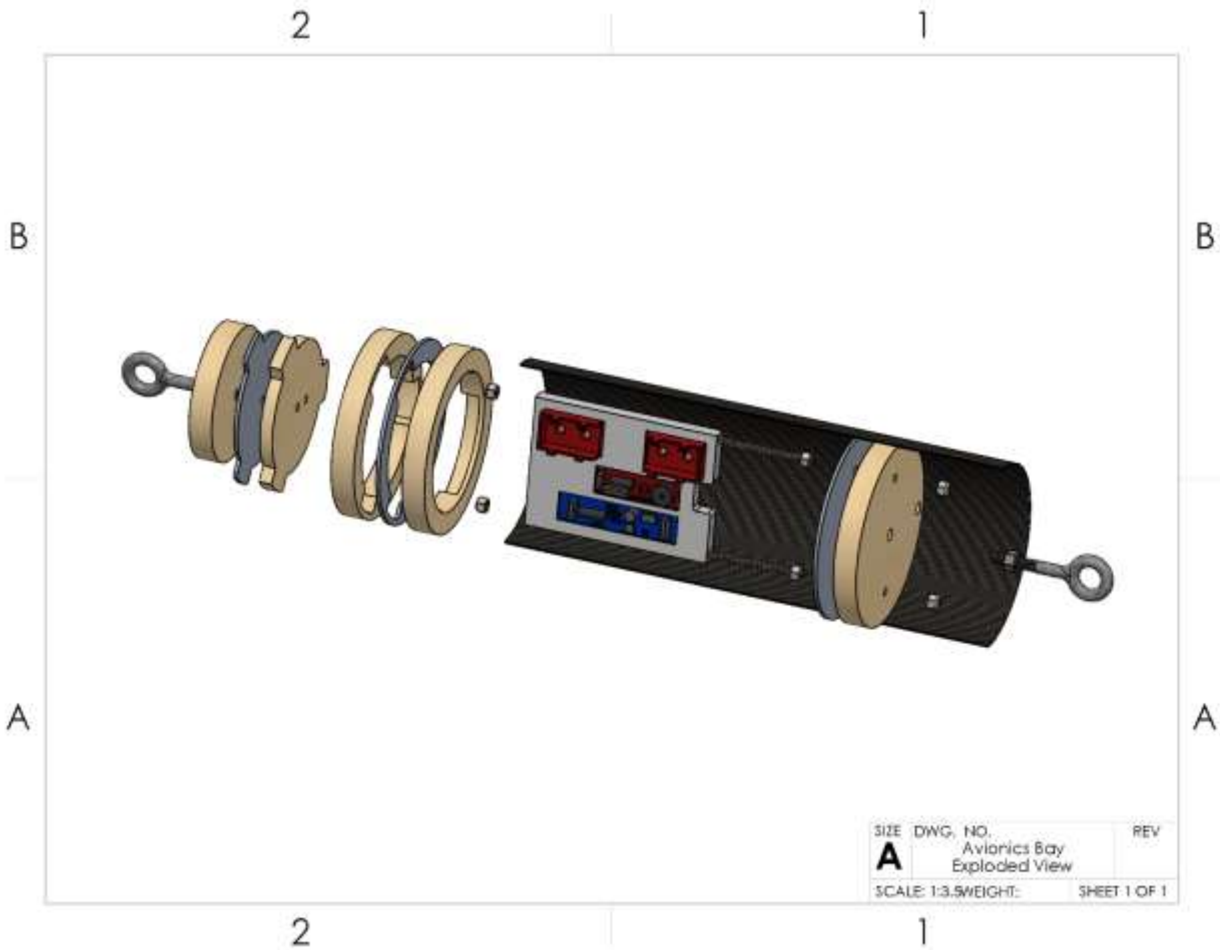

Figure 26: Exploded View of Avionics Bay

The leftmost wood and aluminum assembly is the locking mechanism. This assembly securely fastens the launch vehicle to the launch vehicle while also providing easy access to the avionics bay.

Figure 27: Exploded View of Locking Mechanism

The locking mechanism consists of 6 different components which are reduced into two core components: an inner ring and an outer ring. Both the inner ring and outer ring are manufactured using two cross-grain 0.75” thick slabs of pine wood and 0.12” thick aluminum sheets. Wooden pieces will be manufactured using a CNC mill and aluminum sheets will be waterjet to size. All components comprising each core assembly will be bound together using epoxy. The total thickness of the locking mechanism is 1.62”, not including the galvanized 3/8” eyebolt. Each inner ring tab is 1.3” wide and 1” in length for a total contact area between the inner and outer ring assemblies of 3.9 in^2. The decrease in contact surface area indicates an increase in stress on each tab, which poses a safety hazard. Preliminary testing of the locking mechanism is outlined in section 6.1.1. Vehicle Testing, however, physical testing will also be done. Dimensions of each component is provided in the following figures.

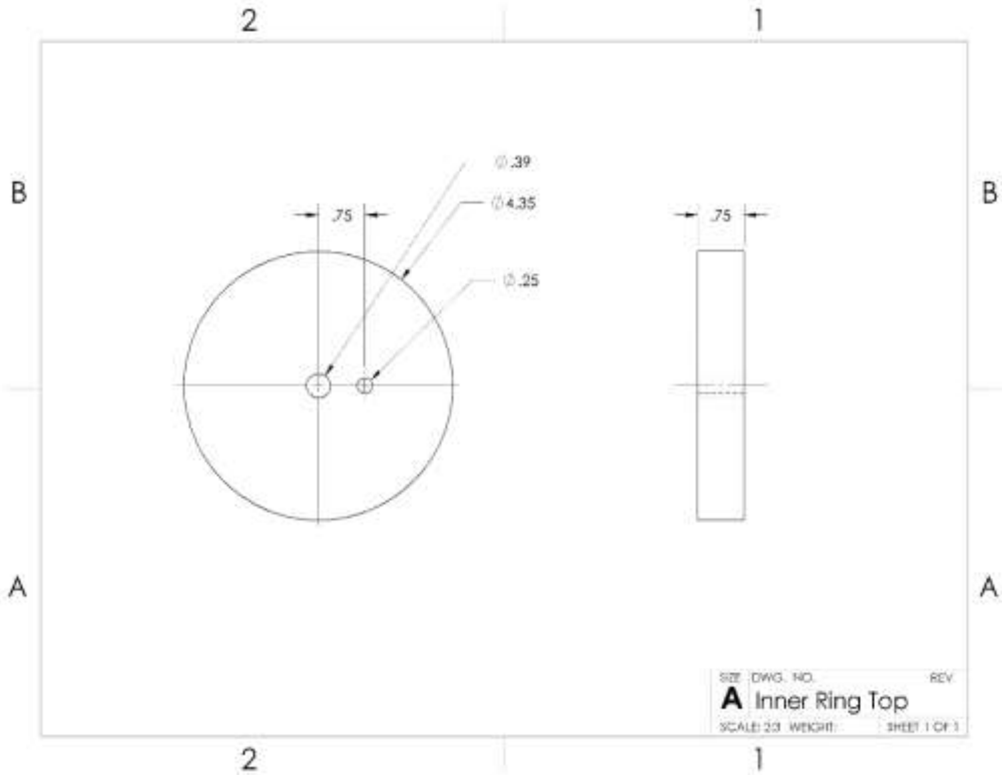

Figure 28: Drawing of Inner Ring Top

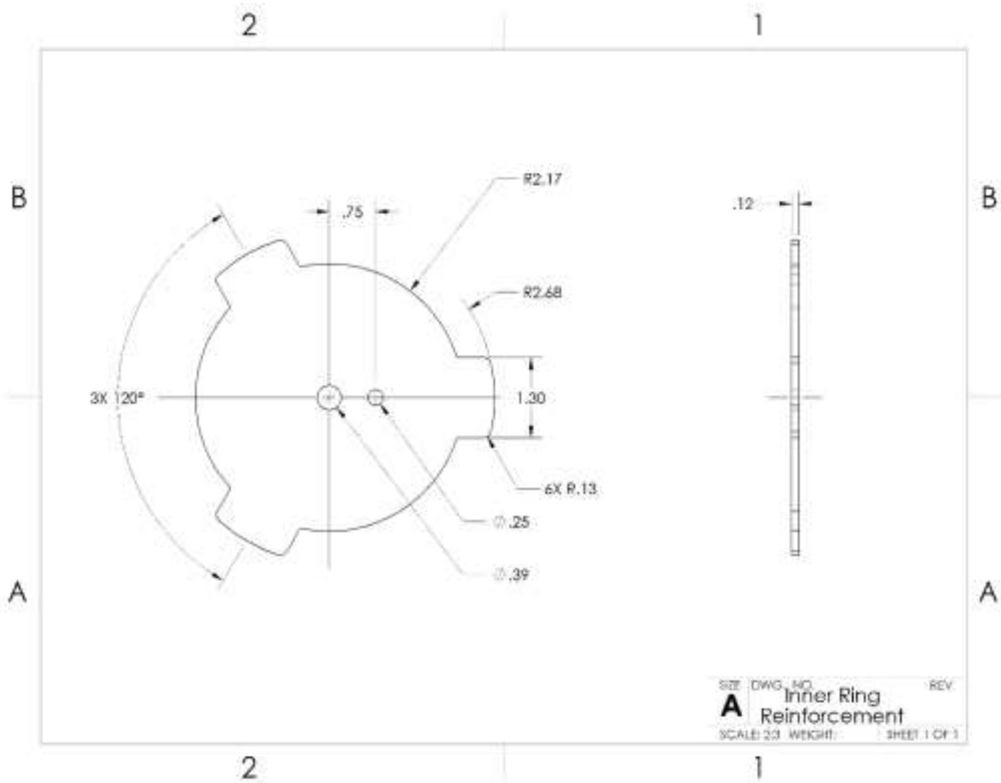

Figure 29: Drawing of Inner Ring Reinforcement

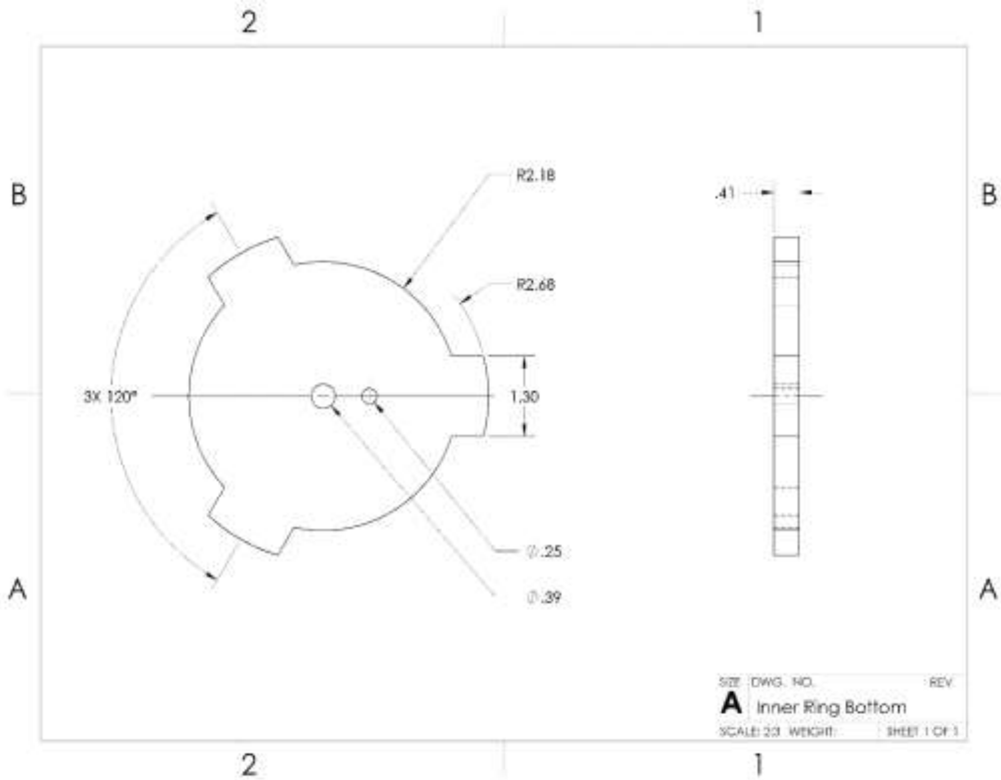

Figure 30: Drawing of Inner Ring Bottom

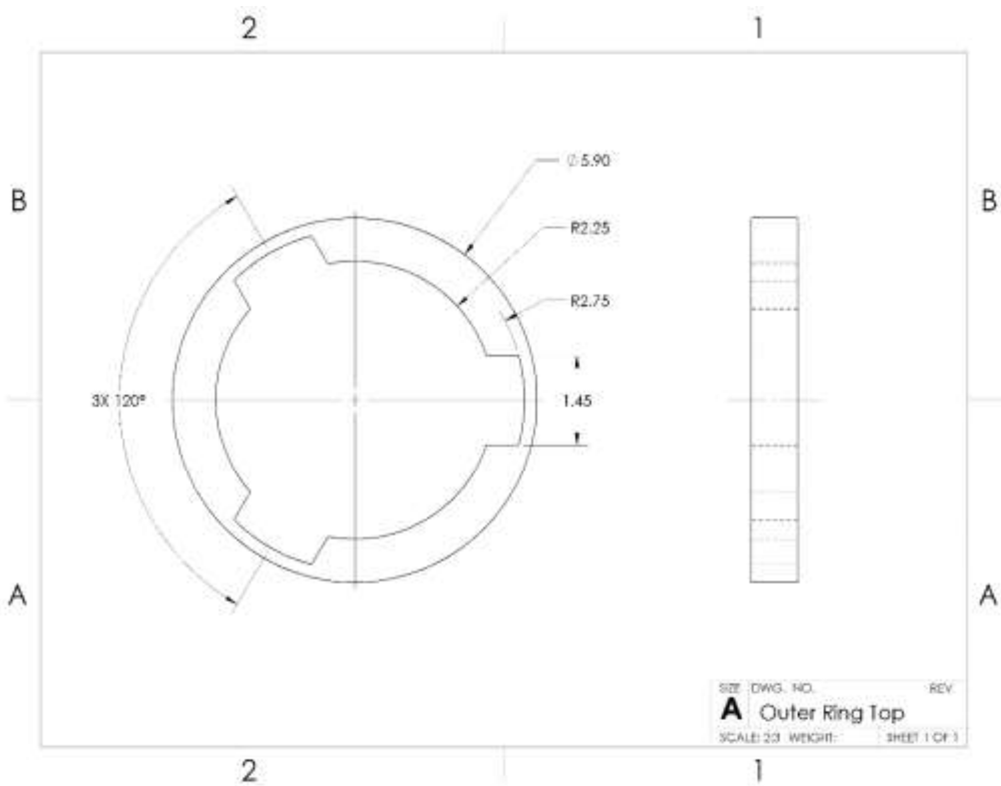

Figure 31: Drawing of Outer Ring Top

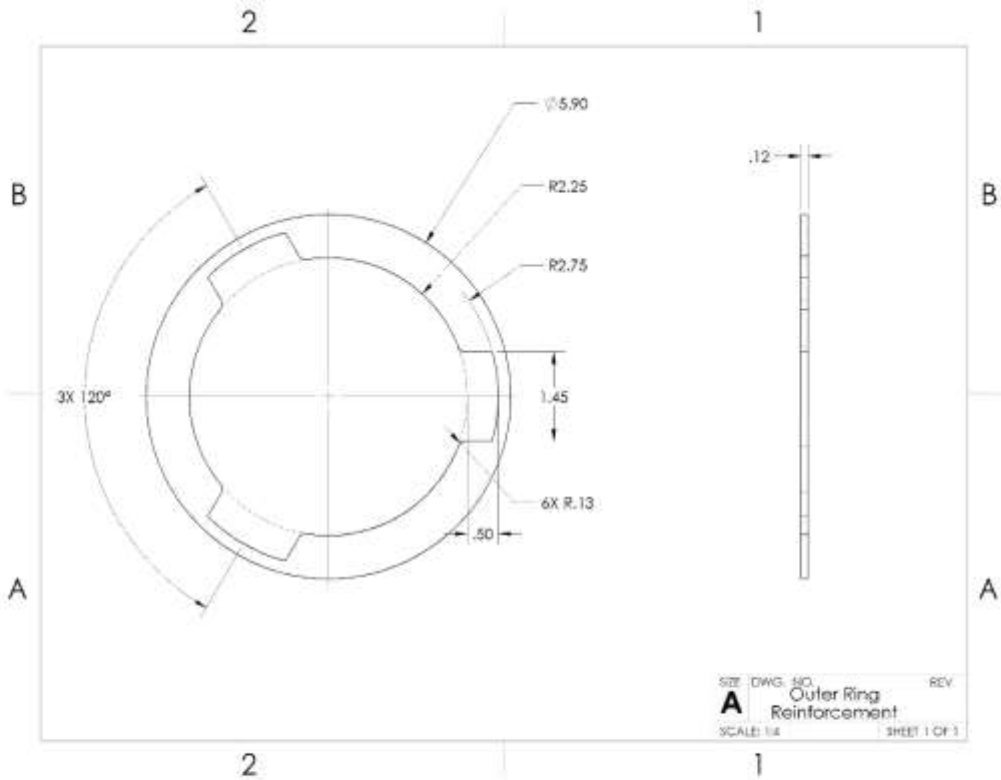

Figure 32: Drawing of Outer Ring Reinforcement

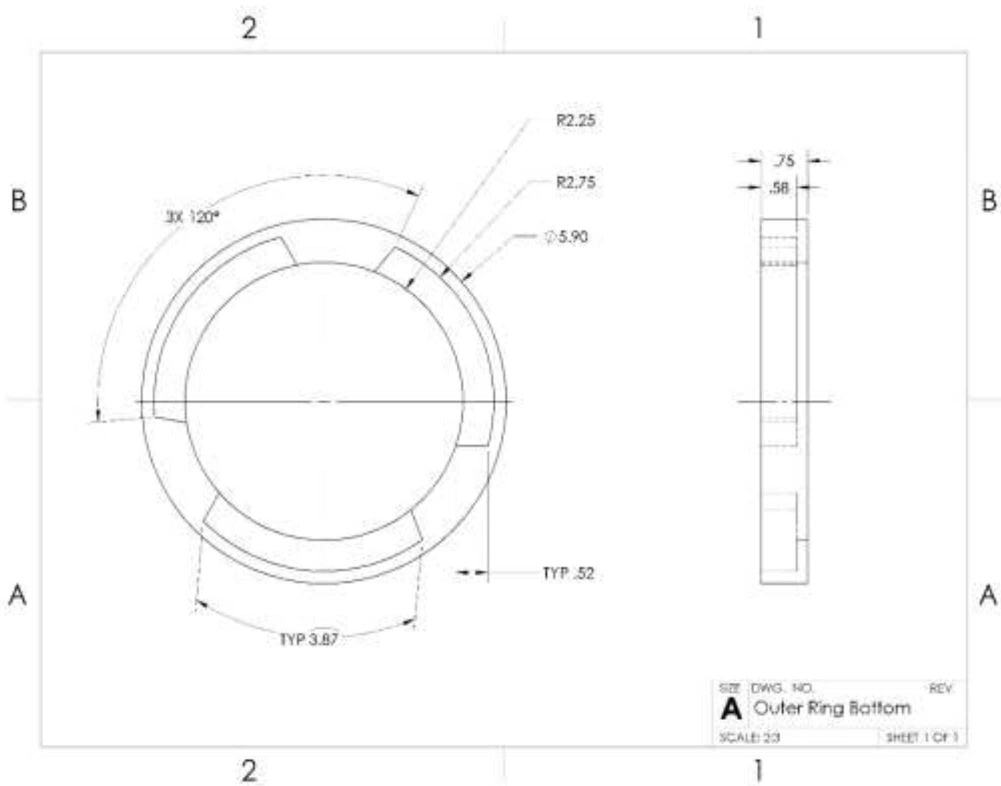

Figure 33: Drawing of Outer Ring Bottom

The bulkhead section that allows the 1/4"-20 threaded rods to fastened to the launch vehicle is composed of a pine bulkhead and an aluminum sheet of reinforcement. This bulkhead is also tasked with fastening the main parachute to the launch vehicle through the use of a 3/8”-16 galvanized steel eyebolt. An aluminum sheet of reinforcement is necessary since the bulkhead section must endure the forces imposed by the deployment of the main parachute. The dimensions of this section are outlined in the following figures. An additional hole towards the outer diameter of the bulkhead is included to run wires for the main parachute ejection charges.

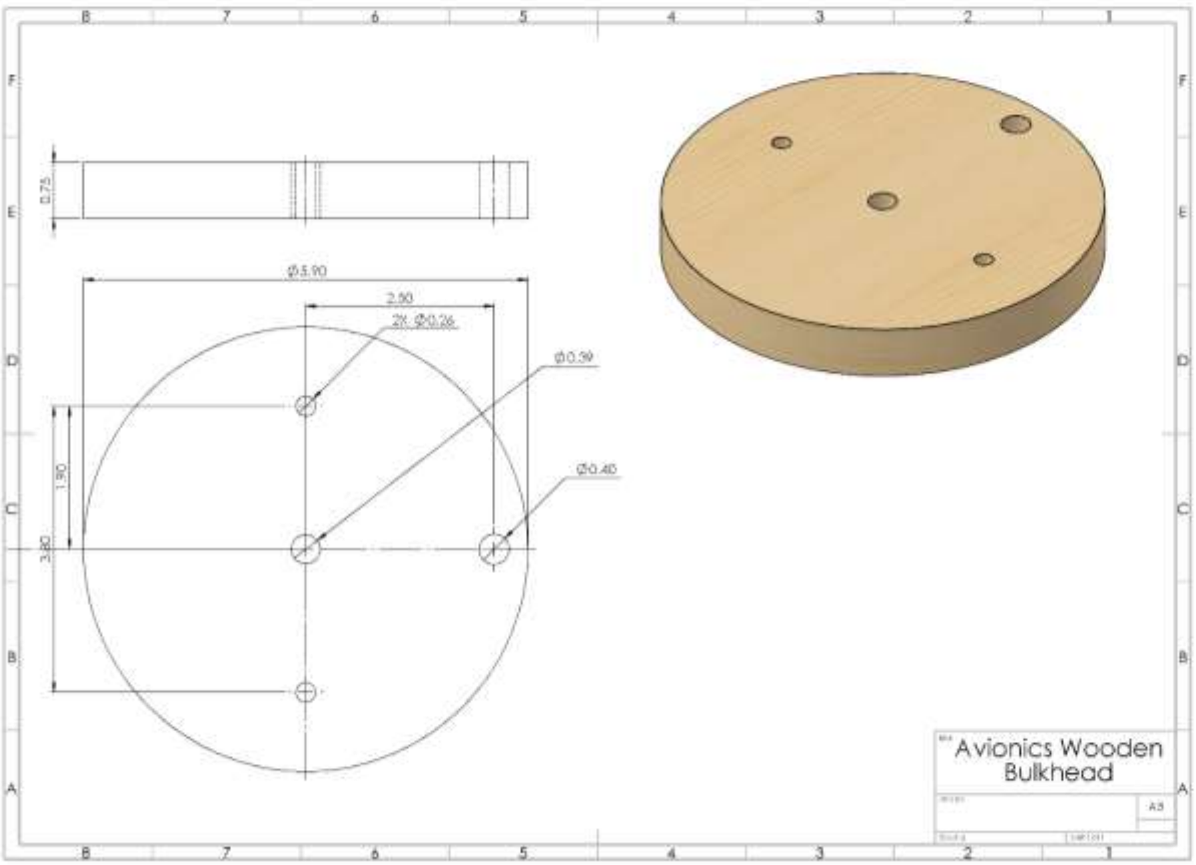

Figure 34: Drawing of Avionics Bay Wooden Bulkhead

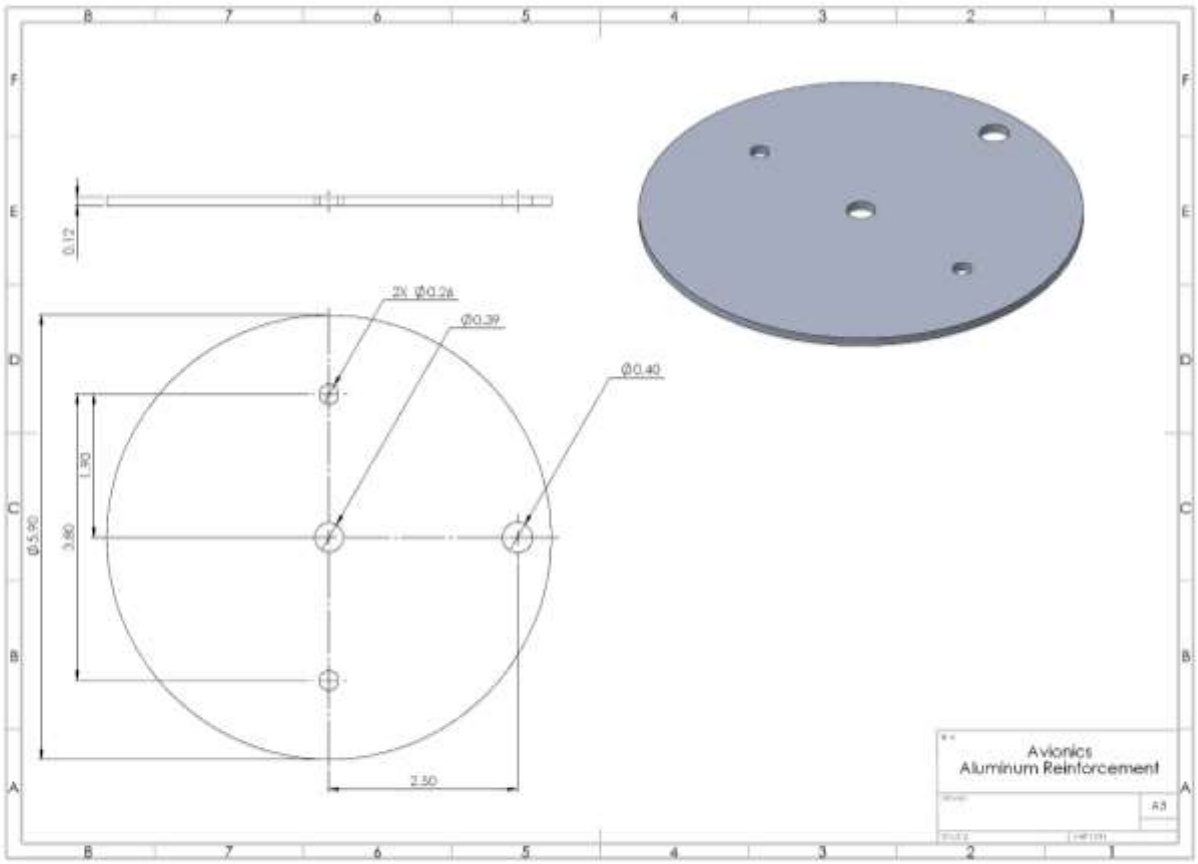

Figure 35: Drawing of Avionics Bay Aluminum Reinforcement Sheet

3.2.3. Electrical Components

3.2.3.1 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. The system itself will be a dual deployment system due to the high projected apogee altitude that will be deployed at specific altitudes once they are reached.

The altimeters that were considered were chosen based on their dual deployment feature, programmability, and size.

Considered Altimeters:

- Entacore AIM Altimeter
  - Has dual deployment
  - Included with software, needs USB dongle
  - 2.56” X 0.98” X 0.59” (L X W X H)
- Stratologger SL 100 Altimeter
  - Has dual deployment
  - Included with software, needs USB dongle
  - 2.75” X 0.90” X 0.50” (L X W X H)

- RRC3 Sports Altimeter
    - Has dual deployment
    - Included with software, needs USB dongle
    - 3.92” X 0.92” X 0.46” (L X W X H)

The selected altimeters were the Stratologger SL 100 Altimeter and the RRC3 Sports Altimeter, due to their lower height which let them fit better in the avionics bay. Not only that, but two different altimeters were used, once again to promote redundancy and safety within the system. 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. This is also so that if one fails, there is still another altimeter that works, although testing of the two altimeters will always be done prior to any launch.

They will be programmed to deploy at apogee and at 500 feet AGL without delays in order to have a safe descent.

Both altimeters will be individually powered by standard 9V alkaline batteries, once again in order to introduce redundancy within the system and avoid a malfunction of both altimeters. The 9V batteries will be adequate for the altimeters since the Stratologger SL 100 Altimeter has an operational voltage of 4V – 16V and the RRC3 Sports Altimeter has an operational voltage of 3.5V - 10V, where both have an optimal voltage of 9V. Furthermore, the 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.

As another layer of redundancy within the system, each altimeter will be individually powered on by its own key switch. This is done to keep each altimeter as separated from each as possible, and key switches were chosen over buttons since they are less likely to be accidentally turned on, making the system even safer.

Both altimeters have the ability to collect flight data at a rate of 20 samples per second regarding altitude, temperature, and battery voltage. They can then store the data for later use; however, the Stratologger SL 100 Altimeter can store 31 separate 9-minute flights, while the RRC3 Sports Altimeter can store 15 separate 28-minute flights.

Vent Holes Calculation

4 vent holes will be drilled into the body tube in order to obtain accurate pressure readings. They will be drilled in at 90-degree angles to each other in order to line up to the center of the avionics bay.

The size of the vent holes are calculated using the following formulas:

- Area = (*diameter* / 2)^2 * π)
- If the volume of electronics bay < 100 cubic in.
    - *Single Port Diameter = Volume of Electronics Bay* / 400
- If the volume of electronics bay >= 100 cubic in.
    - *Single Port Diameter* = 2 * *√(Volume of Electronics Bay* / 6397.71*)*

The diameter is converted into an area to find the port diameter.

- If several ports are used, the diameter of each hole is:
    - *Multi Port Diameter* = 2 * √(*Single Port Vent Area* / # *of Ports* / π)

The calculations and values for the launch vehicle:

- *Electronics Bay Radius* = 3 in.
- *Electronics Bay Length* = 7.5 in.
- *Electronics Bay Volume* = $3^2 * 7.5 * \pi = 212.06''^3$

Since the Electronics Bay Volume is larger than 100 cubic in.

- *Single Port Diameter* = 2 * √(212.06 / 6397.71) = 0.3641”

With 4 total holes, each hole will have a diameter of

- *Multi Port Diameter* = 2 * √((π * $(0.3641 / 2)^2$) / 4 / π) = 0.182”

3.2.3.2 GPS

A small GPS tracking device will be used to track the rocket’s position, which will be placed inside the rocket. Moreover, it will be placed in the nose cone which is made out of PLA plastic instead of the carbon fiber body tube, since placing it in the body tube in previous years resulted in the GPS losing signal.

The selected device is the T3 (Tiny Telematics Tracker) GPS. This device has the ability to track through a Bluetooth connection with an Android device, with an operational range of up to 9 miles. It is small enough to fit in the nose cone. The dimensions of the GPS are 1” by 2.075” with a 6” antenna.

The GPS will be powered by a 9V nickle hydride battery.

The GPS will be powered on by a push button, which will act as an external method of turning the GPS on, as well as a way to decrease air drag.

3.2.4. Design Overview

(sketches, block diagrams, electrical schematics)

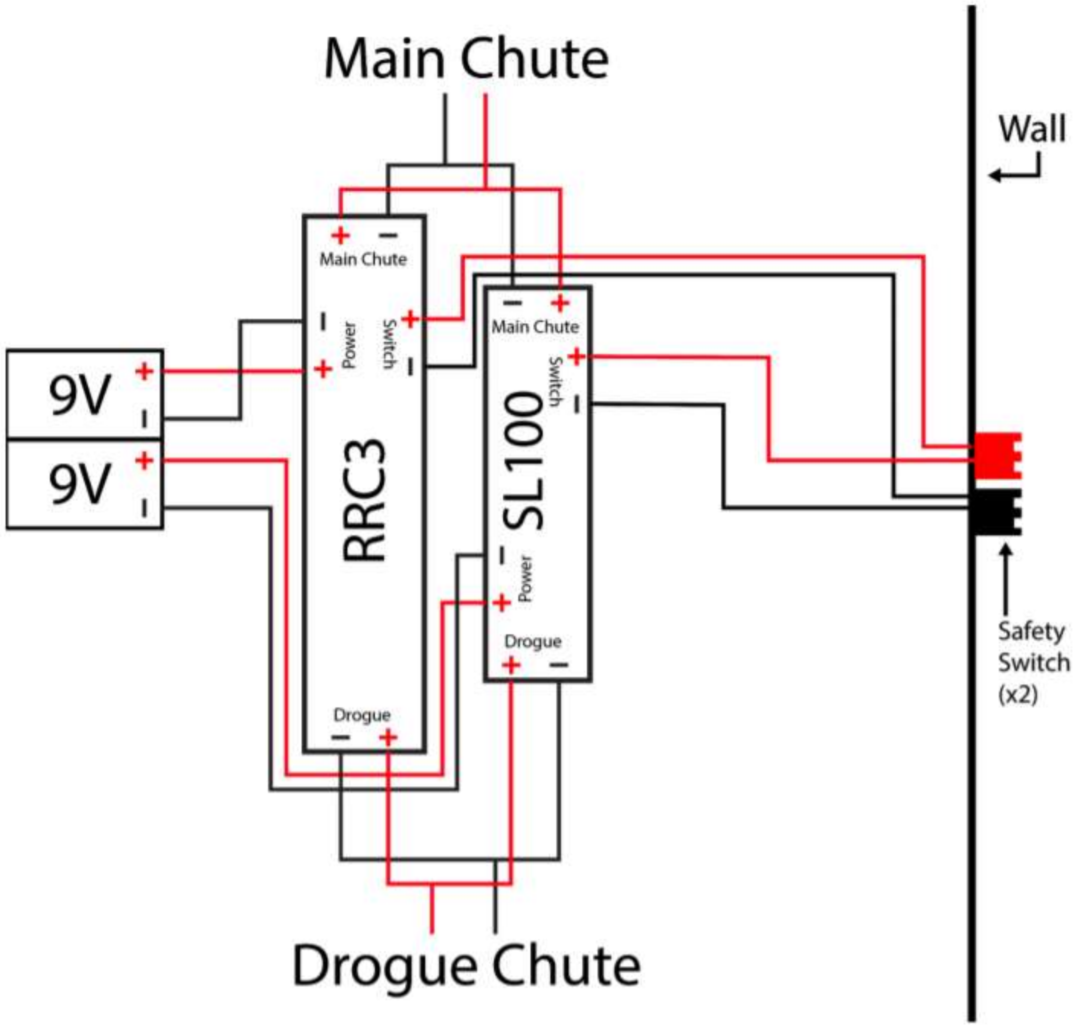

Figure 36: Recovery System Wiring

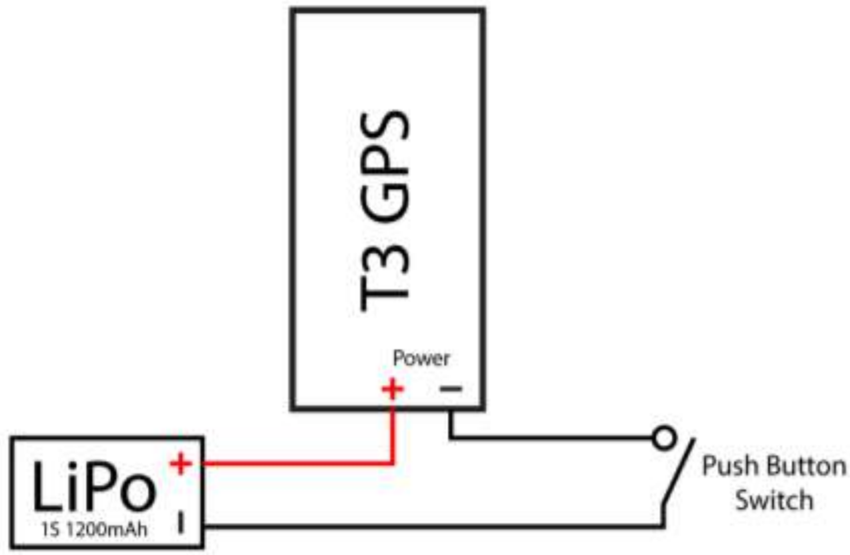

Figure 37: GPS System Wiring

3.2.5. Operating Frequency

To ensure maximum range, and minimum attenuation all trackers will operate at the lowest allowed frequency before needing a specialized license (2.4 GHz)

3.3. Mission Performance Predictions

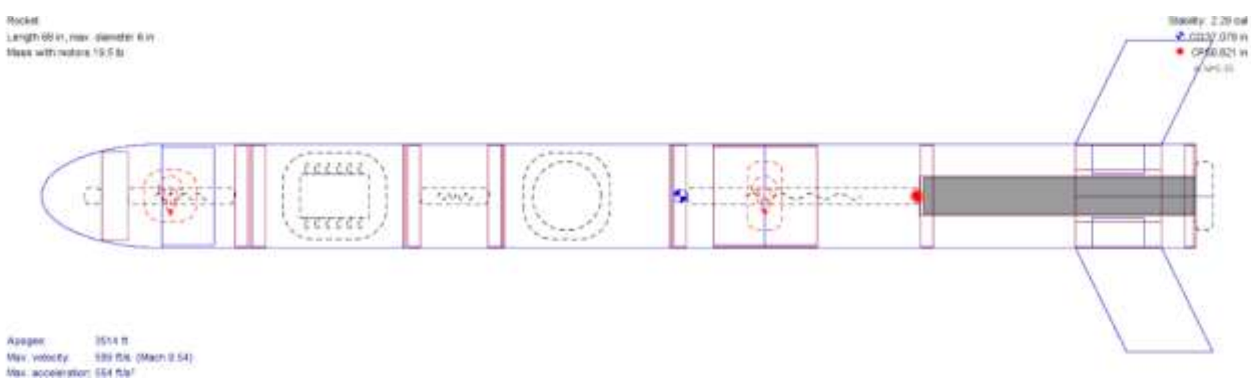

Figure 38: OpenRocket Model

Provided above in Figure 38 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.

For component weights, refer to Section.

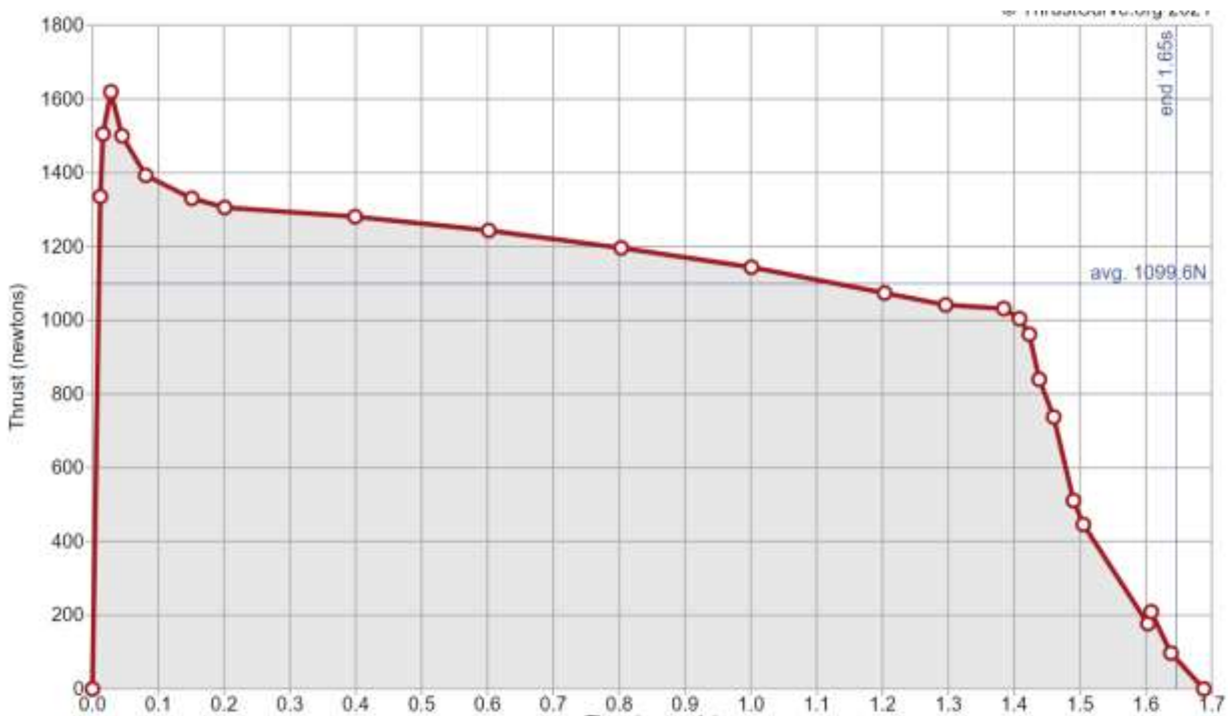

Figure 39: Motor Thrust Curve – K1103X-14

Table 5: Alternate Design 2 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.

Aerotech K-1103X motor shown above with the corresponding thrust curve.

3.3.1. Flight Profile

The official target altitude is set to 3600 ft AGL exactly, based off the estimated apogee of the leading rocket vehicle design simulations and probable additional loss in apogee height through other actors such as launch rail friction.

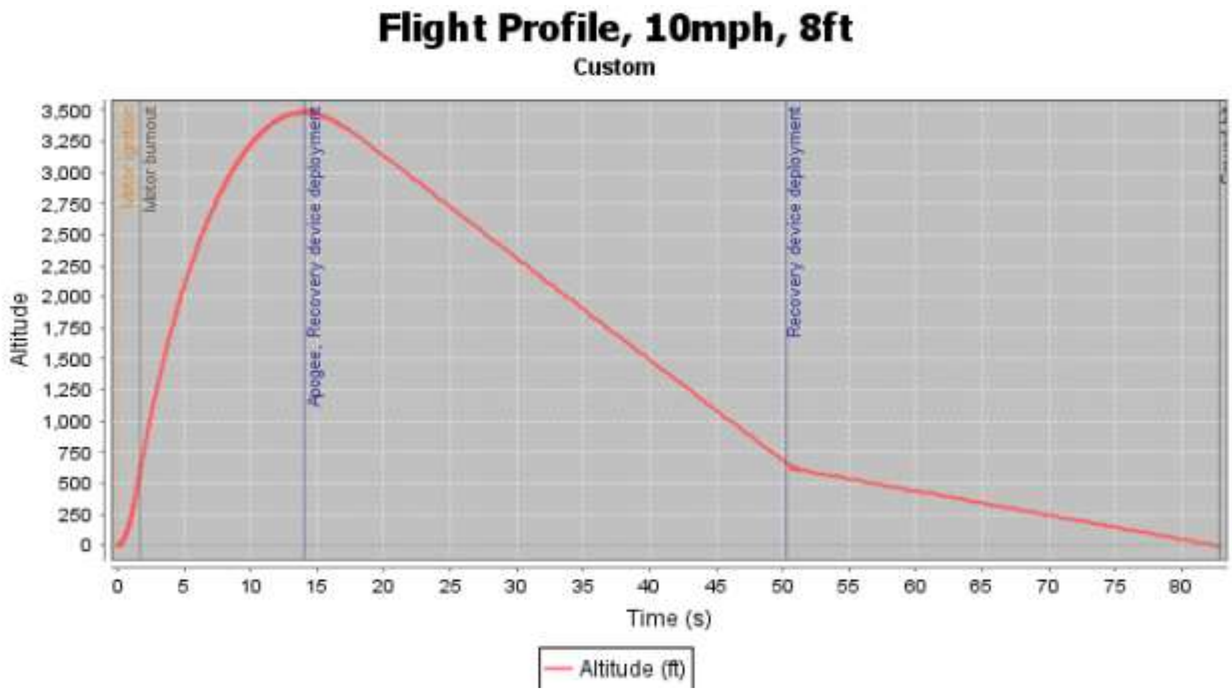

Figure 40: Flight Profile with 10mph winds, 8 foot launch rods

3.3.1.1. Design Robustness

Refer to section 6.1.1 Vehicle Testing to verify the vehicle design is robust enough to withstand the expected loads.

3.3.2. Stability

The CG and CP locations (denoted by the blue checkered circle and red dot with concentric circular border respectively) are as follows:

- CG: **37.08 in.** from the tip of the nose cone.
- CP: **50.82 in.** from the tip of the nose cone.

Together, with a 6 in. diameter body tube, the resulting stability is anticipated to be **2.29**.

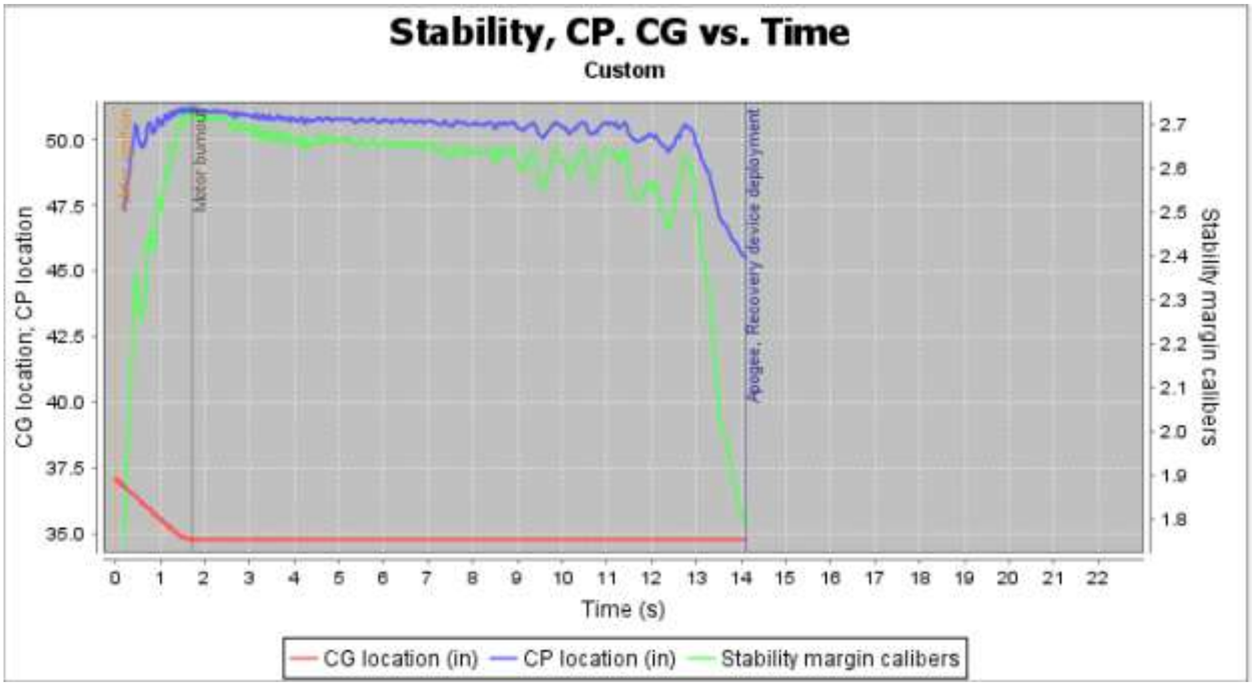

Figure 41: Stability, CP, CG vs. Time

3.3.3. Kinetic Energy

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.

KEmax = 75 ft-lbf = 0.5mmaxvdescent^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.

vdescent = 19.4 ft/s (for a post-burn mass of 17.67lb)

m1= (2 lbf)/(32.2 ft/s^2) -> KE1 = 0.5*m1*vdescent^2 => KE1 = 11.69 ft-lbf.
m2= (9.53 lbf)/(32.2 ft/s^2) -> KE2 = 0.5*m2*vdescent^2 => KE2 = 55.69 ft-lbf.
m3= (4.76 lbf)/(32.2 ft/s^2) -> KE3 = 0.5*m3*vdescent^2 => KE3 = 27.80 ft-lbf

3.3.4. 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 = 80.6 ft/s (for a post-burn mass of lb)
hapogee = 3514 ft AGL, hmain-deploy = 700 ft AGL

Descent Time= (hapogee-hmain-deploy)/vdrogue + hmain-deploy/vmain
Descent Time= 70.996 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 6: Drift Relation to Wind Speed

Wind Speed	0 mph	5 mph	10 mph	15 mph	20 mph
Horizontal Drift	0 ft.	520.614 ft.	1041.298 ft.	1561.912 ft.	2032.8 ft.

3.3.6. Calculation Accuracy Validation

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 7: Landing K.E. for Vehicle Section Trials

Vehicle Section	Nose Cone	Upper Body Tube	Lower Body Tube
Landing Kinetic Energy (1)	12.01 ft-lbf	57.56 ft-lbf	29.36 ft-lb
Landing Kinetic Energy (2)	12.01ft-lbf	57.56 ft-lbf	29.36 ft-lb
Landing Kinetic Energy (3)	12.01 ft-lbf	57.56 ft-lbf	29.36 ft-lb
Landing Kinetic Energy (4)	12.01 ft-lbf	57.56 ft-lbf	29.36 ft-lb

Table 8: Drift relation to Wind Speed Trials

Wind Speed	0 mph	5 mph	10 mph	15 mph	20 mph
Horizontal Drift (1)	0 ft.	131.1 ft	354.5 ft.	642.9	796.4
Horizontal Drift (2)	0 ft.	127.0 ft	346.4 ft.	625.7	812.3
Horizontal Drift (3)	0 ft.	135.2 ft	370.4 ft.	630.3	821.2

Horizontal Drift (4)	0 ft.	125.8 ft	367.8 ft.	683.2	782.8

3.3.7. Differences Between Calculations

In the kinetic energy calculations, little discrepancy is present as descent rate given by the vendor as well as estimated masses of the vehicle components are well measured and precise quantities.

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 much greater discrepancy can be observed. The farthest drift calculations vary by more than a thousand 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.

3.3.8. 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.

4. Payload Criteria

4.1. PDR Alternate Selection

During the preliminary design phase, a 3-DOF system was selected. This payload implementation oriented the base of the payload rather than orient the payload itself. This violates Requirement 4.3.2 in the Student Launch Handbook as the definition of the landing system also includes the base of its landing system. To accomplish the mission without violating design requirements, the simple 3-legged lander concept was selected from the PDR. Further development on the 3-legged lander concept is outlined in this report.

4.2. Design Review

4.2.1. Payload

4.2.1.1. Payload Assembly

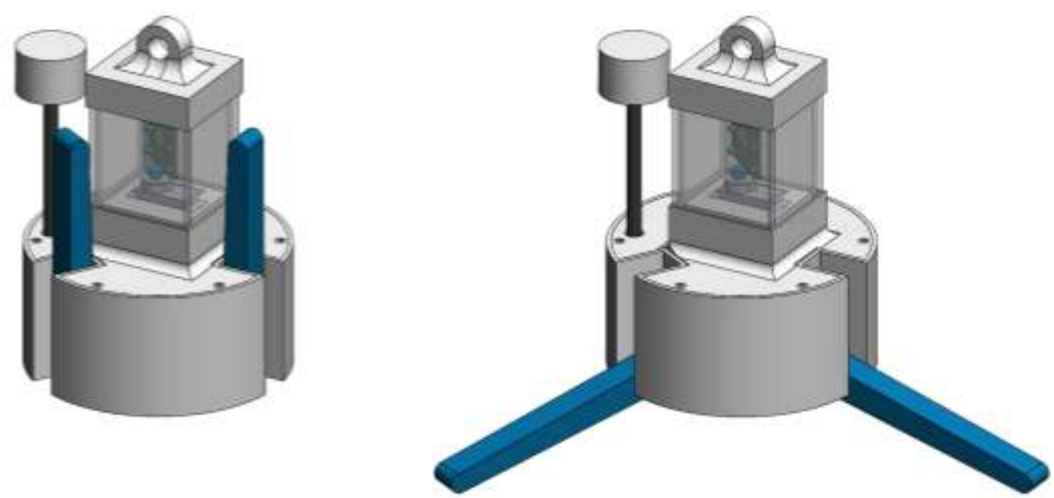

Figure 42: Packed Payload (left) and Unpacked Payload (right)

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 acrylic sheets are also load bearing structural components as the parachute is tethered to the top of the payload's central column. These acrylic sheets are epoxied to the main cover of the payload and the top cap that harnesses the parachute. 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.

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

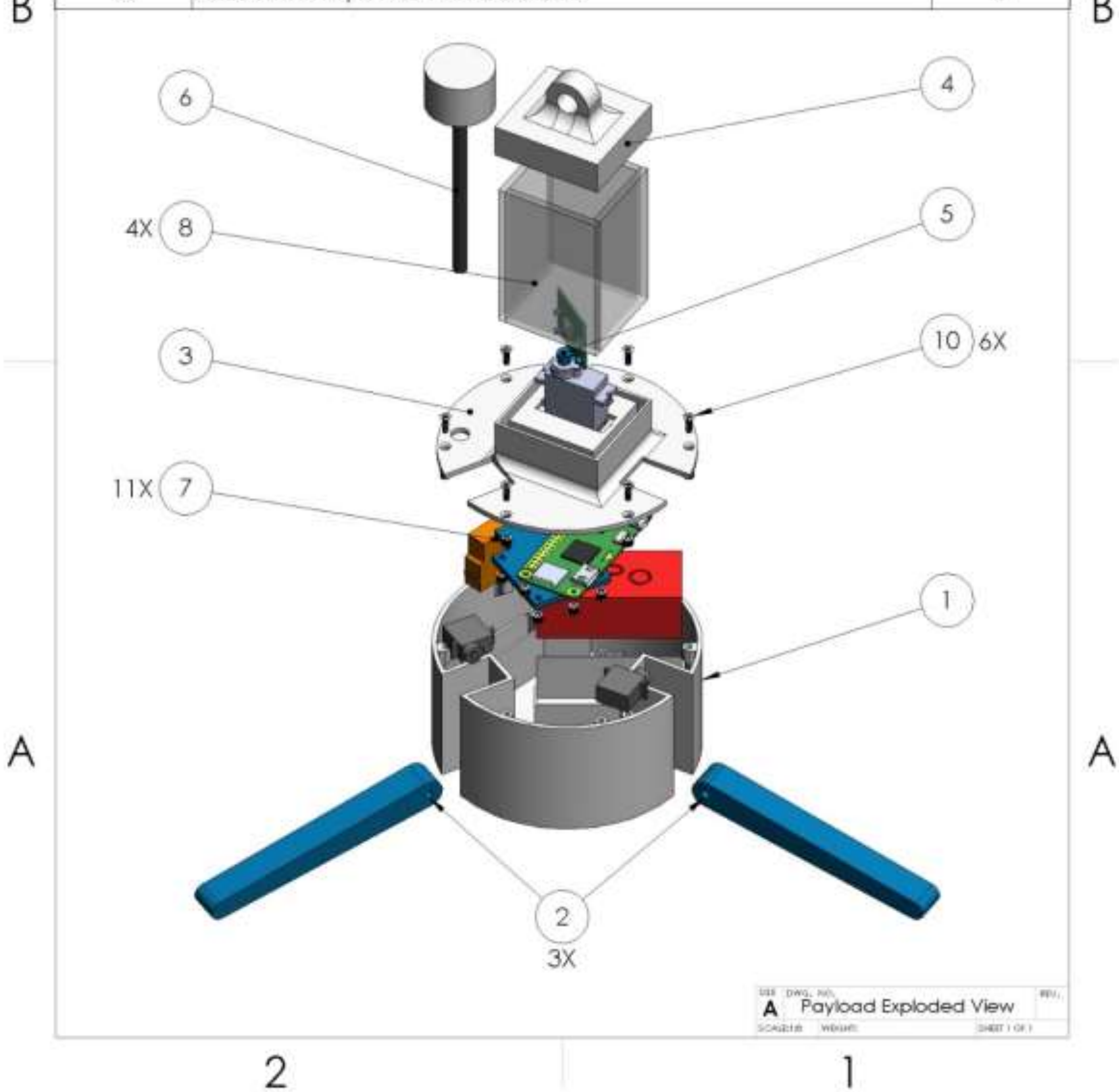

Figure 43: Exploded View of Payload

4.2.1.2. Payload Components

Base

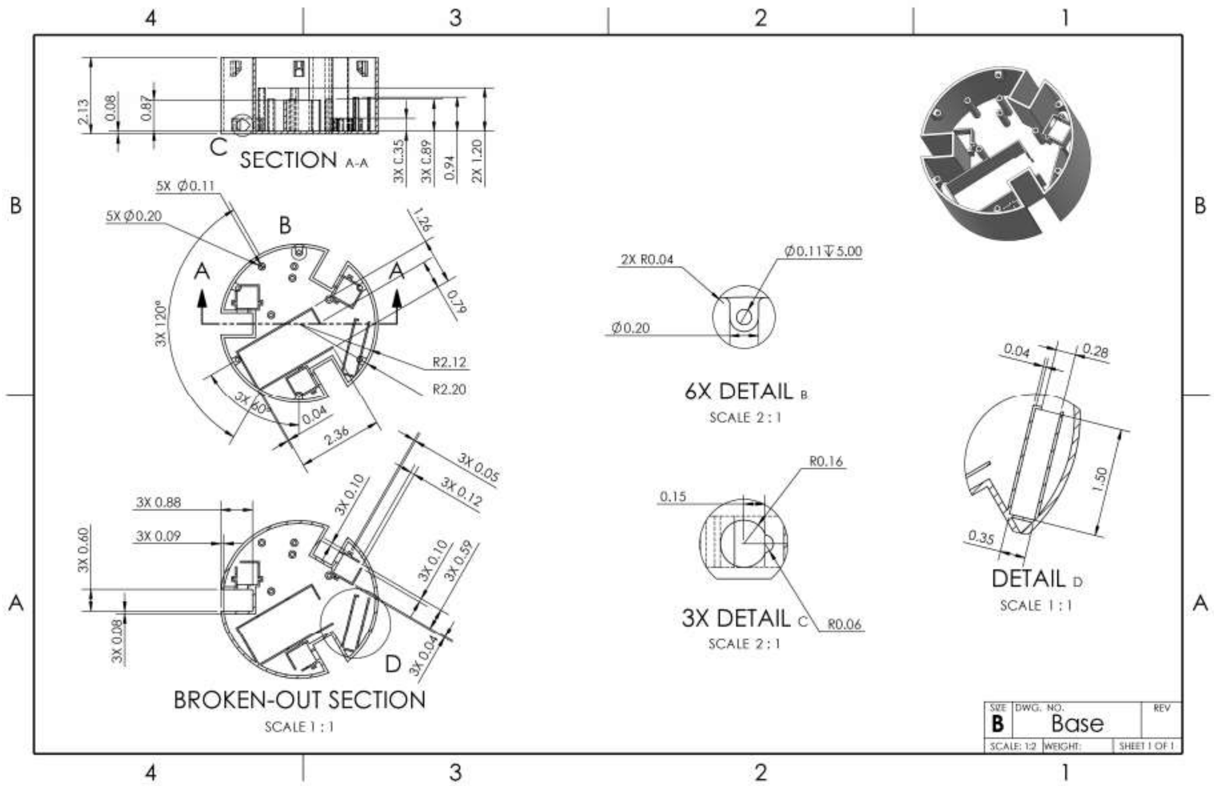

Figure 44: Drawing of Payload Base

The core component of the payload is the base component that allows for all the necessary components to be consolidated into one unit. The base will provide a way to safely hold each necessary electronic component that allows for an operational payload. The base is 2.13 inches tall with an inner wall diameter of 4.24 inches and an outer wall diameter of 4.40 inches. The base includes three uniform slots (.88-inch Length x .60-inch Width) that are orient with even spacing around the base diameter, that serve as the slots for retractable stabilizing legs. The hallow section within the base serves as the essential area in which all electronics are safely stored to allow for success in the functionality of the payload. There are three uniform housing features of .35-inch height that safely secure each of the three Sub-Micro Servo motors that operate each leg of the payload. The 11.1V LiPo battery is housed within the base of the payload in a feature designed to its specifications with a height of .87 inches. Another critical component of the payload found within the base is the FPV transmitter that is secured within its housing in the base in a feature of .94-inch height. The Raspberry Pi Zero WH microcontroller is placed on two raised features of 1.20-inch height to provide clearance and space. This is held in place using two M2.5 Heat Set inserts along with two Phillips flat head screws. The power distribution board is prompted on three features that provide .89-inch clearance from the floor of the base. This is also held in place using M2.5 Heat Set inserts along with Phillips flat head screws. With each component within the base being housed in a feature specific area with the necessary positioning and clearance, the base includes six features around the perimeter that allow for a secure cover to enclose the base using six heat set inserts and screws.

Legs

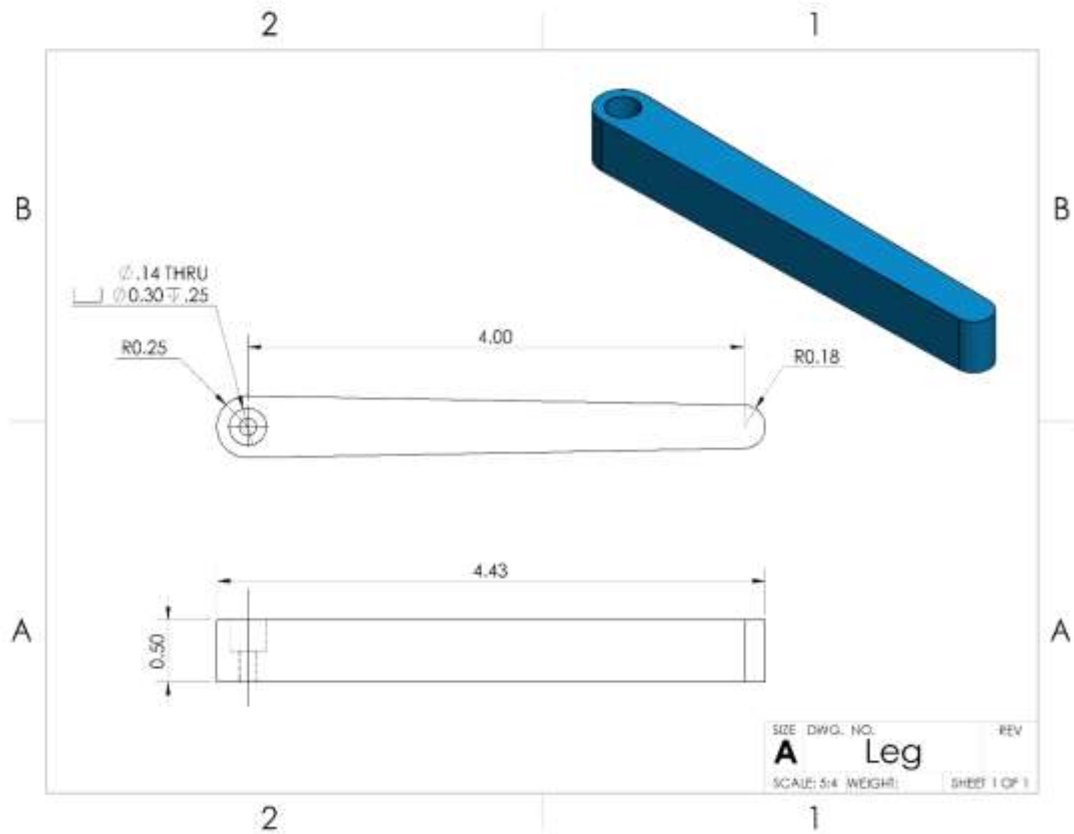

Figure 45: Drawing of Payload Leg

The 3 legs of the payload are tasked with increasing the payload's surface area during landing and levelling the entire payload within 5° of vertical using servo motors within the payload. The legs will be mounted to the servo motors using screws. The 0.5" thickness of the leg fits within the allocated 0.6" wide space within the payload's body component. The 4.43" length of the leg was selected such that legs in the payload's packed configuration don't reach the parachute attachment point. This is to prevent possible entanglement between the legs and the parachute's shock cord. Because of the leg's particular geometry, the component will be 3D printed with PLA plastic with a high infill density for increased structural strength.

Main Cover

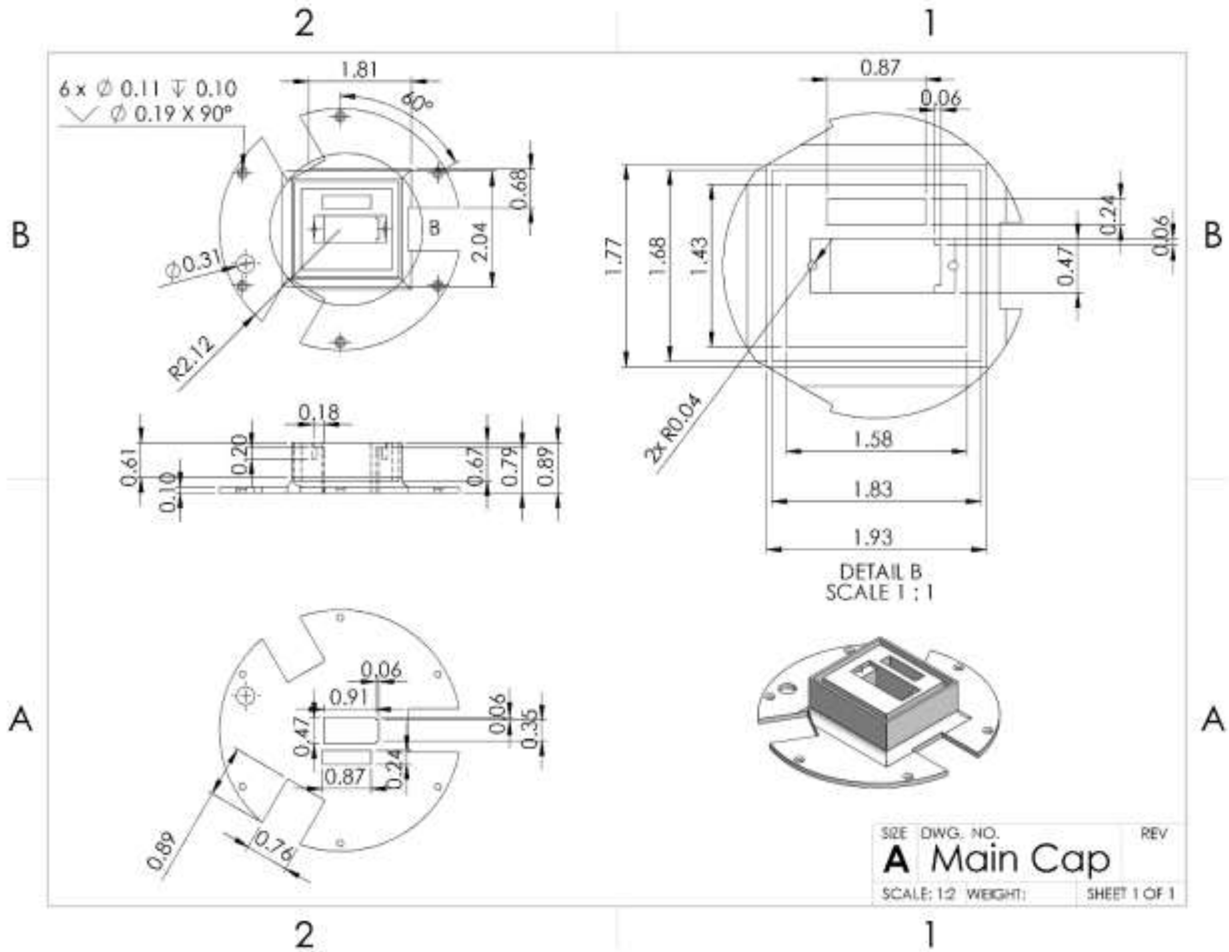

Figure 46: Drawing of Main Cap

The main cover protects the electronics needed for the payload as well as provide a surface to mount the camera. It is attached to the base of the payload via six screws on the outer diameter of the cover. The circular base of cap has a radius of 2.12 inches, this platform then has 3 rectangular cuts of length 0.89 inches and width of 0.76 inches, to allow for the rotation of the legs. Built upon the circular base, the main cover has a rectangular extrusion intended to be able to secure the acrylic sheets, which would be attached with epoxy to the inner walls of the extrusion. The thin outer rectangle has a dimension of 1.77x1.93 inches with a thickness of 0.09-0.10 inches. The inner rectangular extrusion has dimension of 1.43x1.58 inches and it has a further extrusion to hold the camera itself. The indent of the camera is 1.58 inches long, 0.48 inches wide, and 0.73 inches deep. Mounting holes are provided for the servo motor of the camera to fasten to.

Acrylic Sheets

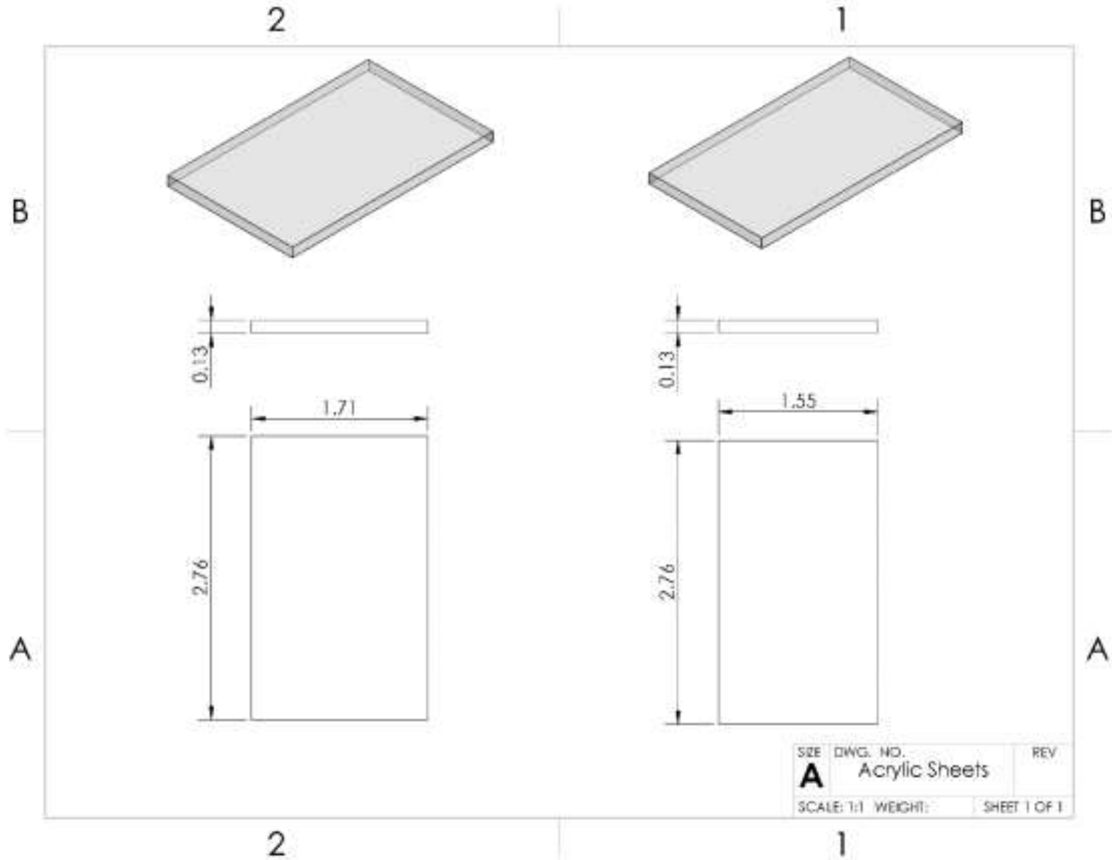

Figure 47: Drawing of Acrylic Sheets

The acrylic sheets on the central column of the payload are load bearing components that shield the camera from debris and allow the camera to obtain a 360° view of the landing site. Because of the rectangular shape of the main cover component, acrylic sheets of two different dimensions are needed. The acrylic sheets are mounted to the main cover and top cap using the allotted indentations for the acrylic sheets. The indentations of each component are increased for an increase in contact surface area between the acrylic sheet and the component for a stronger epoxy hold. The acrylic sheets will be epoxied onto the other components without obstructing the camera's view. The acrylic sheets will be waterjet from 1/8" thick clear acrylic sheets for a precise and clear cut.

Top Cap/Harness

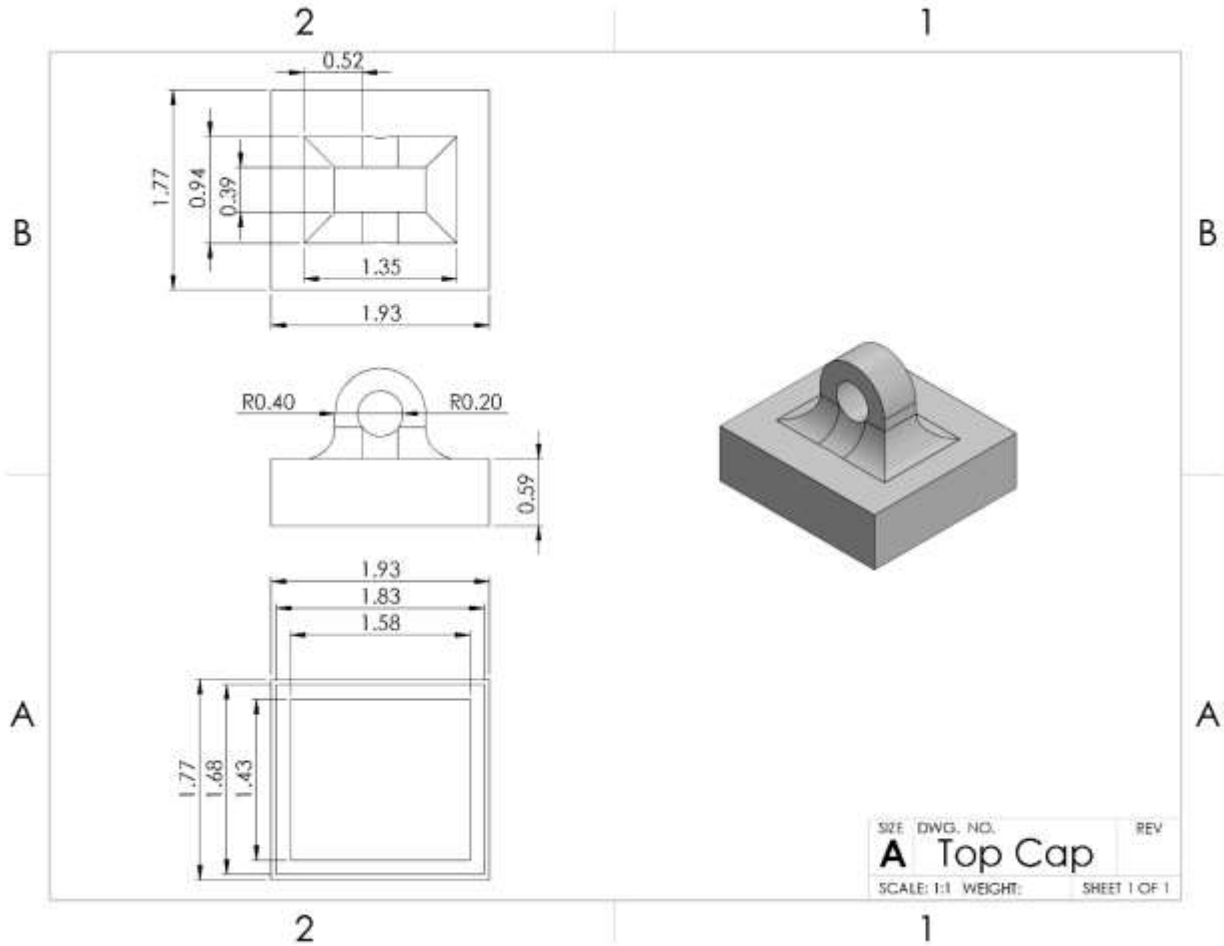

Figure 48: Drawing of Top Cap

The top cap attaches to the top of each acrylic sheet using epoxy. The four sheets fit into the top cap in a similar way to how they attach to the main cover. There is a rectangular indentation in the top cap which has dimensions 1.68x1.83 inches, similar to that of the sheets. The rectangular base of the top cap has outer dimensions of 1.77x1.93 inches and a height of 0.59 inches. The top cap features a horizontal, hollowed out cylinder with an outer radius of 0.4 inches an inner radius of 0.2 inches and a height of 0.39 inches. This cylindrical surface is used as an attachment point for the shock cord of the parachute and will experience the brunt of the force on the payload during ejection.

Parachute

The parachute selected for the payload is an Apogee Components 18” nylon parachute with a hexagonal parachute shape. The parachute has an area of 1.46ft^2, a max carrying capacity of 15 oz, and a max descent rate of 22 ft/s. The payload has a mass of 14.5 oz, which is within the carrying capacity of the parachute. The payload’s max kinetic energy is 9.22 ft-lbf, which follows Requirement 3.3 of the Student Launch Handbook which states that no independent section will have a kinetic energy greater than 75 ft-lbf.

Assuming 20 mph windspeeds, the payload will deploy at 700 ft AGL a distance of 704 ft due to drift during the launch vehicle’s flight. After the payload deploys at 700 ft, the payload will drift 857 ft for a total drift of 1561 ft from the launch site. This is within the bounds of the 2500 ft radius area provided by the competition.

To distance the payload from the parachute after landing, a 0.375” in diameter strap nylon shock cord from Public Missiles will be used to connect the payload to the shroud lines of the parachute. The strap nylon shock cord has a 1000 lbs max load which far exceeds the expected load of the payload (0.9lbf). The knot used to attach the shock cord to the top of the payload will be a square knot for its simplicity and tightness while also being able to thread through the designated hole.

4.2.2. Retention System

4.2.2.1. Retention System Assembly

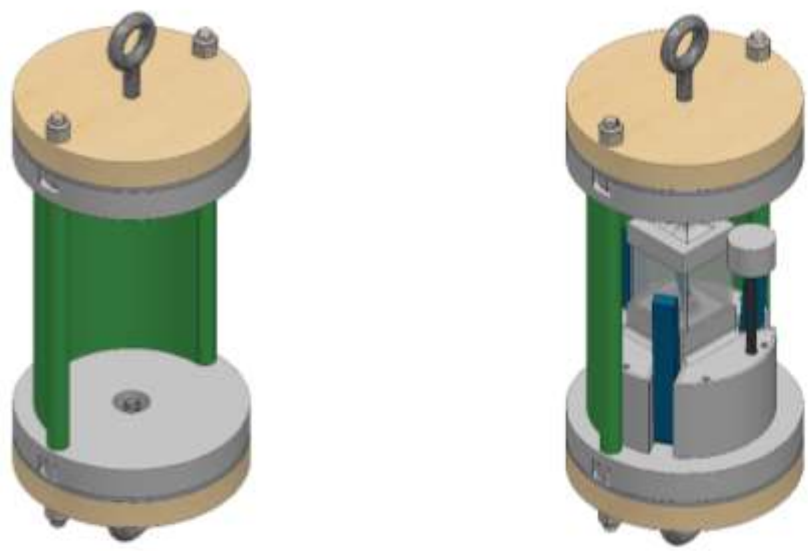

Figure 49: Retention System (left) and Retention System with Payload (right)

In order to safely retain the payload within the launch vehicle during flight and jettison the payload at 700 ft AGL, a cage like mechanism will be employed. The retention system will tether to the launch vehicle’s main parachute shock cord, deploy during the launch vehicle’s main ejection phase, and jettison the payload using gravity once outside the body tube. 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 are epoxied together and further fastened to each other with 3/8”-16 locknuts that interface with 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.

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

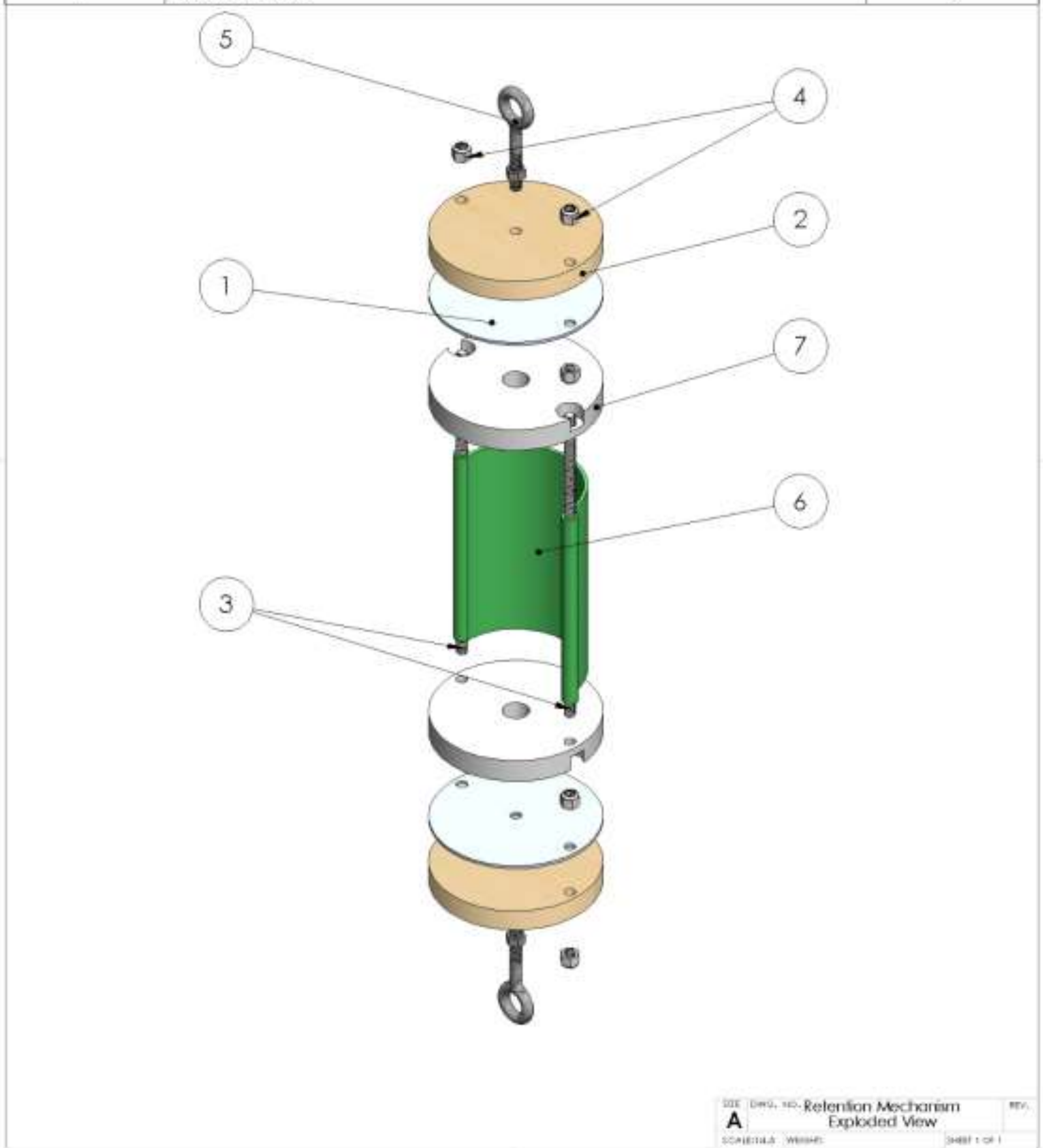

Figure 50: Exploded View of Retention System

4.2.2.2. Retention System Components

Pine Bulkhead

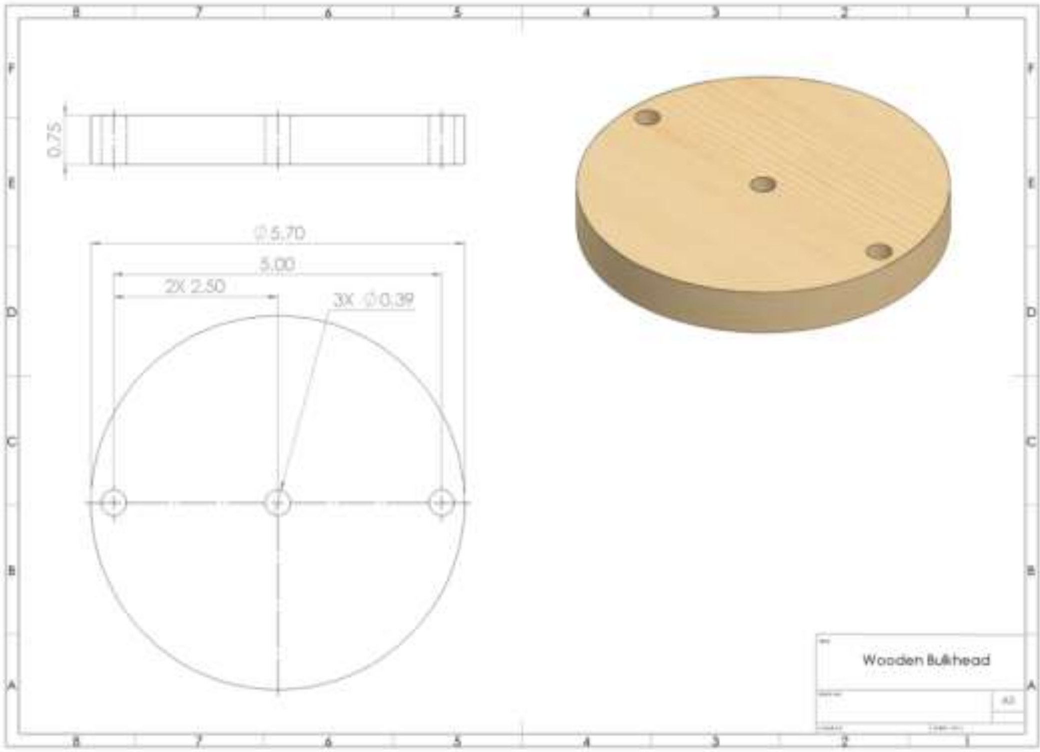

Figure 51: Drawing of Wooden Bulkhead

The wooden bulkhead in the retention system allows us to fasten the entire retention system together in addition to attaching the eyebolt. The bulkhead is made of pine since the material is strong enough to withstand the stress that the attachments will exert on it as they are fastened. It has a diameter of 5.7 inches and a depth of 0.75 inches, with three holes of 0.39 inches in diameter each. One hole is placed in the middle for the eyebolt, with the two other holes (placed 2.5 inches from the center) used to place the threaded rods.

Aluminum Reinforcement Sheet

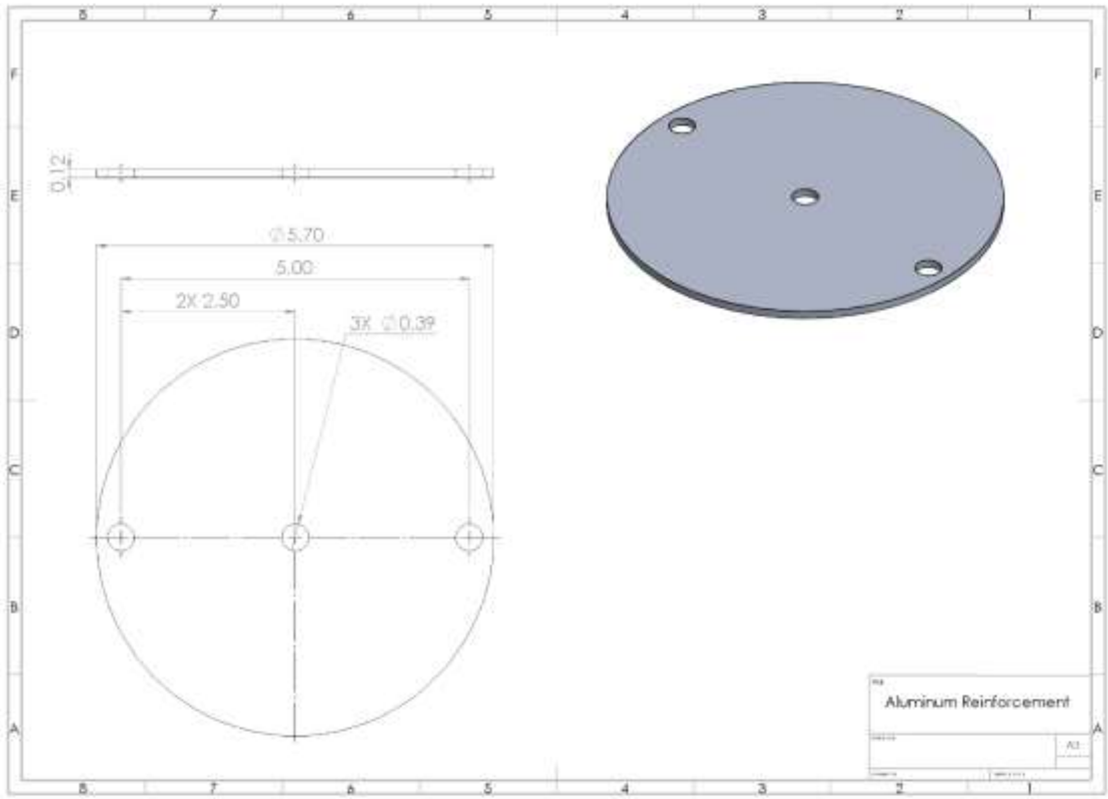

Figure 52: Drawing of Aluminum Reinforcement

The aluminum reinforcement will be placed between the wooden bulkhead and eyebolt cover to prevent damage to the payload. Aluminum is a strong metal for its purpose in the retention system that is both light and relatively inexpensive. The reinforcement is 0.12 inches thick and, like the wooden bulkhead, has a diameter of 5.7 inches and three holes of 0.39 inches in diameter each for the eyebolt and two threaded rods. Since pine wood is a soft and non-ductile material, the aluminum sheet reinforces the pine bulkhead to endure the impulse from the main parachute event in a much more predictable manner.

Semicircle Enclosure

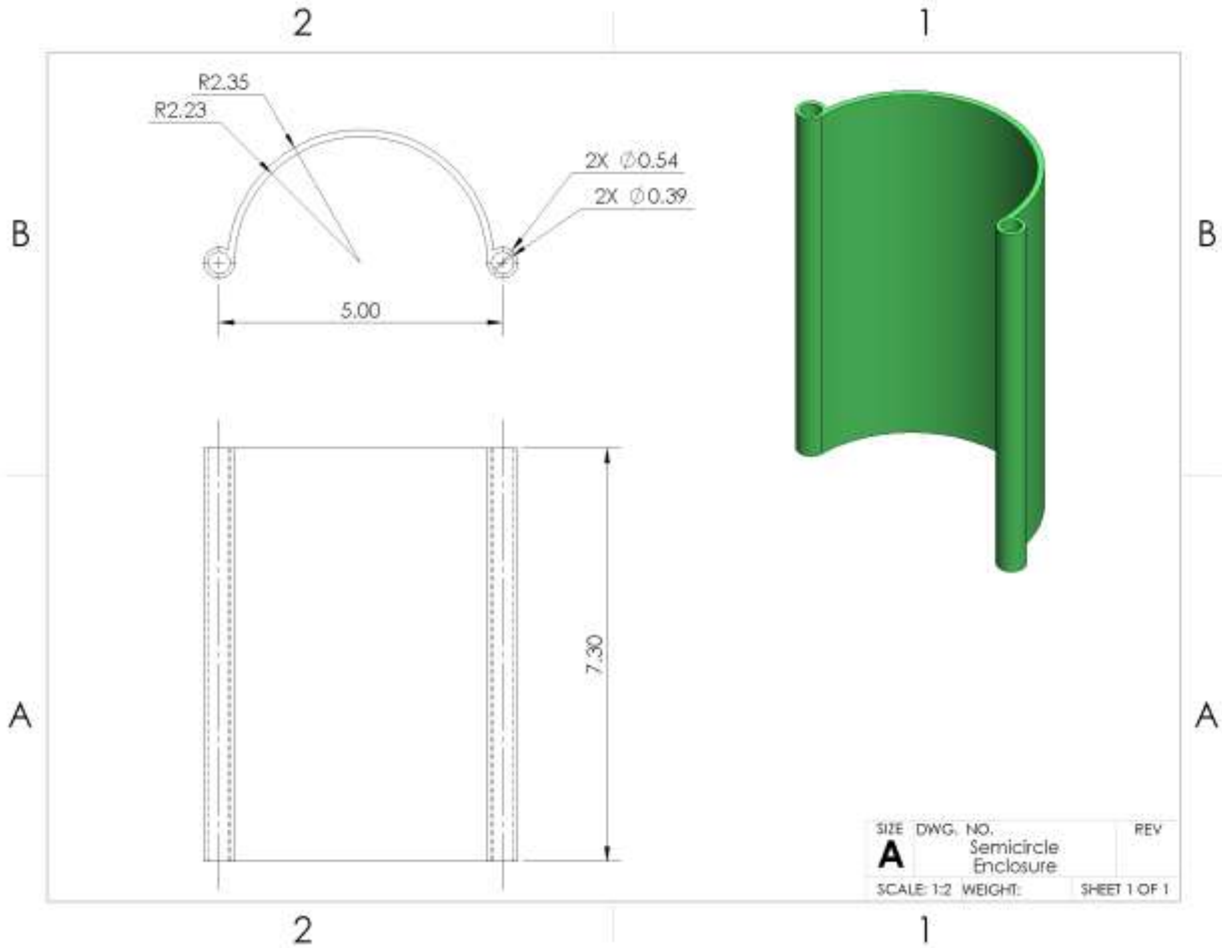

Figure 53: Drawing of Semicircle Enclosure

The semicircular enclosure is tasked with preventing the payload from jettisoning towards the opposite side of the parachute deployment. This component prevents the parachute and the payload from moving towards one side of the retention system, essentially controlling the direction of deployment of the payload system. Without this component, there is a chance the parachute may deploy on one side of the retention system while the payload jettisons on the other side, essentially ensnaring the payload with the retention system. Because of its unique geometry, the part will be 3D printed using PLA plastic.

Eyebolt Cover

The eyebolt cover is designed to avoid the excess length of the eyebolt on the payload side of the bulkhead and to create a platform upon which the payload could lay on. It is a 0.75-inch tall cylinder of radius 2.85 inches with three circular cuts. All of the cuts have a completely hollow area with diameter 0.39 inches and a larger cut of diameter 0.67 inches with a 0.54inch depth. The hollowed-out areas are to accommodate for the diameter of the threaded area of the eyebolt and the outer threaded rods. The larger diameter cut that doesn’t go through the entire surface is meant to fit a 3/8-inch nut that would allow for the cylindrical surface as a whole to fasten to the eyebolt and the outer threaded rods.

4.2.4. Integration with Launch Vehicle

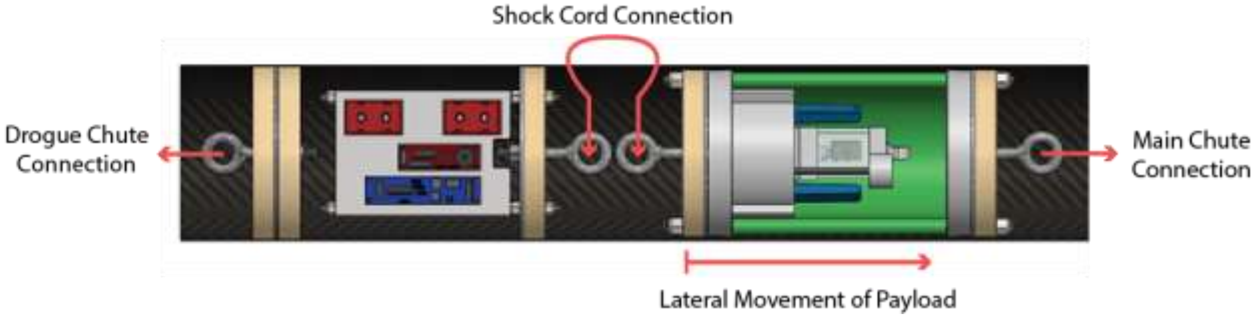

Figure 54: Cross-Section of Payload within Launch Vehicle

The payload and its retention mechanism will be located within the launch vehicle's upper body tube, next to the avionics bay. Referencing the figure above, the main chute is located to the right of the payload and retention system and the drogue chute is located to the left of the locking mechanism of the avionics bay. The payload will be nestled within the retention system which deploys at the same time as the launch vehicle's main parachute event at 700 ft AGL. A shock cord is connected between the avionics bay eyebolt and the leftmost eyebolt of the retention system. The shock cord between the two eyebolts within the launch vehicle will be cut to a length such that the entire retention system is fully outside the body tube. The rightmost eyebolt of the retention system is connected to the main parachute using a shock cord as well. Because the retention system is fastened to the launch vehicle and the main parachute, then the launch vehicle is also tethered to the main parachute through the use of the retention system. This system has the added benefit of simplifying the deployment of the payload by deploying both the payload and the main parachute in one singular event while also shielding the payload from ejection charge forces. Because the retention system is a load bearing component of the recovery hardware of the launch vehicle, conclusive physical testing must be done to ensure the system is capable of safely enduring the impulse of the deployment of the main chute during the launch vehicle's descent. Preliminary virtual testing of the pine bulkhead with aluminum reinforcement and of the steel threaded rods is provided in section 6.1.2. Payload Testing.

4.3. Design Completeness

Design verification is implemented though thorough inspection and testing, presented in 6.1.2. Payload Testing. For further analysis, consult 5.1 Launch Concerns and Operation Procedures.

4.4. Payload Electronics

4.4.1. Drawings and Schematics

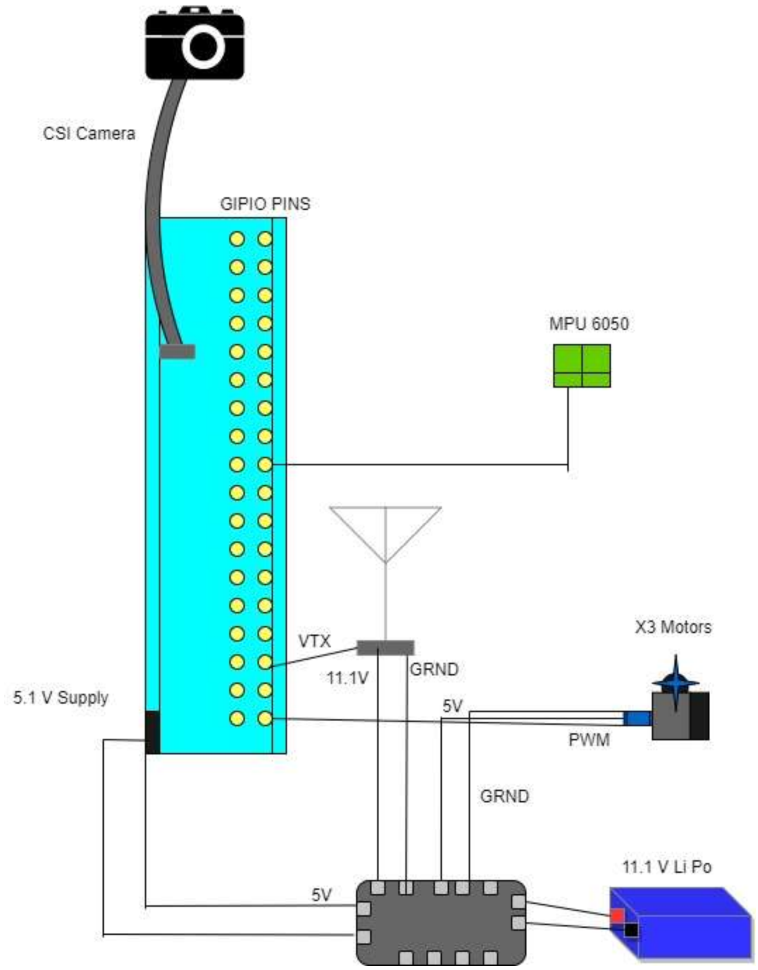

Figure 55: Payload Electronics Wiring Diagram

4.4.2. Batteries and Power

The payload electronics will all source power from a 3s 11.1V 6000mAh Lithium Polymer battery. Such a battery was chosen because of the high power density and lack of replacement needed during repeated testing. For saftey asper the handbook the battery will also receive a fire hazard label. This battery however will have its voltage stepped down to 5V for all electronics except the Video Transmitter. This is will be done using a X-T60 Power Distribution Board (PDB) , which will also connect the ground of all electronics to the battery. The more demanding electronics such as the motors will recieve their power from the PDB and PWM control from the PI Zero microcontroller. The MPU 6050 Gyroscope and accelerometer, and the camera module will receive power and

control signals directly from the PI Zero using its General Input Output Pins which are rated at both 5V and 3.3V. Finally the camera module will be using a standard CSI Mobile camera port on the PI Zero.

4.4.3. Switches, Indicator Wattages, Locations

The following table lists the power requirements of each component, but in summary the components can last in standby mode for 4 hours. Transmitter under 250 mW as per handbook.

Table 9: Electronics Power Usage

Device	Current Draw (Max)	Voltage	Power
*Powered by GPIO on PI ZERO			
Raspberry Pi Zero WH	1.2 A	5 V	6 W
MPU 6050 (Gyroscope + Accelerometer) *	100 mA	3.3 V	330 mW
Furious FPV Transmitter 2.4 GHz	20 mA	11.1V	200 mW
FEETECH Micro Servo Motor w/ Position Feedback	500 mA	5 V	2.5 W
FS90n Continuous Rotation Micro Servo	500 mA	5 V	2.5 W
ArduCAM for Raspberry PI *	250 mA	5 V	1.25 W
Standby Time: 4 hrs			

4.5 Justification of Unique Aspects

Payload Central Column

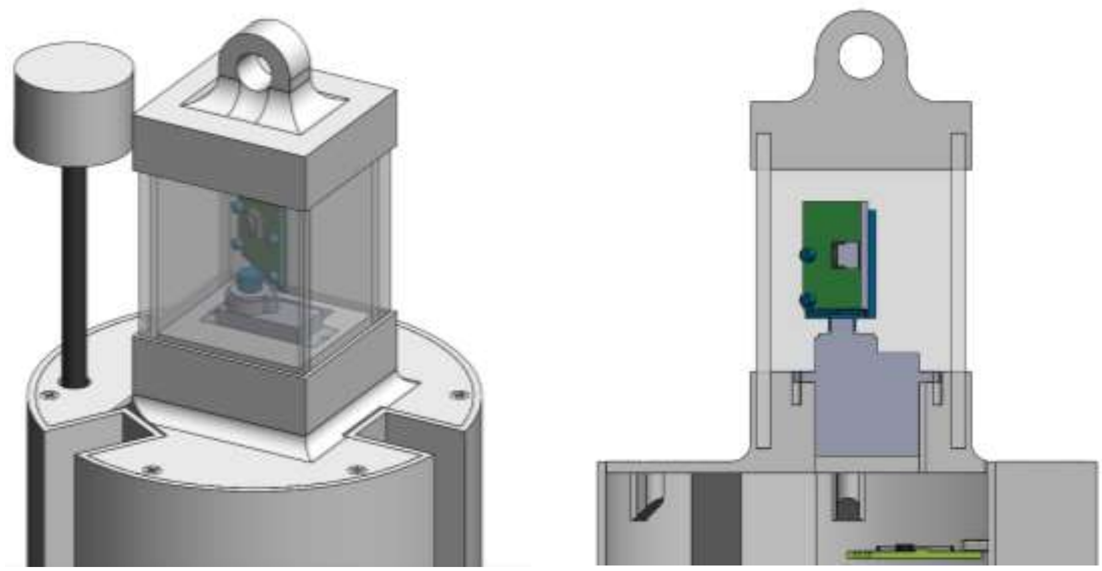

Figure 56: Payload Central Column (left) and Cross-Section of Central Column (right)

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. An alternative to this is to use 4 cameras in a square orientation with a wide lens angle to generate a panoramic image. While this alternative allows the parachute to be tethered in the center, more cameras means more pins are required for the microcontroller. Since space within the payload is scarce, a bigger microcontroller to deal with the greater number of cameras is not feasible. Another alternative to using acrylic sheets is to simply tether the parachute on the ‘Main Base” component of the payload in at least 3 separate attachment points. This eliminates the load on the acrylic sheets as the parachute is attached to the main base. While this parachute configuration allows changes in the center of mass of the payload to not affect the attitude of the payload during descent, it is susceptible to becoming entangled with the camera or the antenna if a rotational motion is experienced by the payload during descent. 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, which causes the shock cords to gravitate towards the center of the payload. For these reasons, an acrylic sheet central column design was considered in which the camera and parachute are centered on the payload to take advantage of both components being centered.

Retention System

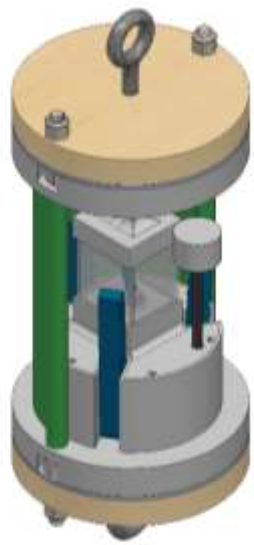

Figure 57: Retention System with Payload

The use of a retention method that deploys through the use of the launch vehicle's main parachute shock cord and deploys the payload through gravity is also 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 multiple 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 analyzed in 6.1.2. Payload Testing. A majority of these issues are mitigated through careful design of the retention system. 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. 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.

5. Safety

5.1 Launch Concerns and Operation Procedures

The following section will provide a drafted version of all pre- and post-launch proceedings for this year's specific vehicle. Proceedings will be written with an emphasis on safety and accident mitigation.

5.1.1. Final Assembly and Launch 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 10: 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 is 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

- Tool box
- 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

5.1.1.2. Recovery Preparation

Required Personnel: Project Manager and Structures Lead

To Be Completed: Pre-launch

Table 11: 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 firecloth 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 hould have quicklink tied 2/3rds of the way down for drogue chute.
		Drogue shock cord should have firecloth 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 cetnering 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.
		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.

Table 11: Recovery Pre-launch Preparation

Initial	Completed Substeps	Task
	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 nubmer 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.
		Personell Required: Team Mentor
		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.

Table 11: Recovery Pre-launch Preparation

Initial	Completed Substeps	Task
		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 covery 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 losely and place into the nosecone shoulder and upper body tube atop the REA.
		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 stil 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 reminiang shock cords losely and place into the upper body tube after the parachute.

Table 11: Recovery Pre-launch Preparation

Initial	Completed Substeps	Task
		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 Goggels
		Alignment point should be marked at all parent componetn interfaces. This was checked in the Pre-Packing section.
		Align the alightment 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.		

5.1.1.3. Payload Preparation

Table 12: Payloads Pre-launch Preparation

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

Table 12: Payloads Pre-launch Preparation

Initial	Completed Substeps	Task
		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
		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

5.1.1.4. Electronics Preparation

Required Personnel: Project Manager and Electronics Lead

To Be Completed: Upon launch site arrival

Table 13: 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 air tight 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 other interface if it is not deemed airtight.
		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 back up 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.	

Table 13: Electronics Pre-launch Preparation

Initial	Completed Substeps	Task
		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.
		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.	

5.1.1.5. Rocket Preparation

Required Personnel: Project Manager and Structures Lead

To Be Completed: Day before launch & upon launch site arrival

Table 14: 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.

Table 14: Rocket Pre-Launch Preparation

Initial	Completed Substeps	Task
		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.	
		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.

Table 14: Rocket Pre-Launch Preparation

Initial	Completed Substeps	Task
		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. 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:

Table 14: Rocket Pre-Launch Preparation

Initial	Completed Substeps	Task
		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.
	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 laying flat.
		Reinspect both parachutes for rips or 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.

Table 14: Rocket Pre-Launch Preparation

Initial	Completed Substeps	Task
		Tighten knot as much as possible.
		Repeat for other 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 mid point 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.	
		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 mid point 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.

Table 14: Rocket Pre-Launch Preparation

Initial	Completed Substeps	Task
		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.	

5.1.1.6. 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.

5.1.1.7. Setup on Launch Pad

Required Personnel: Team Mentor
To Be Completed: At Launch

Table 15: 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	
		Igniter installed
		See section 5.1.1.8.
	Warning: Personnel hazard as well as failed launch possible if step is incorrectly competed.	

5.1.1.8. Igniter Installation

Required Personnel: Team Mentor
To Be Completed: At Launch

Table 16: 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 pont.
		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.	

5.1.1.9. Launch Procedure

Required Personnel: Team Mentor
To Be Completed: At Launch

Table 17: 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.

Table 17: Launch Procedure

Initial	Completed Substeps	Task
		Launch is announced by Range Safety Officer to alert al personnel.
		Countdown is initiated and rocket is launched using a dual key turn signal.
		Success criteria met when rocket is launched.
	Warning: Personnel hazard if steps are not followed.	

5.1.1.10. Troubleshooting

Required Personnel: Team Mentor

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

Table 18: 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.	

5.1.1.11 Post-flight Inspection

Required Personnel: Project Manager, Structures Lead, and Electronics Lead

To Be Completed: Post-successful launch

Table 19: 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.
		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 firecloth must be utilized in place of firecloth 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.	

5.2. Safety and Environment

Close inspection of our tentative project timeline, laboratory, 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 20: 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 21: Risk Impact & Consequence Level

Description	Member and Personnel Safety	Equipment and Facility	Project Plan & Timeline	Environment
-A- High or Severe	Fatal injury/death. Permanent disability or impairment with serious repercussions.	Elimination and loss of equipment. Irreparable damage and possible dissipation of location.	Immense effect on project lifetime and results on complete halt and/or termination of project.	Irreparable and immense physical damage to the surroundings. Violates codes/laws and regulations.
-B- Medium or Moderate	Fair amount of damage, usually repairable, moderate pain, or adequate illnesses	Significant or notable enough damage to systems, 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 22: 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.

5.2.1. Personnel Hazard Analysis

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 23: Environmental 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 and ground themselves prior. To reduce the gravity of the explosion, small amounts of ejection powders are to be handled at any given time.	3A	Consultation of MSDS before working near or handling powder charges. Members will be adequately trained and certified to handle. Only small amounts are to be handled.
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	3C	Required consultation of MSDS prior to use; Respirators and relevant PPE when working with chemical fumes.

				fume-hood when possible.		
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	Epoxing 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 power build-up; damaged wires	Electrical component failure; black powder explosion; epidermal injury; limb loss	2A	All wires should be checked for damaged cording before plugging. Refrain from water usage around electronics. Handlers of sensitive equipment will ground themselves to discharge static buildup.	3B	Medical attention should be 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 ear muffs 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 problems when ingested or inhaled; difficulty breathing	2A	If lead based solder is used, it will be done in an environment with a fan to diffuse the fumes away from the user, under fume hoods, while user wears a respirator mask.	3C	PPE enforcement of P100 respirators.
Shop Fire	Chemical cross contamination	Moderate to Fatal injuries or death;	2A	Always label and store chemicals separately. Always be aware of one's	2B	All lab coats are fire resistant. Fire protocol and exit route is included

		irreparable damage to equipment and lab space		surroundings and be diligent when working in a lab environment; fire extinguishers kept in shop.		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.

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.

5.2.2. Failure Modes and Effects Analysis

Table 24: 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 transportati on	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 transportati on/ handling	Improper protection during transportati	Unusable components; incapable of safe launch; potential	1B	Proper storage overseen by safety advisor and student safety	2B	Adhere to safety protocol

	on/ handling	damage to/loss of rocket		officer, especially for motor handling		
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	Miscalculation of rocket's	Decrease in stability of the launch	3A	Simulations are conducted virtually and physically,	3C	Verify with and consult simulations.

minimum velocity before leaving the launch rail	mass. Motor failure	vehicle; rocket plummets down; possible explosion		checked against one another for redundancy.		
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	2A	Ensure all batteries fully charged and checked using the voltmeter prior to assembly	3A	Pre-launch checklist assures battery testing and replacement if necessary
Parachute sections and/or shroud line come apart	Weak stitching or materials; inadequate parachute design	Recovery system failure; damage to/loss of rocket and payload	2A	Sew reinforcement onto shroud lines; use semi-flat felled seam between sections; verification testing of recovery system	3A	Visual inspection of parachutes prior to launch
Altimeter failure	Circuitry failure due to improper wiring; loss	Failure to ignite drogue and/or main ejection	2A	Individual power supply module for each redundant altimeter; fully	3A	Pre-launch checklist assures proper circuitry

	of or insufficient power to operate altimeters and fire ejection charges	charges; deploy parachutes at undesired altitudes or lack of deployment altogether; damage to/loss of rocket		ground-based altimeter testing before each flight		
Rocket comes loose from launch pad	Rail buttons not securely mounted to rocket; extreme wind; team error in aligning rocket while attaching to pad	Rocket breaks free during initial phase of launch; potential damage to rocket, payload, bystanders, and property	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

5.2.3. Environmental 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 25: 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 planned launch area	Excessive wind; improper timing of main parachute deployment	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-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 trajectory; vertical stability complication	2A	Ensure launch vehicle has an ample margin of stability.	2C	Enhanced analysis of vehicle design choice of fins and mass distribution.
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	Unexpected vehicle trajectory	3B	Ensure rail buttons are aligned properly; coat rail in Vaseline	3C	Vehicle design ensures alignment of rail buttons

	to sunlight, low humidity					
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.

5.2.4. NAR Safety Code Compliance

NAR/TRA Personnel are launch-vehicle certified members that will be responsible for purchasing, handling, storing, and assembling the rocket's motor, ejection charges, and ignitors. They are to be present at all testings, signing off on all standard operating procedures and overseeing all NAR/TRA safety regulations.

Compliance with NAR Safety Code

Table 26: NAR Safety Codes and Compliances

Code	Compliance
1. Certification. I will only fly high power rockets	Team members are only allowed to handle and launch with appropriate certifications: Level 1

or possess high power rocket motors that are within the scope of my user certification and required licensing.	certification is required for motor classes H and up, Level 2 is required for motors J and up, and Level 3 will be required for motors M and up. Our team mentor possesses Level 2 clearance certification and will be the sole individual responsible for handling and obtaining the high-power rocket motors used for the launch of our vehicle.
2. Materials. I will use only lightweight materials such as paper, wood, rubber, plastic, fiberglass, or when necessary ductile metal, for the construction of my rocket.	Structures team lead and members will be held responsible for ensuring appropriate materials are utilized in the construction of the rocket as outlined in section two above. MSDS research has been elevated, and materials have been compared to ensure adequate selections for the construction of our launch vehicle and payload.
3. Motors. I will use only certified, commercially made rocket motors, and will not tamper with these motors or use them for any purposes except those recommended by the manufacturer. I will not allow smoking, open flames, nor heat sources within 25 feet of these motors.	Motors that are purchased are to be exclusively certified and stored safely, as well as only handled by NAR/TRA personnel. Motors will be solely handled and purchased for our high-powered rocket by our team mentor, who possesses Level 2 certification.
4. Ignition System. I will launch my rockets with an electrical launch system, and with electrical motor igniters that are installed in the motor only after my rocket is at the launch pad or in a designated prepping area. My launch system will have a safety interlock that is in series with the launch switch that is not installed until my rocket is ready for launch, and will use a launch switch that returns to the “off” position when released. The function of onboard energetics and firing circuits will be inhibited except when my rocket is in the launching position.	The safety officer and team leads will be responsible for proper ignition system installation as outlined in the aforementioned code. All launch pad procedures have been briefed to team leads and the standing safety officer.
5. Misfires. If my rocket does not launch when I press the button of my electrical launch system, I will remove the launcher’s safety interlock or disconnect its battery, and will wait 60 seconds after the last launch attempt before allowing anyone to approach the rocket.	The team will collectively ensure that in the case of a misfire, the battery is disconnected, and 60 seconds have elapsed before anyone is to approach the rocket. Note that the Range Safety Officer has encompassing final decisions; therefore, alterations may be addressed by the RSO and additional limitations/regulations may be subject to realize.
6. Launch Safety. I will use a 5-second countdown before launch. I will ensure that a means is available to warn participants and spectators in the event of a problem. I will ensure that no person is closer to the launch pad than allowed by the accompanying Minimum Distance Table. When	As stated, the team will follow the appropriate launch safety guidelines set forth at the launch site, by the Range Safety Officer, and at a safe distance away from the launch pad. Rocket stability will be checked. Center of gravity and center of pressure will be presumptively identified and labeled on the launch vehicle. In addition, a

arming onboard energetics and firing circuits I will ensure that no person is at the pad except safety personnel and those required for arming and disarming operations. I will check the stability of my rocket before flight and will not fly it if it cannot be determined to be stable. When conducting a simultaneous launch of more than one high power rocket I will observe the additional requirements of NFPA 1127.	hard copy of 2020 NASA Student Launch Handbook and Request for Proposal has been obtained for our records. This allows us to have resources such as the minimum distance table on hand.
7. Launcher. I will launch my rocket from a stable device that provides rigid guidance until the rocket has attained a speed that ensures a stable flight, and that is pointed to within 20 degrees of vertical. If the wind speed exceeds 5 miles per hour, I will use a launcher length that permits the rocket to attain a safe velocity before separation from the launcher. I will use a blast deflector to prevent the motor's exhaust from hitting the ground. I will ensure that dry grass is cleared around each launch pad in accordance with the accompanying Minimum Distance table, and will increase this distance by a factor of 1.5 and clear that area of all combustible material if the rocket motor being launched uses titanium sponge in the propellant.	The team will ensure that the stability of the rocket is safe for launch and that all parameters are approved by the Range Safety Officer for proper flight and that the launch field is properly equipped, maintaining safe distances away. All team members have been briefed on and understand the importance of maintaining a safe distance away from the launch pad before the vehicle is set to launch. To safely comply with the standards of the code, we will ensure that our offset vertical degree amount is well within the 20-degree threshold and is dependent on the wind speeds on launch day and time.
8. Size. My rocket will not contain any combination of motors that total more than 40,960 N-sec (9208 pound-seconds) of total impulse. My rocket will not weigh more at liftoff than one-third of the certified average thrust of the high-power rocket motor(s) intended to be ignited at launch.	All leads will collectively ensure the size and design of the rocket satisfies the requirement and will adhere to the constraints set forth. Our predetermined dimensions have all been designed well within the bounds set forth by the code. All possible design options consider the restrictions and allow for marginal freedom to expand pot-design and
9. Flight Safety. I will not launch my rocket at targets, into clouds, near airplanes, nor on trajectories that take it directly over the heads of spectators or beyond the boundaries of the launch site, and will not put any flammable or explosive payload in my rocket. I will not launch my rockets if wind speeds exceed 20 miles per hour. I will comply with Federal Aviation Administration airspace regulations when flying and will ensure that my rocket will not exceed any applicable altitude limit in effect at that launch site.	The guideline set for all flight safety will be followed in conjunction with directions provided from the Range Safety Officer, who has the final say on all launches.
10. Launch Site. I will launch my rocket outdoors, in an open area where trees, power lines, occupied buildings, and persons not involved in the launch	The team leads and Safety Officer will ensure that the team complies with all regulations regarding the location of the launch site. The launch is to take place in a large, open area with preset

do not present a hazard, and that is at least as large on its smallest dimension as one-half of the maximum altitude to which rockets are allowed to be flown at that site or 1500 feet, whichever is greater, or 1000 feet for rockets with a combined total impulse of less than 160 N-sec, a total liftoff weight of less than 1500 grams, and a maximum expected altitude of less than 610 meters (2000 feet).	parameters that are to be strictly adhered to regarding safe launching. In addition, a hard copy of 2020-2021 NASA Student Launch Handbook and Request for Proposal has been obtained for our records, allowing us to have resources such as the minimum distance table available. The 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.
11. Launcher Location. My launcher will be 1500 feet from any occupied building or from any public highway on which traffic flow exceeds 10 vehicles per hour, not including traffic flow related to the launch. It will also be no closer than the appropriate Minimum Personnel Distance from the accompanying table from any boundary of the launch site.	The Safety Officer and team leads will ensure that the launch is positioned away from all persons and property. The launcher will strictly adhere to the launcher location parameters and remain at a safe distance away from the launch pad. All team members have read through the 2020 Handbook and recognize the importance of adhering to the minimum personnel distance as outlined by the regulations.
12. Recovery System. I will use a recovery system such as a parachute in my rocket so that all parts of my rocket return safely and undamaged and can be flown again, and I will use only flame-resistant or fireproof recovery system wadding in my rocket.	All team leads and Safety Officer will ensure the rocket is successfully designed with an excellent recovery system that abides to the guidelines set forth. In addition, our recovery system electronics will not be adversely affected by any other on-board electronic devices during flight. It will be physically located in a separate compartment within the vehicle from any other radio frequency transmitting devices.
13. Recovery Safety. I will not attempt to recover my rocket from power lines, tall trees, or other dangerous places, fly it under conditions where it is likely to recover in spectator areas or outside the launch site, nor attempt to catch it as it approaches the ground.	The team leads and Safety Officer will collectively ensure that the team safely recovers the rocket by abiding to the preset guidelines. We will collectively wait for approval from the RSO in case of potentially hazardous conditions that may be encountered.

Federal Aviation Regulations 14 CFR

In accordance to 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 to 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.

Hazardous Materials

All team members will be required to consult MSDS whenever dealing with unknown or hazardous materials. Hazardous material will be disposed of by coordinating with UCLA's Environmental Health and Safety office, complying with their guidelines and appropriately written procedures. Commonly used materials for the rocket's manufacturing include quick set epoxy, acetone, graphite, and WD-40: all of which will be handled with gloves and respirators. If hazardous materials such as fiberglass or carbon fiber are being cut, it will be done in a well-ventilated area, with all members involved wearing respirators, gloves, goggles, and lab coats. Any additional materials that exhibit large corrosive, flammable, or health indices will be reviewed and precautions will be taken in an effort to mitigate potential risks.

6. Project Plan

6.1. Testing

(see handbook for what should be included)

Table 27: Testing Template

Objective:	
Success Criteria:	
Variables:	
Constants:	
Step-by-Step Execution:	
Relevant Safety Concerns:	
Status:	
Justification:	
Possible Necessary Changes:	

Results (if completed):

6.1.1. Vehicle Testing

Testing has a focus on structural load bearing aspects due to their high level of impact to the vehicle if failure occurs. Since virtual testing is very much an idealistic situation, it will be used as a preliminary test for all components. If virtual testing fails or is close to doing so, then a physical test is warranted and will be planned and performed. All virtual testing will be conducted on SolidWorks and a description of the virtual set up will be provided. Since all virtual testing has yet to be completed, a full list of necessary physical testing will be presented with the FRR.

There are three major forces that will be felt by the vehicle during flight: the maximum thrust exerted by the motor, the impulse of the drogue chute deploying, and the impulse of the main chute deploying. The maximum thrust can be found from the selected motor thrust curve to be 1620 N. The impulse of each chute deploying can be found from OpenRocket using the instantaneous acceleration as well as the known mass of the vehicle. The force due to the drogue chute is 78 lbf and the force due to the main chute is 85 lbf. All structural testing is presented below.

It is also interesting to examine the interface strengths within the vehicle. While load bearing hardware itself may not fail, if the interface between it and the body of the vehicle does then major problems will occur. Since the interfaces are held in place using epoxy it is difficult to estimate the exact strength since aspects such as the temperature it is cured, thickness of the epoxy layer, and actual surface contact could vary due to how the resin is applied. For the sake of these tests, it will be assumed that epoxy was spread evenly over the entire interface and the shear strength of the epoxy will be compared to a simple force to area calculation. More advanced force phenomena will not be considered.

Table 28: Nosecone Structural Integrity (Virtual)

Objective:	To ensure that the nose cone can withstand both the normal forces during flight as well as the shear stresses put onto it from the bulkhead upon deployment of the main parachute.
Success Criteria:	Stress placed onto nose cone in both scenarios do not exceed the approximated yield stress of the structure.
Variables:	Stresses/Directions • Maximum normal force due to acceleration through air: 1620 N • Maximum shear force due to deployment of recovery hardware: 78 lbf
Constants:	• Nose Cone geometry • Nose Cone material: ABS plastic ○ Flexural strength of ABS plastic: 10800 PSI.
Step-by-Step Execution:	For normal force: 1. Fix shoulder of nose cone. 2. Enforce 1620 N force in a singular direction coming into the leading edge of the nose cone, as in launch. 3. Evaluate results. For shear force: 4. Fix outer edge of nose cone. 5. Enforce 78 lbf in a singular direction along the inside face of the nose cone, as the bulkhead would create. 6. Evaluate results.
Relevant Safety Concerns:	None.
Status:	Planned
Justification:	Nosecone failure during ascent can compromise its interface with the main parachute and possibly interfere with deployment. This could cause a personnel hazard from parts falling with a large kinetic energy. Similarly nose cone failure during parachute deployment can cause detachment of recovery hardware, posing a personnel hazard.
Possible Necessary Changes:	If failed, a thicker nosecone must be implemented.

Status/Results: (if completed):
Uncomplete

Table 29: 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
	  ○ 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):
Uncomplete

Table 30: Centering Ring Structural Integrity (Virtual)

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

Table 30: Centering Ring Structural Integrity (Virtual)

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):
Uncomplete

Table 31: 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 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
	  ○ To be acquired from the manufacterer

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.

Table 31: Nosecone Bulkhead Interface Testing

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):
Uncomplete

Table 32: 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 exceeds the 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.
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):
Uncomplete

Table 33: Bulkhead 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 exceeds the 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
	  ○ To be acquired from the manufacterer

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):
Planned

Table 34: 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 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 manufacterer

Step-by-Step Execution:	1. Divide the total force by the total contact area

Table 34: Centering Ring Interface Testing

	2. Compare to the strength of the epoxy used 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):
Planned

Table 35: Fin Flutter Structural Integrity

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

Justification:	If fin set breaks, the rocket cannot accurately fly, and continual structural failures are likely to occur, compromising the safety of those near the rocket and the rocket integrity.

Table 36: 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.

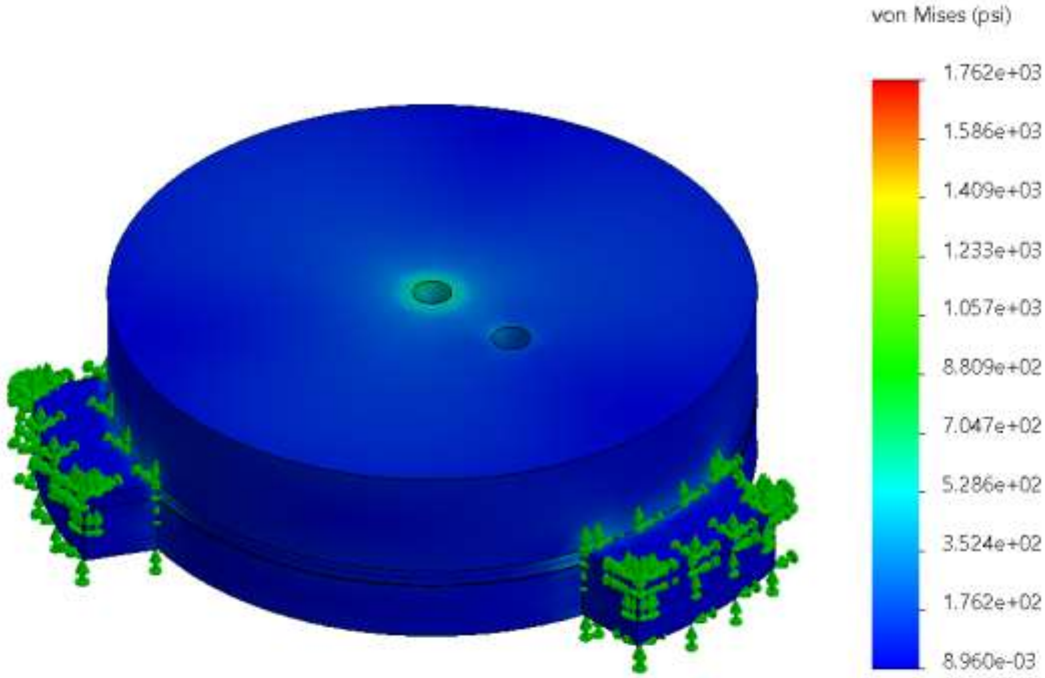

Figure 58: Inner Locking Mechanism Stress Results

Table 37: Outer Locking Mechanism Testing

Objective:	Analyze the stress experienced by the slots of the outer locking mechanism composed of a top and bottom pine bulkhead and an aluminum reinforcement because of the force expended by the tabs on the slots.
Success Criteria:	The maximum force felt by the slots of the outer locking mechanism on the during launch does not exceed the expected yield strength.
Variables:	Force: 74.79 lbf of normal force

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

Step-by-Step Execution:	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.

Table 37: Outer Locking Mechanism Testing

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.

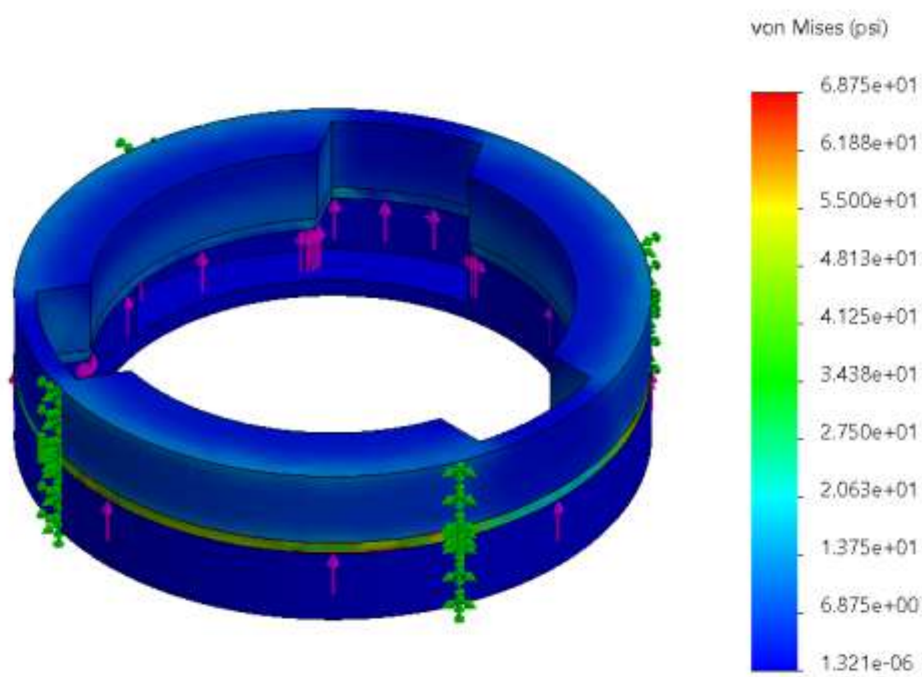

Figure 59: Outer Locking Mechanism Stress Analysis

Table 38: Body Tube Buckling Virtual Testing

Objective:	Determine if the body tube may be subject to buckling under peak loading of the motor.
Success Criteria:	Buckling factor of safety is not between 0 and 1 inclusive.
Variables:	Force: 1620 N of axial force
Constants:	• Carbon fiber body tube material ○ Elastic Modulus: 10 Mpsi

Table 38: Body Tube Buckling Virtual Testing

	○ Poisson's Ration: 0.2 ○ Mass Density: 0.07225 lb/in^3 ○ Yield Strength (shear): 13500 psi • Components Tested ○ Upper body tube ○ Coupler ○ Lower body tube
Step-by-Step Execution:	1. Fix upper face of upper body tube facing the nose cone 2. Place total force over the bottom face of the lower body tube 3. Mesh components 4. Examine results
Relevant Safety Concerns:	None.
Status:	Complete
Justification:	Since selected motor has a very high initial force, the body tube may be subject to buckling which can highly jeopardize the structure of the vehicle. By examining behavior we can make necessary changes to vehicle design as necessary.
Possible Necessary Changes:	If failed, further physical testing is needed. A thicker body tube may be necessary if physical testing supports a buckling result.

Results (if completed):

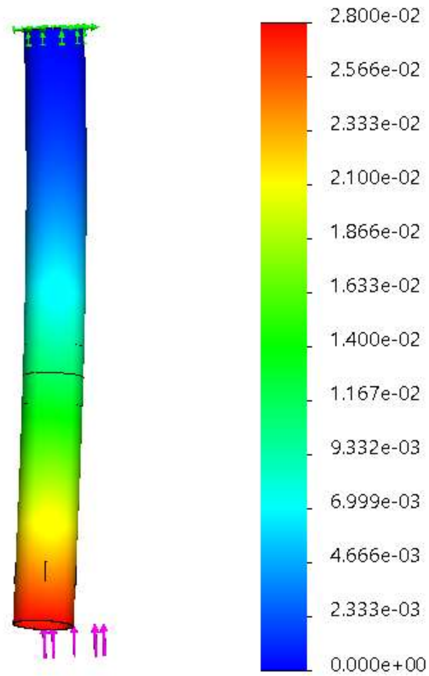

Figure 60: Body Tube Buckling Analysis

Buckling factor of safety is 0.04578, meaning the structure is currently at risk of buckling. Since this component was tested under typical carbon fiber material properties it is not exactly representative of how the physical body tube may perform. For FRR, exact material properties will be acquired and an updated simulation will be run with those simulations. Further physical testing is needed.

Table 39: Body Tube Buckling Physical Testing

Objective:	Determine if the body tube may be subject to buckling under peak loading of the motor.
Success Criteria:	Buckling factor of safety is not between 0 and 1 inclusive.
Variables:	Force: 1620 N of axial force
Constants:	Physical body tubes and coupler
Step-by-Step Execution:	1. Place body tube and coupler assembly in instron machine 2. Start compressive loading 3. Measure stress throughout test during increased loading until failure or until a factor of safety of 2.0 is reached (3240 N). 4. If buckling occurs before the maximum loading is reached, the test fails.

Table 39: Body Tube Buckling Physical Testing

Relevant Safety Concerns:	None.
Status:	Complete
Justification:	Since selected motor has a very high initial force, the body tube may be subject to buckling which can highly jeopardize the structure of the vehicle. By examining behavior we can make necessary changes to vehicle design as necessary.
Possible Necessary Changes:	If failed, a thicker body tube is necessary.

Results (if completed):
Uncomplete.

Table 40: 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 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

Table 40: Locking Mechanism Test

	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):

6.1.2. Payload Testing

Table 41: 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:	1. Fix the surface of the bulkhead and aluminum sheet in contact with the .375" nuts. 2. Place an axial force of 81.20 lbf on the hole that will be containing the eyebolt. 3. 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.

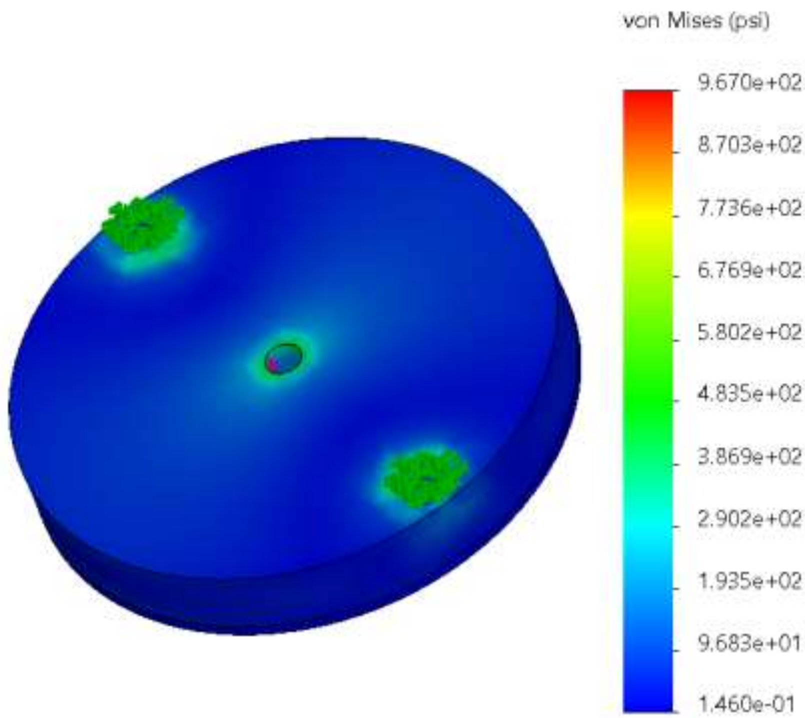

Figure 61: Retention System Stress Results

Table 42: Rods in Retention System Testing

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.

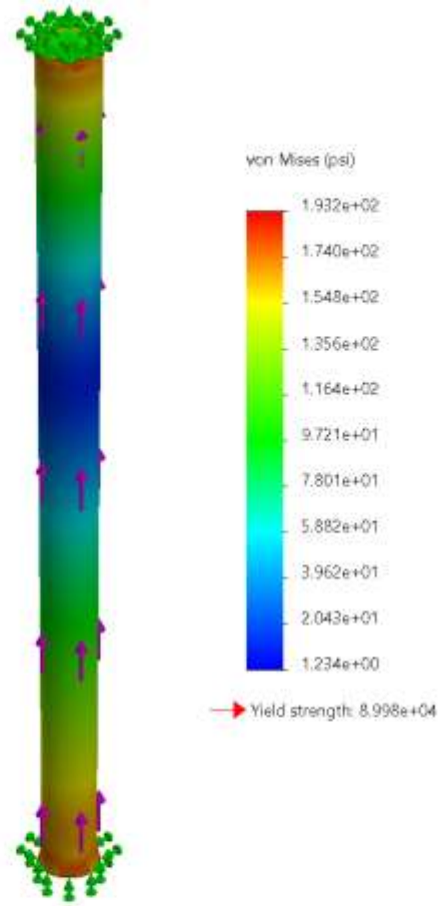

Figure 62: Rods in Retention System Stress Results

Table 43: Payload Top Cap Testing

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.
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.

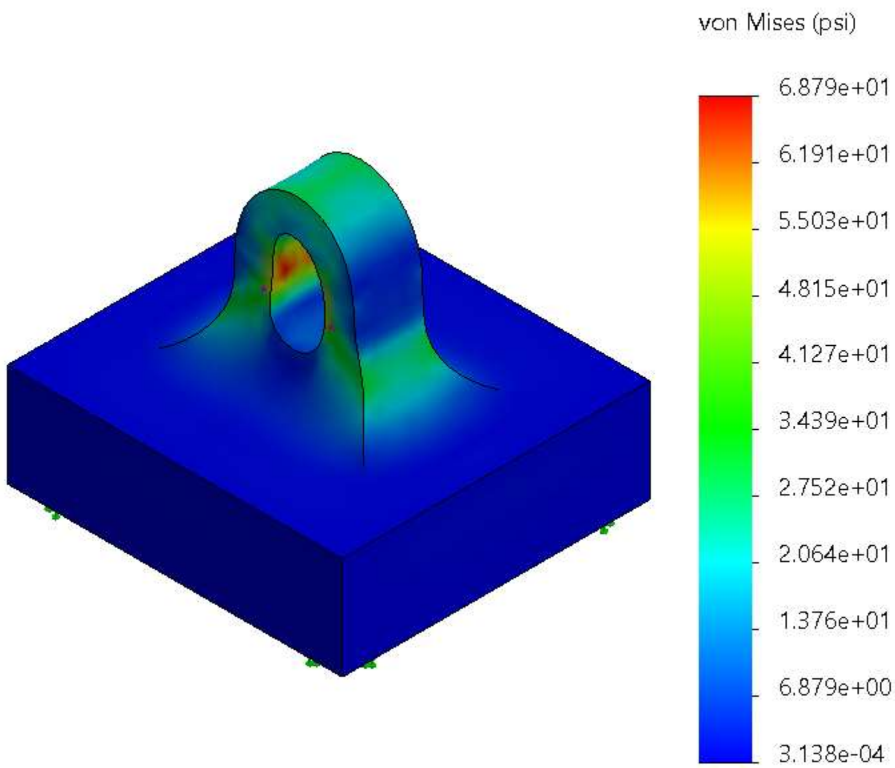

Figure 63: Payload Top Cap Stress Analysis

Table 44: 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 44: 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

Table 45: 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 (250 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 45: Wireless Transmission Range Test

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

Status/Results: (if completed): Planned

6.2. Requirements Compliance

6.2.1. SL Handbook Requirements Compliance

Table 46: 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

Table 46: USLI Handbook Requirements Compliance

Requirement	Method of Verification	Verification Plan	Status
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.			
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.	In Progress
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

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Requirement	Method of Verification	Verification Plan	Status
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 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.	Demonstration	Equipment necessary for virtual presentations will be acquired before presentation date and properly tested prior to presentation.	In Progress
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.	In Progress
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	Demonstration	A qualified mentor has been identified	Completed

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Requirement	Method of Verification	Verification Plan	Status
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.			
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
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.	In Progress
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.	In Progress
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	Analysis, Inspection	Launch vehicle was designed to have 3 independent sections tethered together.	Complete

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Requirement	Method of Verification	Verification Plan	Status
separately from the main vehicle using its own parachute.			
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
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

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Requirement	Method of Verification	Verification Plan	Status
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.	Not Needed
2.11. The launch vehicle will be limited to a single stage.	Demonstration	Vehicle will be designed to be single stage.	Complete
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:	Demonstration	Team will not utilize pressure vessels.	Complete
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.			
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

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Requirement	Method of Verification	Verification Plan	Status
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 confirmed using simulation software.	Complete
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	Not 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	Demonstration	Team will not be conducting Demonstration Flight due to competing in Design Competition.	Not Needed

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Requirement	Method of Verification	Verification Plan	Status
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:			
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			

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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).			
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:	Demonstration	Team will not be conducting Payload Demonstration Flight due to competing in Design Competition.	Not Needed
2.18.2.1. The payload must be fully retained until the intended point of deployment (if applicable), all retention mechanisms must			

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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.			
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.	Not 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			

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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
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	Test, Demonstration	All transmitters will communicate to the team using frequency hopping to	Complete

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other means to mitigate interference caused to or received from other teams.		prevent interference with other teams.	
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
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.	Not 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	Complete

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		landing speed to ensure completion of this. Main parachute deployment can be altered to alter speed and kinetic energy at landing.	
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
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	Complete

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		demonstration will verify simulation.	
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 vehicle's location from at least a mile radius to the team.	Complete
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

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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
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	Analysis, Demonstration	Payload is designed to be jettisoned from rocket at main	Complete

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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.		parachute deployment at 700ft AGL	
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
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

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4.3.4.4. The image should be included in your PLAR.	Analysis	Not needed for design competition.	Not 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
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.	Planned

Table 46: USLI Handbook Requirements Compliance

Requirement	Method of Verification	Verification Plan	Status
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 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.	-
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
5.3.1.4. Ground testing of vehicle and payload			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			Planned
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.	Not 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	Demonstration	No test flights planned	Not Needed

Table 46: USLI Handbook Requirements Compliance

Requirement	Method of Verification	Verification Plan	Status
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.			
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
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	Not 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	Not 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			

Table 46: USLI Handbook Requirements Compliance

Requirement	Method of Verification	Verification Plan	Status
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.			
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.			

6.2.2. Team Derived Requirements Compliance

Table 47: 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 and correct work is representing our school.	Demonstration	Team has carried out several recruitment events and several retention meetings.	Incomplete
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	New member communication with team leads is often lacking due to the level of technicality of the	Demonstration	Team has and continues to hold socials for new and returning members	Complete / Continued

Table 47: Team Requirements

Number	Team Requirement	Reason for Enforcement	Method of Verification	Verification Plan	Status
	encourage membership and team bonding throughout the year.	team. Social events where new recruits and leads were both present would help increase communication and retention.			
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 meet with the webmasters to check the progress of the website as well as offer formatting tips.	Demonstration	Webmaster continued to code website	In Progress
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	Demonstration	Design will be constrained to include fins within rectangular leading edge.	Completed

Table 47: Team Requirements

Number	Team Requirement	Reason for Enforcement	Method of Verification	Verification Plan	Status
		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.			
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 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.	Demonstration	No structural protuberance will be placed in the design of the vehicle	Completed
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					

Table 47: Team Requirements

Number	Team Requirement	Reason for Enforcement	Method of Verification	Verification Plan	Status
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
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	In Progress
3.4	All static interfaces must be reinforced	Reinforcing interfaces with epoxy or screws when possible allows for	Demonstration	Epoxy planned for use on all static interfaces	Compelted

Table 47: Team Requirements

Number	Team Requirement	Reason for Enforcement	Method of Verification	Verification Plan	Status
	with epoxy or screws.	greater load-bearing capabilities so they will be less likely to fail during deployment.			
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 communication is hindered.	Observation	Payload has been designed around this requirement. Payload features a parachute to slow its descent	Complete
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

Table 47: Team Requirements

Number	Team Requirement	Reason for Enforcement	Method of Verification	Verification Plan	Status
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

6.3. Budgeting and Timeline

6.3.1. Budget

Table 48: Budget

Grand Total					**$12,854**
	Expense	**Vendor**	**Projected Units**	**Projected Unit Price**	**Projected Total Price**
Structures	***Totals:***				$2,259
	Contingency			10%	$205
	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
	Fiberglass Sheet	McMaster-Carr	1	$17	$17
	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

Table 48: Budget

	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
	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

Table 48: Budget

	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

6.3.2. Funding

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.

6.3.3. Timeline

An up-to-date timeline of USLI deliverables, STEM outreach events, and individual team schedules has been compiled below in a series of Gantt charts. Projected beginning and ending dates are displayed and team is on track for completion of project at this this point.

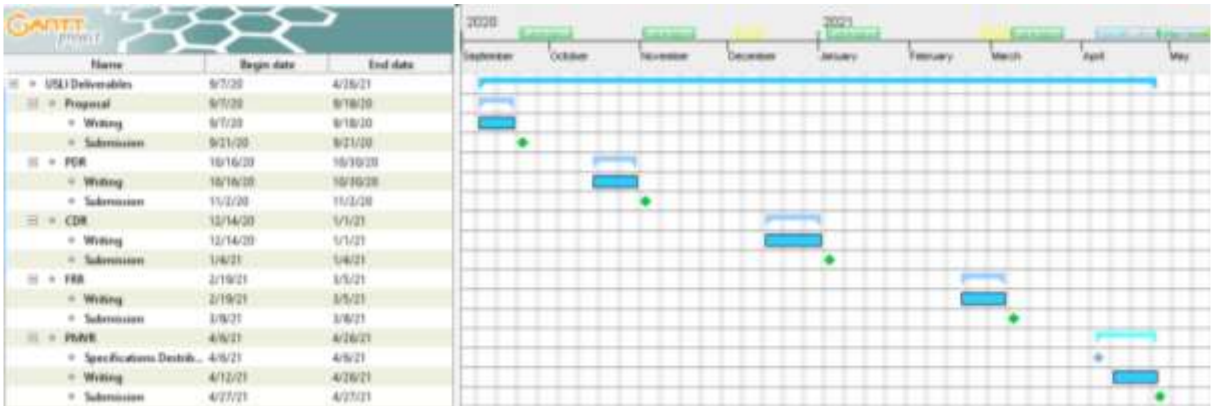

Figure 64: Gantt Chart of USLI Deliverables

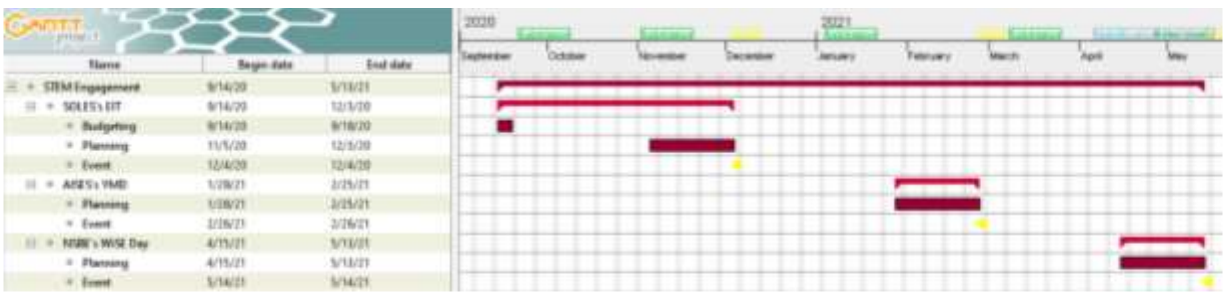

Figure 65: Gantt Chart of STEM Engagement

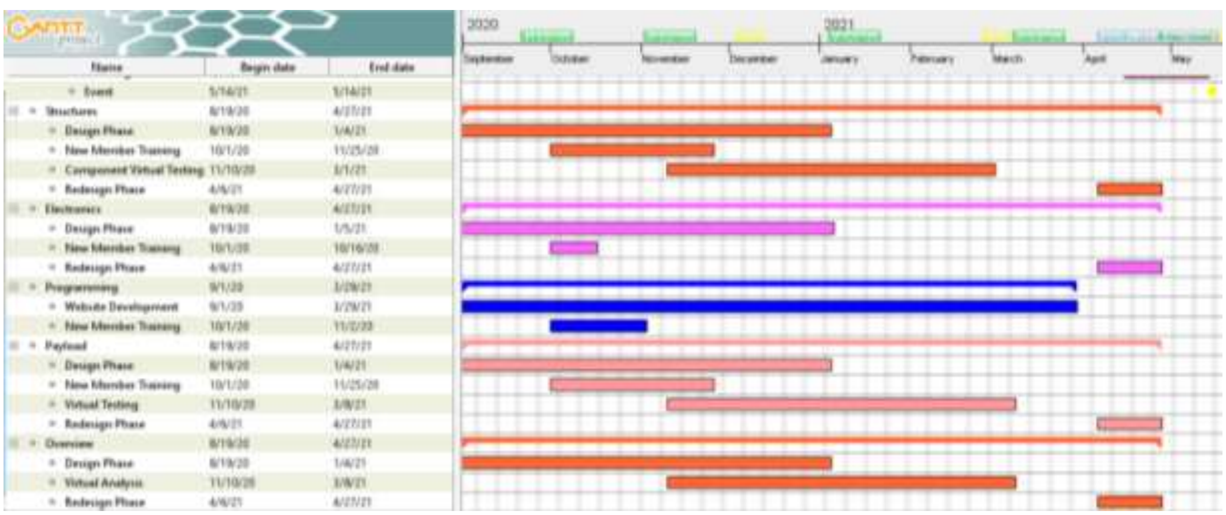

Figure 66: Gantt Chart for Technical Teams