Bearospace at UCLA
(LEXS)
Lunar Environment eXcavation Simulation
2019 - 2020 NASA Student Launch
Critical Design Review (CDR)

University of California, Los Angeles
420 Westwood Plaza
Los Angeles, CA, 90095
2685 Boelter Hall

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0. General

0.1 Adult Educators

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0.2 Student Leader

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0.4 Team Structure

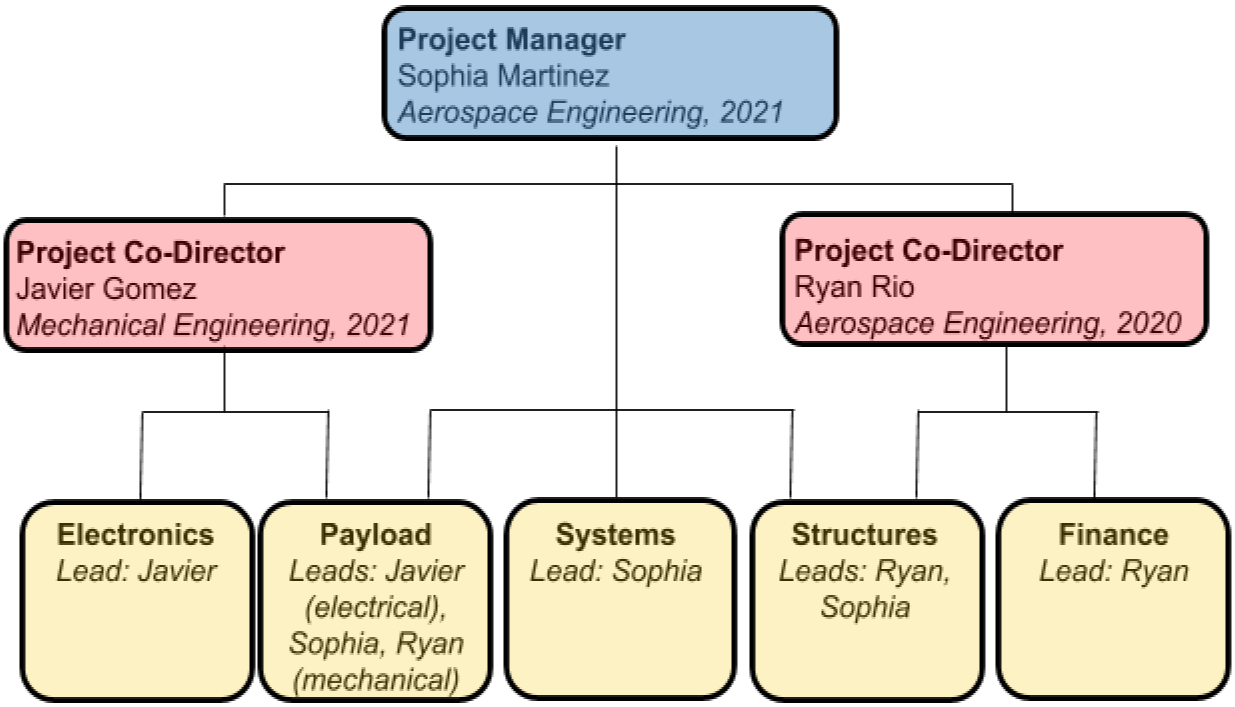


Figure 1: Current Team Structure

Sophia Martinez, Javier Gomez, and Ryan Rio are the project managers and oversee that the club runs smoothly. Each subteam has a team lead which will ensure a robust design and timely completion of the project. Below is a breakdown of the roles each subteam will carry out.

Table 1: Subteam Purposes

Subteam	Purpose
Electronics	Design, construct, and code electrical components of the rocket, excluding those within the scientific payload.
Payload	Design and construct electrical and mechanical components of the scientific payload.
Systems	Ensure full completion of all reports, project schedule management, and planning and executing testing of electrical and mechanical components of the vehicle and payload.
Structures	Design and manufacture vehicle (with a focus on stability and weight distribution), excluding the electronics bay and scientific payload.
Finance	Keep track of purchase orders through the UCLA project account, apply to various travel and project grants, plan and execute outreach events.

0.5 Team Member List

Table 2: Team Member List

Member Name	Degree	Role
Sophia Martinez	Aerospace Engineering, B.S. 2021	*Project Manager, Systems Team Lead, Payload Team Co-lead*
Ryan Rio	Aerospace Engineering, B.S. 2020	*Project Co-Director, Finance Team Lead, Structures Team Lead*
Javier Gomez	Mechanical Engineering, B.S. 2021	*Project Co-Director, Electronics Team Lead, Payload Team Co-lead*
Andy Muratalla	Aerospace Engineering, B.S. 2021	*Safety Officer*
Andres Cruz	Computer Science, B.S. 2023	*Webmaster*
Eduardo Ramirez Torres	Computer Science, B.S. 2023	*Webmaster*

Table 2: Team Member List

Jaime Perez	Computer Engineering, B.S. 2023	*Webmaster*
Anais Hernandez	Aerospace Engineering, B.S. 2023	*Media Coordinator*
Jasmine Gomez	Aerospace Engineering, B.S. 2021	*General Member*
Juan Silva	Materials Science and Engineering, B.S. 2021	*General Member*
Rossana Rico	Mechanical Engineering, B.S. 2020	*General Member*
Achille Hebert	Aerospace Engineering, B.S. 2020	*General Member*
Mitchell Rivas	Aerospace Engineering, B.S. 2022	*General Member*
Karina Ballesteros	Aerospace Engineering, B.S. 2020	*General Member*
Karla Bonilla	Aerospace Engineering, B.S. 2023	*General Member*
Elijah Bratcher	Aerospace Engineering, B.S. 2023	*General Member*
Armando Rendon	Electrical Engineering, B.S. 2022	*General Member*
Marcus Vidaurri	Aerospace Engineering, B.S. 2023	*General Member*
Damian Meza	Aerospace Engineering, B.S. 2023	*General Member*
Jason Salgado	Electrical Engineering, B.S. 2023	*General Member*
Justin Lopez	Aerospace Engineering, B.S. 2023	*General Member*
Miranda Diaz-Infante	Bioengineering B.S. 2023	*General Member*
Jorge Roji	Aerospace Engineering, B.S. 2023	*General Member*
Fredy Gochez Gonzalez	Aerospace Engineering, B.S. 2020	*General Member*

0.6 NAR/TRA Mentor

Rick Maschek
TRA # 11388
Level 2

1. Summary of CDR Report

Team Name:	UCLA Bearospace
Team Mailing Address:	420 Westwood Blvd Boelter Hall Room 6291 Los Angeles, CA 90095
Mentor:	Rick Maschek TRA #11388 Level 2
Rocket Dimensions:	77.9 in 27.6 lbs
Final Motor Choice:	2856-L910-CS-0
Target Altitude:	4100 Feet
Recovery System:	Dual deployment of drogue and main chute using two commercial altimeters for redundancy (Missile Works RRC3 Sports Altimeter and StratoLogger SL100 Altimeter). Deployment of drogue chute will be at apogee and main chute will be 500ft above ground level.
Rail Size:	8 ft
Payload Title:	Lunar Environment eXcavation Simulation (LEXS)
Payload Summary:	Payload will automatically deploy in the proper orientation using a rover ejection assembly embedded into the launch vehicle. Once deployed, the rover will be operated manually via radio telecommunication using feedback provided from an on-board camera. Radio telecommunication will be used as the primary means of travel if autonomy is not developed in time. The driver will operate 5 motors: 4 DC motors to drive the treads and 1 servo motor to move the collection arm. The collection arm and collection bin contains a volume greater than 10 mL as specified in the NASA Student Launch Handbook. The rover will be 11”x5”x4”.

2. Changes Made Since PDR

2.1. Changes to Launch Vehicle

The overall rocket vehicle design has not changed much since the PDR. The most significant points are the following:

1. Static stability has changed from 2.44 to 2.33 as a result of a more conservative estimate on the payload weight.
2. The nose cone's wall has been thickened to better withstand impact and deformation from landing.
3. The trapezoidal fins are now located 3 in. farther back down the lower body tube so as to accomodate a reasonable stability.
4. The main parachute has now been sized to a 10 ft. ripstop nylon parachute with a drag coefficient of 0.97 versus a 12 ft. ripstop nylon parachute with a drag coefficient of 0.8.

2.2. Changes to Payload

The payload now features a compartmentalized electronics bay from which to mount all rover electronics onto. A separate compartment exists solely for the selected lithium polymer battery to prevent electronic exposure to the potentially hazardous lithium polymer battery. Each compartment attaches to itself using nuts and bolts as fasteners. The compartments will connect using tabs built into the compartments and size 6-32 nuts and bolts.

The electronics bay has been updated to reflect the decision to use a lead screw as the method of deployment from the launch vehicle. The holes within the electronics bay are reinforced to support the weight of the rover.

Treads on the rover have been reduced from a width of 1" to 0.75" for the rover to fit within the launch vehicle. In addition to this, antennas have been included and an additional mechanism has been developed to retract the antenna while inside the launch vehicle and return to an upright position once deployed.

Rover electronics have been updated to include one large lithium polymer battery to power all electronics instead of the previous decision to use two smaller lithium polymer batteries to power sections within the rover. The use of a single lithium polymer battery necessitates the use of a power distribution board with voltage regulators which were previously not considered. Wiring within the rover electronics will now include a power distribution board with 5V voltage regulators.

2.3. Changes to Project Plan

The project schedule has been updated to delineate past milestones and STEM outreach events completed, and to provide a comprehensive testing plan for the testing phase to ensure the rocket vehicle and payload virtually and experimentally meet the requirements and for launch, delineated in Section 6.

2.4. PDR Action Items

1. Conduct testing to determine if the nose cone bulkhead is able to handle typical flight and recovery forces.

   The two identified failure modes of the nose cone bulkhead are the bulkhead not able to withstand forces during flight and the interface between the bulkhead and nose cone failing due to excessive shear force. The first mode can be tested for virtually by using common material values while the second must be tested physically since the shear strength of epoxy varies with material and amount applied. Both these tests are detailed in section 6.1.1. Vehicle Component Test Plans/Status as well as their status.

2. Conduct testing to determine if the bulkhead access door is able to handle typical flight and recovery forces.

   The three identified failure modes of the locking mechanism are the mates not supporting the forces during flight, the interface between the mechanism and the body tube failing due to excessive shear force, and the lock coming loose during flight. The first can be virtually tested with common material values, the second must be tested physically due to variant epoxy shear strength with material and amount, and the third must be tested physically by finding the real coefficient of friction within the mechanism. These tests are detailed in section 6.1.1. Vehicle Component Test Plans/Status as well as their status.

3. Utilize mechanical switches to turn on the flight computers.

   Previously, the term “mechanical switch” was misinterpreted by the team. The design has been altered to include push buttons as a form of mechanical switches. This is detailed in section 3.3.2. Hardware Components.

3. Vehicle Criteria

3.1. Design Verification of Launch Vehicle

3.1.1. Mission Statement

Bearospace at UCLA will design, manufacture, test, and launch a vehicle to an apogee of 4100 feet, deploys parachutes at major events, and lands safely. This vehicle will be designed for the purposes of NASA USLI 2020 competition, harboring a scientific payload specific to that year's competition. Furthermore, minimizing cost will be at the focus of design and manufacturing stages while not compromising such aspects as sustainability of the vehicle for multiple launches if needed.

3.1.2. Mission Success Criteria

A successful mission will be categorized by the vehicle's completion of the following tasks:

1. Reaching an apogee within 100 ft of 4100 ft.
2. Deploying a drogue parachute at apogee and a main parachute at 500 ft agl and landing with no visibly detectable damage to the body of the vehicle.
3. Safely retaining a payload during flight with no signs of damage to the structure and electronics of the rover, as verified through post-landing testing and inspection.
4. Avionics components collecting and storing in-flight data such as pressure, temperature, speed, and altitude of the launch vehicle. Altitude data accuracy will be defined as both altimeters reading altitude within 10ft of each other.

3.1.3. Alternative Selections

In the PDR, three design alternatives were presented to provide a variety of solutions that addressed the mission success criteria in different ways, focused around different motor selections. To recap, the three are summarized below:

<u>Alternative Design 1:</u> 2856-L910-CS-0

- Alternative Design 1 uses the shortest motor that is able to supply a great enough impulse to achieve an apogee comfortably within the apogee window given, 2856-L910-CS-0. This comparatively smaller size allows for greater flexibility in designing the payload, especially in regards to its size, as more space could be found and made should the payload exceed predicted size expectations.

<u>Alternative Design 2:</u> L1482-0

- Alternative Design 2 utilizes a longer motor than the previous design, L1482-0, and supplies a far greater impulse as well, pushing the apogee close to the upper limit on the flight ceiling. It also features an ellipsoid nose, so as to create more drag subsonically than an ogive nose and contribute to lowering the apogee estimate. Though this design does not offer the same freedom of space and pushes the upper limit on apogee, its comparatively larger impulse allows for greater freedom in weight gain during the design and construction of the rocket should discrepancies in estimated component weights occur, especially in regards to the payload. The ellipsoid shape of the nose cone also allows a bulkhead of sufficient diameter to be secured farther towards the tip of the nose cone, allowing for greater room for the main parachute and its assembly.

<u>Alternative Design 3:</u> L780-SF-0

- Alternative Design 3 utilizes the longest motor, L780-SF-0, out of the alternative designs with a comparatively smaller impulse. Though it has the greatest restriction in terms of freedom of space and unforeseen weight gain during the manufacturing and assembly process, its comparatively smaller impulse allows for greater freedom in weight loss during the design and construction of the rocket should discrepancies in estimated component weights occur,especially in regards to the payload.

Our leading selection is Alternative Design 1 with the 2856-L910-CS-0, primarily due to the spaciousness that its motor, the shortest of all the alternative designs, allows for. It's estimated apogee is also at an optimal level, almost exactly midway between the upper and lower limits of the apogee window, allowing for both weight gain and weight loss due to discrepancies in the estimated weight of vehicle and payload components. In simpler terms, this rocket designs affords an even margin of error towards both extremes in terms of apogee and weight, as well as affording the most freedom of space out of the three alternative rocket vehicle designs.

3.1.4. Launch Vehicle Components

Overview

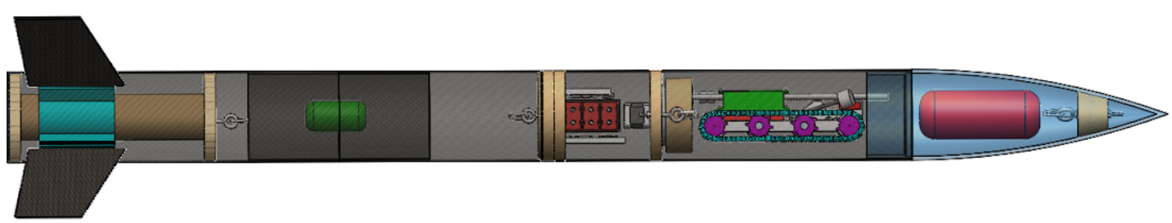


Figure 2: Launch Vehicle Overview

Total Estimated Weight: 27.6 lb.
Stability Margin: 2.33

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

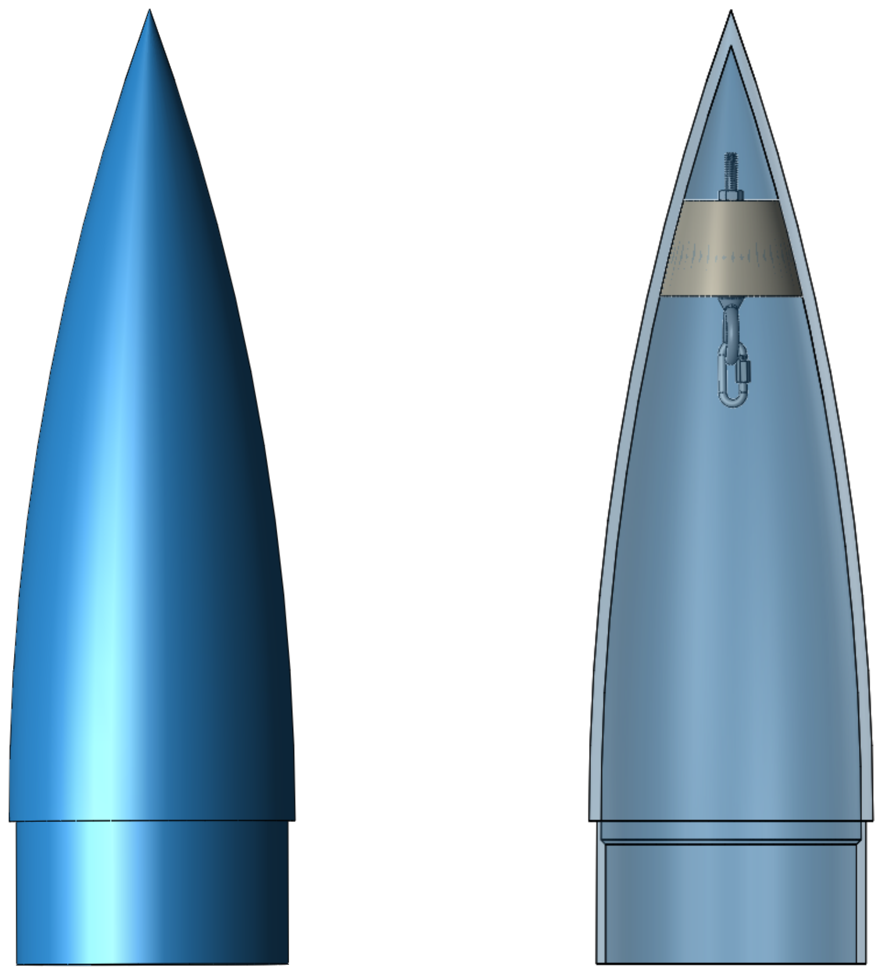


Figure 3: Nose Cone Overview

Estimated Rocket Vehicle Section Weight: 1.89 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

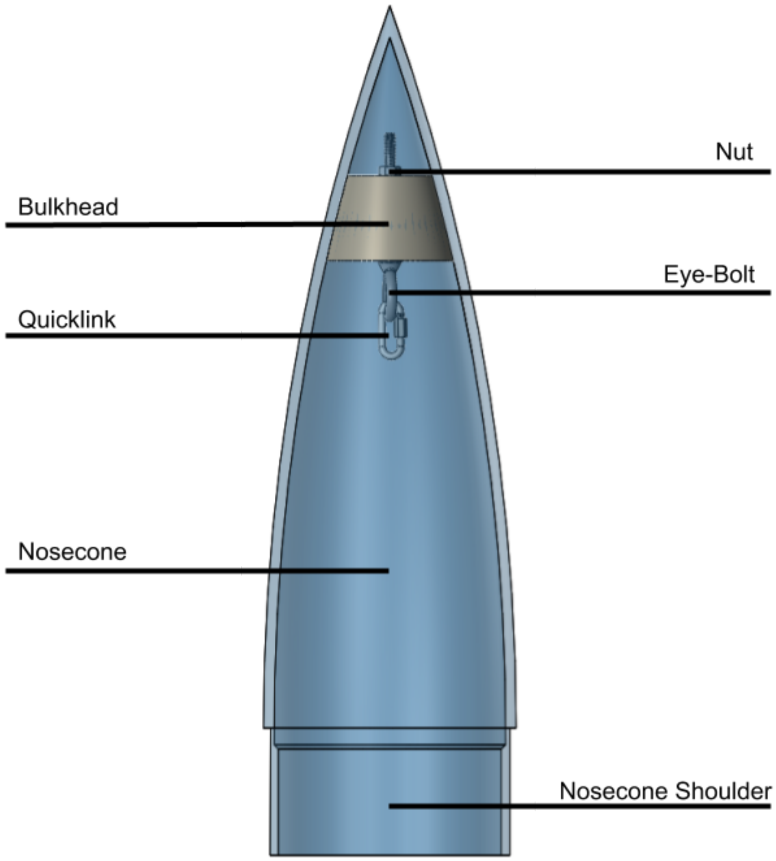


Figure 4: Nose Cone Components

Table 3: Nose Cone Section Components

Component	Material	Dimensions
Nose Cone	ABS Plastic	Cone Length: 23 in. Cone Thickness: 0.2 in. Cone Base Diameter: 5.9 in. Shoulder Length: 0.121 in. Shoulder Thickness: 0.121 in. Shoulder Diameter: 5.821 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.

Table 3: Nose Cone Section Components

Bulkhead	Pine Wood and Epoxy	Thickness: 2 in. Minimum Diameter: 2.02 in. Maximum Diameter: 3.02 in.
	Pine wood is selected as the base material due to its relative ease of sourcing, price point, and ability to precisely manufacture in student engineering and manufacturing shops. Epoxy will be used as the bonding adhesive between the bulkhead and the nose cone interior wall, as well as between different layers of the pine wood, as it is the stronger adhesive in comparison to wood glue, despite its increased price point.	The dimensions are given so the bulkhead is thick enough to secure an eyebolt to which the main parachute recovery assembly is attached, and its sides are sloped to be flush to the interior wall of the nose cone to better epoxy it to the nose cone.
Eyebolt	Stainless Steel	Length: 3 in. Diameter: 1 in.
	Stainless steel is the material of choice for eyebolts due to their high strength, a necessary consideration for the loading forces present during the main parachute's deployment.	The diameter of the eyebolt must be wide enough such that a quicklink can be fed through the eye and secured, serving as the attachment point of the main parachute assembly. Additionally, the length of the eyebolt's shank must be long enough to pass through the entirety of the bulkhead, and still have enough length left to fasten a nut to the eyebolt, securing the eyebolt against the bulkhead and thus the nose cone parent component.

Table 3: Nose Cone Section Components

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.

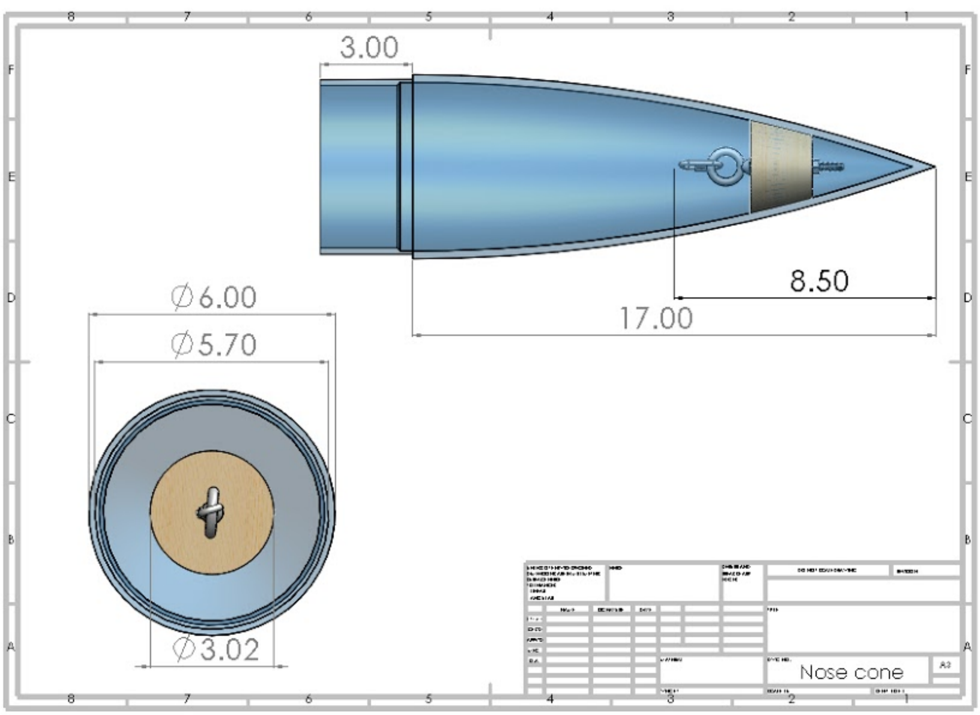


Figure 5: Nose Cone Drawing

Upper Body Tube

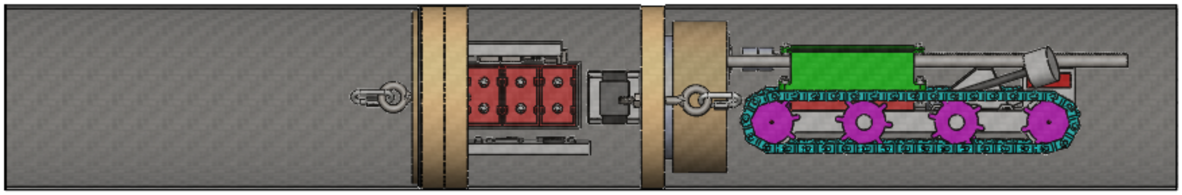


Figure 6: Upper Body Tube Overview

Estimated Rocket Vehicle Section Weight: 9.76 lb

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

1. The upper body tube parent component
2. The rover which will be ejected to complete the competition objective of gathering simulated lunar ice
3. The Rover Ejection Assembly (REA) which will be ejecting and deploying the rover upon the rocket vehicle's landing
4. The electronics bay which houses the electronic "brain" of the rocket, recording data on the rocket vehicle's flight and triggering the REA's activation upon landing.
5. The locking mechanism, which is both the anchor point for the drogue chute assembly and the access point for the electronics bay.
6. The bulkhead, which is used as a base for the REA and separates the rover and REA from the electronics bay, as well as an anchor point for the main parachute assembly to the upper body tube parent component
7. The eyebolt, of which there are two: one for attaching the main parachute assembly to the bulkhead supporting the REA, and another for attaching the drogue chute assembly to the locking mechanism
8. 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
9. The nut, of which fastens the eyebolt of the main parachute assembly to the bulkhead supporting the REA

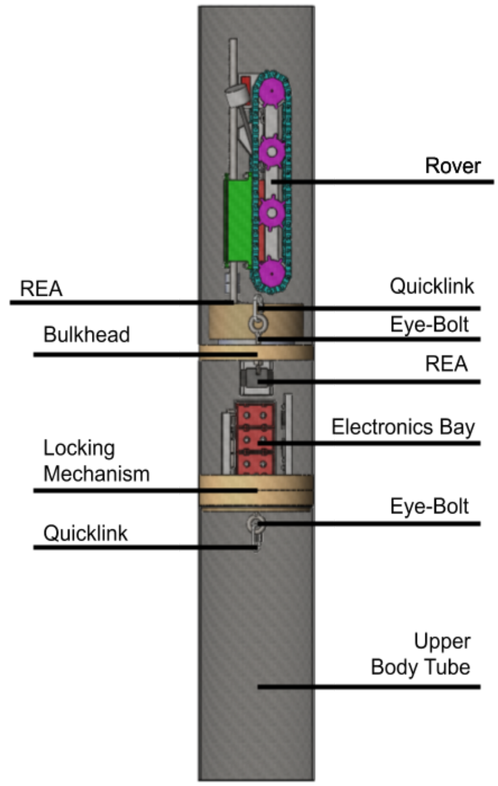


Figure 7: Upper Body Tube Components

Table 4: Upper Body Tube Section Components

Part	Material	Dimensions
Upper Body Tube	Carbon Fiber	Length: 38 in. Thickness: 0.079 in. Outer Diameter: 5.9 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 rover and REA, 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

Table 4: Upper Body Tube Section Components

Rover	*See Section 4.1.4.*	
REA	*See Section 4.1.4.*	
Electronics Bay	*See Section 4.1.4.*	
Locking Mechanism	*See Section 4.1.4.*	
Bulkhead	Pine Wood and Epoxy	Thickness: 2 in. Minimum Diameter: 1.7 in. Maximum Diameter: 2.9 in.
	Pine wood is selected as the base material due to its relative ease of sourcing, price point, and ability to precisely manufacture in student engineering and manufacturing shops. Epoxy will be used as the bonding adhesive between the bulkhead and the body tube interior wall, as well as between different layers of the pine wood, as it is the stronger adhesive in comparison to wood glue, despite its increased price point.	The dimensions are given so the bulkhead is thick enough to secure an eyebolt to which the main parachute recovery assembly is attached
Eyebolt	Stainless Steel	Length: 3 in. Diameter: 1 in.
	Stainless steel is the material of choice for eyebolts due to their high strength, a necessary consideration for the loading forces 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.

Table 4: Upper Body Tube Section Components

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 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 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.

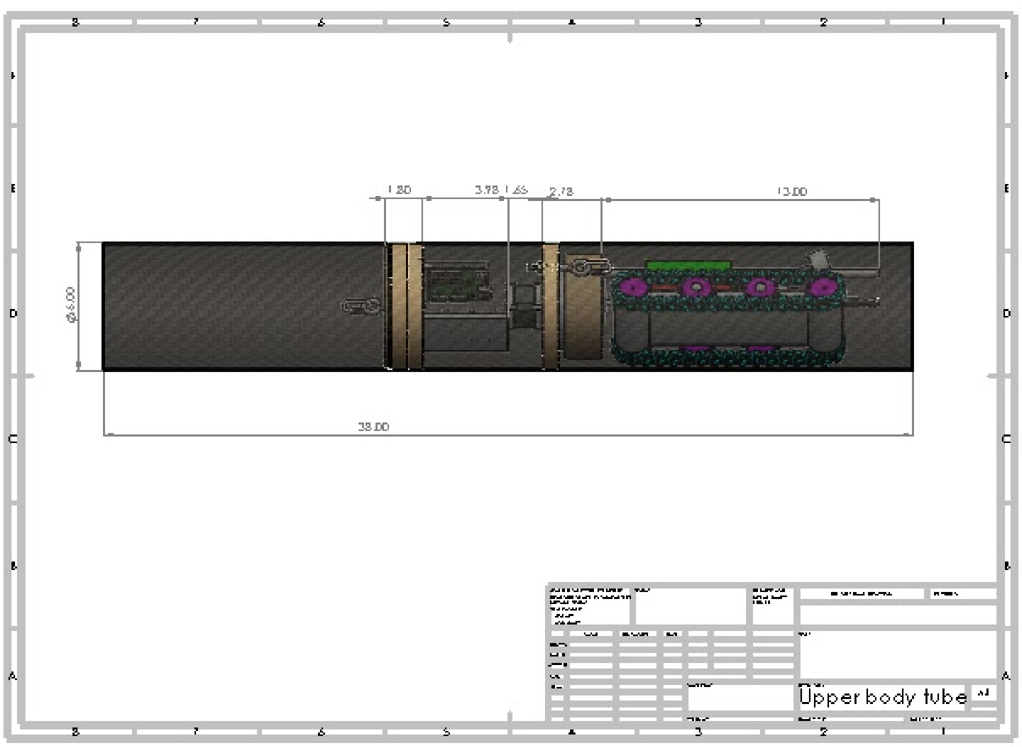


Figure 8: Upper Body Tube Drawing

Lower Body Tube

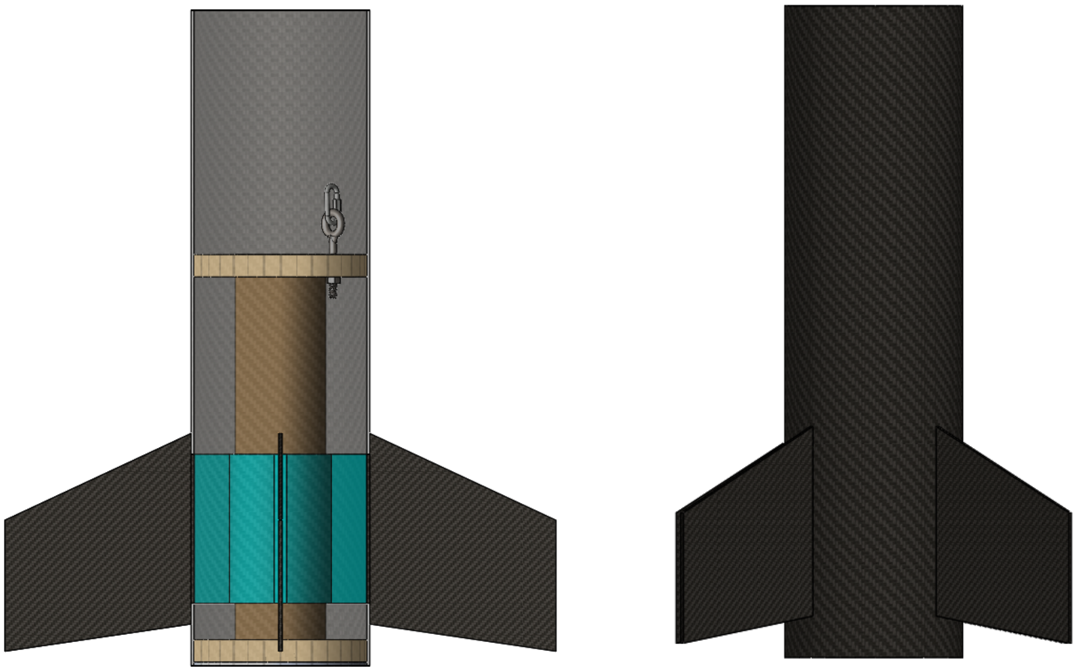


Figure 9: Lower Body Tube Overview

Estimated Rocket Vehicle Section Weight (pre-launch): 12.65 lb
Estimated Rocket Vehicle Section Weight (pre-launch): 9.64 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

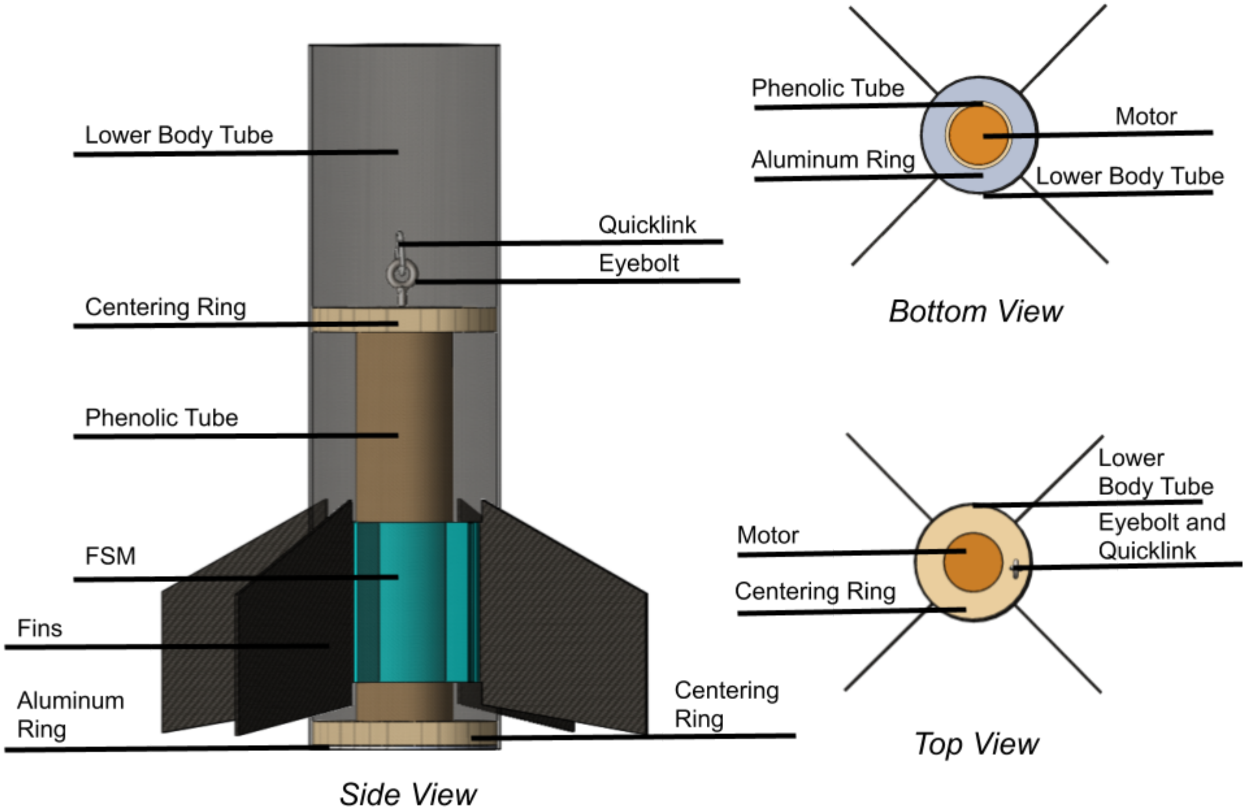


Figure 10: Lower Body Tube Components

Table 5: Lower Body Tube Section Components

Part	Material	Dimensions
Lower Body Tube	Carbon Fiber	Length: 22 in. Thickness: 0.079 in. Outer Diameter: 5.9 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 half the coupler, the phenolic tube, the drogue chute assembly, and the centering rings. As can be seen above, the length is enough to have space dedicated to all of the aforementioned parts.

Table 5: Lower Body Tube Section Components

Centering Ring	Pine Wood and Epoxy	Thickness: 0.75 in. Outer Diameter: 5.9 in. Inner Diameter: 3.05 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.
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.

Table 5: Lower Body Tube Section Components

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: 13.8 in. Outer Diameter: 3.05 in. Inner Diameter: 2.95 in. Thickness: 0.1 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 figure 18 in Section 3.1.5.
	Carbon Fiber is the preferred material of choice for the trapezoidal fins, as it is both stronger and lighter in comparison to fiberglass, though is not as competitive when comparing cost. Due to the large weight of the rocket, the necessity for a strong body tube for landing and payload survival becomes paramount, as well as ensuring a higher apogee capability at the same weight. As such, carbon fiber was selected over fiberglass.	The sizing of the trapezoidal fins is directly a result of trying to influence the stability of the rocket in flight while ensuring a generally streamlined aerodynamic shape for good airflow.
FSM	ABS Plastic	Refer to figure 18 in Section 3.1.5.
	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

Table 5: Lower Body Tube Section Components

Aluminum Ring	Aluminum	Thickness: 0.13 in. Inner Diameter: 3.05 in. Outer Diameter: 5.9 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.

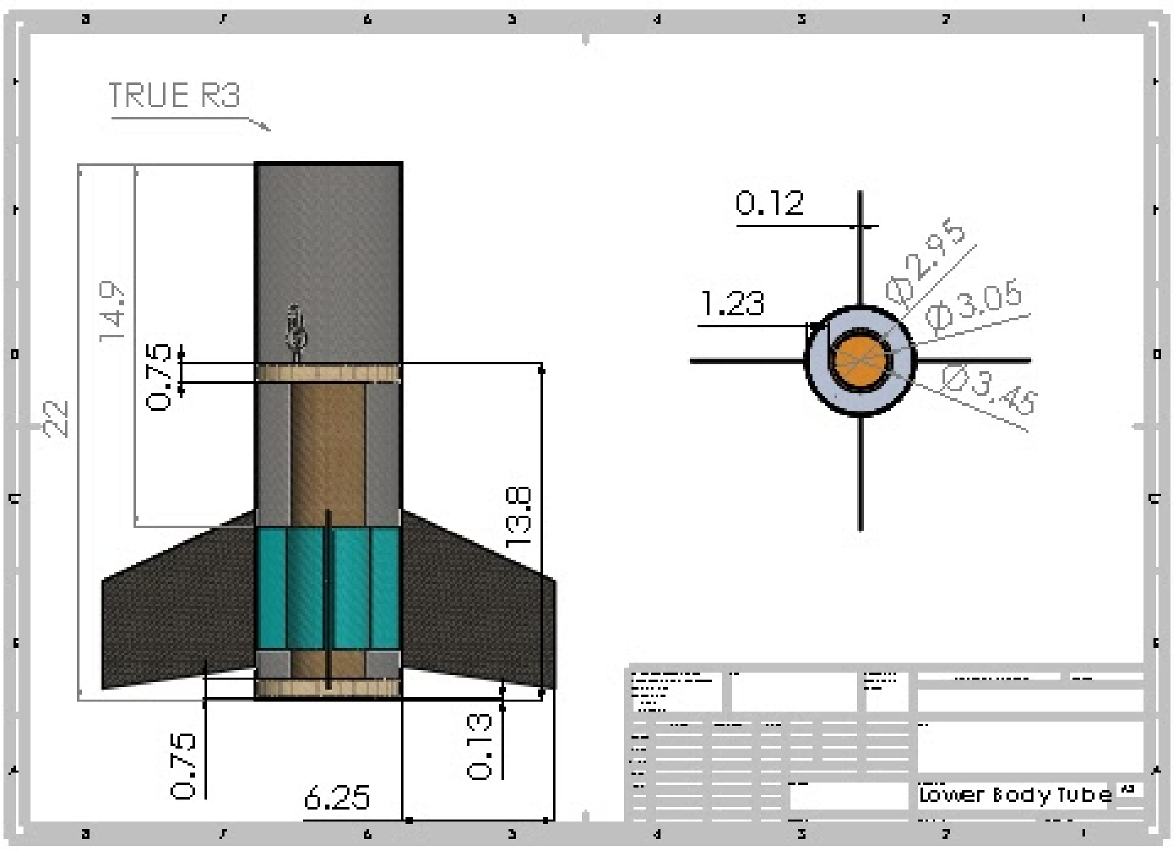


Figure 11: Lower Body Tube Drawing

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.

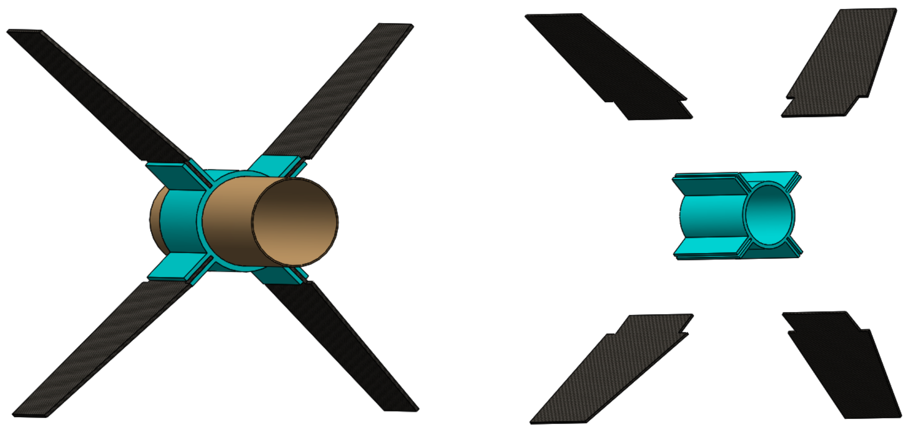


Figure 12: FSM Overview

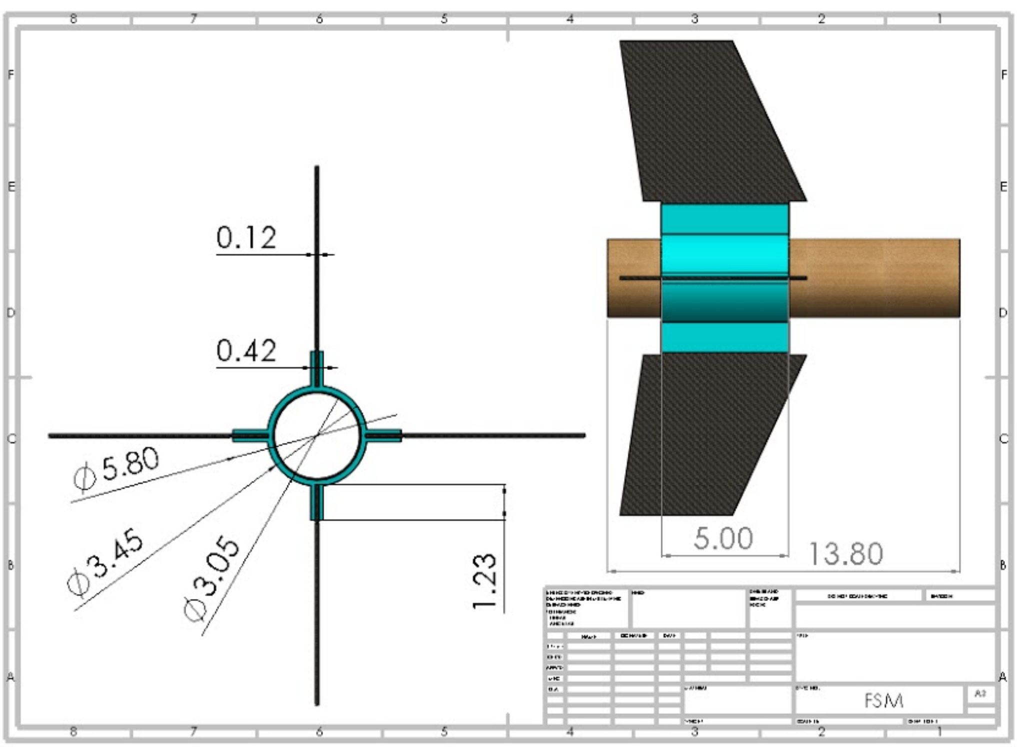


Figure 13: FSM Drawing

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.

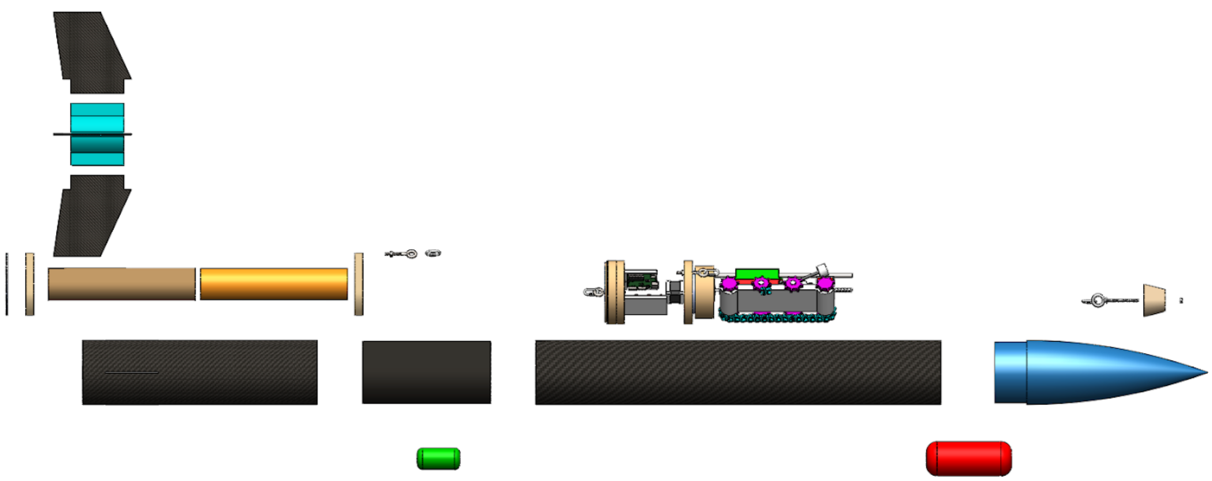


Figure 14: Launch Vehicle Exploded View

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

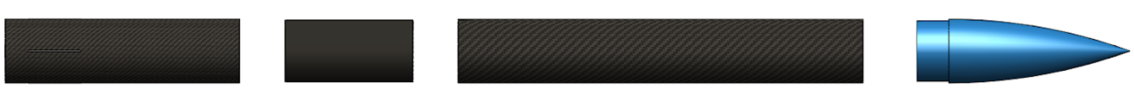


Figure 15: Launch Vehicle Parent Components

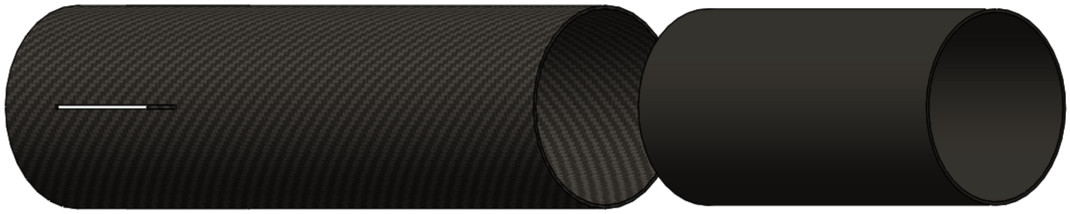


Figure 16: Coupler Assembly

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

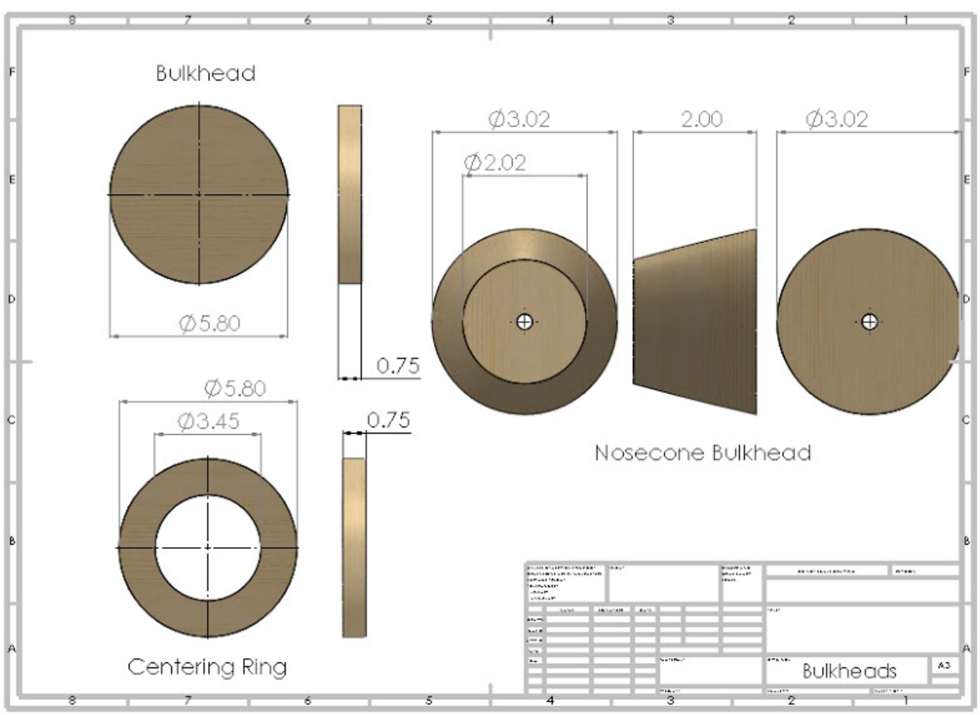


Figure 17: Bulkhead and Centering Ring Drawings

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.

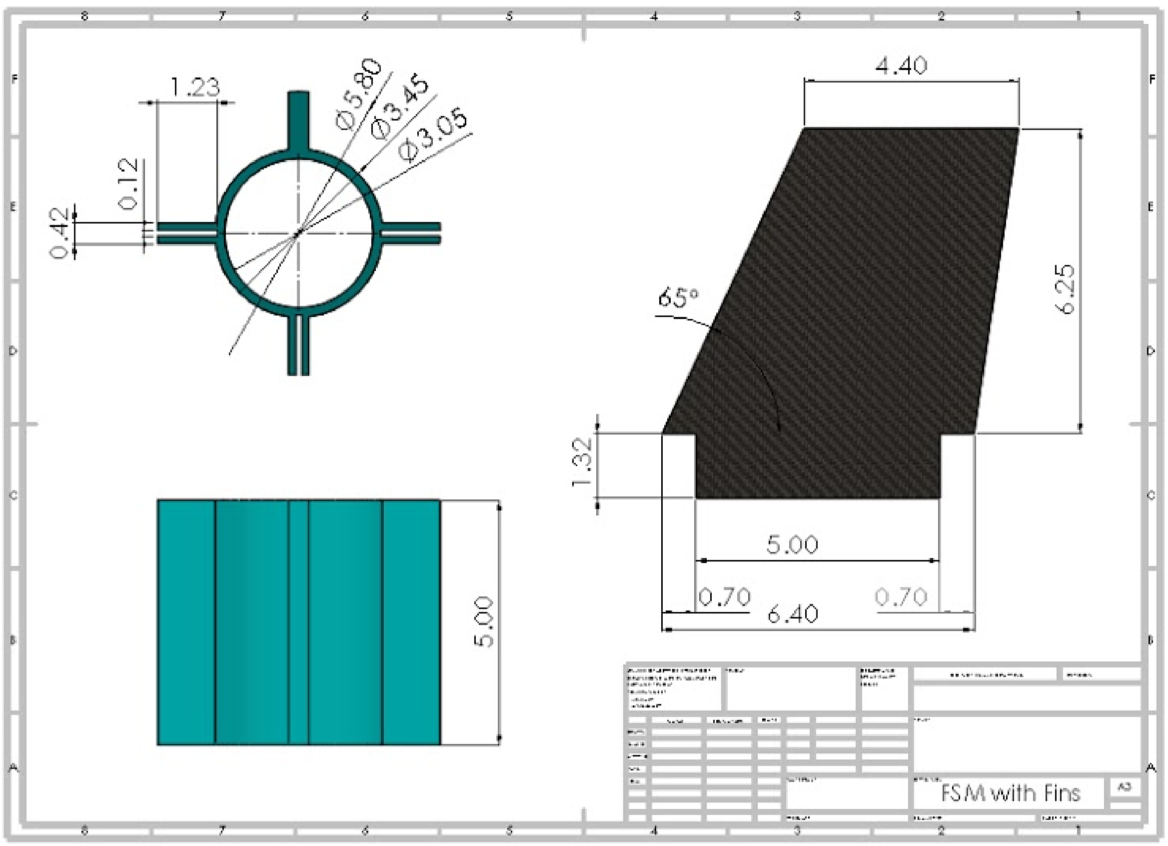


Figure 18: FSM and Fin Drawings

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.

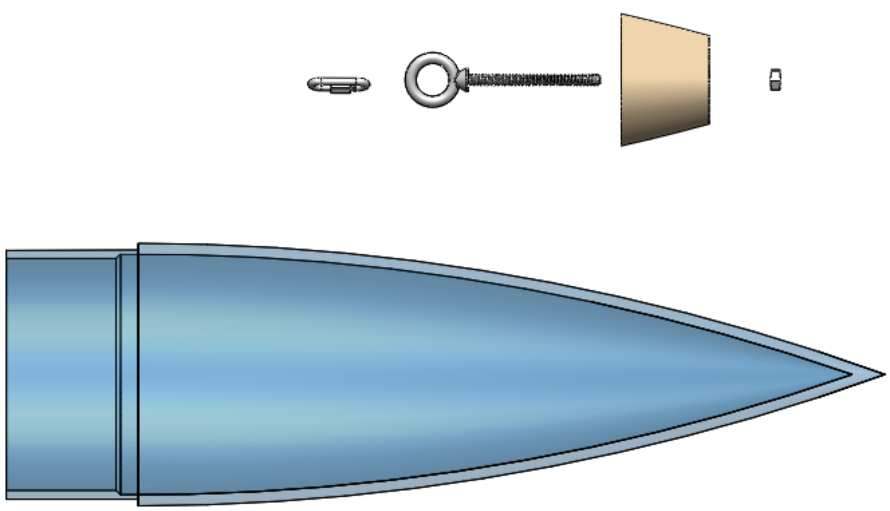


Figure 19: Nose Cone Assembly

Upper Body Tube Vehicle Section Assembly

Refer to Section 4.1.4.

Lower Body Tube Vehicle Section Assembly

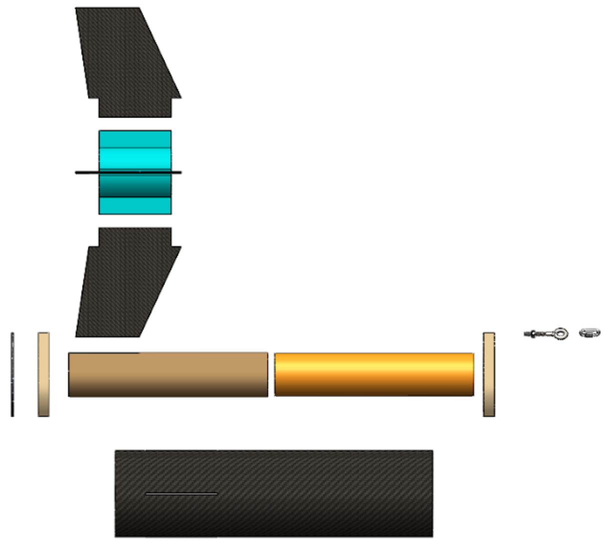


Figure 20: Upper Body Tube Assembly

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.

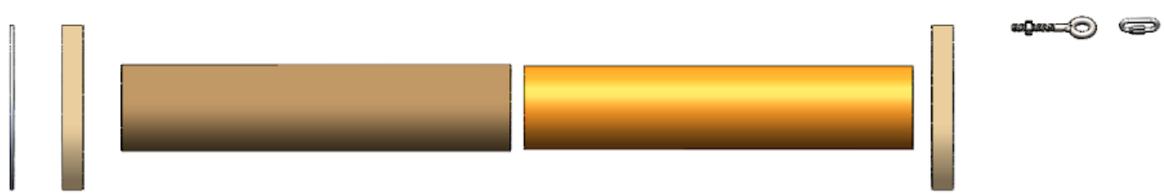


Figure 21: Motor Stabilizing Assembly

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 section 3.1.4. Launch Vehicle Components for each individual component. Material properties and testing is in 6.1.1. Vehicle Component Test Plans/Status.

3.1.7. Material Selection

Justification for material selection, dimensioning, and other design aspects are discussed in Section 3.1.4., and component placement is discussed in Section 3.1.5.

3.2. Subscale Flight Results

3.2.1. Flight Data

During launch, the subscale rocket vehicle carried an altimeter which recorded the altitude of the rocket during flight, as well as the apogee. The flight data recording is provided below, with a recorded apogee of 888 ft. AGL.

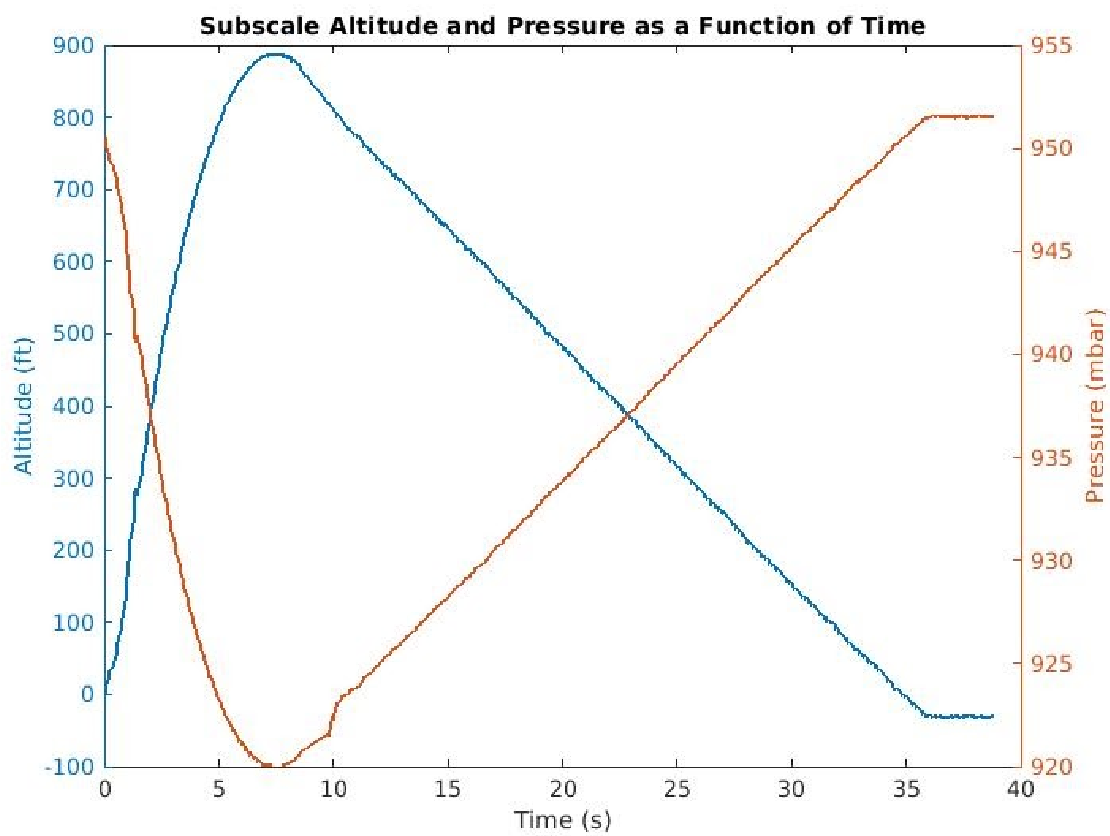


Figure 22: Subscale Flight Data

3.2.2. Scaling Factors

A major consideration when designing the subscale rocket was the need to ensure the data determined from the subscale rocket vehicle would be applicable to the full-scale rocket vehicle, necessitating the use of scaling factors, or non-dimensional ratios and proportions between structural and design parameters of the subscale and full-scale rocket vehicle.

Our subscale rocket vehicle is scaled **0.4353** to the size of our full-scale rocket vehicle. A listing of each scaling factor, its value, whether it is required to be constant or come close to being equal, whether it does, and the reasoning for the scaling consideration is provided below.

Table 6: Scaling Factors

Scaling Factor	Ratio or Proportion	Should It Be Constant?	Was It Constant?
Stability	(CG-CP)/D	Constant	Yes
	Stability is a critical aerodynamic property for a rocket, as its flight characteristics are heavily dependent upon it. As such, stability must be the same between both the subscale and full-scale rockets.		
Nose Cone	Curvature Equation	Constant	Yes
	The nose cone's shape, given in our rockets by the ogive curvature equation, has a large effect on the aerodynamic performance of the rocket by having different coefficients of drag and other aerodynamic considerations for different kinds of flight. Since we want the performance of the subscale rocket to mirror that of the full scale rocket, the nose cone's shape should be constant.		
Nose Cone	Cone Length/Cone Diameter	Constant	Yes
	Similar to the curvature equation, the nose cone's shape proportions are also important, as a short, wide ogive nose cone will have a higher non-dimensional coefficient of drag than a long, slender ogive nose cone will. As such, the ratio between the two nose cones' lengths and diameters must be equal and constant.		

Table 6: Scaling Factors

Nose Cone	Cone Length/Body Length	Constant	Yes
	Similar to the nose cone length and diameter, the nose cone's proportion to the body tube should be constant, as different sized nose cones will have differing aerodynamic performances for the same rocket. This statement is made holding that all other previous proportions and ratios ie shape and curvature are all also proportional, and so carry over. The end result is a nose cone and body tube that are proportionally equal.		
Nose Cone	Cone Surface Area/Body Surface Area	Constant	Yes
	If all previous proportions and ratios are equal, then this proportion will be equal as well, as the nose cone surface area is a function of the outer diameter, length, and curvature, all of which have been made proportional to the body tube.		
Fins	Fin Surface Area/Body Surface Area	Constant	Yes
	Fins have a significant contribution on the aerodynamic properties of a rocket, in our considerations namely on stability and coefficient of drag. In designing the subscale rocket fins, as the majority of the drag contribution from the fins come from skin friction, the ratio of the total amount of fin surface area contributing to the coefficient of drag and the total amount of the rocket body's drag contribution between both the subscale and full scale rocket should be equal. It is also important to note that this must be true while the stability is also equal, as changes to fin surface area greatly affect stability.		
Fins	Fin Position/Body Length	Close	Yes
	The positioning of the fins relative to the length of the body tube does contribute to the stability of the rocket, so the fins on the subscale rocket should be close to where the fins on the full scale rocket are. However, the placement has more significance in terms of maintaining a constant stability between the two rather than any kind of contribution to the coefficient of drag. In the design of the subscale rocket, though it was not deemed as important to be kept constant, the ratio between the positioning of the fin to the body tube length was kept constant.		

Table 6: Scaling Factors

<table>
<tr><td rowspan="2">Fins</td><td>Fin Cross-Sectional Area/Body Cross-Sectional Area</td><td>Close</td><td>No</td></tr>
<tr><td colspan="3">A fin’s contribution from its cross-sectional area to a rocket’s overall coefficient of drag is comparatively small to its contribution from skin friction. As such, during the design of the subscale rocket the total cross-sectional area between the fins of the subscale and full scale rockets were variable by a small margin, and the number of fins was reduced from four to three while maintaining the same total cross-sectional area.</td></tr>
</table>

3.2.3. Launch Day Conditions

Launch day conditions were recorded by launch site staff and Bearospace members from the FAR site weather station’s data, available on the website Weather Underground, and are provided below for the time of launch at 3:20 pm.

Table 7: FAR Launch Site Weather Conditions

Time	**Temperature**	**Dew Point**	**Humidity**	**Wind Direction**
3:20 pm	64.0ºF	34.3ºF	33%	West
Wind Speed	**Wind Gust**	**Air Pressure**	**Precipitation Rate**	**Precipitation Accumulation**
0.0 mph	4.0 mph	30.20 in.	0.00 in.	0.00 in.

Using this weather data and our estimate as to the properties of the motor used, the launch pad inclination, and final pre-flight data on the rocket, a RockSim rocket launch simulation is provided below.

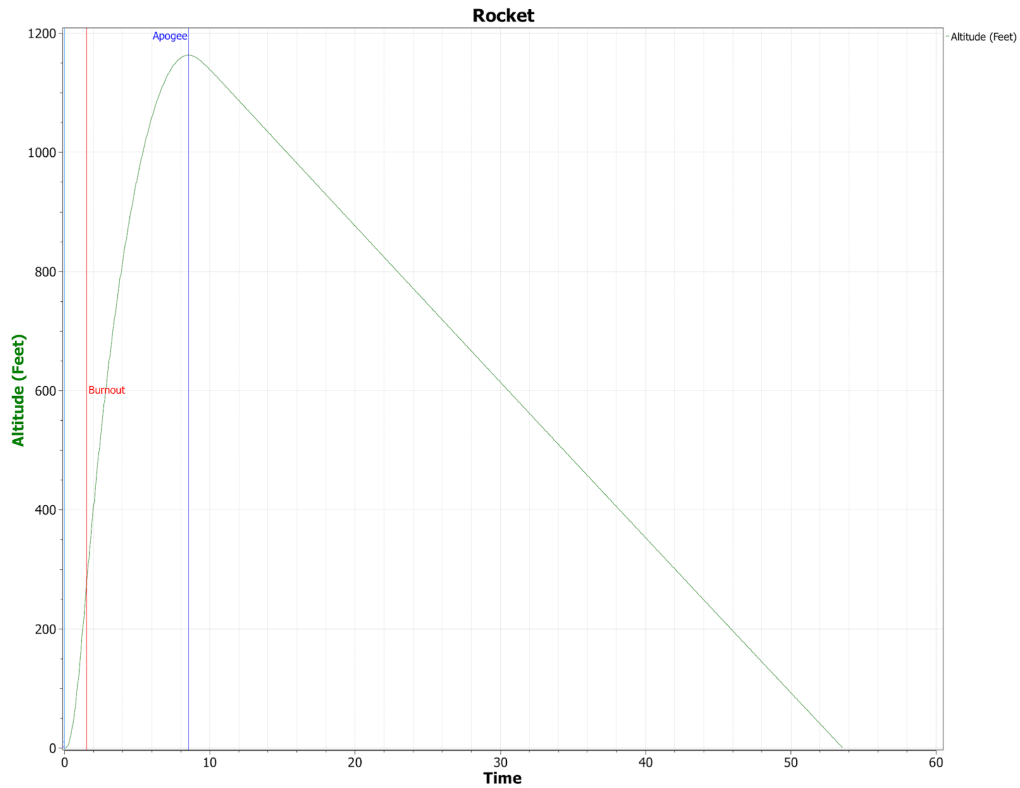


Figure 23:Simulated Subscale Flight Data

3.2.4. Subscale Analysis

Of particular note is the reduction in apogee from what the team initially expected. From observations made during pre-flight checks and the launch, this cause of error can possibly be explained by several considerations:

1. Skin Friction Differences in Material Used versus Material Simulated
    a. During the design of the rocket, the differences in skin friction between the default cardboard material and the actual cardboard material used was not accounted for, nor was minute structural differences in form between simulated and actual cardboard tubes such as seam size, protuberance from the tube, etc. Such differences can lead to a difference in skin friction drag, thus resulting in different coefficients of drag.
2. Deformation of Launch Rail During Launch
    a. During launch, it was observed that as the rocket traveled along the launch rail, the rail flexed and bent slightly, likely due to the forces the rocket was applying to it and the launch pad during motor burn (it should be noted that the subscale launch team used a commercially purchased ¼” 5 ft. launch pad with launch rail from Aerotech). As the simulation software does not have a way to account for

loading on a flexible launch rail and possible resulting deformation due to motor burn, and as such can explain the discrepancy.

Using the subscale launch data, the full-scale rocket vehicle is estimated to have a coefficient of drag of 0.63.

3.2.5. Impact to Full-Scale Design

Due to the error and considered causes presented by comparing the simulated launch and actual launch, several considerations will need to be made going forward when approaching the full-scale rocket vehicle demonstration data for the FRR.

1. Measuring, Estimating, and Changing the Skin Friction of Materials Directly
    a. Though there can be significant differences between cardboard tubes manufactured by different companies, cured carbon fiber tubes are unlikely to have significant differences. However, 3D printed objects, such as our nose cone can have significantly differing skin friction coefficients due to printer settings and characteristics. Currently, design team members have not considered measuring the skin friction coefficient for the same nose cone made from different printers and different speed settings, but that will have to change in order to more accurately predict future launches from current demonstration launch data. With measuring the skin friction coefficient comes the ability to change that number to result in components with a desired target skin friction coefficient to better target a specific coefficient of drag and/or target apogee.
2. Design for an Apogee Some Margin of Safety Higher than the Target Apogee
    a. From the reduction in apogee from the simulation prediction and actual launch, it is critical to design a margin of error into the rocket's apogee target. From this consideration, the full-scale rocket will be designed and optimized for an apogee at least 100 ft. higher than the target apogee for the competition launch. This is because unforeseen differences between actual weight of the rocket and simulated weight of the rocket (a major apogee and stability changing factor) are more easily corrected if these changes result in a lighter rocket, or a higher-than-simulated apogee, which is corrected with the addition of ballast. If the rocket becomes heavier than expected, or a lower-than-simulated apogee, it is corrected by the reduction of the weight of the rocket, a difficulty if there's no ballast to remove and the components are already permanently secured. There's also the risks that reduction in component weight results in reduced structural integrity, or that reduction leads to changes in stability that are not easily correctable.

3.3. 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 500 ft AGL, and touchdown.

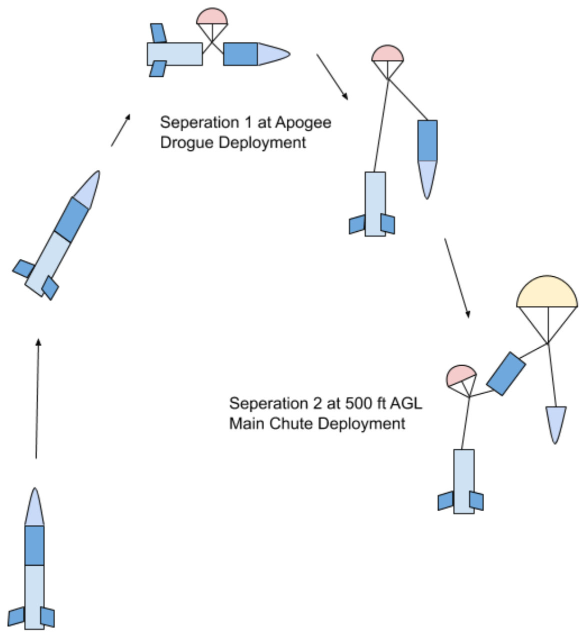


Figure 24: Dual Deployment System

3.3.1. Alternative Selection

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

Parachutes

The parachute to be used in the recovery subsystem is a 10’ ripstop nylon parachute with a coefficient of drag of 0.97, differing from the original 12’ ripstop nylon parachute with a coefficient of drag of 0.8 presented in the PDR, with a resulting 12.3% margin of safety under the maximum landing kinetic energy, as discussed in Section 3.4.3.

Bulkhead Materials

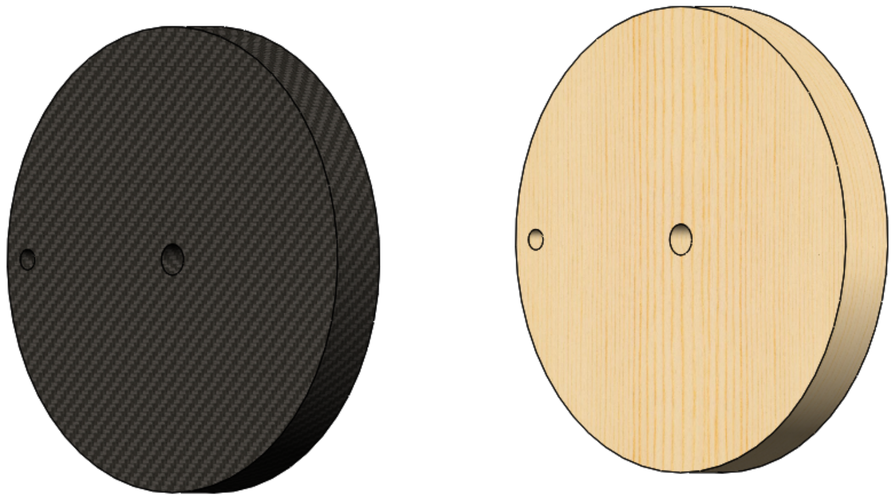


Figure 25: Bulkhead Material Options

Prefacing the hardware components, major load bearing aspects of the recovery system (and therefore the most crucial in failure testing) are bulkheads and the adhesive securing the bulkheads to the inside of the vehicle's airframe. When considering alternative recovery materials, the most important aspects are material strength, weight, and cost. The material that will be utilized for fabrication of bulkheads (or bulkhead like functioning structures such as the locking mechanism) was considered to be either carbon fibre or epoxied pine. As seen by previous uses, pine is less prone to release of particulates when cut to specific dimensions. Carbon fibre 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 fibre is about 20 times stronger than pine.

Table 8: Comparison of Bulkhead Materials

Young's Modulus	Pine Wood (along grain)	8.963 GPa
	Carbon Fiber Reinforced Plastic	181 GPa
Weibull Modulus	Carbon fiber in a laminate	1600 MPa
	Pine wood (parallel to grain)	40 MPa

Since the force exerted on the locking mechanism will be a sudden jolt at high speeds then a suspension with not a large amount of stress pulling the material, rigidity should be optimized and focused on instead of strain of the material. The tensile strength and rigidity of carbon fibre is greater than pine wood, however previous tests have been successful with pine and there must be a decision between strength and efficiency.

Ultimately, the locking mechanism's disk will be made of pine. It is more accessible, cheaper and lighter than carbon fibre. Carbon fibre's strength is optimal when the force exerted is along the surface. In addition, carbon fibre is brittle and shows no sign of cracks and fatigue as failure of the material is catastrophic. Overall, the force exerted on the mechanism would not even be close to a failure when using carbon fibre or pine. The pine will also be treated with a resin.

Regarding resins, most of the components of the rocket were treated with epoxy but before deciding on the resin between polyester resin and epoxy resin were compared.

The Düzce University and Gazi University Department of Wood Products Industry Engineering detailed the specifics of the two resins. In the conference paper, *The Effect of Modification with Epoxy and Polyester Resins on Some Mechanical Properties of Pine and Chestnut Wood*, various properties of each material are compared.

The following table details the properties of both resins and its hardness is recorded on the Barkol scale.

Table 9: 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. Overall, pine wood with epoxy resin was chosen for the locking mechanism, it has held its properties of being stiff and resists elongation. Epoxy is slightly more expensive than polyester resin, but the greater hardness and resistance to elongation is preferred.

Bolt Type

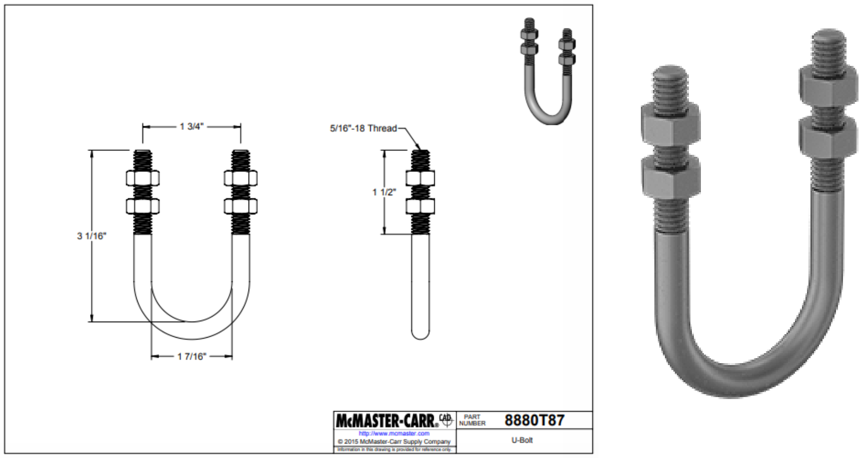


Figure 26: U-bolt

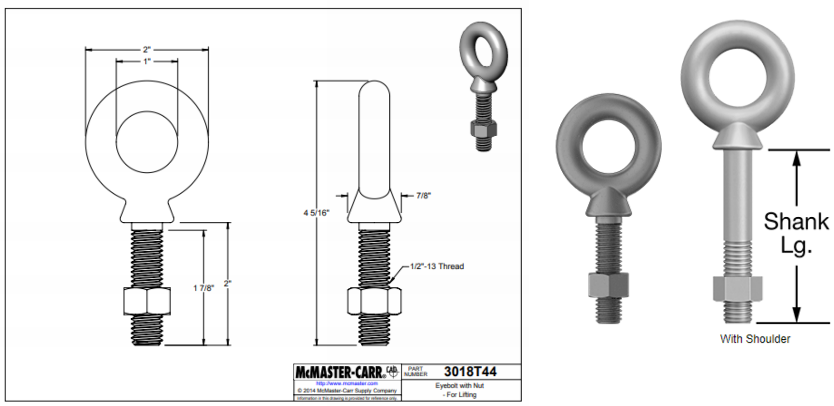


Figure 27: Eye-bolt

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. Eye Bolts 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 2,100 lbs, far exceeding the force that will be seen by the vehicle during flight.

For these reasons, eye-bolts will be used in the final design.

Locking Mechanism Design

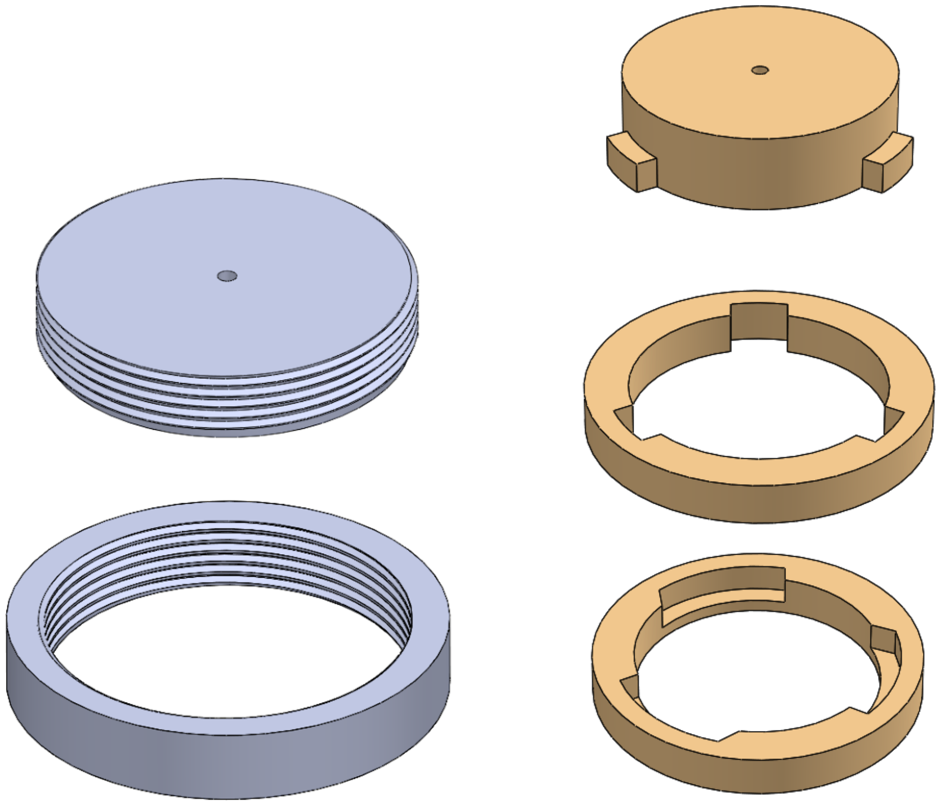


Figure 28: Locking Mechanism Options

Two structural alternatives were considered for the locking mechanism: a threaded mechanism, and a simple slide-and-lock mechanism. The threaded mechanism involves a male screw cap that interlocks with a female threaded bulkhead ring.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 do not permit these large parts to be printed.

The slide-and-lock mechanism involves an inner ring which slides into place vertically and then rotates axially to lock into place. 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 will be implemented. The locking mechanism will be manufactured using two 0.75” slabs of wood with the cross grains of each slab being perpendicular to each other for increased strength.

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 since flight forces will increase the normal force experienced on the outer ring, which increases friction opposing rotational motion to unlock. This problem must be considered when deciding the sufficient clearance between the outer and inner components of the locking mechanism. 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.

Further discussion on the locking mechanism is provided in section 4.1.4.

3.3.2. Hardware Components

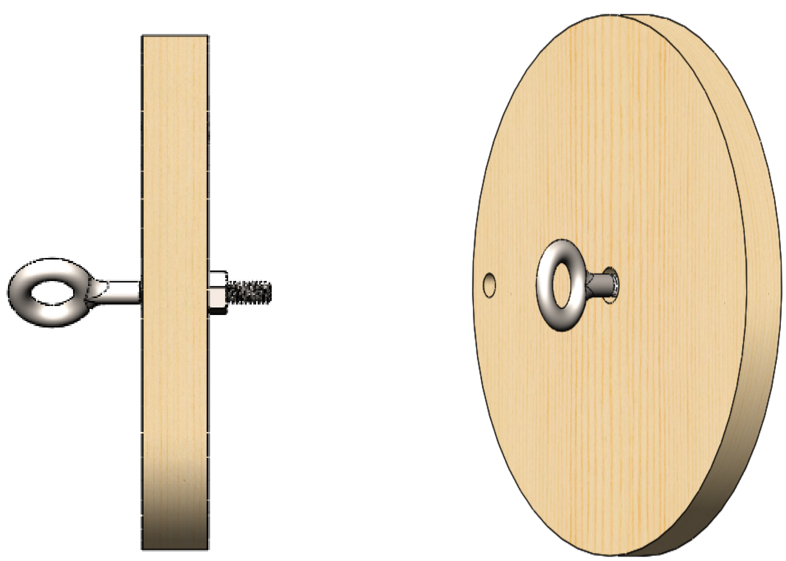


Figure 29: Pine Bulkhead

Since pine bulkheads are easier to manufacture, pine will be selected over carbon fiber. Further testing will allow our team to ensure that this material can withstand the forces of launch. Also, eyebolts were chosen as the retention hardware due to their higher strength compared to U-bolts as mentioned earlier.

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.

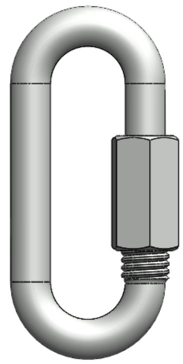


Figure 30: Quicklink

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.

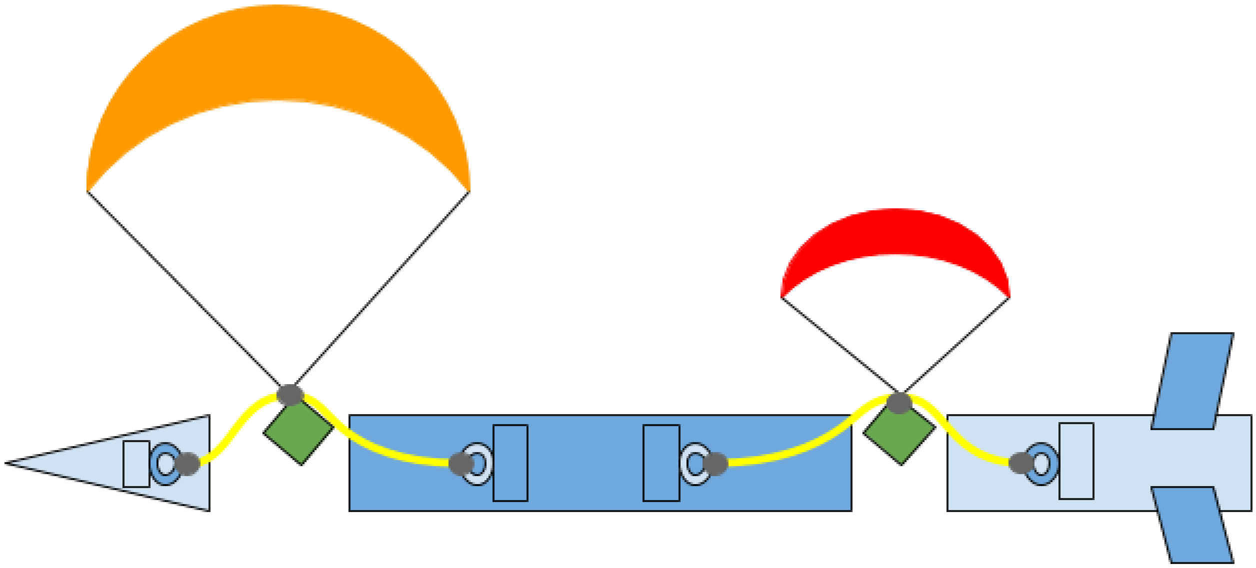


Figure 31: Recovery Component Overview

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

Avionics Sled

In order to safely fasten the electronics to the launch vehicle, an avionics sled will attach to the locking mechanism. This component features a flat circular base with 3 protrusions intended to house the avionics electronics. The circular base will be the same size as the inner ring of the locking mechanism to maximize surface area contact between the two parts for a stronger epoxy bond. The avionics sled has grooves intended for the following electronics:

- Missile Works RRC3 Sports Altimeter
- Stratologger SL 100 Altimeter
- Arduino Uno
- Gyroscope/Accelerometer module
- 3 9V Alkaline Batteries

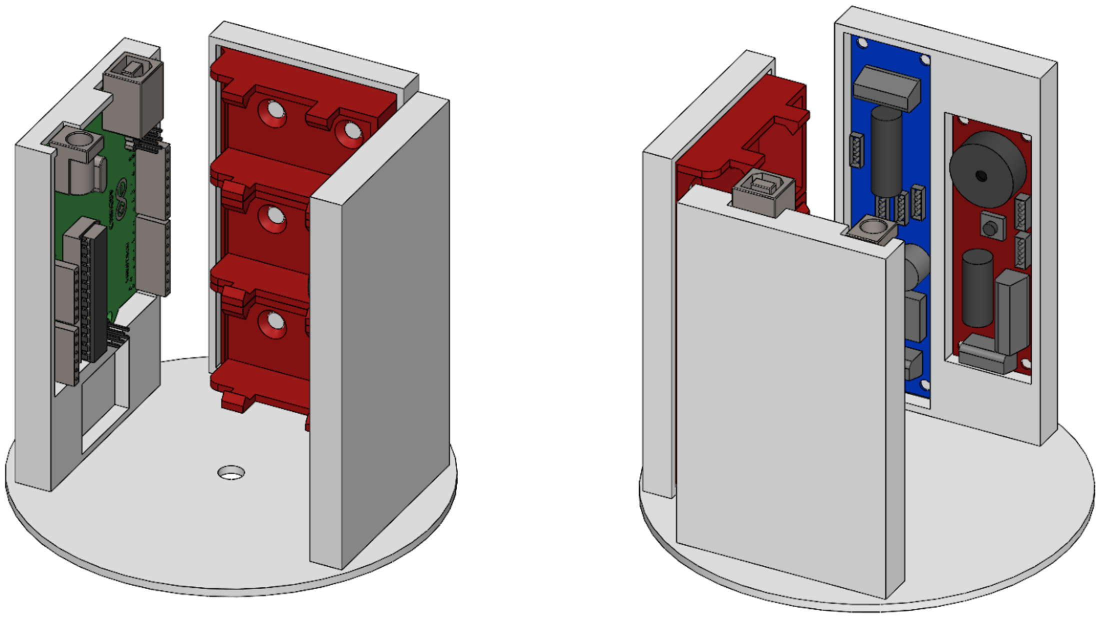


Figure 32: Electronics Sled

Multiple electronic components will be housed within the avionics bay, so space management is crucial. All electronics will face inwards to prevent wires from getting caught with the locking mechanism when trying to place the sled. Inward facing electronics will cause all wires to be localized within the sled, which prevents wires from getting stuck with the locking mechanism. The sled features an empty central volume for wire accessibility and space for the rover ejection assembly's orientation motor (discussed in section 4.4.1). This design effectively manages the space of onboard electronics while providing an ordered and secure platform for which to attach the electronics.

To fasten onboard electronics to the designated indentations, a combination of screws and wood will be used. Thin slabs of wood will be cut to size and epoxied into the indentations. These slabs are a soft material for which to drill the screws into. The 9V batteries will be attached to the sled using 3D printed 9V battery case holders which are then epoxied onto the avionics sled. Although lithium polymer batteries will not be used, the 9V battery holders will be 3D printed using bright red plastic to visibly identify the location of the batteries.

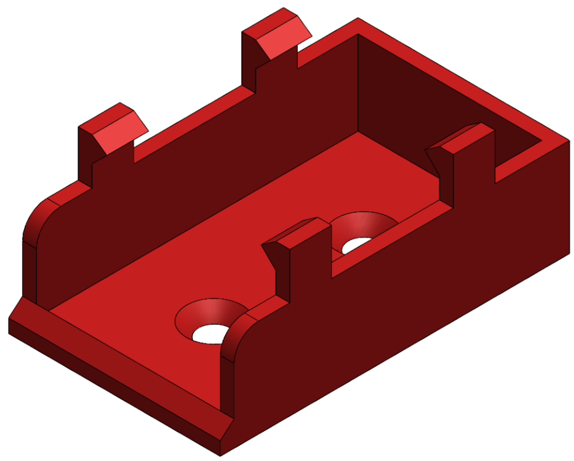


Figure 33: Battery Holder

3.3.3. Electrical Components

3.3.3.1 Altimeters

Altimeters in the avionics bay are responsible for safely deploying the recovery parachute system at specified altitudes for a safe recovery of the launch vehicle. A dual deployment system will be adopted because of the high projected apogee altitude. Since altimeters deal with the safety of the launch vehicle and spectators in the surrounding area, two commercially available altimeters will be used for redundancy. This is in compliance with Section 2.3 and Section 3.4 of the Student Launch Handbook.

When selecting the proper altimeters, the following properties were considered:

- Dual deployment feature
- Ease of programmability
- Size

Altimeters used in the past and immediately available are outlined in the following table.

Table 10: Altimeters

Altimeter	Dual Deployment	Dimensions (L x W x H)	Programming
Entacore AIM Altimeter	Yes	2.56" x 0.98" x 0.59"	-Software included -Requires an additional USB dongle
Stratologger SL100 Altimeter	Yes	2.75" x 0.90" x 0.50"	-Software included -Requires an additional USB dongle

Table 10: Altimeters

RRC3 Sports Altimeter	Yes	3.92" x 0.92" x 0.46”	-Software included using an additional USB dongle -Alternative plug in LCD Terminal

Since all altimeters immediately available to UCLA Bearospace are dual deployment and require an additional USB dongle that has to be purchased, altimeter selection is based on dimensions. Altimeter sizes within the avionics bay are constrained by their height because the electronics on the sled face inwards. Altimeters with a bigger height will collide with the stepper motor used for orienting the rover, which is outlined in section 4.1.4. The Stratologger SL100 and RRC3 Sports altimeter will be selected because of their lower profile than the Entacore AIM altimeter. Although the Stratologger SL100 is smaller than the RRC3 Sports Altimeter, two Stratologger SL100 altimeters will not be used to in order to have different altitude measuring tools. Both altimeters have different pressure sensors, so having multiple pressure sensors provide a better average accuracy than two of the same kind. Although altimeters are meant to be reused for multiple flights, the altimeters will be tested prior to each major launch to mitigate component failure and to verify accuracy.

Both the Stratologger SL100 and Missile Works RRC3 Sports altimeters will be programmed to deploy at apogee and 500 feet AGL with no delays to accomplish a safe and timely descent.

The Stratologger SL 100 has an operational voltage of 4V to 16V, with 9V being the optimal voltage, and the RRC3 Sports has a similar operational voltage of 3.5V to 10V, with 9V also being the optimal voltage. As such, each altimeter will be individually powered by a standard 9V alkaline battery, once again to introduce a redundancy within our system so that the likelihood of both altimeters failing due to a malfunction is reduced since each has its own power source. With the standard 9v alkaline battery capacity at 500 mAh, this means the Stratologger SL 100 will have an operational time of around 333.33 hours with a power consumption of 1.5 mA, while the RRC3 Sports will have an operational time of around 83.33 hours with a power consumption of 6 mA.

Each altimeter will also have its own push button as a mechanical switch in order to power them on, once more to introduce yet another layer of redundancy in our system. The push button also functions as an external method of turning the altimeters on.

Both altimeters collect flight data regarding altitude, temperature, and battery voltage, at a rate of 20 samples per second, storing them for later extraction. However, the Stratologger SL 100 can store up to 31 9 minute flights, while the RRC3 Sports stores up to 15 28 minute flights.

Vent Holes

To ensure accurate pressure readings, 4 vent holes will be drilled in the body tube at 90 degree angles to one another to line up with the center of the avionics bay (21” from the tip of the nose cone). The size of these vent holes are calculated using the following formulas (areas are calculated using the formula $area = (diameter/2)^2 * \pi$). If the volume of the electronics bay is less than 100 cubic inches:

$$Single\ Port\ Diameter = Volume\ of\ EBay\ /\ 400$$

If the volume of the electronics bay is greater than or equal to 100 cubic inches:

$$SinglePort\ Diameter = 2 * \sqrt{(Volume/6397.71)}$$

The diameter is then converted into an area to find the port diameter. If several ports are used, the diameter of each hole is:

$$MultiPort\ Diameter = 2 * \sqrt{(SinglePort\ Vent\ Area\ /\ \#\ of\ Ports\ /\ \pi)}$$

The calculation and values for the launch vehicle can be seen below:

$$Electronics\ bay\ Radius = 3"$$
$$Electronics\ bay\ Length = 6"$$
$$Electronics\ Bay\ Volume = 3^2 * 6 * \pi = 169.64"^3$$

Since the electronics bay volume is larger than 100 in^3:

$$SinglePort\ Diameter = 2 * \sqrt{(169.64/6397.71)} = 0.3257"$$

Since four ports are planned, each hole will have a diameter of:

$$MultiPort\ Diameter = 2 * \sqrt{((\pi * (.3257/2)^2/4/\pi)} = 0.163"$$

3.3.3.2 GPS

In order to keep track of the rocket’s position, a GPS tracker will be placed inside of the rocket. In past years, the team has noticed that placing the GPS inside of the carbon fiber body tube results in a loss of signal. To prevent this, the GPS will be located inside of the nose cone made out of PLA plastic. Due to space limitations, a small GPS tracking device is preferred.

The T3 (Tiny Telematics Tracker) GPS device is capable of tracking through bluetooth connection with an Android device and is small enough to fit into the nose cone. Its operational range is up to 9 miles, more than the desired range of half a mile. UCLA Bearospace has used this GPS tracker in previous projects, so it can be reused to minimize costs.

The GPS tracker will be placed inside the nose cone to minimize signal loss and ensure proper tracking of the rocket. In past years, the GPS has been placed within carbon fiber body tubes, which reduces signal strength and renders the GPS system useless. The T3 Tiny Telematics Tracker being used is 1” by 2.075” and its 6” antenna is capable of locating the rocket within a 9 mile radius, a distance way greater than the allowable range of the competition.

The operational voltage of the T3 is 3.5 volts to 7.4 volts using a 1S Li-Po battery and the power consumption is about 175 mA. The recommended batteries to be used with the GPS, according to its manual, are 1S LiPo batteries. The GPS can be used with a 2S LiPo battery, however, this battery will dissipate a lot of heat in the process. The benchmarks when using a 750 mA 1S LiPo battery was roughly under 4 hours. So to reach the minimum 4 hour goal, the battery we are using is a 1200 mAh 3.7V battery, which is the recommended Voltage for the battery to run on while increasing the operational time to 6.86 hours.

A push button for the GPS which will be connected to the LiPo battery for the GPS. Also, a push button will be used as a mechanical method to decrease drag on the rocket and to have an external method of turning the GPS on.

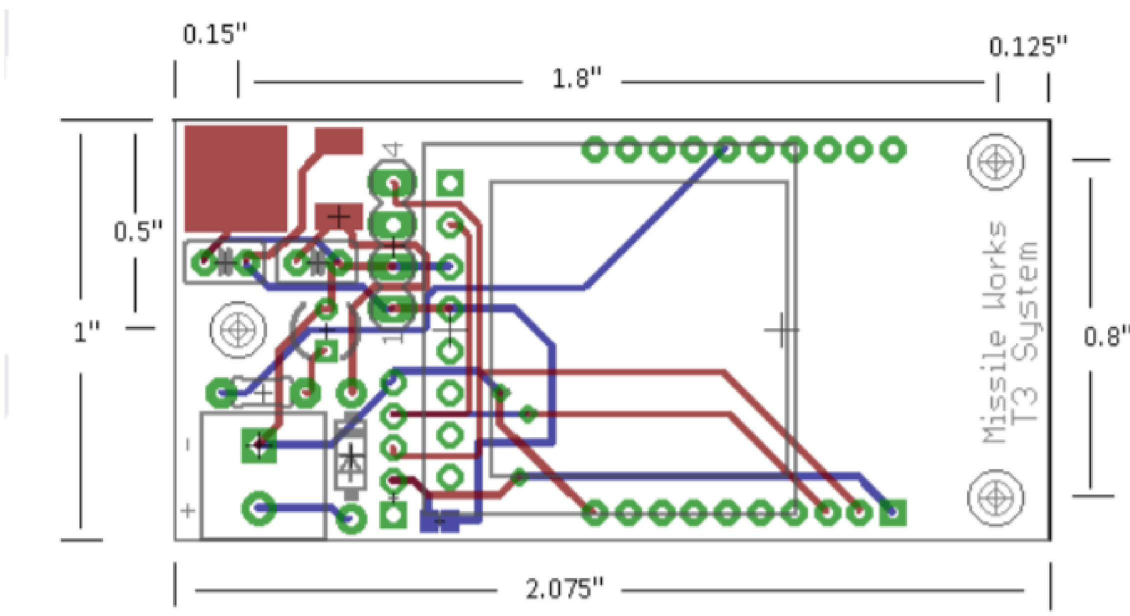


Figure 34: Drawing of Missile Works T3 System

3.3.4. Electrical Schematics

3.3.4.1 Altimeters

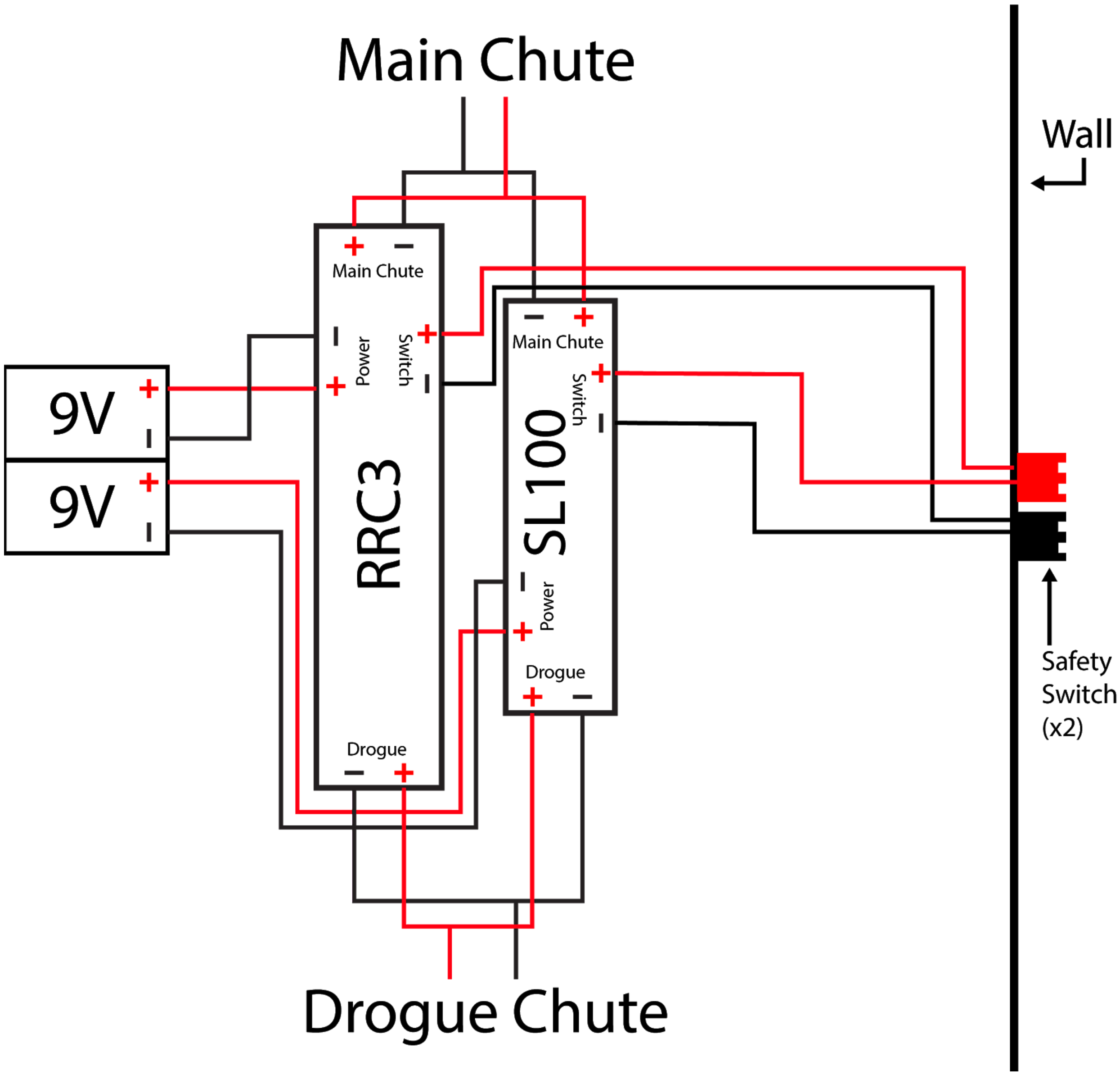


Figure 35: Altimeters Wiring Schematic

3.3.4.2 GPS

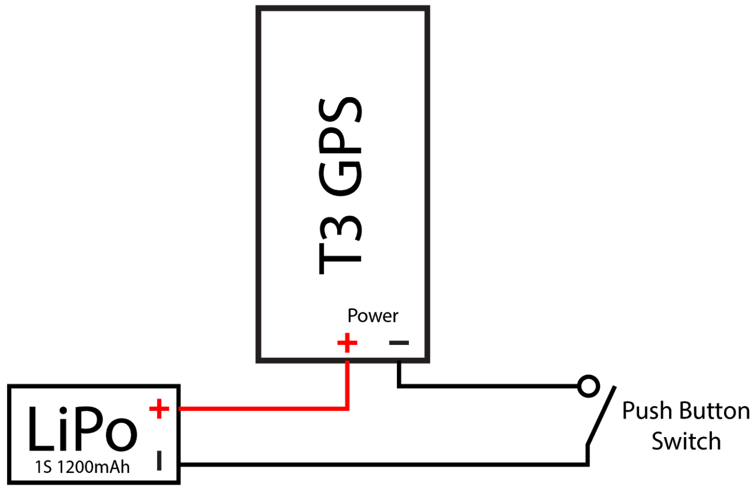


Figure 36: GPS Wiring Schematic

3.3.5. Operating Frequency

The Missile Works Tiny Telematics Tracker GPS will operate on a frequency of 902 to 928 MHz, achieving a maximum range of approximately 9 miles.

3.4. Mission Performance Predictions

3.4.1. Simulated Verifications

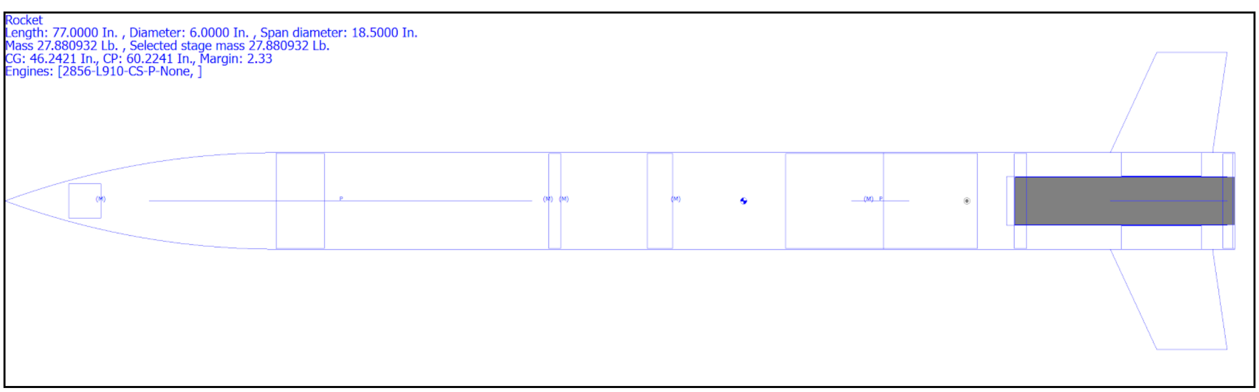


Figure 37: RockSim Model

Provided above in Figure 37 is the ongoing RockSim 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 6.1.1.

For component weights, refer to Section 3.1.4.

3.4.2. Stability Margins

As represented in Figure 37, the CG and CP locations (denoted by the blue checkered circle and gray dot with concentric circular border respectively) are as follows:

- CG: **46.24 in.** from the tip of the nose cone.
- CP: **60.22 in.** from the tip of the nose cone.

Together, with a 5.9 in. diameter body tube, the resulting stability is anticipated to be **2.33**.

3.4.3. Kinetic Energy at Landing

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

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

Using the kinetic energy equation above and the vehicle section mass values (where 1, 2, and 3 denote the nose cone, upper body tube, and lower body tube vehicle sections respectively), and the descent rate for the main parachute given by the vendor, the landing kinetic energy of each vehicle section is determined.

$$v_{descent} = 18.3\,ft/s\ (for\ a\ post - burn\ mass\ of\ 24.62\ lb)$$

$$m_1 = (1.81\ lbf)/(32.2\,ft/s^2)\ {->}\ KE_1 = 0.5 * m_1 * v_{descent}{}^2\ => KE_1 = 9.41\,ft - lbf\ .$$
$$m_2 = (12.65\ lbf)/(32.2\,ft/s^2)\ {->}\ KE_2 = 0.5 * m_2 * v_{descent}{}^2\ => KE_2 = 65.78\,ft - lbf\ .$$
$$m_3 = (10.16\ lbf)/(32.2\,ft/s^2)\ {->}\ KE_3 = 0.5 * m_3 * v_{descent}{}^2\ => KE_3 = 52.83\,ft - lbf\ .$$

3.4.4. 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.

$$v_{main,\ descent} = 18.3\ ft/s,\ v_{drogue,\ descent} = 61.3\ ft/s\ (for\ a\ post-burn\ mass\ of\ 24.62\ lb)$$
$$h_{apogee} = 4200\ ft\ AGL,\ h_{main-deploy} = 500\ ft\ AGL$$

$$Descent\ Time = (h_{apogee} - h_{main-deploy})/v_{drogue} + h_{main-deploy}/v_{main}$$
$$Descent\ Time = 87.7\ s$$

3.4.5. Drift Calculations

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

Table 11: Drift Relation to Wind Speed

Wind Speed	0 mph	5 mph	10 mph	15 mph	20 mph
Horizontal Drift	0 ft.	642.8 ft.	1286 ft.	1929 ft.	2572 ft.

3.4.6. Calculation Verification

Using the RockSim simulation software, these calculations can be verified against a rigorously tested and trusted simulation code. Below are provided RockSim's predictions on the landing kinetic energies of each rocket vehicle section, the descent time, and the horizontal drift estimates.

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

Table 12: Landing K.E. for Vehicle Section Trials

Vehicle Section	Nose Cone	Upper Body Tube	Lower Body Tube
Landing Kinetic Energy (1)	9.67 ft-lbf	67.60 ft-lbf	54.29 ft-lb
Landing Kinetic Energy (2)	9.67 ft-lbf	67.60 ft-lbf	54.29 ft-lb
Landing Kinetic Energy (3)	9.67 ft-lbf	67.60 ft-lbf	54.29 ft-lb
Landing Kinetic Energy (4)	9.67 ft-lbf	67.60 ft-lbf	54.29 ft-lb

Table 13: Total Descent Times per Trial

Descent Time (1)	88.98 s
Descent Time (2)	88.98 s
Descent Time (3)	88.98 s
Descent Time (4)	82.66 s

Table 14: Drift relation to Wind Speed Trials

Wind Speed	0 mph	5 mph	10 mph	15 mph	20 mph
Horizontal Drift (1)	0 ft.	151.1 ft	414.5 ft.	642.8	996.4
Horizontal Drift (2)	0 ft.	147.0 ft	406.4 ft.	728.8	820.7
Horizontal Drift (3)	0 ft.	151.2 ft	380.4 ft.	730.1	1001.2
Horizontal Drift (4)	0 ft.	135.8 ft	397.8 ft.	781.3	982.3

3.4.7. Calculation Discrepancies

Little discrepancy is present in the kinetic energy calculations, 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, attributed to a slight delay in drogue chute deployment at apogee.

In the drift calculations, a much greater discrepancy can be observed, as the farthest drift calculations vary by more than a thousand feet. This can best be attributed to the constant wind speed assumed in Section 3.4.5., 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.

3.4.8. Verification of Preciseness

As seen in section 3.4.6, the implementation of RockSim simulation software allowed these calculations to be verified against a rigorously tested and trusted simulation code. We have provided various trials to elevate the precision of simulation estimates, running simulations four times.

4. Payload Criteria

4.1. Design of Payload Equipment

4.1.1. Mission Statement

Bearospace at UCLA will design, manufacture, test, launch, and carry out the scientific payload challenge as defined in the NASA USLI 2020 competition. This payload will be able to navigate various terrains, identify specified collection zones, collect simulated “lunar ice” sample, and retain collected samples while traveling.

4.1.2. Mission Success Criteria

A successful mission is categorized by the payload’s completion of the following tasks:

1. Payload being successfully retained within the launch vehicle during all phases of the flight with no detectable damage to the payload or vehicle.
2. Navigable portion of the payload being deployed successfully post-vehicle landing with no detectable damage to the payload or launch vehicle.
3. Mobile portion of the payload able to traverse terrain of landing site (mainly soil and slight debris).
4. Payload successfully locating specified collection zone.
5. Payload collecting and retaining at least the required volume of sample as defined by the competition.

4.1.3. Alternative Selection

The two general payload alternatives that were considered were rovers and UAVs. The main restriction during design was space within the top body tube. The tube is approximately 6” in diameter and 12” in length, not including the amount of space for the rover ejection system. A rover was selected as the payload due to its simplistic operation and smaller size. The main components of the rover include: electronics, wheel system, collection arm, and collection container.

Several other methods of payload deployment were considered, such as a scissor jack mechanism, rail gun, and electromagnetic retention and deployment. Since the rail gun and electromagnetic option create an unwanted electric and magnetic field that may tamper with other electronics, such as the altimeters, these ideas were discarded. The scissor jack mechanism introduces additional points of failure due to its complex geometry and additional parts. A lead screw and nut retention and deployment mechanism was selected for its manufacturing simplicity, reduced number of parts, and robustness.

4.1.4. Design Review

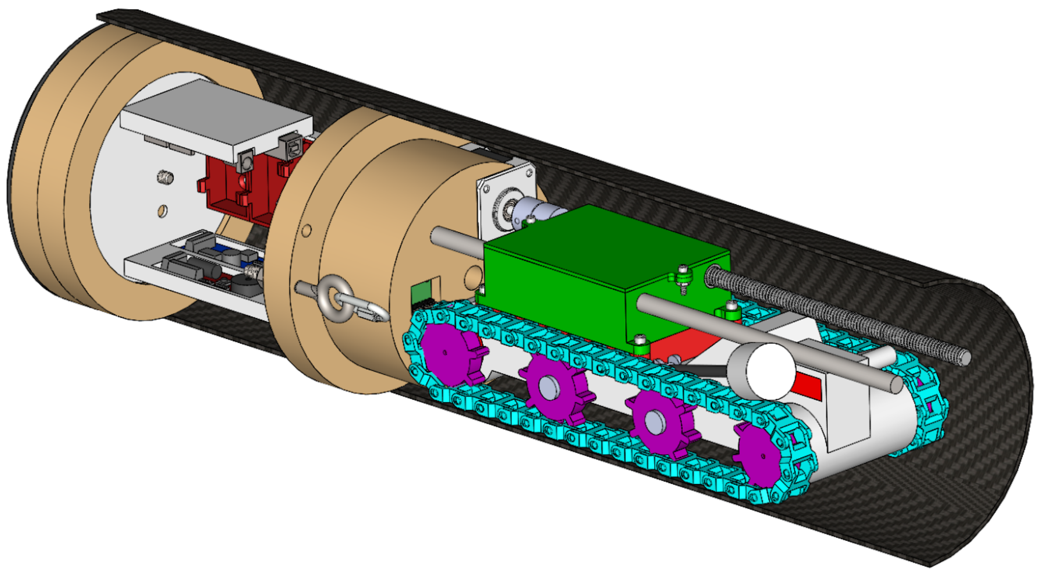


Figure 38: Payload and Rover Ejection Assembly

The payload design features two main components: the rover ejection assembly and the rover payload itself. The rover ejection assembly is tasked with retaining and deploying the rover in the correct orientation after a landing event has been identified. Once deployed, the payload will begin radio frequency communication with a driver on the ground. The rover will receive inputs from the driver and return video feedback to the driver to complete the mission.

4.1.4.1 Rover Ejection Assembly

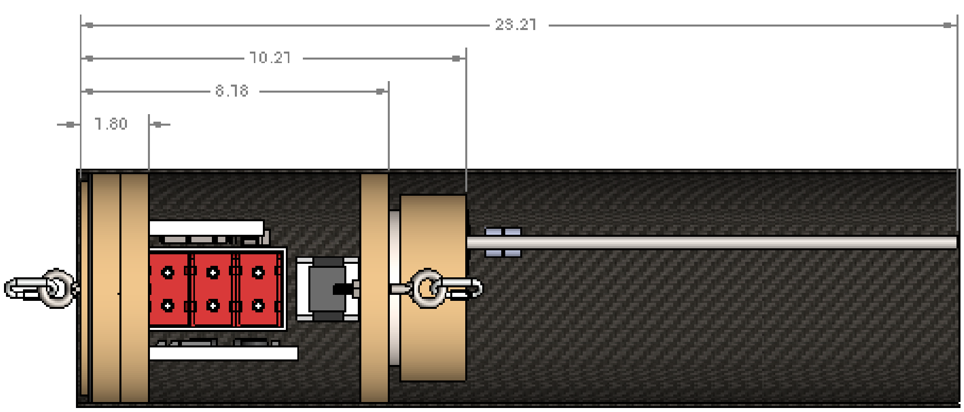


Figure 39: Rover Ejection Assembly

The rover ejection assembly consists of the avionics bay, which houses some of the electronics necessary for correctly deploying the rover, and the deployment section, which orients and deploys the rover. The avionics section has a volume of 158.57in^3 with a 1.8in thick locking mechanism. The deployment section is 15in in length which contains a 12in lead screw and 12in steel rod. A center 0.75in thick bulkhead divides the avionics section and deployment section while also fastening components for the rover ejection assembly to the launch vehicle. The following figure illustrates how individual components interface with each other within the rover ejection assembly.

ITEM NO.	QTY.	PART NUMBER	/Material
1	1	Locking Mechanism Assembly	Pine
2	1	Avionics Sled Assembly	PLA
3	2	NEMA 17 Stepper Motor	Aluminum, Copper, Steel
4	1	Bulkhead	Pine
5	2	Eyebolt	Steel
6	1	Stepper Motor Interface	PLA
7	1	Bearing Ring	Aluminum Alloy
8	1	Circular Block Holder	Pine
9	1	5mm to 10mm Coupling	Aluminum
10	1	0.375-12 x 12 Lead Screw	Carbon Steel
11	1	0.375 x 12 Rod	Carbon Steel

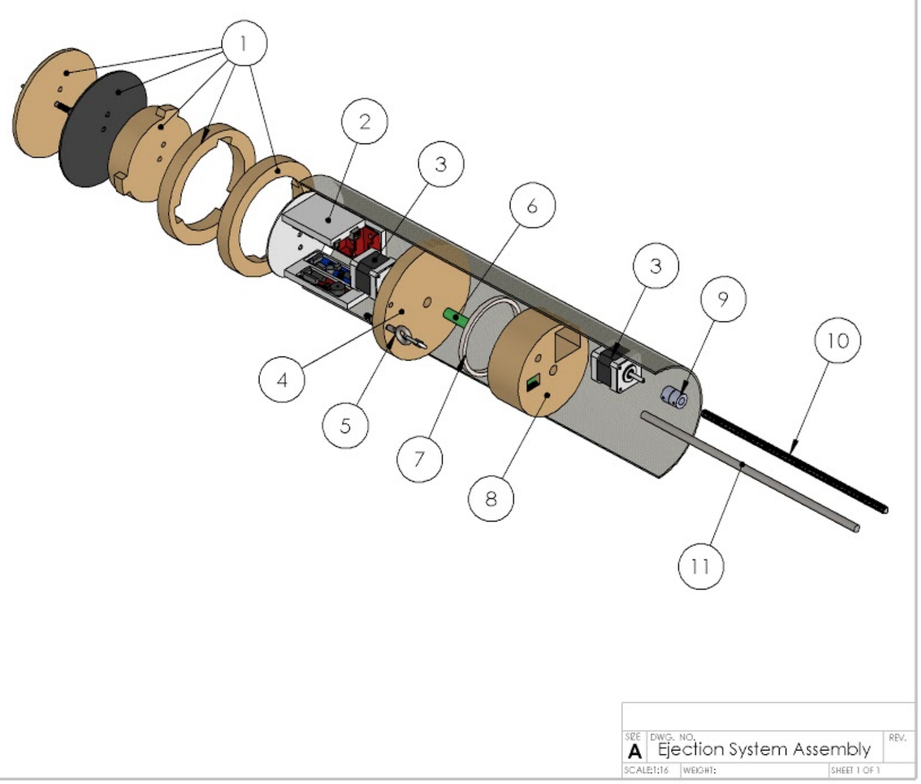


Figure 40: Exploded View of Rover Ejection Assembly

Locking Mechanism

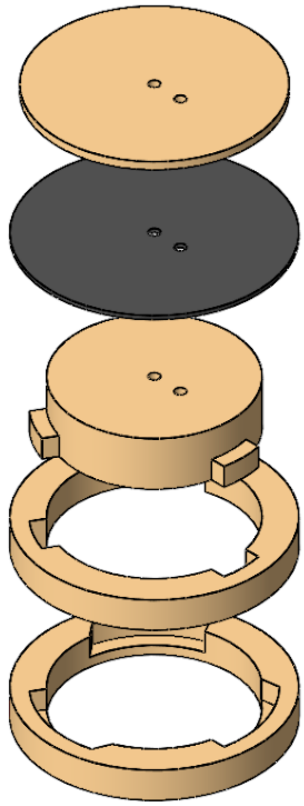


Figure 41: Exploded View of Locking Mechanism

In order to shield onboard electronics, provide easy access to the avionics bay, and tether the main parachute to the launch vehicle, a pine wood locking mechanism bulkhead will be implemented. 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 0.75in thick slabs of pine wood. Slabs will be manufactured using a CNC mill and bound together using epoxy. Dimensions of each component are outlined in the following figures. The total thickness of the locking mechanism is 1.80in.

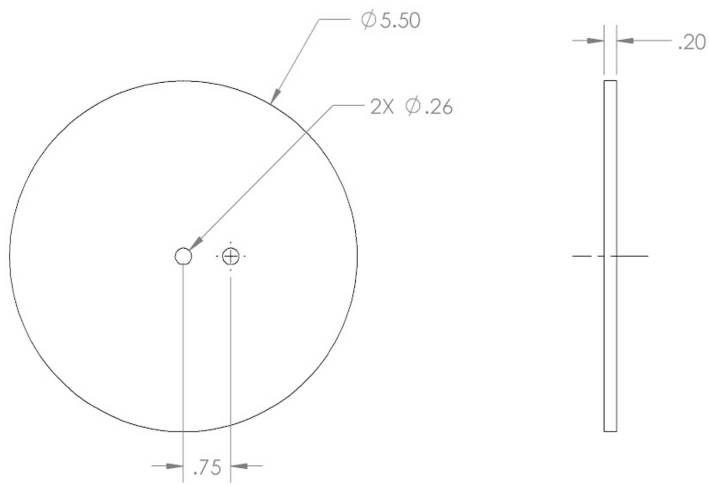


Figure 42: Locking Mechanism Wooden Cover Drawing

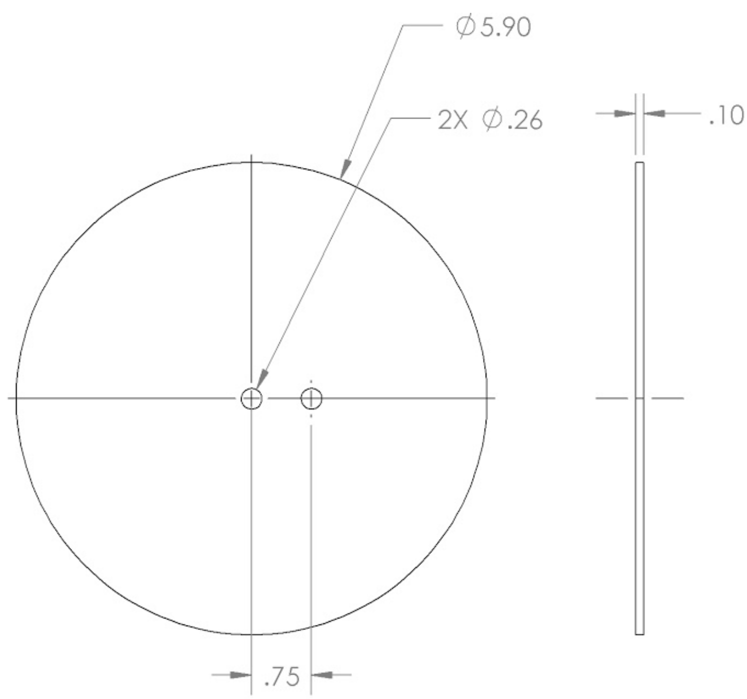


Figure 43: Locking Mechanism Rubber Sheet Drawing

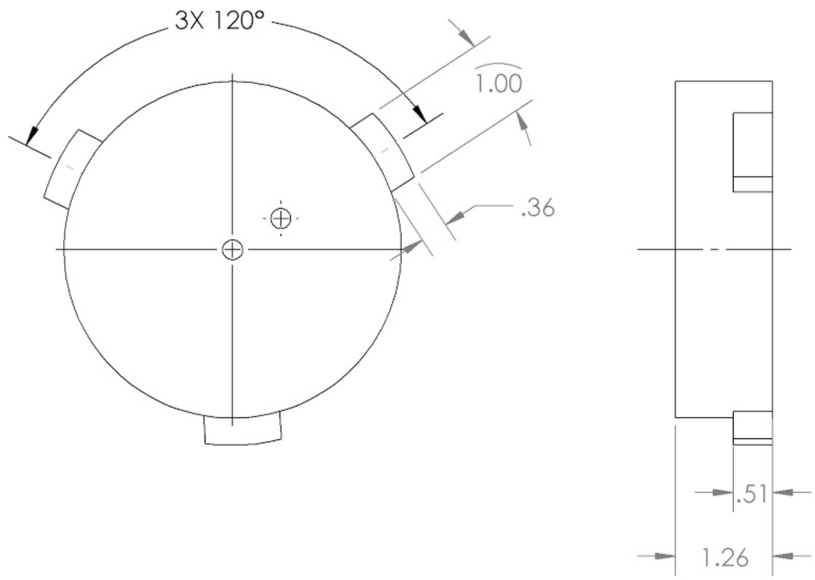


Figure 44: Locking Mechanism Inner Ring Drawing

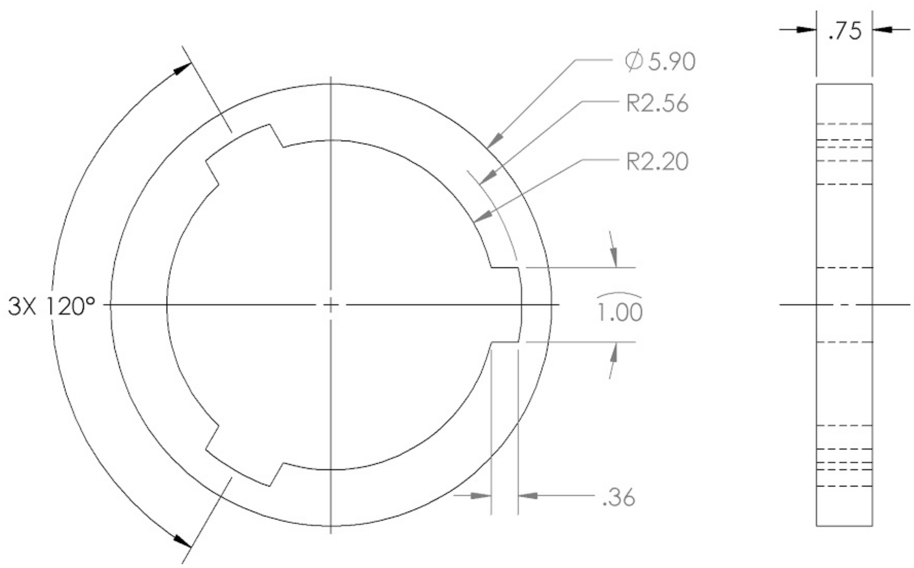


Figure 45: Locking Mechanism Top Outer Ring Drawing

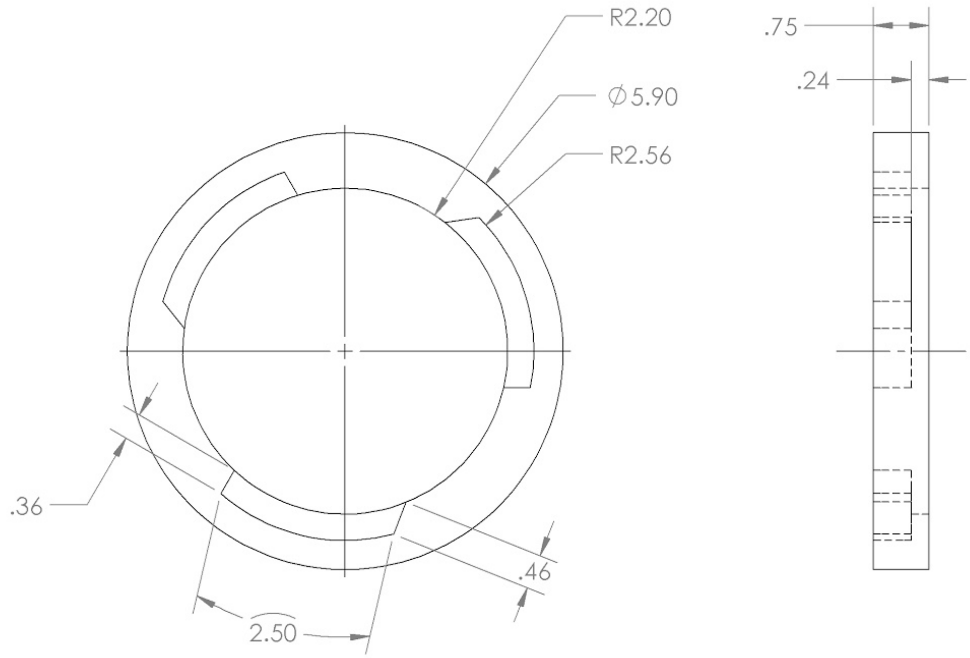


Figure 46: Locking Mechanism Bottom Outer Ring Drawing

It is important to note that the rubber sheet is bigger than the inner diameter of the body tube. This ensures an airtight seal is achieved. The wooden cover layered over the rubber sheet adds rigidity to the rubber so it does not peel off.

Analysis on the strength of the locking mechanism is provided in section 6.1.1.

Avionics Sled

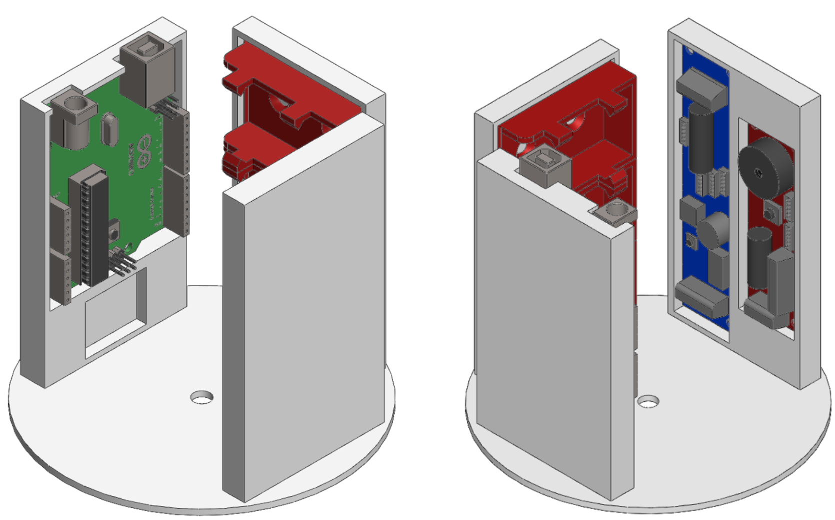


Figure 47: Avionics Sled with Electronics

The avionics sled is an extension of the locking mechanism. It safely and efficiently stores the onboard electronics necessary for deploying the rover, located within the avionics bay of the launch vehicle. The avionics sled will retain three 9V batteries, two commercial altimeters, an Arduino Uno, and a BMP180 barometric pressure sensor. These electrical components will be attached to the sled using appropriate 4-40 screws which will drill into wooden cutout slabs placed within each indentation. To further secure each electrical component, zip ties will wrap around each protrusion. The avionics sled has a large surface area at its base to provide greater adhesion when epoxied to the inner ring of the locking mechanism. Additionally, an eyebolt will be placed through the avionics sled and inner ring for greater retention to the inner ring, as seen in figure 49.

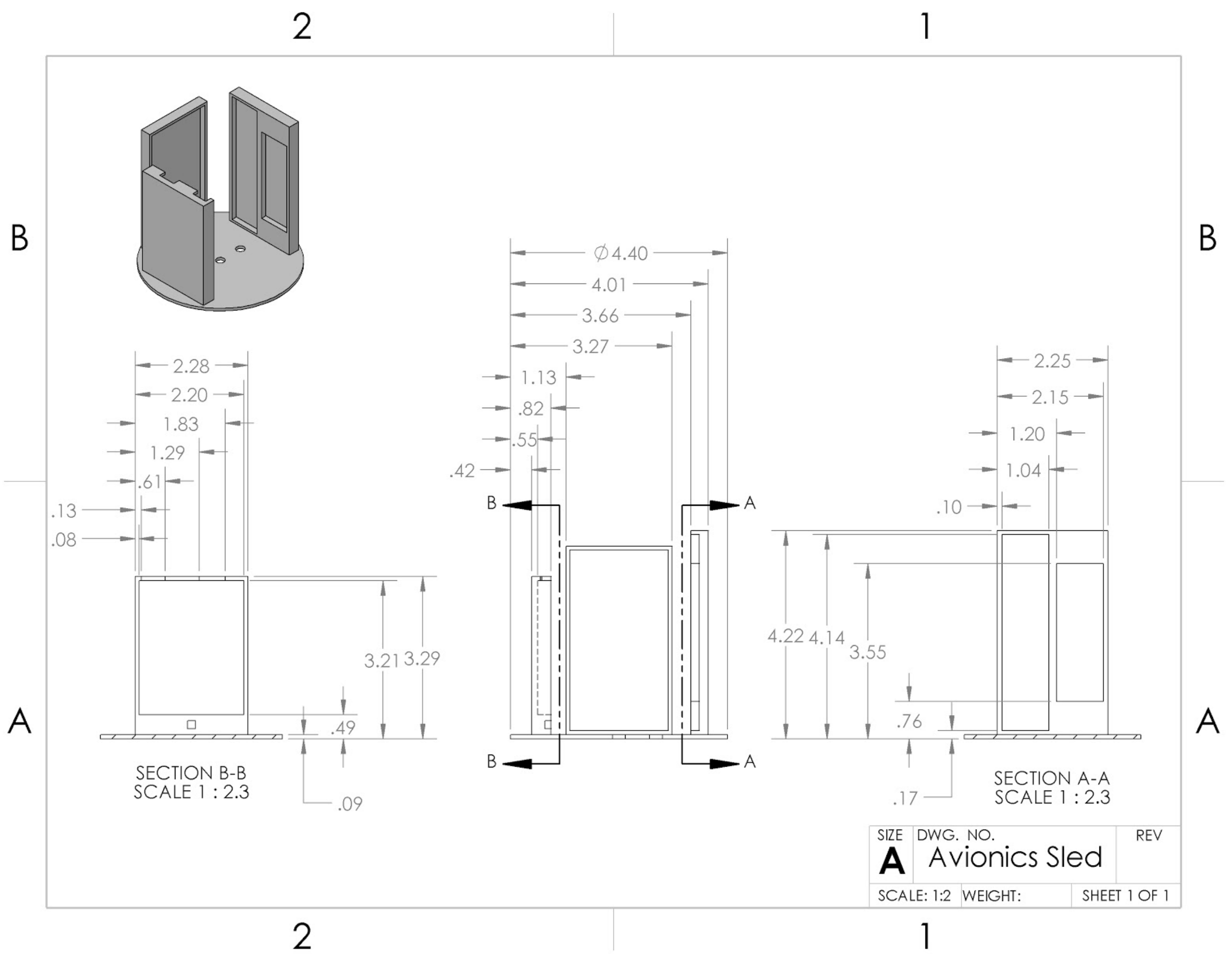


Figure 48: Avionics Sled Drawing

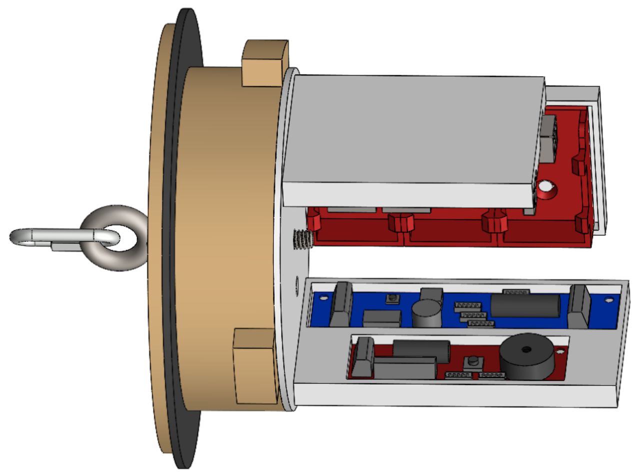
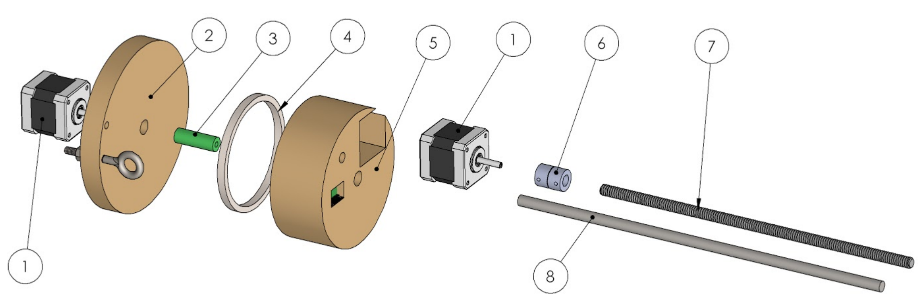


Figure 49: Fully Assembled Avionics Sled with Inner Ring

Rover Deployment Mechanism

In order to deploy the rover after landing, two NEMA 17 stepper motors, a 4in diameter ball bearing ring, a circular block holder, stepper motor interfacer, a coupling shaft, a ⅜"-12 12in long lead screw, and ⅜" 12in long rod are used.

ITEM NO.	QTY.	PART NUMBER	/Material
1	2	NEMA 17 Stepper Motor	Aluminum, Copper, Steel
2	1	Bulkhead	Pine
3	1	Stepper Motor Interface	PLA
4	1	Bearing Ring	Aluminum Alloy
5	1	Circular Block Holder	Pine
6	1	5mm to 10mm Coupling	Aluminum
7	1	0.375-12 x 12 Lead Screw	Carbon Steel
8	1	0.375 x 12 Rod	Carbon Steel



SIZE DWG. NO. REV
A Rover Deployment
SCALE: 1:12 WEIGHT: SHEET 1 OF 1

Figure 50: Exploded View of Rover Deployment Mechanism

Using the above figure as reference, the leftmost stepper motor (1) is attached to a bulkhead (2) using epoxy. This stepper motor will rotate the entire assembly, however, this implies a large force and moment will be induced on the stepper motor from the protruding rods and payload resting on the rods. To prevent this, an additional aluminum alloy bearing ring (4) will be used. The bearing ring will support the entire assembly so that the leftmost stepper motor will only rotate the assembly, not support it. All load bearing forces will be applied to the bearing ring. A circular tube (3) will fit around the shaft of the stepper motor and will be epoxied into a large circular block holder (5). The circular block holder acts as a rotating bulkhead for which to attach the rods onto. Cutouts for another stepper motor, a gyroscope/accelerometer module, and a steel rod are provided. The unthreaded rod (8) and stepper motor (1) will be epoxied into the designated hole inside the circular block holder. In order to attach the lead screw (7) onto the stepper motor, a 5mm to 10mm coupling (6) will be used. The coupling allows two shafts of different diameters to be attached by adjusting the force applied on each using screws. Both the lead screw and unthreaded rod are ⅜” in diameter to provide enough rigidity to support the weight of the payload. The following figures provide the dimensions of the unique aspects of the rover ejection assembly. Simple geometric components will not be included.

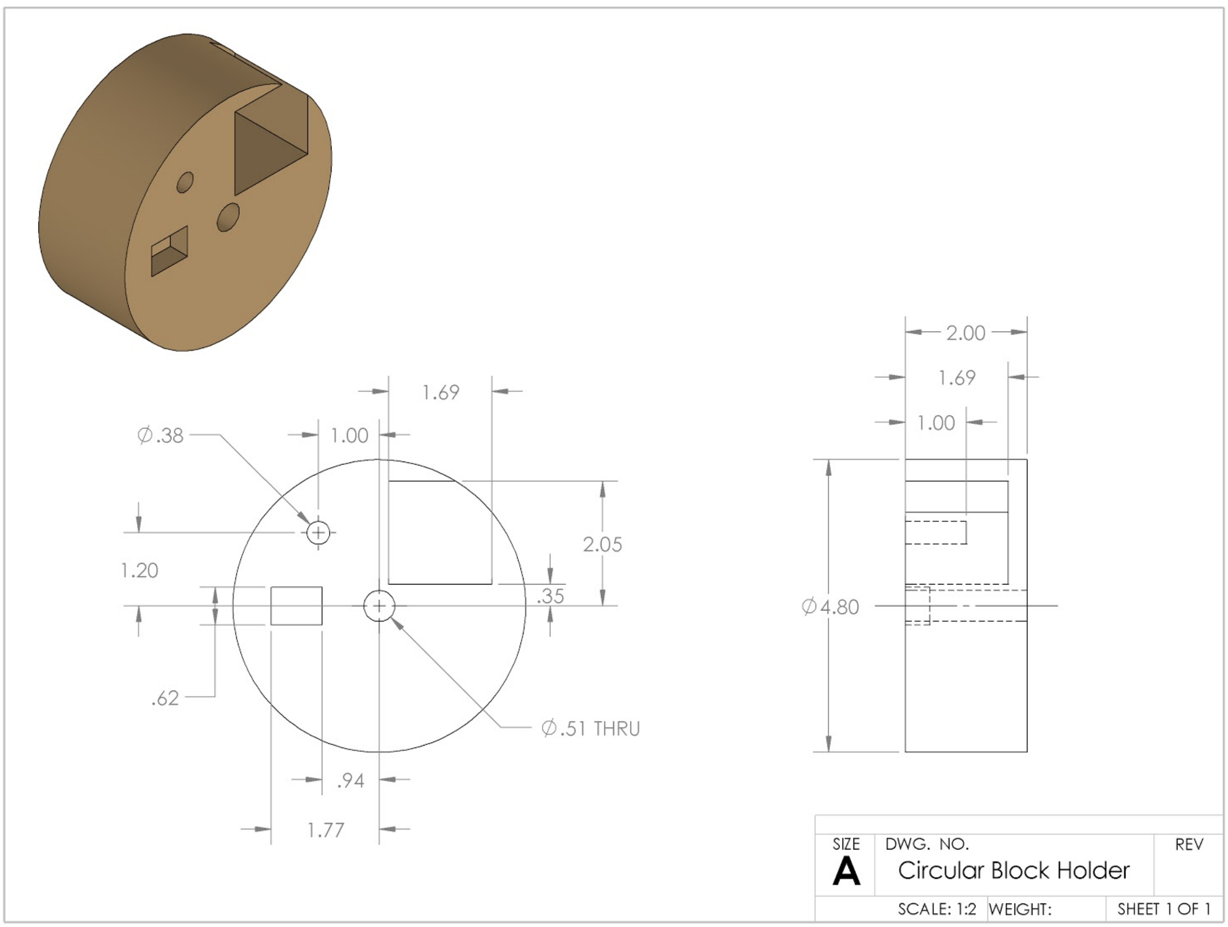


Figure 51: Circular Block Holder

Further insight on the design choice of the circular block holder is provided in section 4.1.7.

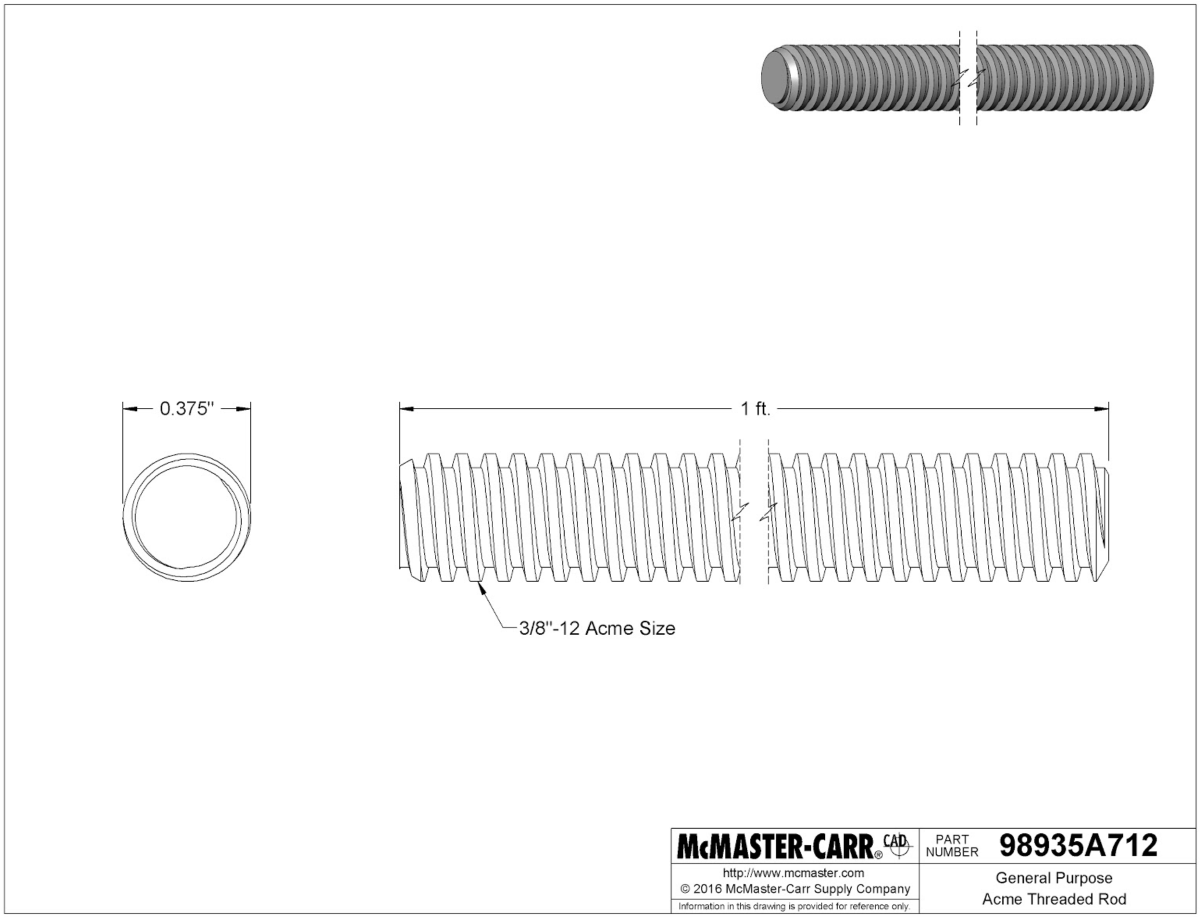


Figure 52: ⅜"-12 x 12in Lead Screw

4.1.4.2 Rover

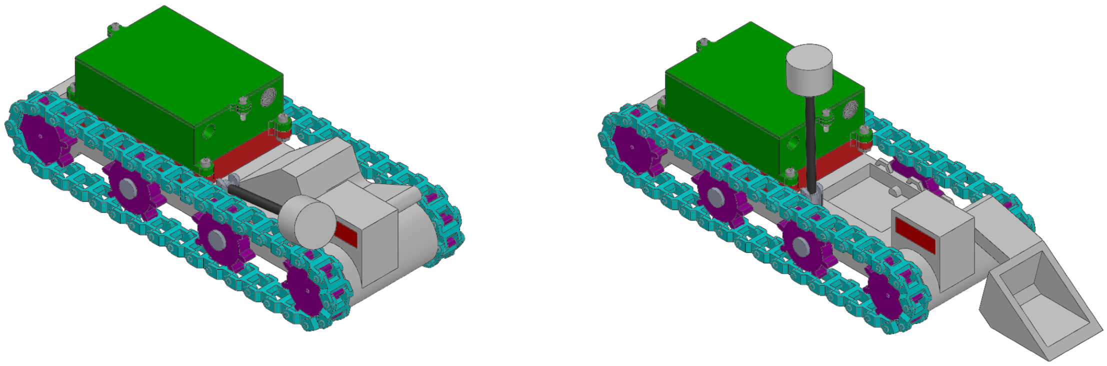


Figure 53: Packed Rover (left) and Unpacked Rover (right)

The payload features an 11.3” x 4.5” x 3.4” rover with a collapsible collection arm and antenna for storage within the launch vehicle. A 2.3” x 1.9” x 0.4” (~28.6mL) storage area within the chassis of the rover will store simulated lunar ice samples. The same collection arm doubles as a cap for the collection bin to ensure collected samples are retained within the rover during transportation. A separate 2.4” x 3.0” x 4.0” compartmentalized section, located on the back side of the rover, is dedicated to housing all onboard electronics. Requirement 2.21 in the Student Launch Handbook states that all lithium polymer batteries must be sufficiently protected and marked as flammable.To satisfy this requirement, the single lithium polymer battery powering onboard electronics is located in a separate, bright red compartment within the electronics bay. All other electronics are placed on the top half of the electronics bay for easier access to electronics. Both compartments and lid are fastened to each other using 6-32 nuts and bolts. The bottom red compartment of the ebay is attached to the chassis using epoxy. The contact area between the chassis and the bottom ebay compartment is maximized to increase the amount of epoxy applied between the two parts. The rover uses treads instead of wheels as its form of movement. This allows the rover to overcome obstacles located under its center since there is continuous traction the entirety of the rover. The following figure demonstrates the interfaces between each component of the rover.

ITEM NO.	PART NUMBER	QTY.
1	Chassis	1
2	Collection Arm	1
3	Servo Motor	1
4	DC Motor	4
5	Axle	4
6	Sprocket	8
7	Tread	72
8	Ebay Lower	1
9	Ebay Upper	1
10	Ebay Cover	1
11	Antenna Transmitter	1
12	Antenna Interface	1
13	Antenna Holder	1
14	3/8" Custom Nut	1
15	4-40 1/2" Long Bolt	2
16	6-32 5/8" Long Bolt	4

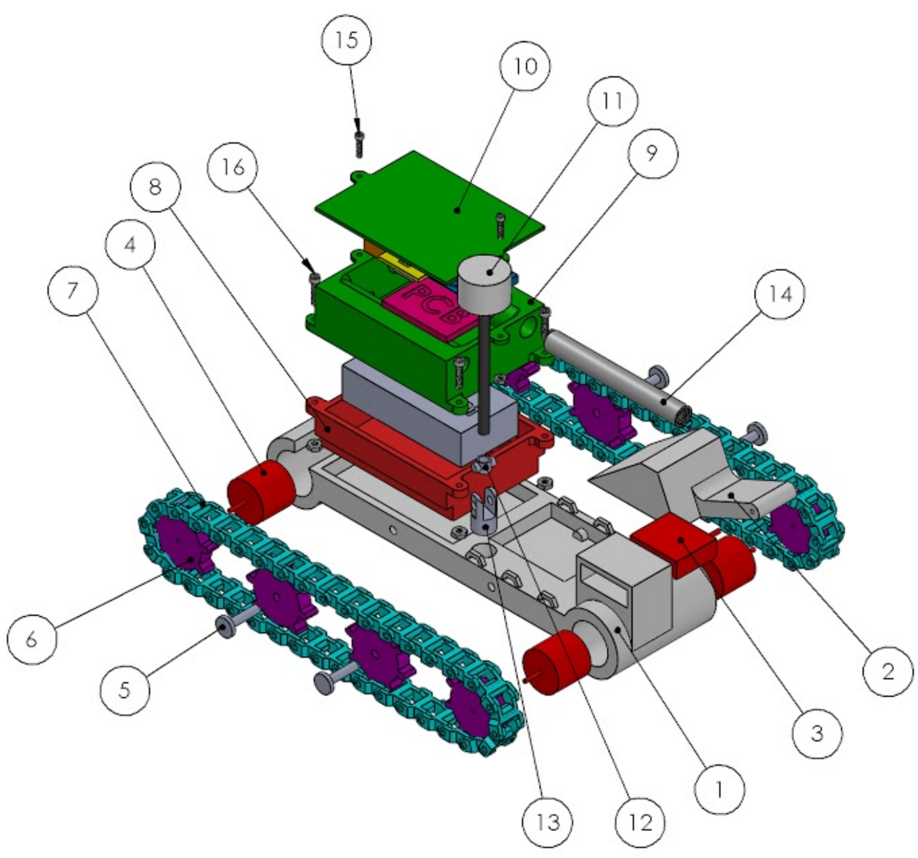


Figure 54: Exploded View of Rover

Chassis

The core component of the rover is the chassis, which allows all other components to be consolidated into one cohesive unit. The chassis will support the weight of the entire payload during its mission. The payload features indentations for easier fastening between multiple components. The rear section of the payload is designated for epoxying the electronics bay of the rover onto the chassis. Space on the chassis was tailored to maximizing the volume for the electronics bay to simplify wiring. The front indentation is used for storing collected simulated lunar ice samples. The volume of the collection area is approximately 28.6mL, which exceeds the required 10mL sample size, as specified in the Student Launch Handbook (Requirement 4.3.3). Two long tubular sections are located at the ends of the chassis for epoxying the selected DC motors to the rover. In order to run wires to the motors once the motors have been epoxied, the tubular sections were "opened" so that pre-attached wires fit. At the front of the chassis, a block segment with a rectangular cut houses a servo motor to rotate the collection arm. The cut goes through the entirety of the block segment so that wires of the servo motor are easier to manipulate. The chassis has the following dimensions.

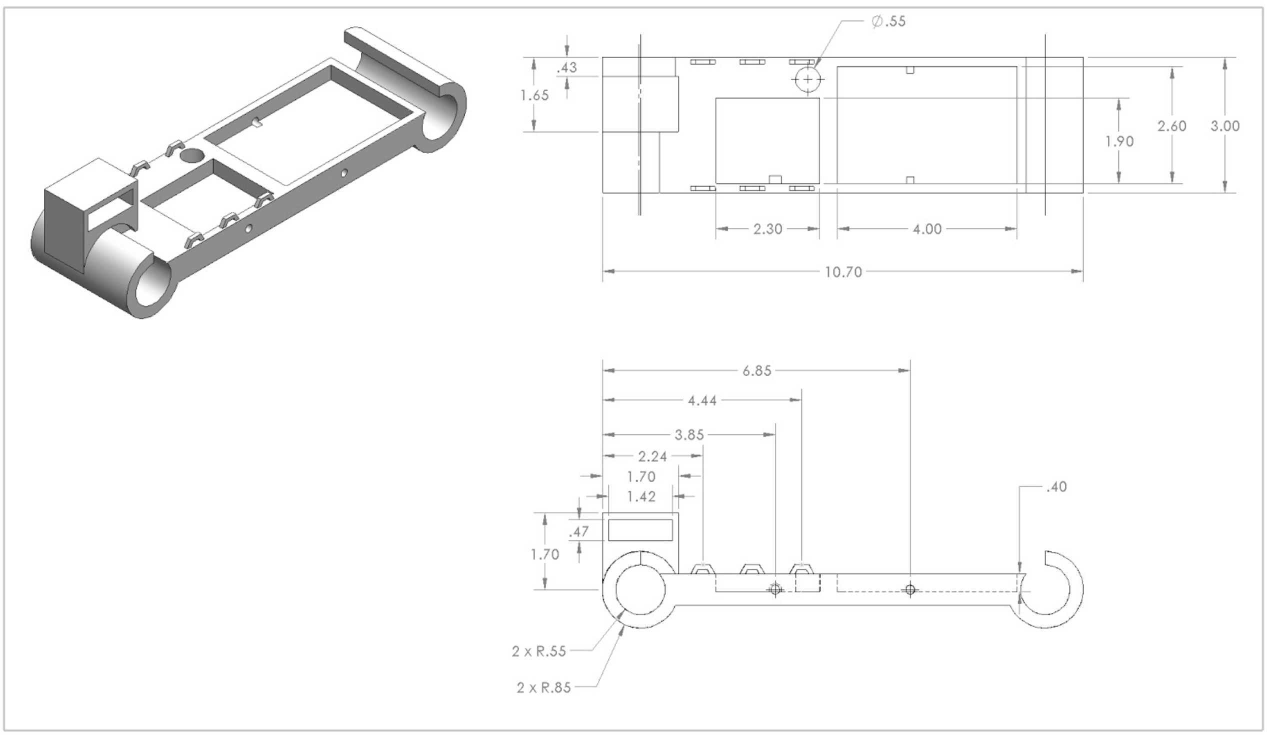


Figure 55: Payload Chassis Drawing

Collection Arm

The collection arm is tasked with collecting simulated lunar ice samples. To accomplish this, a bulky yet robust collection arm was adopted to prevent the arm from snapping or breaking. The geometry of the collection arm is able to dig into the ground to collect samples and move the samples over the chassis' servo motor protrusion. The collection arm is also able to completely cover the collection zone on the chassis to act as a sort of lid. This prevents samples from escaping during transportation.

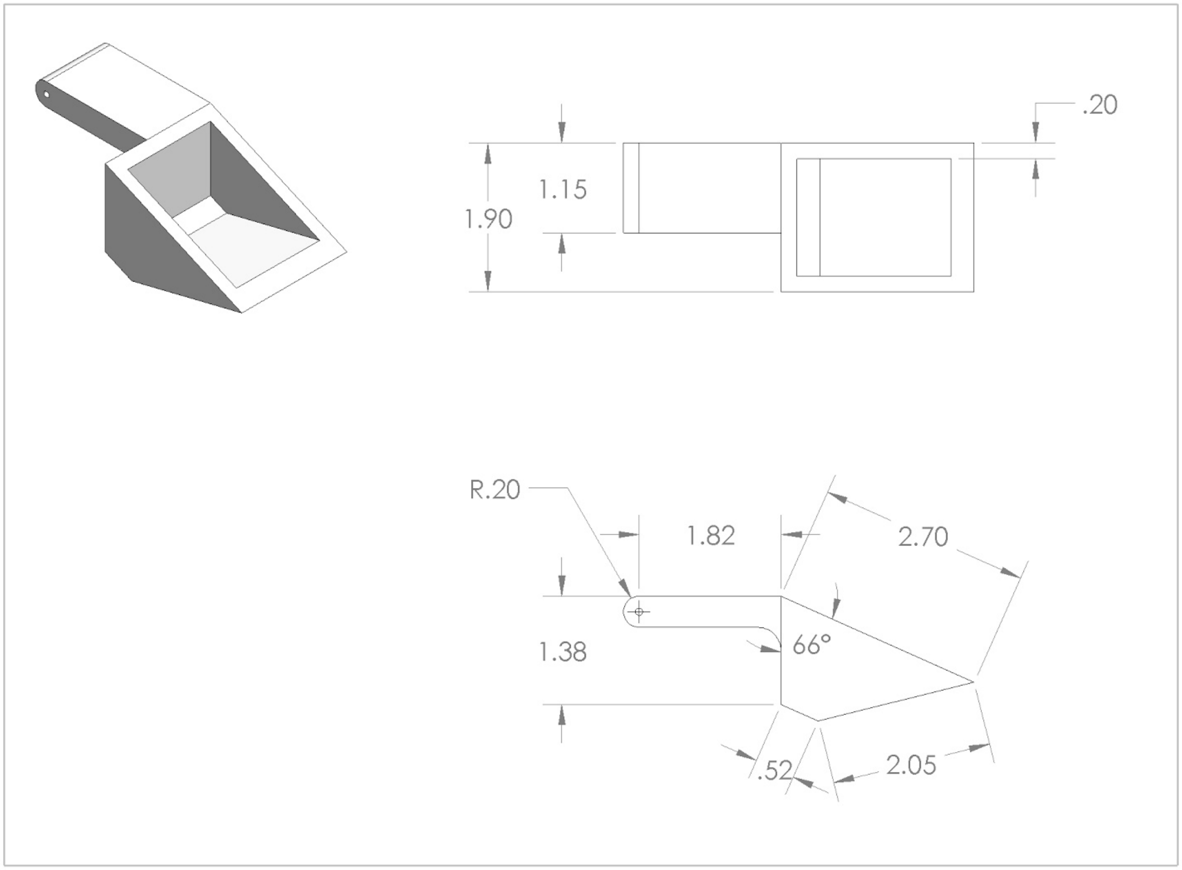


Figure 56: Collection Arm Drawing

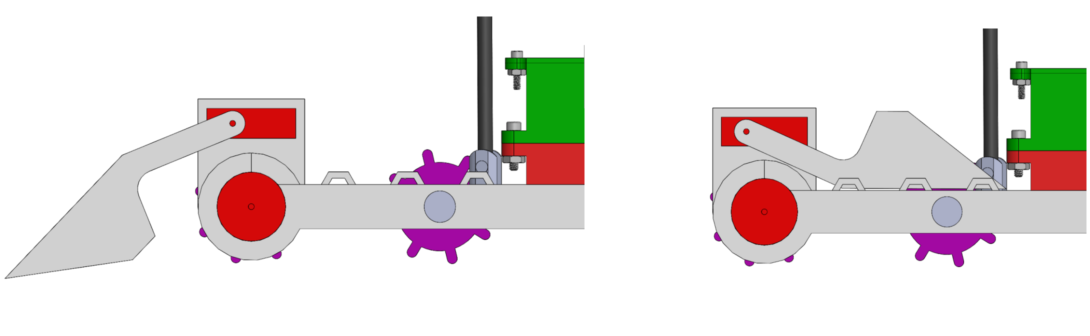


Figure 57: Collection Arm Positions

Electronics Bay

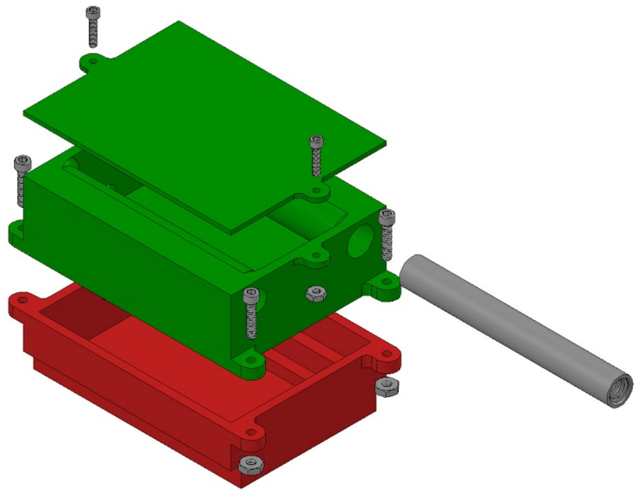


Figure 58: Exploded View of Electronics Bay

A crucial component for deploying the rover and managing electronics onboard the rover is the electronics bay. Since the electronics bay interfaces with the deployment mechanism's rods, the electronics bay must support the weight of the rover and landing impact forces while stored within the launch vehicle. The design of the electronics bay is governed by its ability to support the rover and its ability to store a long-lasting lithium polymer battery in a separate compartment from other electronics. The bottom compartment of the electronics bay will be epoxied onto the designated area of the chassis. A large contact surface area between the bottom electronics bay and chassis ensures a strong bond between the two parts. The upper compartment of the electronics bay is fastened to the bottom electronics bay using 6-32 nuts and bolts in 4 different tabs. Each tab is 0.2in thick for a total of 0.4in support for each connection point. Thick tabs are necessary for enduring flight forces without damaging the electronics bay. A lid is fastened to the electronics bay using smaller 4-40 screws. Since the lid does not bear a load, tab sizes were kept at a minimum to reduce weight. Dimensions of each component are outlined below

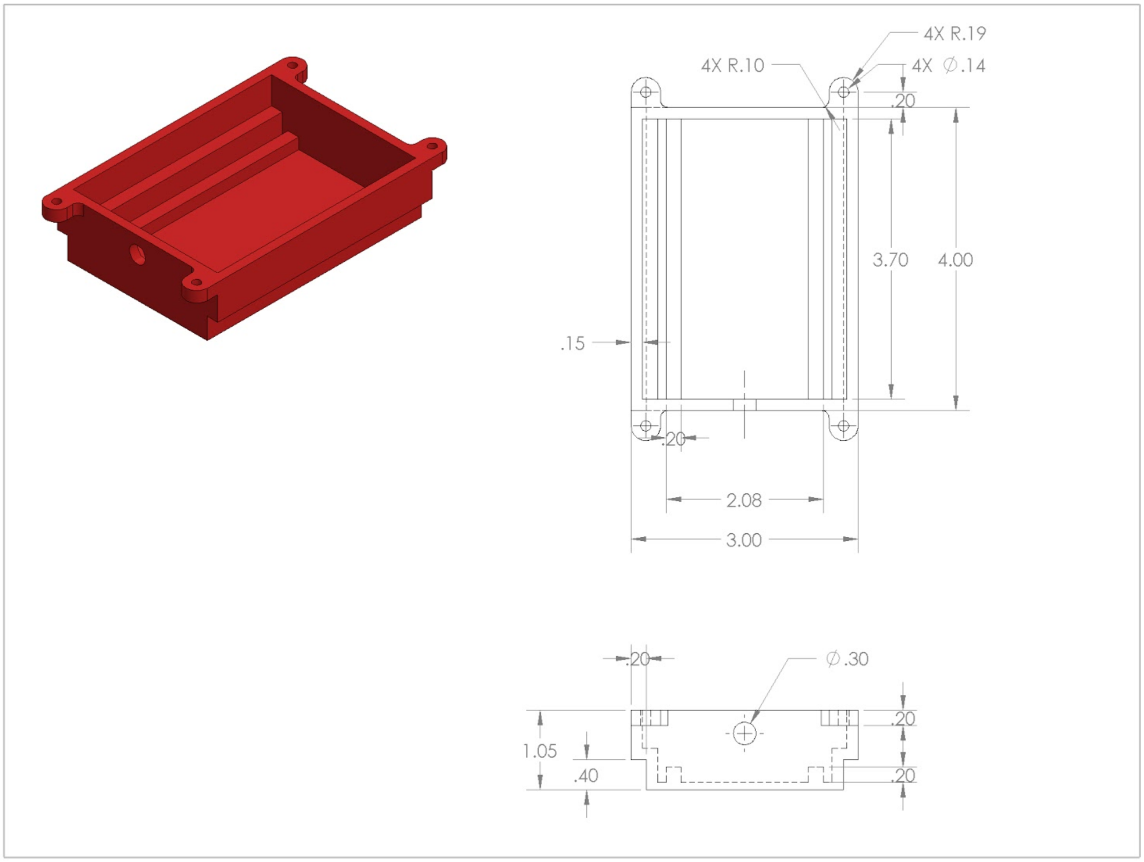


Figure 59: Lower Electronics Bay Compartment Drawing

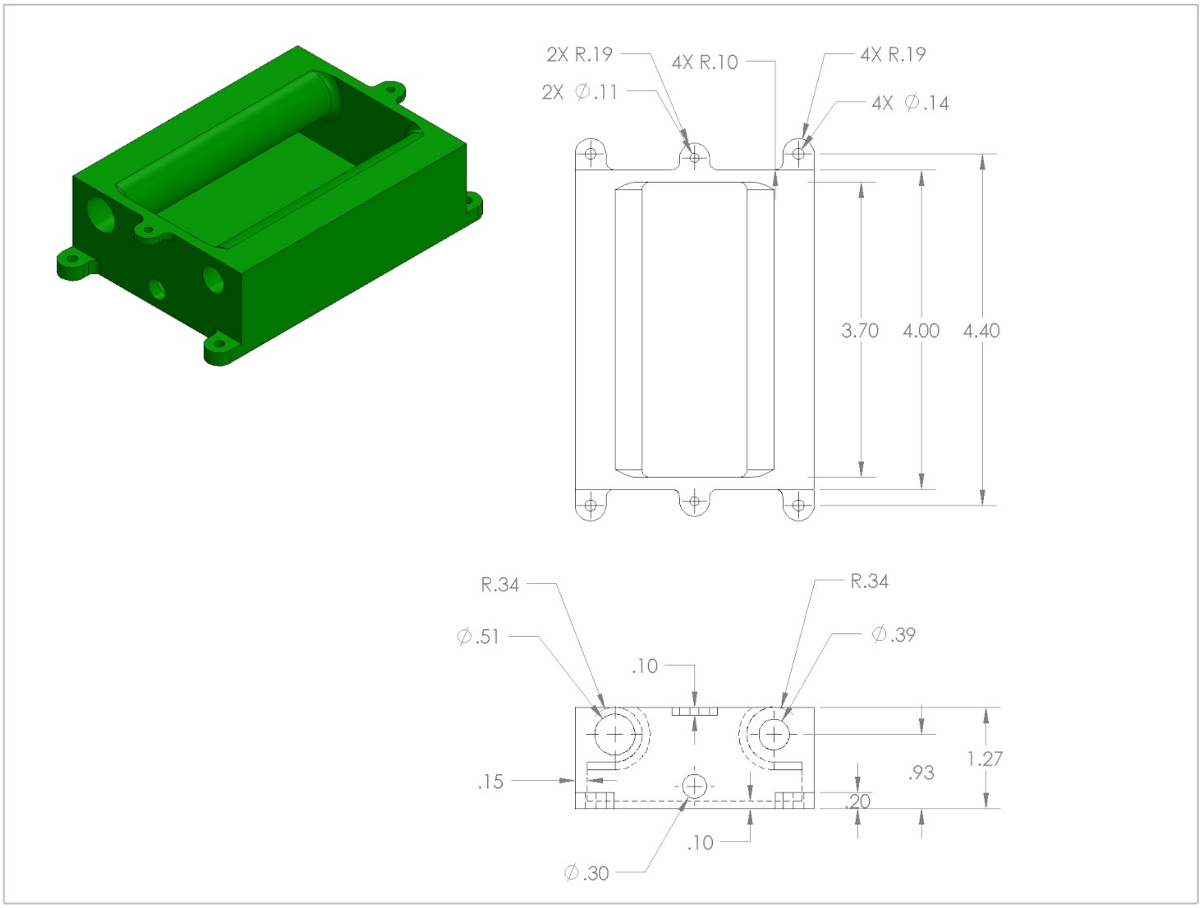


Figure 60: Upper Electronics Bay Compartment Drawing

Important features of the upper electronics bay are the holes where rods of the rover ejection assembly interface with the rover. Each hole is reinforced with a 0.15in beam so that impact forces during landing do not warp or damage the electronics bay. Since one of the rods is threaded, an additional long nut must be included. The long nut will fit into a 0.51in diameter hole in the electronics bay. The dimensions of the long nut is provided below.

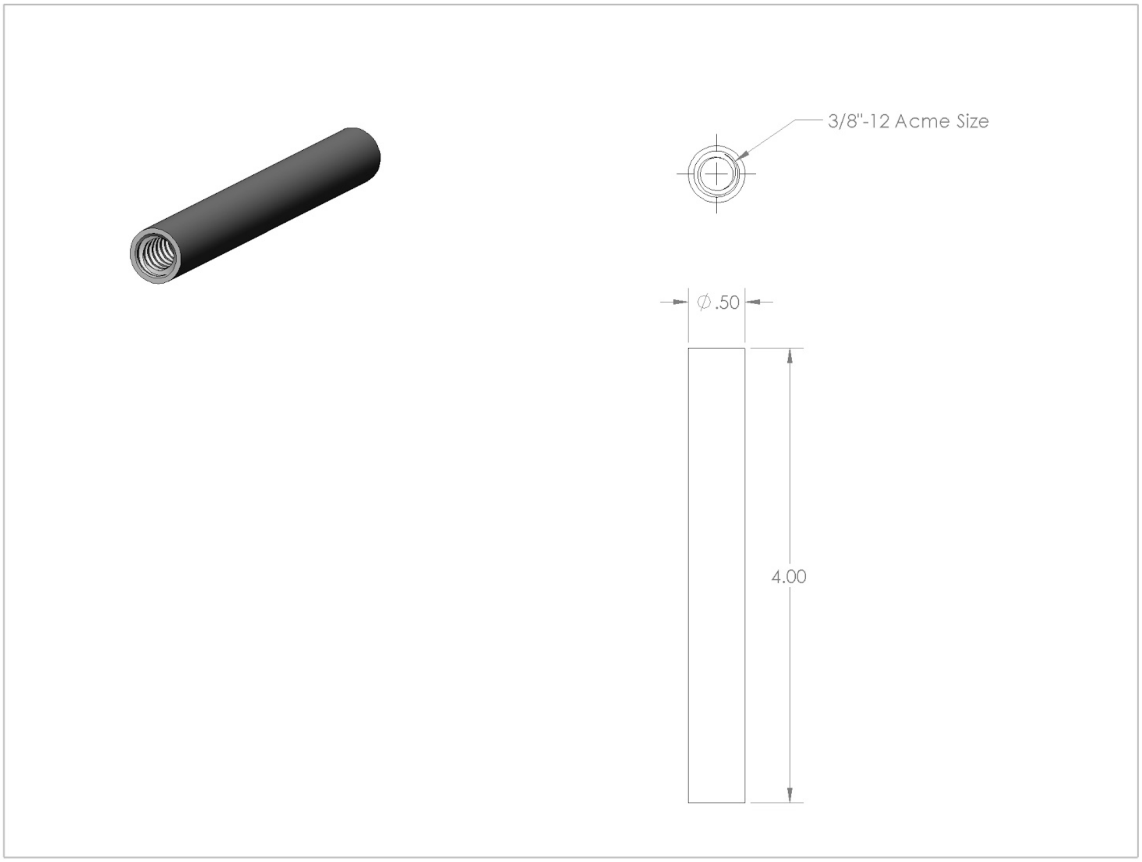


Figure 61: Custom Long Nut

To fabricate the long nut, a 1/2in diameter steel rod will be tapped to create the appropriate ⅜"-12 female thread size to interface with the lead screw.

Treads and Sprockets

In order to provide sufficient traction and overcome obstacles in the terrain, a tread system will be implemented within the rover. The treads will be rotated by four sprockets powered by DC motors. Four additional sprockets are placed in between the powered sprockets to add structure to the tread chain. To increase traction, rubber cement will be applied to the outer area of the treads. Each tread is 0.97in in length spanning around a 23.34in long path. A total of 36 treads is necessary to span the entire length of the rover's wheel base. The interfacing sprocket features a pitch diameter of 1.625in. All components will be 3D printed using PLA plastic. Further dimensions are provided below for all components necessary for the rover's driving chain.

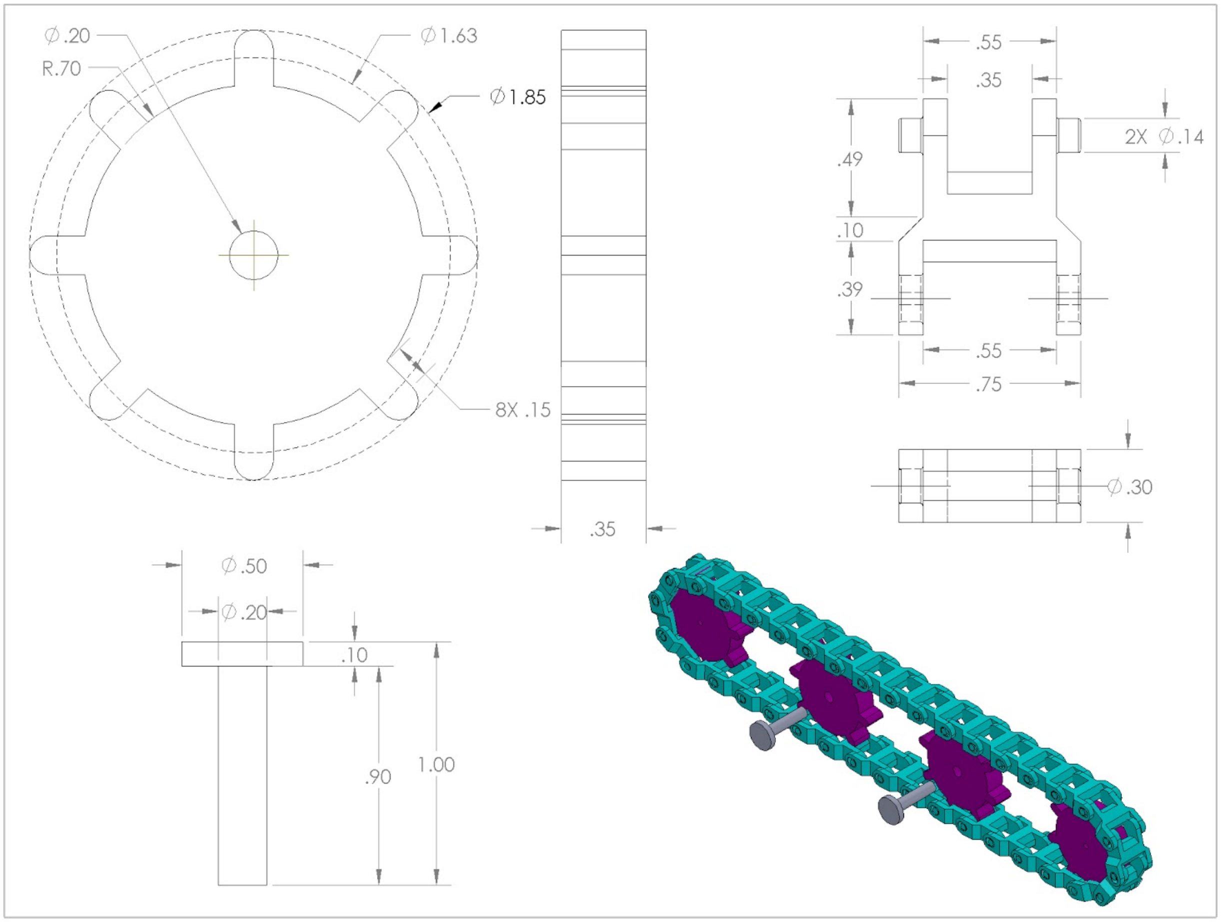


Figure 62: Tread and Sprocket Assembly Drawing

Antenna Mechanism

Figure 63: Antenna Mechanism

A simple rotating antenna mechanism will be used to properly store antennas while the rover is packed within the launch vehicle. The base of the mechanism will be epoxied into the chassis while a rubber band fastened to the electronics bay wraps around the rod of the antenna. The purpose of this rubber band is to place the antenna in its upright position after the rover is deployed. The body tube of the launch vehicle will prevent the antenna from being in an upright position. Once deployed out of the launch vehicle, the antenna will mechanically spring into position. The following image demonstrates how the antenna will fit within the launch vehicle without interfering with other payload components.

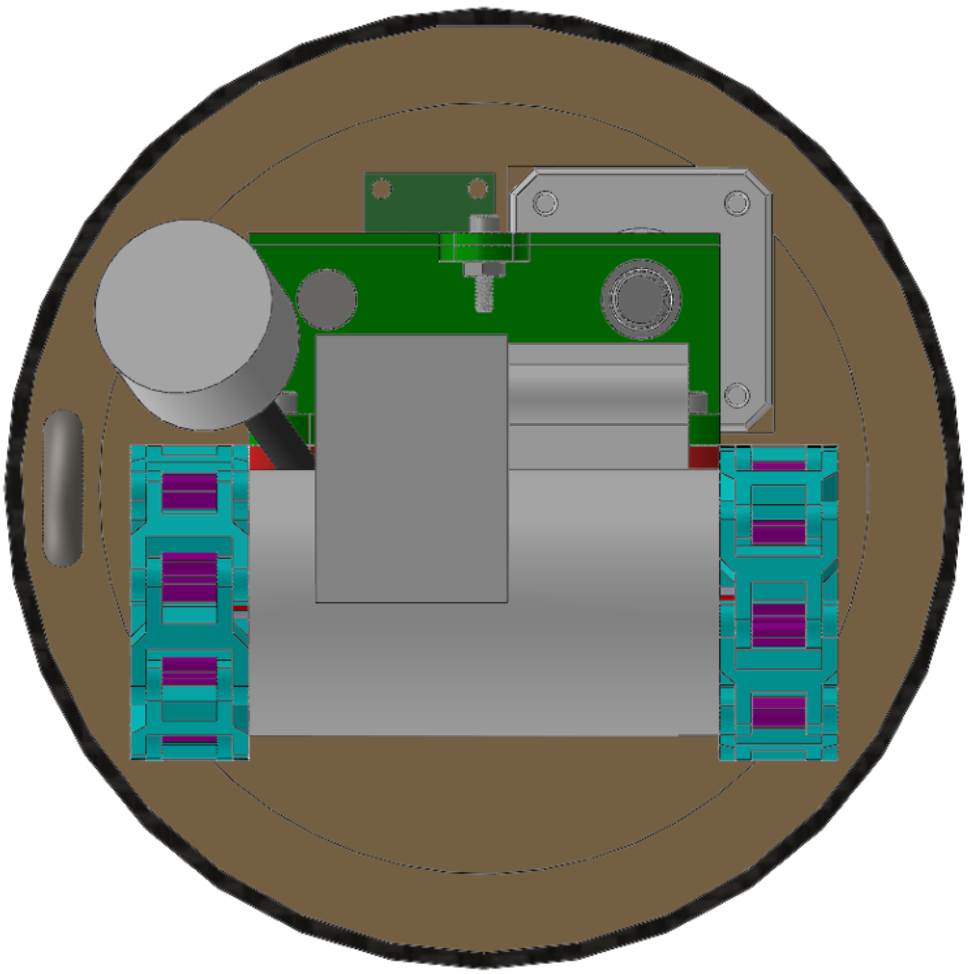


Figure 64: Packed Rover Antenna within Launch Vehicle

4.1.5. Design Completeness Verification

Design verification is implemented through thorough inspection and testing, presented in 6.1. For further analysis, consult Operation Procedures.

4.1.6. Payload Electronics

4.1.6.1 Rover Ejection Assembly

For properly orienting the rover prior to deployment, the rover ejection assembly will employ a series of electronics for automatic deployment. This bypasses the challenge of establishing RF communication that can penetrate carbon fiber and removes the need of extra clunky antennas. The individual components are discussed in the following sections.

Microcontroller

The Arduino Uno Microcontroller Board will be used to control the operations of all the electrical components involved in the REA. The Arduino Uno has an operating voltage of 5V and input voltage limits ranging from 6-20V (7-12V recommended input voltage). The Arduino Uno microcontroller utilizes 14 digital pins, of which 6 provide PWM output and 6 analog input pins. Furthermore, the Arduino Uno contains 32 KB of flash memory, 2 KB SRAM and a clock speed of 16 MHz. The IDE software of the Arduino Uno make it easily programmable using C++ and the pins that are readily available on the board make it convenient for wiring hardware.

Pressure Temperature Sensor

The BMP180 barometric pressure sensor will be used to measure the altitude of the rocket throughout the course of the mission. The BMP180 can take pressure measurements at a range of 30-110 kPa. This means pressure readings are accurate to ±0.4 kPa from sea level to an altitude of 30,000 feet above sea level. The BMP180 on average consumes a small amount of current to operate (only 3 **µ**A) and a wide range of operating temperatures (-40 - +85°C). Seeing that the rocket will experience altitudes and temperatures that are well within the measuring capabilities of the BMP180, and due to its low power consumption and high measurement accuracy, it is clear that this is the ideal pressure sensor to track the altitude of the rocket during the launch.

Accelerometer+Gyroscope Sensor

The MPU-6050 sensor will be used to determine the orientation of the rover at the time of touchdown and has an operating voltage of 3~5V provided by the arduino microcontroller. The MPU-6050 has a triple-axis accelerometer with range of ±2g, ±4g, ±8g and ±16g and digital output X-, Y- and Z-Axis angular rate sensors with a range of ±250, ±500, ±1000, ±2000 deg/sec. The sensor’s ability to detect roll pitch and yaw motions make it ideal for detecting the orientation of the rover as the stepper motor positions it to the correct, upright, orientation before being deployed.

Motor Driver
A A4988 Stepper Motor Driver module will be used to regulate the current supplied to the stepper motors. The driver is 20x15x11(LWH) and has minimum and maximum operating voltages of 8V and 35V respectively. The maximum current output can be set by adjusting the potentiometer on the module. Doing this sets a limit on the amount of current going through the step motors and the driver itself to prevent components form overheating while in service. The maximum current will be set to 2A which is the max current per phase of the A4988 driver.

Stepper Motors
The REA will utilize two NEMA 17 Stepper Motors to drive the mechanical components that eject the rover. The NEMA 17 has a rated voltage of 12V and a current of 1.2A at 4V. The NEMA 17 has a step resolution of 1.8 degrees making it capable of 200 steps per revolution and can withstand a holding torque of 22.2 oz-in. The step resolution and holding torque make the stepper motors capable of rotating the deployment section and ejecting the rover during the deployment phase of the mission.

Power Supply
A 9 volt alkaline battery will be used to power the Arduino Uno microcontroller, switch, pressure sensor and accelerometer. The motor driver and NEMA 17 stepper motors will be powered by an additional voltage source provided by two 12V alkaline batteries connected in series. A higher voltage is needed to increase the performance of the stepper motors but not greater than 35 volts as to not cause the motor driver to overheat.

Rover Ejection Assembly Major Events
Since the rover is automatically deployed, the Arduino microcontroller must be able to identify when a touchdown event has occurred after a launch. The additional BMP and accelerometer/gyroscope modules help the Arduino Uno decide when to deploy. The following flow chart illustrates the steps taken by the Arduino Uno for safe deployment.

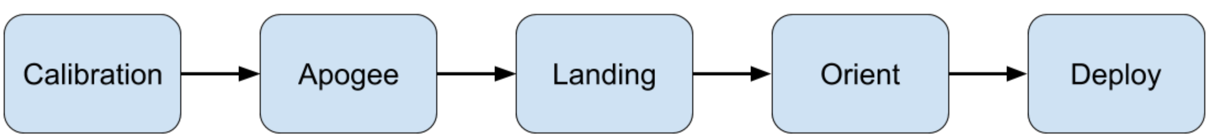


Figure 65: Rover Ejection Assembly Major Events

Calibration: once power is connected, the Arduino will take data measurements from the BMP and average altitude values to determine its current altitude on the launch pad.
Apogee: the Arduino code will define apogee as the highest point after reaching an arming altitude of 1000 ft higher than the calibrated ground level altitude. This

is necessary so the Arduino can differentiate between when the launch vehicle is on the pad and when it has landed.
Landing: once values stop fluctuating during descent, a landing will be detected. Current altitude will be compared with calibrated altitude to initiate a two minute delay before the next step.
Orient: after the delay, angular position of the rover will be analysed using the accelerometer and gyroscope module. A stepper motor will drive the REA until the correct orientation is achieved.
Deploy: a second stepper motor will drive the REA's linear actuator to deploy the rover.

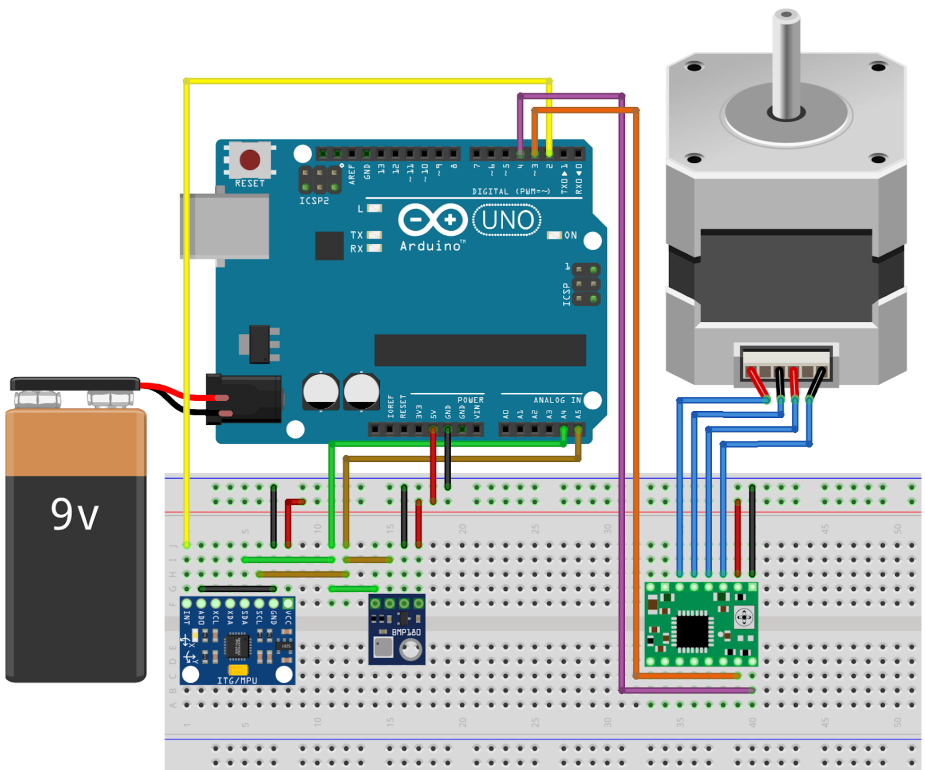


Figure 66: Rover Ejection Assembly Wiring Diagram

The previous figure illustrates the wiring of the rover ejection assembly. Only one stepper motor and stepper motor driver are shown to simplify the diagram, despite the rover ejection assembly requiring two motors to operate. A breadboard will not be included in the avionics bay. All connections will be soldered.

4.1.6.2 Rover

Flight Controller
The CC3D's compact design, quick start open source firmware, 32-Bit memory processing, modular Rx and TRx sections, and low price make it an excellent choice for regulating the

electronics on the compact payload. In comparison to the Naze32 its MPU 6000 is more resilient to noise from the selected motors, and other team's transmissions. Additionally it's ability to load the open source firmware CleanFlight, allows for fine tuning if necessary after using quick start terrain settings on the default OpenPilot GCS which drastically simplifies and accelerates troubleshooting. Additionally the CC3D was designed with GPS and varying transmitters in mind with its two sets of Rx and TRX sections, which allow for more data processing while completing ESC Feedback, despite having less pins and being smaller than other controllers like the Arduino Mega. The CC3D also has 6 motor output pins, which is necessary since 5 motors will be used for completing the mission.

The CC3D Flight Controller operates on 5V, which will be provided by the power distribution board. A power distribution board with a 5V regulator is necessary since the battery has a 11.1V nominal voltage rating. The power distribution board will be discussed later in this section. The CC3D has no designated V-in pin. Instead, it is located in the motor output pins. Powering one of the pins powers the entire module. The CC3D also connects and powers the receiver and operates the electronic speed controllers for controlling the motors.

Antennas
In order to achieve a communication distance of 0.5 miles, matching 2.4GHz circularly polarized directional antennas will be used. The selected TrueRC Singularity 2.4GHz Antenna has a gain of 1.6dBic and interfaces with both the receiver and transmitter. Circular polarization antennas will be used since only matching circular directions can communicate with each other. Oppositely circularly polarized antennas prevent signals from interfering with each other such that only a right hand circularly polarized (RHCP) antenna can communicate with another RHCP antennas. This is necessary since two antennas will communicating with the driver.

A 2.4GHz frequency increases the range of a signal permeating the air at the expense of latency. The energy loss of a wave permeating the air is governed by its frequency. The larger the frequency, the lower the energy loss. This ensures a stronger signal for a longer range. Using the Friis Transmission Equation and the fact that wavelength equals *c/f*, we can calculate the received power of any antenna system to be:

$$P_r = \frac{P_t G_t G_R \lambda}{(4\pi R)^2}$$

Where P_r is the power received (in dBm), P_t is the power of the transmitter (in dBm), G_t is the gain of the transmitter antenna (in dBi), G_r is the receiver gain (in dBi), λ is the wavelength of the transmitted wave (in meters), and *R* is the length of antenna separation (in meters). For the following calculations, both the transmitter and receiver will use the same TrueRC Singularity 2.4GHz Antenna with a gain of 1.6dBic such that G_t and G_r are 1.6. Additionally, to test the power received at 0.5 miles, *R* will have a value of 804.672 meters.

Table 15: Transmitter and Receiver Signal Strengths

RX/VTX	Output Power (W)	Sensitivity (dBm)	Received (dBm)
RX	0.1	-104	-74.94
VTX	0.2	-90	-71.94

With the given receiver and antenna setup on the rover, a 0.5 mile signal can successfully be transmitted to and from the rover. The sensitivity of each receiver and transmitter on the rover indicates how much power the module must receive in a signal for it to detect it. The current setup provides a signal far greater than the necessary sensitivity, so communication with the rover with at least a half mile radius is possible. The sensitivities of each receiver and transmitter onboard the rover will be discussed in the following sections.

Receiver

The rover will utilize a Radiolink R8Ef receiver with a sleek profile of 1.58” x 0.79” x 0.35”. The receiver will communicate with the remote controller that a driver will be operating on site. The inputs received by the receiver can be output as S-BUS/PPM/PWM signals, all of which are readable by the CC3D flight controller. The Radiolink receiver is powered by a 5V pin within the CC3D flight controller, which is the specified operating voltage of the receiver. The receiver also includes 8 channels, meaning up to 8 motors could be controlled. Since the flight controller controls up to a maximum of 6 motors, 8 channels is more than needed.

Since many teams will be using radio frequency communication, frequency hopping is required to avoid excessive interference. The selected receiver comes with FHSS spread spectrum, 67 channels pseudo random frequency sequence hopping.

Video Transmitter

The rover will be equipped with a long-range 2.4 GHz video transmitter in order to provide the team a live feed of the rover. The video transmitter selected is the FuriousFPV Stealth 2.4GHz transmitter. The video transmitter will draw power from a power distribution board at 11.1V, as specified by the battery. The selected video transmitter includes output pins to power other auxiliary electronics, like the camera. The onboard camera operates on 5V and the included output pin of the video transmitter includes a BEC 5V, 2A pin with an LC filter for clearer video feed. The transmitter also includes adjustable power outputs, regardless of the voltage supplied to the transmitter. The max available power output that complies to the 250mW maximum requirement stated in the Student Launch Handbook is 200mW.

Similar to the receiver, the FuriousFPV Stealth transmitter uses FHSS spread spectrum to avoid interference from other teams.

Motors

The Racerstar BR2212 Brushless DC Motor's small 2.77mm diameter, coupled with its brushless DC configuration provides the necessary force to allow for the payload to maneuver the terrain post-ejection. It's reliability, availability, and low weight of 44 grams allows for easy mounting and implementation into the rover. Additionally the brushless design allows for less wear when reversing the current flow for reversing direction, as compared to a brushed variety. The Racestar BR2212 DC motor accepts nominal voltages ranging from 7.4-14,8V. The selected battery has a nominal voltage of 11.1V, which is within the limits of the motor. This simplifies the wiring procedure as a power distribution board can be used to supply direct voltage to the motors from the battery. Each DC motor will be connected to an electronic speed controller to control the voltage each motor receives. The Racerstar BR2212 DC motor has a max current draw of 10.6A, which is crucial for determining the specifications that connect to the DC motor.

The Micro High Torque Servo fits the desired 5V power, light weight at 14 grams, and 180 degree rotation necessary for the collection arm. It's only drawback is the low Spline Count of 20, however, since the rover will do simple, slow movements the low count is negated by the freedom of motion. As opposed to a DC motor, the selected servo motor will not require the use of an electronic speed controller, as it will be directly controlled by the flight controller. The flight controller is able to provide the necessary 5V voltage needed to operate the motor.

Electronic Speed Controllers

To allow the DC motors to spin in both CW and CCW directions and to draw more voltage, electronic speed controllers (ESC) are needed. The selected ESC, the Lumenier Mini 25A, features a "4-in-1" ESC, which consists of four individual electronic speed controllers that are stacked on top of each other. This compact arrangement occupies less crucial space on the rover. Each ESC is in charge of controlling a single DC motor that moves one of the four wheels. The ESC will be connected to the flight controller for instructions and the power distribution board for additional voltage. The flight controller will send the ESC OneShot communication output, which is read by the selected ESC, despite being adapted for DSHOT communication. The power distribution board will provide a theoretical maximum of 11.1 V of power to the ESC using two wires, one for positive charge and another for negative charge. An additional connection from the flight controller is needed to tell the ESC how much voltage to draw from the power distribution board. When the rover needs to go in reverse, the ESC will reverse the polarity, causing the DC motors to rotate in the opposite direction.

The individual ESCs are rated to accept a maximum continuous current of 25A. Each individual DC motor will not draw more than 10.6A, so throttling the DC motor to its limit will not damage the ESC.

Power Distribution Board

The power distribution board (PDB) simplifies the way power is distributed among the different electrical components within the rover by soldering wires to pads on the PDB which connect to a single battery. The selected PDB is the HobbyMate XT60 PDB which features 4 motor outputs for motors to have access to the selected battery, a BEC 5V output with LC filtering, and a BEC 12V output. The motor outputs are able to withstand up to a total of 50A of continuous current. As mentioned before in the motor selection section, each motor will draw 10.6A, so the max that will be drawn at any time will be 42.4A. This is within the range of 50A, so component failure of the selected PDB will not occur.

The included BEC 12V output regulator is specialized for powering the video transmitter as it has a linear regulator for maintaining a steady voltage. Since only 11.1V are supplied to the PDB, the output of the BEC 12V is reduced to 10.1V, which is still within the range of the video transmitter. The included BEC 5V output will connect to the flight controller to power the module. The PDB allows components of different working voltages to be powered using a single consolidated battery. The next section goes into more detail of the selected power supply.

Power Supply

The rover will utilize a lithium polymer battery rated at 11.1 V 3S 4000mAh 50C. This battery will provide sufficient power to each of the electronic parts for approximately 4.1 hours with an expected mission time of 30 minutes. This satisfies the team's goal of designing an electrical system to last four hours in order to surpass the Student Launch Handbook requirement of a minimum launch pad idle time of two hours. A total of 3660mAh is predicted to be consumed if the rover is under constant operation for 4 hours. The current draw of each electrical component is outlined in the table below.

Table 16: Current Draw of Rover Electronics

Section	Part	Voltage Range (V)	Current Draw (mA)	Hours (h)	mAh
Controls	DC Motor	6.6 - 7.2	1250	0.5	625
	DC Motor	6.6 - 7.2	1250	0.5	625
	DC Motor	6.6 - 7.2	1250	0.5	625
	DC Motor	6.6 - 7.2	1250	0.5	625
	Servo Motor	5	80	0.5	40
	CC3D	5 - 15	70	4	280
	Receiver	10	30	4	120
	Total	-	**5180**	-	**2940**

Table 16: Current Draw of Rover Electronics

Video	Transmitter	7.4 - 25.2	90	4	360
	Camera	5	90	4	360
	Total	-	**180**	-	**720**
Final Total			**5360**		**3660**

In accordance to Requirement 2.21 of the Student Launch Handbook, the battery will reside in its own bright red, 3D printed compartment to distinguish the battery as flammable and protect other electronics from damage if the battery were to fail. The battery will be connected to the power distribution board that will control the flow of power to each of the electronic components as needed. It is noted that the voltage rating of the battery is significantly higher than the maximum voltage capacity of some electronics on the rover system. The power distribution board is tasked with regulating the voltage for some onboard electrical components. The 50C current rating indicates not only how fast the lithium polymer battery can be charged, but also how fast it can discharge current before the battery is damaged. The battery is able to discharge a continuous current of 200A, which is sufficient for the rover. The max current that can be drawn is primarily influenced by the four onboard ESCs, which are rated at 25A each. A total of 100A will be drawn directly for the motors, which indicates the selected battery will not fail. However, further testing will be conducted to ensure proper use of the lithium polymer battery.

Schematic

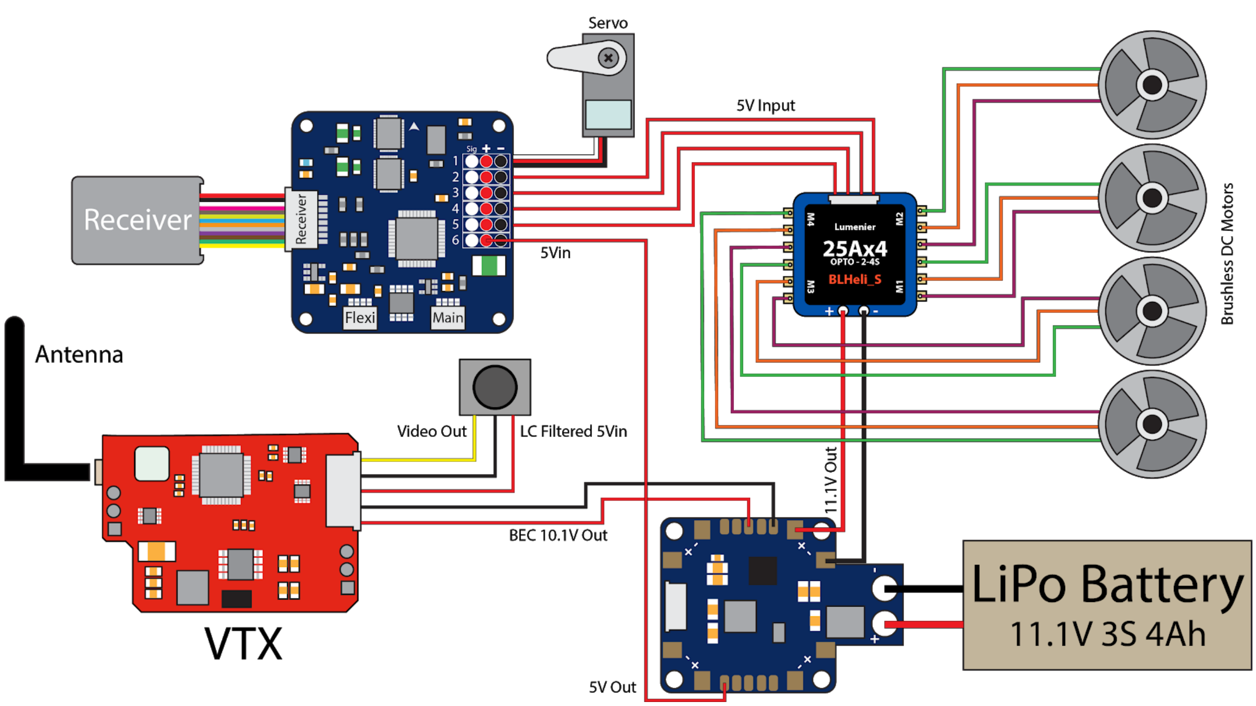


Figure 67: Schematic of Electronics within Rover

4.1.7. Justification of Unique Aspects

Bearing Ring

A unique aspect of the rover ejection assembly is the use of a bearing ring during the orientation phase of deployment. Since the payload will exert a cantilever moment on the stepper motor orienting the rover, the use of a 4in outer diameter bearing ring relieves the motor from excessive forces. In essence, the bearing ring will endure all load bearing forces while the stepper motor only has to focus on rotating the assembly. In order to rotate the entire payload block, an extra 3D printed shaft must be attached from the motor to the circular block holder.

Circular Block Holder

The dimensions of the circular block were dictated by the size of the selected stepper motors, the size of the payload, and the use of an eyebolt for tethering the main parachute to the launch vehicle's bulkhead.

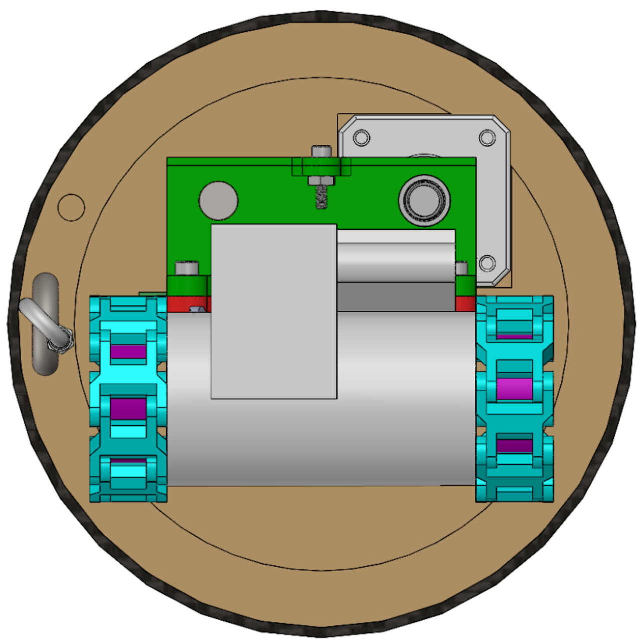


Figure 68: Front View of Rover Inside Launch Vehicle

Viewing the rover inside the launch vehicle, it is evident that the stepper motor is not fully retained within the circular block holder. This is a result of how the rods intersect the payload. While the hole placement within the avionics bay could be lowered, this would cause the rods to intersect the collection arm and servo motor holder near the front. A different approach to this problem would be to bring the rods closer together, essentially making the entrance of the electronics bay smaller. While this would improve the design of the rover, it would make wiring and electrical placement within the electronics bay difficult. Another option is to increase the size of the circular block holder, however, this would cause interference between the eyebolt and the circular block holder. The selected option is to let part of the stepper motor to jut out the circular block holder. Testing throughout the project's timeline is necessary to verify the circular block holder's unique geometry does not jeopardize the integrity of the component.

The unique geometry also introduces a new problem. Since the stepper motor is not retained within the circumference of the circular block holder, the stepper motor will collide with the eyebolt. The electronics team will develop code that will analyze its position relative to the eyebolt and move accordingly such that it does not collide with the eyebolt.

Collection Arm
Since the rover ejection assembly's rods extend the entirety of the payload, the collection arm's size had to be reduced to prevent interference with rods.

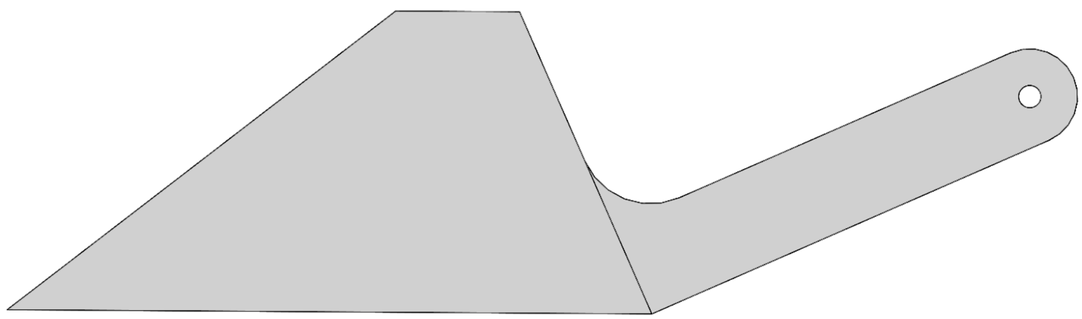


Figure 69: Collection Arm

Treads
To allow a greater amount of tolerance of the payload fitting within the launch vehicle, the treads have a 0.75in width. This leaves a 0.17in clearance from the bottom of the treads to the closest point of the launch vehicle.

The treads will be 3D printed using PLA plastic,however, to increase traction, a rubber cement coating will be applied to the area that is in contact with the terrain.

Threaded Rod and Custom Nut
Since a threaded rod will be used as a form of moving and deploying the rover, a matching sized nut must be made. A ⅜"-12 4in long nut does not commercially exist, so a metal rod with a 0.5in outer diameter and 4in length will be selected and tapped into using the correct thread size. While this can cause complications when manufacturing, it is necessary to have a precisely machined part for interfacing with threads.

5. Safety

5.1. Student Safety Officer

UCLA's Student Launch Safety Officer, Andy Muratalla, has adjusted and enhanced his responsibilities for the duration of the project's timeline. He will work in conjunction with subteam leads, group leads, and team mentors to ensure adequate understanding of safety information and quality communication throughout the project's timeline. In addition, he will oversee the overall safety and launch procedures of the team and will work to fulfill the requirements listed in the SL Handbook (as well Team Derived Requirements delineated in 6.2.2). The team SO is responsible for:

- Keeping track of who has completed training for the team's general lab space and other workspaces on the UCLA campus, to ensure that only qualified and certified members are given tasks involving said workspaces.
- Monitoring all team activities with an emphasis on safety during the design and manufacturing stages, as well as any launches during the construction of the vehicle and any vehicle ground testing, sub-scale launch, and full-scale launch.
- Ensuring all disposable PPE (gloves, respirators, etc.) and First Aid supplies are kept in stock and purchased as necessary.
- Obtaining and holding a full list of Material Safety Data Sheets.
- Reviewing launch vehicle and recovery system design and assembly.
- Subscale launch test analysis and ensuring safe handling.
- Ensuring full compliance with NAR safety code and all law compliances.
- Assisting in the writing and development of team hazard analysis, failure modes, and operational procedures.
- Maintaining contact with and establishing clear communication with all team members.

In addition, the Safety Officer will be responsible for making sure all team members obtain the necessary training for all lab spaces and manufacturing locations. The Safety Officer's focus is to ensure the team works in a low-risk, readily available, and fully stocked environment. Any questions regarding policy and procedures may be consulted with the Safety Officer throughout the duration of the project's timeline. The standing safety officer is also required to train and cultivate a safety assistant during the manufacturing stage.

5.2. Written Safety Statements

In addition, further steps have been taken to strictly comply with all NAR Safety Codes, federal and state laws, and UCLA Machine Shop Safety regulations, as will be seen in the extension to the hazard analysis conducted in section 5.3.

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.

Table 17: NAR Safety Codes and Compliances

Code	Compliance
1. **Certification.** I will only fly high power rockets or possess high power rocket motors that are within the scope of my user certification and required licensing.	Team members are only allowed to handle and launch with appropriate certifications: Level 1 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.

Table 17: NAR Safety Codes and Compliances

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.

Table 17: NAR Safety Codes and Compliances

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 dependant 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.

Table 17: NAR Safety Codes and Compliances

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 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).	The team leads and SO 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 parameters that are to be strictly adhered to regarding safe launching. In addition, a hard copy of 2020 NASA SL Handbookhas 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.

Table 17: NAR Safety Codes and Compliances

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 will 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 potential hazardous conditions that may be encountered.

The culmination of the above statements and regulations yields our team's written safety agreement. ALL team members have received, acknowledges, and signed the agreement listed below. The standing Safety Officer has obtained a signed, physical form each team member and compiled them into a folder held within the primary lab space for the UCLA team, the Student Creativity Center.

UCLA Bearospace Team Safety Agreement

By signing this agreement, I, ________________________________, agree to adhere to the following regulations regarding safe protocols and proper procedures.

I understand that I will be required to complete UCLA Lab Safety and UCLA Machine Shop Safety online training courses. Additional safety training courses may be required of team members, depending on corresponding team involvement and the facilities/equipment needed. If additional training is needed for my involvement, the Safety Officer will provide me with the resources necessary to fulfill this training. I agree to follow the safety procedures outlined by UCLA's Environmental Health and Safety office, UCLA's MAE department, and UCLA Bearospace's team leads and Safety Officer whenever working on UCLA Bearospace projects.

In addition, I agree to read and abide by the regulations and guidelines discussed in the following three documents: (1) Federal Aviation Regulations 14 CFR, Subchapter F, Part 101, Subpart C; (2) Handling and Use of Low Explosives (Ammonium Perchlorate Rocket Motors, APCP), Code of Federal Regulation 27 Part 55: Commerce in Explosives; (3) Fire Prevention, NFPA 1127 "Code for High Powered Motors". I also agree to read, understand, and adhere to the regulations set forth by the NAR High Power Rocket Safety Code.

Lastly, I agree to adhere to the following regulations:

1. Range safety inspections will be conducted on each rocket before it is flown; each team must comply with the determination of the safety inspection or may be removed from the program.

2. The Range Safety Officer has the final say on all rocket safety issues; therefore, the Range Safety Officer has the right to deny the launch of any rocket for safety reasons.

3. The Team Mentor is ultimately responsible for the safe flight and recovery of team's rocket; therefore, a team will not fly a rocket until the mentor has reviewed the design, examined the build, and is satisfied the rocket meets the established amateur rocketry design and safety guidelines.

I have read the above statements and agree to abide by them. I am aware that failure to adhere to any of the information provided above will result in immediate discipline, beginning with the termination of membership on the UCLA Bearospace team. I certify that I have read this agreement in its entirety.

________________________________ ________________

Member Signature Date

Figure 70: Team Agreement

5.3. Hazard Analysis

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 hazardly experience and will be assessed on a leveled pattern based on likelihood and impact

5.3.1. Defining Risk Levels

Likelihood

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

Table 18: 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 19: 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 lifeltime 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 20: 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.

5.3.2 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 21: Personnel Hazard Assessment

Personnel Hazard Risk 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.

Table 21: Personnel Hazard Assessment

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 be worn at all times when working with volatile chemicals & will be handled in well-ventilated rooms, under a fume-hood when possible.	3C	Required consultation of MSDS prior to use; Respirators and relevant PPE when working with chemical fumes.
Chemical contact with eyes	Improper handling of chemicals	Temporary to Moderately sustained blindness; burning sensation	1B	Proper eye protection will be worn at all times when handling chemicals. Always ensure chemicals are kept away from face and ensure proper lab etiquette is always enforced.	3B	Required consultation of MSDS; Eye protection PPE is to be used.
Spilled or contact with epoxy resin and/or hardener	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.

Table 21: Personnel Hazard Assessment

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.

Table 21: Personnel Hazard Assessment

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 contaminati on & equipment overheating; incorrect wiring; explosion	Moderate to Fatal injuries or death; irreparable damage to equipment and lab space	2A	High power circuitry completed with safety officer present; fire extinguishers kept in shop. Always be aware of one's surroundings and be diligent when working in a lab environment	2B	All lab coats are fire resistant. Fire protocol and exit route is included in all lab safety certified courses.

Table 21: Personnel Hazard Assessment

Caught in a machining equipment	Loose clothing; overhanging jewelry; hair draped over face	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 work days.
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.

5.3.3 Environmental Concerns & Hazard Analysis

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

Table 22: 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.

Table 22: Environmental Hazard Assessment

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.
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.

Table 22: Environmental Hazard Assessment

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 well being of the launch day attendees.	3C	Team members and leads would consult the RSO and establish ways to proceed
Excess weatherrocking	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.

Table 22: Environmental Hazard Assessment

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.
Parachute destruction	Excessive wind	Increased vehicle damage due to large horizontal velocity; high drift from pad	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.

5.3.4 Launch Vehicle Hazard Analysis

Table 23: Launch Vehicle Hazard Analysis

Launch Vehicle 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.

Table 23: Launch Vehicle Hazard Analysis

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.
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.

Table 23: Launch Vehicle Hazard Analysis

Launch vehicle does not reach minimum velocity before leaving the launch rail	Miscalculation of rocket's mass. Motor failure	Decrease in stability of the launch vehicle; rocket plummets down; possible explosion	3A	Simulations are conducted virtually and physically, checked against one another for redundancy.	3C	Verify with and consult simulations.
Bulkheads do not sustain intended force	Incorrect calculation of forces that bulkheads can support	Intended support provided by bulkheads will no longer secure internal parts. Possible explosion, payload and recovery system damage, and destruction of vehicle	3B	We will ensure the accuracy of calculations using OpenRocket software and test the strength of materials, physically and virtually, used prior to assembly.	3C	Verify that forces encountered by bulkheads can be supported through future flight tests.
GPS tracking malfunction	General malfunction; battery depletion; erroneous code	Unable to locate the launch vehicle in extreme cases	3B	Ensure all batteries fully charged and checked using the voltmeter. GPS rigorously tested prior to launch.	3C	Consult Operations and Pre-Launch Checklist.

5.5 Launch Concerns and Operation Procedures/Checklist

5.5.1 Hardware & Supplies

The following list of supplies is essential for the vehicle launch day, and it is necessary that all boxes are checked. Each material listed will be included in either a large toolbox, which will be shipped to the launch site, or a large storage container that will be accompanying the team on their travels to the launch site.

Table 24: Pre-Launch Checklist

✓?	Vehicle Assembly
	Both Body tubes & Nose Cone
	Philips Screw Driver
	Nylon Shear Pins
	Washers
	Epoxy Resin and Hardener
	Drill and Drill Bits
	Dremel and Dremel Bits
	Torx Wrench
	Motor Retention Ring
	Motor
✓?	**Electronics**
	9V Batteries (4)
	9V Battery Adapters
	LiPO Batteries (2)
	Jumper Wires
	Breadboard
	Voltmeter
	Telematriks GPS Module
	Arduino Uno
	Antennas (4)
	Receiver (2.4 GHz)

Table 24: Pre-Launch Checklist

	Component Cables
√?	**Recovery System**
	Main and drogue chutes
	Shock Chords
	Quicklinks (6)
	Fire retardant blankets
√?	**General Supplies**
	Latex Gloves
	P100 Respirators (3)
	Threaded Rods
	Lab Coats (2)
	Eye Protective Goggles (2)
	Tape (Masking, Electrical, and Painters)
	Shears
	Tape Measure
	Trash Bags
	Zip Ties
	Box Cutter (2)

5.5.2 Pre-Launch Checklist

In preparation for our team's subscale launch, we have developed a launch and safety checklist for our vehicle, ranging from pre-departure to post-launch assessments that would be utilized for a high powered rocket. We will be utilizing this tentative list as a threshold minimum for inspecting our vehicle post-subscale launch and ensuring our launch is as successful and risk-free as possible. The Safety Officer must approve all checks and the Project Manager/Corresponding Section's Team Lead must sign off at the end of each Checklist subsection to ensure proper verification,

Some steps are delineated with additional red texts following the step needed to be completed in order to continue with the launch. These red statements elaborate the risks pertaining to significant safety hazards that may result from lack of meticulous inspection. If any issue arises while inspecting the vehicle during the Pre-Launch Checklist, stop proceeding down the checklist and consult the student Safety Officer.

Table 25: Pre-Launch Checklist

Pre-Departure	**Completed (✓)?**
Required Personnel: Project Manager	
1. All team members accounted for and roll is taken. Safety agreements on hand.	
2. Pre-Launch Checklist has been successfully check to completion.	
3. Tool box and equipment securely fastened. Additional parachutes, shock cords, eye bolts, and epoxy are loaded up.	
4. Additional batteries and contingency electronics bay in case of recovery system failure is packed.	
5. Voltmeter secured and boxed. Gloves, eye protection, and respirators on hand.	
6. Launch vehicle and payload packaged for travel.	
	______________ **6/6 ✓ - Ready to Depart?**

Table 25: Pre-Launch Checklist

Recovery System	Completed (✓)
Required Personnel: Structures Lead and Electronics Lead	
1. Electronics bay properly inspected by to ensure wires are secured and components will be static. Potential for premature explosion and fire hazard if components are not secure.	
2. New 9V batteries are installed and tested with voltmeter.	
3. Altimeters are preprogrammed at predetermined chute deployment, fully functional. Double check the altitude settings, as errors in this step can cause recovery failure.	
4. Fire clothes are enveloping the chutes and electronics bay. Protecting parachutes from any explosive discharge is imperative to successful recovery system deployment.	
5. Chutes are neatly folded and packed with ample room. If folding is misadjusted & off-procedure, could risk safe vehicle landing.	
6. Both altimeters are connected to both chutes redundancy. Errors in this step can cause recovery failure.	
7. Bulk heads have been tested against desired force/impulse measurements. Destruction of vehicle impending if internal structural failures. ABORT if failure found post-inspection.	
	_____________ 7/7 ✓ - System Ready?

Table 25: Pre-Launch Checklist

Rover Ejection Assembly (Payload)	Completed (✓)
Required Personnel: Electronics Lead	
1. Arduino Uno working and implemented in position. If arduino is damaged, recovery system unable to deploy. ABORT.	
2. BMP 180 (inside) connected, and responses have been confirmed.	
3. Stepper motor and stepper motor driver board properly placed (one inside, one outside) of assembly.	
4. Gyroscope embedded into bulkhead in ejection assembly.	
5. Rover assembly is per design and functional using remote control. If remote control malfunction, the rover will be unable to obtain sample & MISSION FAILURE.	
6. 12” threaded rods is properly attached to 5mm side of coupler, attached to 10mm side of stepper motor using screws. If damage is noted, ABORT. Risks the payload’s integrity and proper deployment.	
7. Components fit perfectly to scale and pose no risk to rover deployment.	
	______________ **7/7 ✓ - Proper Assembly**

Table 25: Pre-Launch Checklist

4. All bulkheads are fully adhered to interior of carbon fiber body tubes. Destruction of vehicle impending if internal structural failures. ABORT if failure found post-inspection.	
5. Fins are completely attached and as defect-free at adhesion point as possible. Visual confirmation necessary.	
6. All exposed wires are tucked away to the interior. Mechanical switch push button properly flushed to side.	
7. Vehicle is balanced, with center of gravity and center of pressure labeled clearly. Necessary to ensure vehicle retains vertical trajectory.	
8. Inspection fulfilled and approval received from Range Safety Officer.	
	______________ **8/8 ✓ - Vehicle Assembly**
Motor & Igniter Installation	**Completed (✓)**
Required Personnel: Rocketry Mentor	
1. Motor stored in separate container throughout launch day, until needed.	
2. Inspect motor for damage that could result in pertinent flight failures. If damage is identified, ABORT launch.	
3. Insert motor into rocket motor tube and tighten retention ring. Proper installation necessary: can result in major environmental and personnel hazards if installed incorrectly.	

Table 25: Pre-Launch Checklist

4. Insert igniter into the rocket motor.	
5. Attach leads from igniter to ignition trigger.	
	__________ **5/5 ✓ - Motor and Ignition Set**
Launch Procedure	**Completed (✓)**
1. Launch control turns power off and all prior launches have landed.	
2. Carry rocket assembly to the launch pad.	
3. Vehicle is placed onto launch rail and oriented *x* degrees off of vertical centerline, based on wind speed (within 20 degrees).	
3. All electronics are turned on using mechanical button switch.	
4. Igniter is inserted at bottom of vehicle, pushed and reaches end of motor, minus 2 inches.	
5. Safety Officer has verified connection to launch control and has given the OK to launch.	
	_____________ **5/5 ✓ - Ready for Launch!**
Post-Launch Inspection	**Completed (✓)**
PPE Required: Close-Toed Shoes & Long Pants	
1. Range Safety Officer has approved retrieval of launch vehicle.	
2. Locate rocket and attempt safely retrieval. Avoid potentially hazardous areas & proceed accordingly.	

Table 25: Pre-Launch Checklist

3. Rover successfully ejected from body tube in upright orientation.	
4. Vehicle body is recovered.	
5. Check parachutes and shock cords for damages	
6. Properly dispose of any live black powder charges. WARNING!Risk to personnel if not done properly.	
7. Record altimeter data.	
	____________ **7/7 ✓ - Success!**

6. Project Plan

6.1. Testing

6.1.1. Vehicle Component Test Plans/Status

The aspects of the launch vehicle of interest during testing are load-bearing structures and interfaces. Generally, interfaces must be tested physically since there is not an accurate way to predict the bond strength of different adhesives between different interfaces. Load-bearing structures were generally tested virtually on SolidWorks to see if a physical test was warranted. During virtual testing, a series of assumptions were made and these will be explained in each section. The list of tests is below ordered by parent component the aspect being tested is a part of. All virtual testing is done with the results presented and physical testing is outlined and planned.

Nosecone:

1. Nosecone Structural Integrity (Virtual)
2. Bulkhead Structural Integrity (Virtual)
3. Nosecone Bulkhead Structural Integrity

Upper Body Tube:

4. Upper Body Tube Structural Integrity (Virtual)
5. Bulkhead Structural Integrity (Virtual)
6. Bulkhead Structural Integrity
7. Locking Mechanism Structural Integrity (Virtual)

8. Locking Mechanism Structural Integrity (Physical)

Lower Body Tube:

9. Centering Ring Structural Integrity (Virtual)
10. Lower Body Tube Structural Integrity (Virtual)

Derivation of Expected Forces

When testing components for the possibility of failure during flight, estimates must be made about these forces might be as well as assumptions to simplify derivations to make them possible. Here will be an explanation of all numerical forces tested as well as assumptions made during their derivation.

There are two major causes of force during flight that must be tested. The first is the force put onto the airframe by the ambient air during acceleration. The second is the force put onto load-bearing recovery hardware upon deployment and descent. For both estimates, all assumptions that were made were intended to increase the estimated force that will be caused so as to create a safety margin before failure or yield.

To estimate the force during flight on the rocket body the following assumptions were made:

1. Air is unyielding and acts as a hard surface.
2. Fin cross-sectional area is small enough to be neglected.
3. The interface of attack is restricted to the nose cone.
4. Force is evenly distributed over the nose cone.
5. Motor remains unburned during flight (to maximize mass).

These assumptions allow for the modeling of the rocket as standing on the ground on its back end with no fins with the nose cone enduring a maximum force felt during launch. This force can be found by taking the mass of the rocket and multiplying that by the maximum acceleration of the launch vehicle, found with OpenRocket.

Maximum Force = (mass of rocket with unburned motor)(maximum acceleration)*

Mass of rocket with unburned motor = (Weight of rocket)/(acceleration due to gravity)

Mass of rocket with unburned motor = (27.635 lbs) / (32.2 ft/s^2) = 0.86 slug

Maximum Force = (0.86 slug)(243 ft/s^2) =* ***208.5 lbf***

Continuing the model, when testing the airframe the value of 208.5 lbf is used on each component as if its bottom edge is fixed to the ground. This allows for the testing of each individual component as if it were to experience this force on its own. In reality , the force is distributed between all three components so the force felt by each one is below this value. So, it will be assumed that all force felt by the nose cone is completely transferred to the upper body tube, and all the force felt by the upper body tube will be completely transferred to the lower body tube.

The second major cause of failure is through the force that recovery hardware deployment put on the load-bearing hardware. The following assumptions were made for this calculation:

1. Parachute immediately catches wind upon deployment (enforced by OpenRocket).
2. Shock Cords are inelastic.
3. Complete recovery forces are felt by only one component at a time.
4. No force is dissipated through materials or interfaces.
5. Motor remains unburned upon descent (to maximize possible mass).
6. Main parachute recovery hardware is unaffected by drogue parachute deployment (still contained within vehicle body).
7. Drogue parachute recovery hardware is unaffected by main parachute deployment.

Acceleration of the launch vehicle upon recovery hardware deployment can be found using OpenRocket. In reality, parachutes will not immediately catch wind with deployment and this will be a gradual process. By making this assumption, a much higher impulse is made, creating a safety margin. Shock cords being inelastic transfers all of the force of parachute directly to the bulkhead, making the force much higher than reality. It is also expected that the force of deployment will be spread equally between both components to which the shock cord is connected to. Realistically, there will be some inequality based on the exact timing and weight of each component. By enforcing the maximum weight on each component, another margin of safety is created. By ignoring force dissipation, component and component interfacing materials can both be tested for failure points. Each deployment not affecting the other was made due to the expectation that elastic shock cords will realistically absorb a lot of the force and opposite bulkheads will not experience a force great enough to need testing.

For load-bearing hardware, an eyebolt will be imposing some shear stress on the component while the component edges are fixed to a parent component. Derivations of the force from each parachute deployment are below.

Main parachute deployment at 500 ft agl:

MaximumForce = (mass of rocket with unburned motor)(acceleration upon main parachute deployment)*

Maximum Force = (0.86 slug)(1450 ft/2^2) =* ***1247 lbf***

Drogue parachute deployment at apogee:

MaximumForce = (mass of rocket with unburned motor)(acceleration upon drogue parachute deployment)*

Maximum Force = (0.86 slug)(32ft/2^2)=* ***27.52 lbf***

Since the assumptions presented above already introduced a considerable safety margin, the introduction of an extra known factor of safety will be component-based. They will be listed in the introduction of the test.

It should also be noticed that yield strength of a material is most often the value used to quantify the failure of a component. In reality, the yield strength describes when plastic deformation is occuring, not necessarily the complete failure or break of a component. In the interest of sustainability of the launch vehicle which may be flown multiple times, yield strength was used as the failure criteria for virtual tests. In physical tests yielding is much harder to detect, especially if it is done in a very small scale. Physical testing success criteria will be individually presented.

Virtual Testing 1

Table 26: Nose Cone Structural Integrity (Virtual)

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: 208.5 lbf ● Maximum shear force due to deployment of recovery hardware: 1247 lbf
Constants:	● Nose Cone geometry: Reference section 3.1.4. Launch Vehicle Components ● 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 208.5 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 1247 in a singular direction along the inside face of the nose cone, as the bulkhead would create. 6. Evaluate results.
Relevant Safety Concerns:	None.

Table 26: Nose Cone Structural Integrity (Virtual)

Status/Results:	Completed (See Figures Below)
Rationale: From a structural viewpoint, the nosecone can only experience failure due to shear stress or normal stress. When examining the types of forces the nose cone will experience during flight, normal stress will be placed onto it during ascent due to air, while shear stress will be placed on it during recovery hardware deployment and impulsive force on the nose cone bulkhead. Running virtual tests reveals how likely it is for the nose cone to fail due to each of these mechanisms.	

Status/Results: (if completed):

Normal Stress:

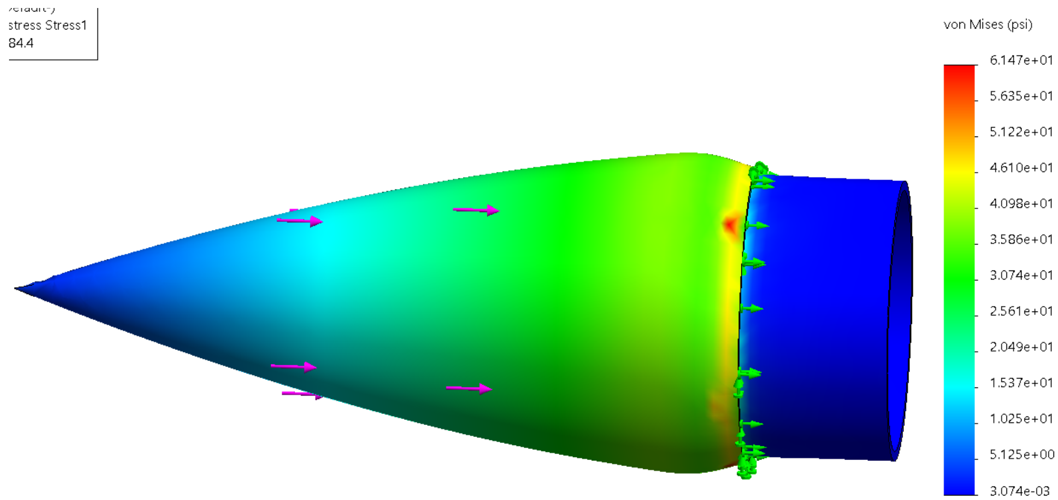


Figure 71: Nose Cone Normal Stress Test Results

Maximum stress felt by the nose cone is shown in red on the figure as 61.47 psi. This is well under the yield stress (10800 psi). This test is passed with no further testing warranted.

Shear Stress:

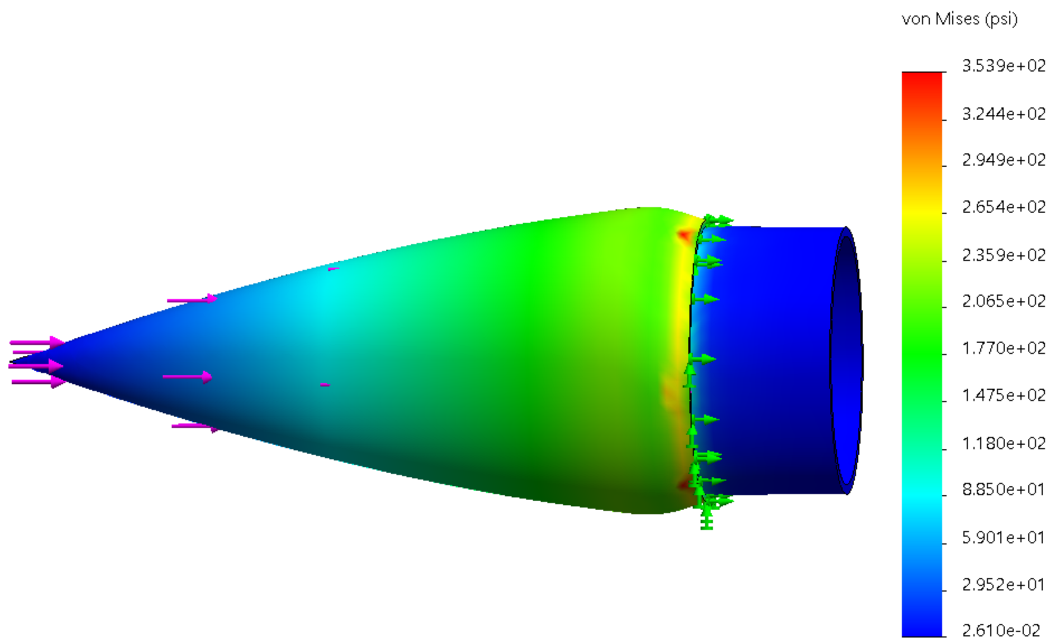


Figure 72: Nose Cone Shear Stress Test Results:

Maximum stress felt by the nose cone is shown in red on the figure as 353 psi. This is well above the yield strength of the material (10800 psi). No further component testing is warranted, but due to the nature of shear stress, the interface of stress transfer must be tested.

Virtual Testing 2

Table 27: Bulkhead Structural Integrity (Virtual)

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	1247 lbf of shear force

Table 27: Bulkhead Structural Integrity (Virtual)

Constants:	● Bulkhead geometry: reference section 3.1.4. Launch Vehicle Components ● 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 1247 lbs on the hole that will be containing eyebolt. 3. Evaluate Results.
Relevant Safety Concerns:	None.
Status/Results:	Completed (See Figures Below)
Rationale: The bulkheads are the first interface on which recovery hardware are exploiting a load during deployment. By examining its behavior under launch conditions virtually, one can determine how likely it is that the part may fail.	

Status/Results: (if completed):

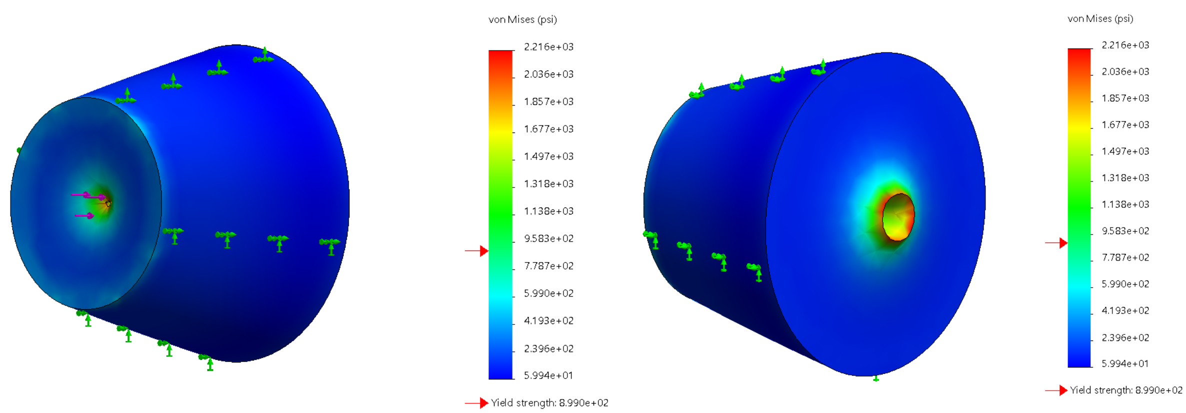


Figure 73: Nose Cone Bulkhead Shear Stress Test Results

The maximum stress felt by the bulkhead is 2216 psi while the yield strength of the object is only 899 psi. The yield stress doesn't assume failure but does mean plastic deformation. This test is failed and requires physical testing.

Since the structural integrity of wood varies greatly between samples, physical testing will have to be performed on bulkheads manufactured with the team's methods to ensure the component doesn't fail.

Physical Testing 1

Table 28: Nosecone Bulkhead Structural Integrity

Nosecone Bulkhead Structural Integrity	
Objective:	Ensure the interface between the nose cone and the nosecone bulkhead is rigid enough to withstand forces experienced during launch.
Success Criteria:	The adhesive interface between the nose cone and nose cone bulkhead can withstand an impulsive force double that of the load the flight is predicted to produce with no visible damage.
Variables:	Impulsive force magnitude: 1247 lbf
Constants:	● Nose Cone geometry: discussed in vehicle section ● Bulkhead geometry ● Adhesive material: Epoxy ● Testing hardware:
Step-by-Step Execution:	1. Gain access to a load frame on campus to test a nose cone and bulkhead assembly.
Relevant Safety Concerns:	● Flying debris - participants present must wear safety goggles (very low risk) ● Freefalling nosecone in event of rope failure - participants will ensure a landing zone 20 ft in diameter will be clear of people (low risk)
Status/Results:	Planned.

Table 28: Nosecone Bulkhead Structural Integrity

Rationale: The real strength of an adhesive (epoxy) interface between the PLA nose cone and pine bulkhead can only be found experimentally since it depends on several uncontrollable factors such as distribution of epoxy. Since epoxy normally fails non-plastically, it is very hard to predict the failure point from displacement of the interface or crack appearance. Because of this, strength cannot be determined from any plastic deformation testing. If interface can sustain the expected launch time force, it can be determined that the interface is structurally sound. The nose cone and bulkhead used on the launch vehicle will not be the same structure tested due to unknown point of fatigue failure. This test will also determine if the bulkhead itself will fail as predicted in the previous test. If this component fails, different materials or lengths may be considered.

Virtual Testing 3

Table 29: Upper Body Tube Structural Integrity (Virtual)

Upper Body Tube Structural Integrity (Virtual)	
Objective:	Ensure the upper body tube can withstand forces felt during all stages of flight.
Success Criteria:	Stress placed on the upper body tube due to the forced experienced during launch do not exceed 1/3rd the approximated yield stress of the material.
Variables:	Stress: 208.5 lbf This value is assuming that all normal stress that the nose cone experiences is directly transferred to the upper body tube
Constants:	Body tube material (carbon fiber) ○ Approximate material properties: ■ Elastic Modulus: 20 Mpsi ■ Poisson's Ratio: 0.2 ■ Mass Density: 0.07225 lb/in3 ■ Yield Strength: 13500 psi Body tube geometry
Step-by-Step Execution:	1. Fix bottom face of the body tube. 2. Place a force acting on the top face of the body tube that will inflict normal stress through the tube. 3. Evaluate results

Table 29: Upper Body Tube Structural Integrity (Virtual)

Relevant Safety Concerns:	None.
Status/Results:	Completed.
Rationale: Upper body tube theoretically only experiences normal stresses whose magnitude comes close to the failure stress of carbon fiber. Because of this, only one case has to be tested, where the force that the nose cone must sustain is being transferred to the body tube. By showing that the object is not predicted to fail, the need to test it physically is not necessary.	

Status/Results: (if completed):

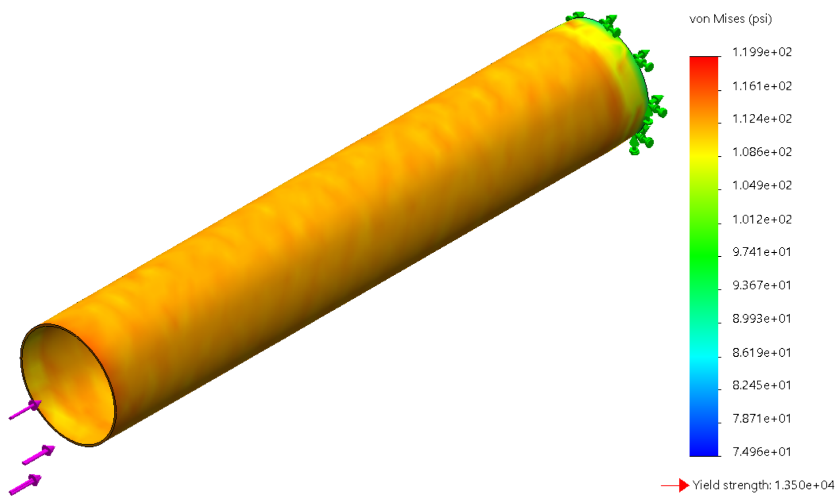


Figure 74: Upper Body Tube Normal Stress Test Results

The maximum stress felt by the structure is 120 psi as seen in the image which is well below the yield strength is 13500. Test is passed.

Virtual Testing 4

Table 30: Bulkhead Structural Integrity (Virtual)

Bulkhead Structural Integrity (Virtual)	
Objective:	Ensure that forces experienced during launch do not exceed the simulated yield strength.
Success Criteria:	Maximum stress felt by the bulkhead during launch does not surpass the expected yield strength.

Table 30: Bulkhead Structural Integrity (Virtual)

Variables:	Force: 1247 lbf (the same force as felt on the other bulkhead)
Constants:	• Bulkhead geometry: reference section 3.1.4. Launch Vehicle Components • Bulkhead material: pine ○ 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 1247 on the hole that will be containing eyebolt. 3. Evaluate Results.
Relevant Safety Concerns:	None.
Status/Results:	Completed.
Rationale: The bulkheads are the first interface on which recovery hardware are exploiting a load during deployment. By examining its behavior under launch conditions virtually, one can determine how likely it is that the part may fail.	

Status/Results: (if completed):

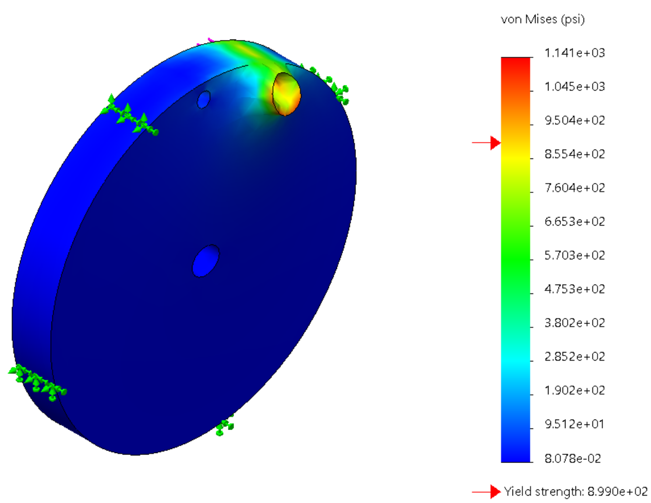


Figure 75: Bulkhead Shear Stress Test Results

The maximum stress felt by the object is 1141 psi while the yield strength is 899 psi. While the yield strength does not imply failure, it still implies plastic deformation. Test fails, physical testing necessary.

It should be noted that the predicted stress that the object will feel is extremely high. This is of course unrealistic since this test was done assuming rigid recovery hardware which isn't true. Physical testing will give the team a better representation of the structural integrity of the component.

Physical Testing 2

Table 31: Bulkhead Structural Integrity

Bulkhead Structural Integrity	
Objective:	Ensure the interface between the upper body tube and the bulkhead is rigid enough to withstand forces experienced during launch.
Success Criteria:	The adhesive interface between the upper body tube and bulkhead can withstand a force the flight is predicted to produce with no visible damage.
Variables:	Force: 1247 lbf (the same force as felt on the other bulkhead)
Constants:	● Body tube geometry: discussed in vehicle section ● Bulkhead geometry ● Adhesive material: Epoxy ● Testing hardware: Load frame
Step-by-Step Execution:	1. Gain access to a load frame on campus to test component.
Relevant Safety Concerns:	● Flying debris - participants present must wear safety goggles (very low risk) ● Freefalling structure in event of rope failure - participants will ensure a landing zone 20 ft in diameter will be clear of people (low risk)
Status/Results:	Planned.

Table 31: Bulkhead Structural Integrity

Rationale: The real strength of an adhesive (epoxy) interface between the carbon fiber body tube and pine bulkhead can only be found experimentally since it depends on several uncontrollable factors such as distribution of epoxy. Since epoxy normally fails non-plastically, it is very hard to predict the failure point from displacement of the interface or crack appearance. Because of this, strength cannot be determined from any plastic deformation testing. If interface can sustain a force that is double the expected launch time force, it can be determined that the interface is structurally sound. The body tube and bulkhead used on the launch vehicle will not be the same structure tested due to unknown point of fatigue failure. This test will also test the previously failed bulkhead to see if it fails. If it does, different materials or lengths will be considered.

Virtual Testing 5

Table 32: Locking Mechanism Structural Integrity (Virtual)

Locking Mechanism Structural Integrity (Virtual)	
Objective:	Ensure that locking mechanism tabs will not break during launch to do launch forces and the weight of the electronics bay.
Success Criteria:	The tabs and tab interfaces can hold at least double the expected force that they will experience in flight.
Variables:	Force: Maximum force due to deployment of recovery hardware: 27.8 lbf
Constants:	● Geometric relation ● Locking mechanism material: pine ○ Elastic Modulus: 1460000 psi ○ Poisson's Ratio: 0.35 ○ Mass Density: 0.0156 lb/in^3 ○ Yield Strength (shear): 899 psi

Table 32: Locking Mechanism Structural Integrity (Virtual)

Step-by-Step Execution:	Tabbed component: 1. Fix outer edge of mechanism. 2. Impose force on center of mechanism where eyebolt will be. 3. Inspect results. Bottom Component: 1. Fix outer edge of mechanism. 2. Impose force on where the tabs will place a load onto the bottom component. 3. Inspect results.
Relevant Safety Concerns:	None.
Status/Results:	Completed.
Rationale: The locking mechanism will be experiencing an impulsive force upon deployment of recovery hardware (drogue parachute). It must be ensured that it will not fail or that may result in freefalling objects during flight.	

Status/Results: (if completed):
Tabbed Component:

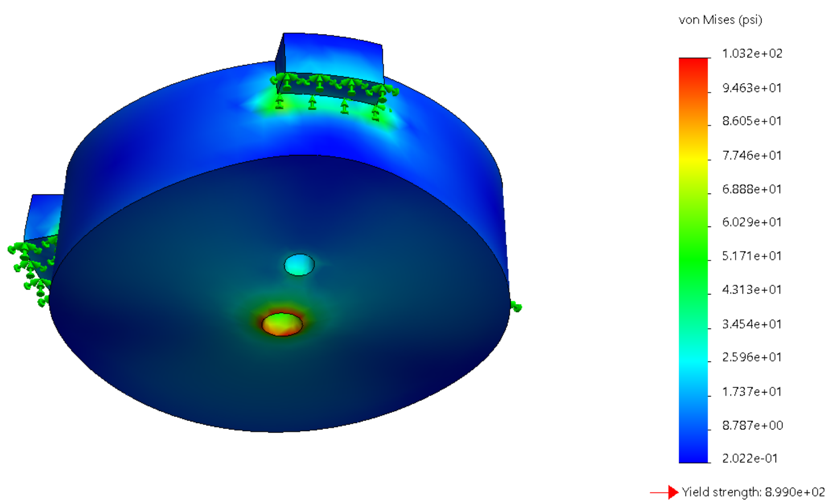


Figure 76: Locking Mechanism Stress Results - Upper Component

The maximum stress of 103 psi is under the yield strength of 899 psi. The virtual testing is implying that this component will not fail during flight. This component is still very much of interest and will be tested physically with some safety factor to prove this.

Bottom Component:

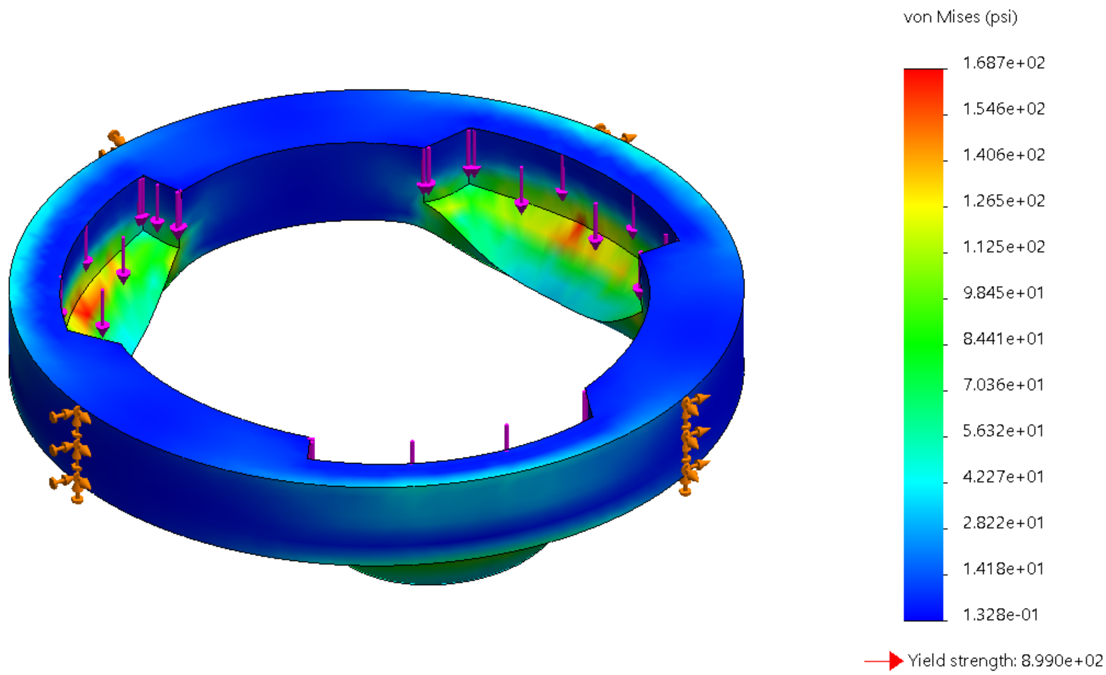


Figure 77: Locking Mechanism Stress Results - Lower Component

The maximum stress felt by this component is 169 psi while the yield strength is 899 psi. The component passes virtual testing.

Physical Testing 3

Table 33: Locking Mechanism Structural Integrity (Physical)

Locking Mechanism Structural Integrity (Physical)	
Objective:	Ensure that locking mechanism tabs will not break during launch to do launch forces and the weight of the electronics bay.
Success Criteria:	The tabs can hold at least double the expected force that they will experience in flight.
Variables:	Force: 56 lbs.
Constants:	Geometric Relation.

Table 33: Locking Mechanism Structural Integrity (Physical)

Step-by-Step Execution:	1. Locking mechanism will be fabricated with a 4 inch diameter and placed into an identical body tube 4in in diameter. 2. Epoxy in an eyebolt as in the full scale version. 3. Tie rope with low coefficient of elasticity around the eyebolt and tie the end to a heavy object that will enforce the needed impulse force by freefalling for about 1 ft. 4. Place mechanism between two tables a few feet off the ground. 5. Drop heavy object at predetermined height so it will create impulse on mechanism. 6. Repeat 3 times 7. Inspect locking mechanism.
Relevant Safety Concerns:	● Rope failure resulting in freefalling object - participants will wear protective eyewear (medium risk). See Section 5.3.2 ● Locking mechanism tabs fail resulting in free falling object and debris - Participants will wear protective eyewear (medium risk). Environmental concerns due to vast scattering of unnatural sources.See Sections 5.3.2 and 5.3.3
Status/Results:	Planned.
Rationale: The same force as expected in the full scale launch will be tested during this experiment. The worry is that the tabs of the mechanism will fail. By testing a smaller scale and therefore smaller tabs, a factor of safety of 1.5 (due to the 4:6 ratio). Since the mechanism is fabricated from pine wood, there is no way to accurately test yielding in the material since it normally deforms due to splintering. By conducting the test 3 times and then inspecting it, we are increasing the chances of failure. Since wood very clearly cracks or splinters, it should be easy to detect any failures after the experiment.	

Virtual Testing 6

Centering Ring Structural Integrity (Virtual)

Table 34: Centering Ring Structural Integrity (Virtual)

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: 28.7 lbf of shear force

Constants:	• Centering RIng geometry: reference section 3.1.4. Launch Vehicle Components
	• 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 28.7 lbf on the hole that will be containing eyebolt. 3. Evaluate Results.
Relevant Safety Concerns:	None.
Status/Results:	Completed.
Rationale: The centering ring is the first interface on which the drogue parachute deployment are exploiting a load during deployment. By examining its behavior under launch conditions virtually, one can determine how likely it is that the part may fail.	

Status/Results: (if completed):

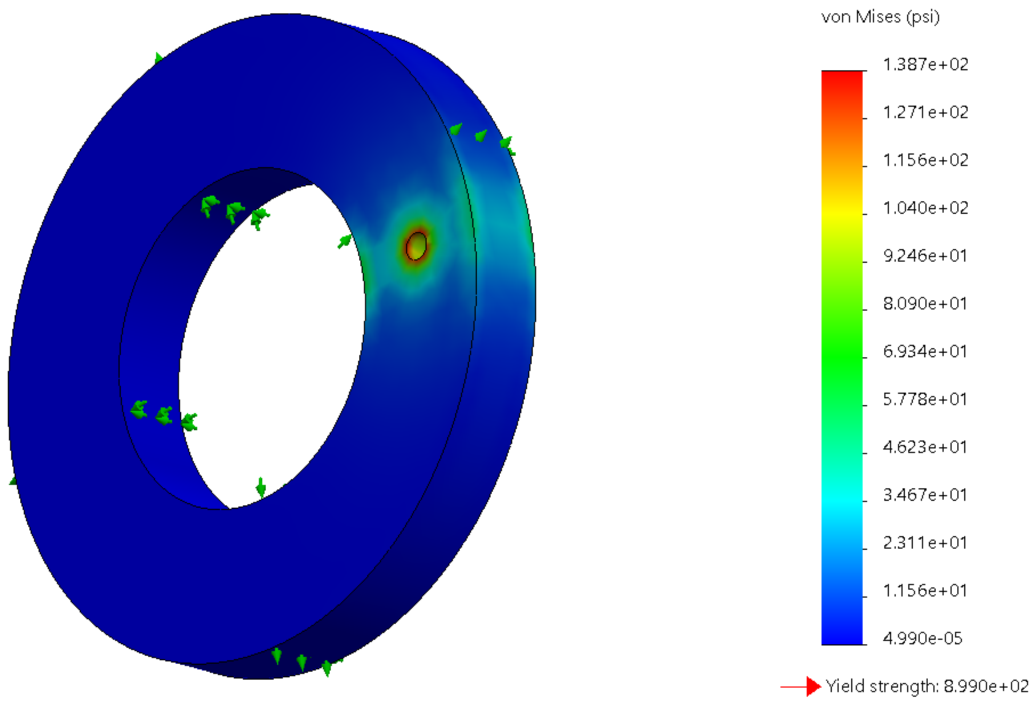


Figure 78: Centering Ring Shear Stress Test Results

The maximum stress felt by the bulkhead is 139 psi while the yield strength of the object is 899 psi. The predicted stress is well below the yield stress. Physical testing is not warranted.

Virtual Testing 7

Table 35: Lower Body Tube Structural Integrity (Virtual)

Lower Body Tube Structural Integrity (Virtual)	
Objective:	Ensure the lower body tube can withstand forces felt during all stages of flight.
Success Criteria:	Stress placed on the lower body tube due to the forced experienced during launch do not exceed 1/3 of the approximated yield stress of the material.
Variables:	Stresses: 208.5 lbf This value is assuming that all normal stress that the upper body tube experiences is directly transferred to the lower body tube.

Table 35: Lower Body Tube Structural Integrity (Virtual)

Constants:	• Body tube material (carbon fiber)
	  ○ Approximate material properties:
	    ■ Elastic Modulus: 20 Mpsi
	    ■ Poisson's Ratio: 0.2
	    ■ Mass Density: 0.07225 lb/in3
	    ■ Yield Strength: 13500 psi
	• Body tube geometry

Step-by-Step Execution:	1. Fix bottom face of the body tube. 2. Place a force acting on the top face of the body tube that will inflict normal stress through the tube. 3. Evaluate results,
Relevant Safety Concerns:	None.
Status/Results:	Completed.
Rationale: The lower body tube theoretically only experiences normal stresses whose magnitude comes close to the failure stress of carbon fiber. Because of this, only one case has to be tested, where the force that the nose cone and upper body tube must sustain is being transferred to the body tube. By showing that the object is not predicted to fail, the need to test it physically is not necessary.	

Status/Results: (if completed):

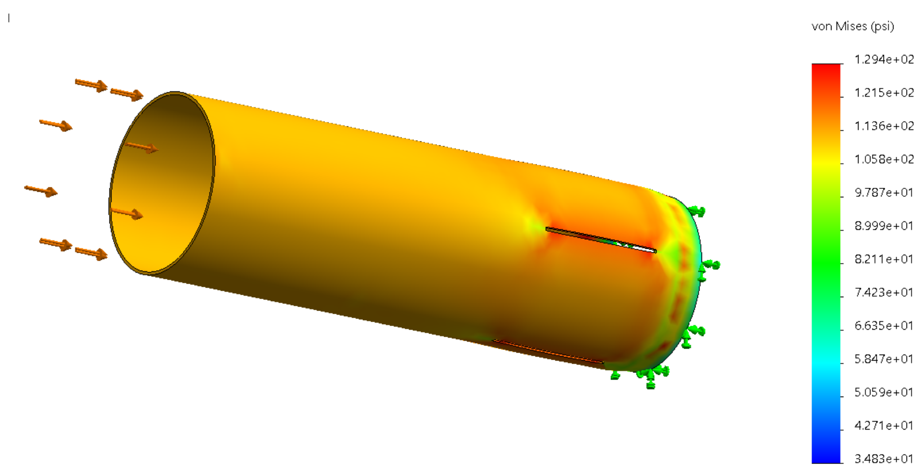


Figure 79: Lower Body Tube Normal Stress Test Results

The maximum stress felt by the structure is 130 psi as seen in the image while the yield strength is 13500 psi. This is less than ⅓ the expected force felt during flight. Test is passed.

6.1.2. Payload Test Plans/Status

Up to this point, the payload team has focused their efforts on identifying possible failure points of the rover and REA and devising a numeric testing strategy to ensure proper functionality. A mixture of virtual and physical testing is planned, and a rationale for each type of test will be provided. Listed below are the planned payload tests.

Rover:

1. Arm Rigidity Against Obstacles
2. Arm Rigidity Against Rover Body
3. Tread Traction
4. Sample Retention Post-Collection
5. Wheel Integrity
6. Body Integrity
7. REA Interface Integrity

REA:

1. Rod Deflection (Virtual)
2. Rod Deflection (Physical)
3. Threading Integrity

Physical Testing 4

Table 36: Arm Rigidity Against Obstacles

Arm Rigidity Against Obstacles	
Objective:	To ensure that the collection arm will not fail due to any unseen hazards on the collection floor.
Success Criteria:	Collection arm will have no visible cracks or deformations after contact with hard surfaces.

Variables:	• Hardness of ground surface
	  ○ Concrete
	  ○ Blacktop
	  ○ Rock

Constants:	• Force at which arm hits the surface:
	  ○ Arm will be deployed at maximum speed to hit the surface.
	• Geometry of the arm
	• Material of the arm:
	  ○ ABS Plastic

Table 36: Arm Rigidity Against Obstacles

Step-by-Step Execution:	1. Place rover on even terrain of specified material found in “variables”. 2. Put arm in the fully collapsed position, against the upper side of the rover. 3. Jolt and hold controls to deploy arm, causing it to slam onto the surface of the terrain. 4. Repeat this 10 times. 5. Inspect arm.
Relevant Safety Concerns:	● Possible debris flying - all participants must wear safety goggles (low risk) ● Arm may break off - all participants must wear safety goggles (low risk)
Status/Results:	Planned.
Rationale: When collecting samples, there may be some debris that the rover arm encounters that is hard and may damage the collection arm. By examining the effect different materials have on the collection arm structural integrity, the team can predict if the arm may fail due to debris on the collection site. During actual collection, the arm will not be slammed on the ground, however, human error may cause this to happen. If this does not occur, the team is putting a factor of safety on the collection arm strength by testing a larger force than will actually be felt.	

Physical Testing 5

Table 37: Arm Rigidity Against Rover Body

Arm Rigidity Against Rover Body	
Objective:	To ensure that the collection arm will not fail due to hitting the body of the rover when depositing sample.
Success Criteria:	Collection arm will have no visible cracks or deformations after contact with rover body
Variables:	● Hardness of contact surface ○ Rover body (PLA plastic)

Table 37: Arm Rigidity Against Rover Body

Constants:	● Force at which arm hits the rover: ○ Arm will be retracted at maximum speed to hit the surface. ● Geometry of the arm ● Material of the arm: ○ ABS Plastic
Step-by-Step Execution:	1. Place rover on eaven terrain of specified material found in “variables”. 2. Put arm in the fully collapsed position, against the upper side of the rover. 3. Jolt and hold controls to deploy arm, causing it to slam onto the surface of the terrain. 4. Repeat this 10 times. 5. Inspect arm.
Relevant Safety Concerns:	● Possible debris flying - all participants must wear safety goggles (low risk) ● Arm may break off - all participants must wear safety goggles (low risk)
Status/Results:	Planned.
Rationale: When depositing sample into the collection bin, there is a chance that the arm will be accidentally “slammed” into the rover body, possibly causing damage to the arm as well as the rover. By testing the damage that could be done, unanticipated damage during collection is very likely. Also, the team member controlling the collection arm will be instructed to avoid making forceful contact with the rover during sample deposit.	

Physical Testing 6

Table 38: Tread Traction

Tread Traction	
Objective:	To ensure an appropriate speed of the rover on various terrains.
Success Criteria:	Rover traverses about 80% of a set distance with a constant time and set movement in one direction.

Table 38: Tread Traction

Variables:	Terrain type: ○ Rough gravel ○ Grass ○ Soil ○ Sand ○ Cement (level) ○ Cement (20°-30° upwards slope) ○ Cement (20°-30° downwards slope)
Constants:	Time.
Step-by-Step Execution:	1. Place the rover at a constant placement on a set terrain and 2. Drive rover forward (no load) at full speed for 15 seconds with final distance mark at 140 ft 3. Mark the distance traveled and should be between 105ft or 140 ft
Relevant Safety Concerns:	● Observers will wear safety glasses when around the experiment (in case of brittle failure and flying debris - extremely unlikely)
Status/Results:	Planned.
Rationale: One major concern that the payloads team has is the traction on the treads may not be great enough to traverse some softer or smoother terrains. To test the traction efficiency, the team will ensure that the rover is able to traverse a set amount in a set amount of time on several different types of terrain. If the distance traveled on a certain type of terrain is much smaller than needed, a feature to increase the tread's friction coefficient or area will have to be devised or that type of terrain may have to be avoided during the mission, but this is not always possible.	

Physical Testing 7

Table 39: Sample Retention Post-Collection

Sample Retention Post-Collection	
Objective:	To ensure at least the minimum sample size is retained post-collection for the minimum distance that the rover must travel away from the collection zone.

Table 39: Sample Retention Post-Collection

Success Criteria:	Rover retains at least 80% of sample over 20 feet
Variables:	Terrain type: ○ Rough gravel ○ Grass ○ Soil ○ Sand ○ Cement (level) ○ Cement (20°-30° upwards slope) ○ Cement (20°-30° downwards slope)
Constants:	• Original sample volume: 20mL • Collection arm position: flat against rover body • Measured traveling distance: 20 ft
Step-by-Step Execution:	1. Place 20 mL of simulated sample in collection bin of rover. 2. Set rover's collection arm to completely retracted, therefore fully covering the collection bin. 3. Place rover onto terrain being tested (listed above) ensuring no sample is lost in the process. 4. Drive rover forward at full speed for 20ft. 5. Collect any sample retained in the collection bin and measure the volume. **To be successful at least 16 mL must be retained.** 6. Repeat for each type of terrain, three times per each terrain.
Relevant Safety Concerns:	All observers will stand at least 5 ft away from the rover in case of flying debris (very unlikely).
Status/Results:	Planned.

Table 39: Sample Retention Post-Collection

Rationale: Once the sample is collected, it must be ensured that at least the minimum 10 mL sample can be transported at least 10 ft from the collection zone. The rover collection bin can hold 28.6 mL of sample while remaining flush with the rover body and a maximum of over 40 mL by overflowing and filling the collection arm (this number is physically very improbable to obtain so a realistic amount that can be collected would be between these two numbers). For the test, 20 mL was chosen since it was below the maximum amount the bin could carry alone and above the minimum sample size. Also if it is proven that at least 80% of a 20 mL sample can be retained under all of these conditions, a 1.8 factor of safety is put onto collection retention, making it very probable that the sample will be successfully retained during the mission. These terrains were chosen because they best resemble the terrain possibilities of the retrieval area. Only cement was chosen to be tested with a gradient because only one mode of sample loss wanted to be tested at a time. By testing different terrain and then sloped terrain, our team can identify if terrain or slope drives sample loss.

Physical Testing 8

Table 40: Wheel Integrity

Wheel Integrity	
Objective:	To ensure wheels are rigid enough to support the full weight of the rover.
Success Criteria:	Wheels do not plastically deform under various weights over the course of 24 hours.
Variables:	Weight being supported by the wheels: ○ Weight of rover ○ Weight of rover x 1.5 ○ Weight of rover x 2.0 ○ Weight of rover x 3.0
Constants:	Weight distribution between wheels: equal since this will be conducted on flat surface Time left under force: 24 hrs

Table 40: Wheel Integrity

Step-by-Step Execution:	1. Fully assemble rover and record the weight. 2. Use caliber to measure the diameter of the wheels to the nearest hundredth of an inch. 3. Place weights onto the rover to create the desired weight being supported by the wheels. 4. Place rover on flat, stable surface. 5. Ensure all wheels are touching the surface. 6. Leave untampered for 24 hours. 7. Use caliber to measure the diameter of the wheels to the nearest hundredth of an inch. 8. If the difference between the two diameters is less than one tenth of an inch, it is deemed that no plastic deformation has occurred and test is successful. Repeat for each weight.
Relevant Safety Concerns:	Observers will wear safety glasses when around the experiment (in case of brittle failure and flying debris - extremely unlikely)
Status/Results:	Planned.
Rationale: The entire weight of the rover must be supported by the wheels alone for a long period of time. If plastic deformation occurs over the course of the experiment, it is clear that creep is occuring and wheels must be replaced frequently since this could imply crack growth and imminent failure. If there is no plastic deformation, the wheels could stay on the rover for long periods of time without needing to be replaced.	

Physical Testing 9

Table 41: Body Integrity

Body Integrity	
Objective:	To ensure body is rigid enough to support the full weight of the rover.
Success Criteria:	Rover body do not plastically deform under various weights over the course of 24 hours.

Table 41: Body Integrity

Variables:	Weight being supported by the rover body: ○ Weight of rover ○ Weight of rover x 1.5 ○ Weight of rover x 2.0 ○ Weight of rover x 3.0
Constants:	Time left under force: 24 hrs
Step-by-Step Execution:	1. Fully assemble rover and record the weight. 2. Use caliber to measure the dimensions of the rover in the specified locations to the nearest hundredth of an inch. 3. Place weights onto the rover to create the desired weight being supported by the wheels. 4. Place rover on flat, stable surface. 5. Ensure all wheels are touching the surface. 6. Leave untampered for 24 hours. 7. Use caliber to measure the specified dimensions of the rover to the nearest hundredth of an inch. 8. If the difference between the two diameters is less than one tenth of an inch, it is deemed that no plastic deformation has occurred and test is successful. Repeat for each weight.
Relevant Safety Concerns:	Observers will wear safety glasses when around the experiment (in case of brittle failure and flying debris - extremely unlikely)
Status/Results:	Planned.
Rationale: If the rover body were to fail under the weight of electronics or other components it carries, this would not allow it to complete its mission. If plastic deformation occurs over the course of the experiment, it is clear that creep is occuring and rover body must be replaced frequently since this could imply crack growth and imminent failure. If there is no plastic deformation, the rover body could stay on the rover for long periods of time without needing to be replaced.	

Physical Testing 10

Table 42: REA Interface Integrity

REA Interface Integrity	
Objective:	Ensure that the rover can “hang” from the REA for sufficient periods of time with no sign of failure.
Success Criteria:	Female mates to the REA on the rover do not plastically deform over some period of time due to the weight of the rover.
Variables:	Effective weight of the rover: ○ Weight of rover ○ Weight of rover x 1.5 ○ Weight of rover x 2.0 ○ Weight of rover x 3.0
Constants:	Time that the rover mate will have to support this weight: 24 hrs
Step-by-Step Execution:	1. Weigh the completely assembled rover. 2. Measure the diameter of the female mate on the rover to the nearest hundredth of an inch. 3. Attach the rover to the rover ejection assembly as if it were preparing for launch. 4. Attach extra weight to rover (if applicable) in a manner that doesn’t contact the interface being tested or any supporting element such as the ground. 5. Leave untampered for 24 hours. 6. Remove rover from the REA. 7. Measure the diameter of the female mate on the rover to the nearest hundredth of an inch. 8. If there is less than one tenth of an inch discrepancy from the original value, it is decided that no plastic deformation occurred and the test was successful. 9. Repleat for all weights.
Relevant Safety Concerns:	Observers will wear safety glasses when around the experiment (in case of brittle failure and flying debris - extremely unlikely)
Status/Results:	Planned.

Table 42: REA Interface Integrity

Rationale: If no plastic deformation occurs within this time frame for increased weights on the rover, it can be concluded that the rover/REA interface can support the rover for long periods of time. This way the rover can remain “packed” for long periods of time without any components needing replacement.

Virtual Testing 8

Table 43: Rod Deflection (Virtual)

Rod Deflection (Virtual)	
Objective:	Verify the REA rod will not fail or deflect to the point of rover ejection failure due to the weight of the rover at any point in the ejection process.
Success Criteria:	The REA rods to not experience a deflection so large that the edge is displaced more than .25 inches.
Variables:	Rover weight: 2.33 lbs
Constants:	Position of the rover along the REA rods: varying throughout experiment, causing differing deflection.
Step-by-Step Execution:	1. Fix the end of the rod that is attached to the REA bulkhead. 2. Induce a force mimicking the weight of the rover at the end of the rod (this should cause maximum deflection) 3. Examine results and repeat for each rod individually.
Relevant Safety Concerns:	None.
Status/Results:	Completed.
Rationale: In testing an important aspect such as this, a range of failure points is preferrable, so it can be ensured that a factor of safety is chosen that will not allow the possibility of failure. By conducting this test virtually, the team can examine whether rod failure is probable. Also by imposing the entire weight of the rover on each beam individually, a safety factor of 2.0 is already induced since in reality, the weight is distributed between the two rods equally.	

Status/Results: (if completed)

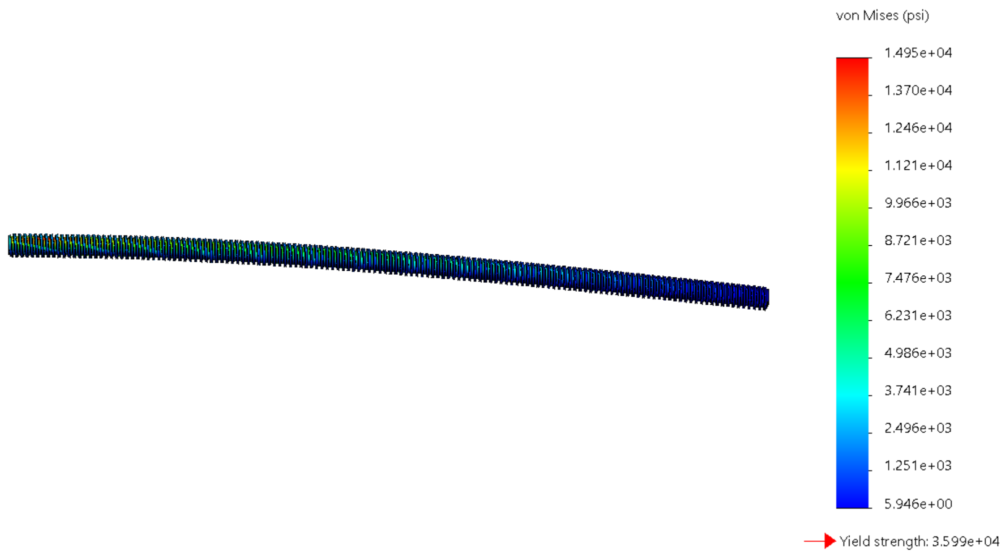


Figure 80: Threaded Rod Stress Results

The maximum stress felt by this feature is 14950 psi while the yield strength is 40000. The threaded feature is not to yield, physical tested is not needed but will be conducted. Test is passed.

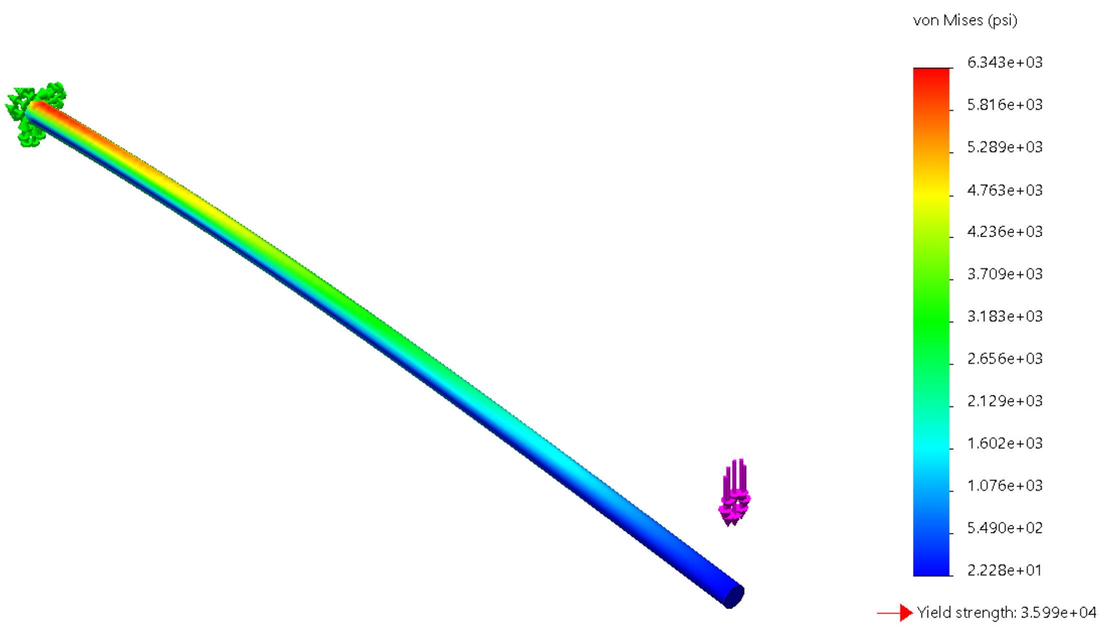


Figure 81: Unthreaded Rod Stress Results

The maximum stress felt by this feature is 6343 psi while the yield strength is 40000 psi. The feature is not predicted to yield so this test is passed for this component.

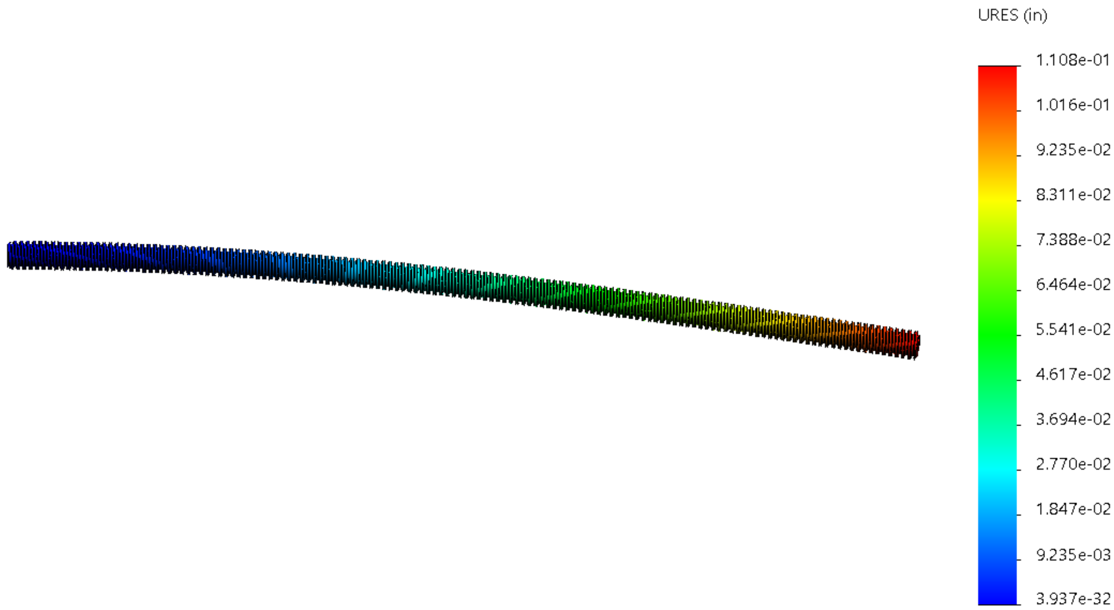


Figure 82: Threaded Rod Deflection Test Results

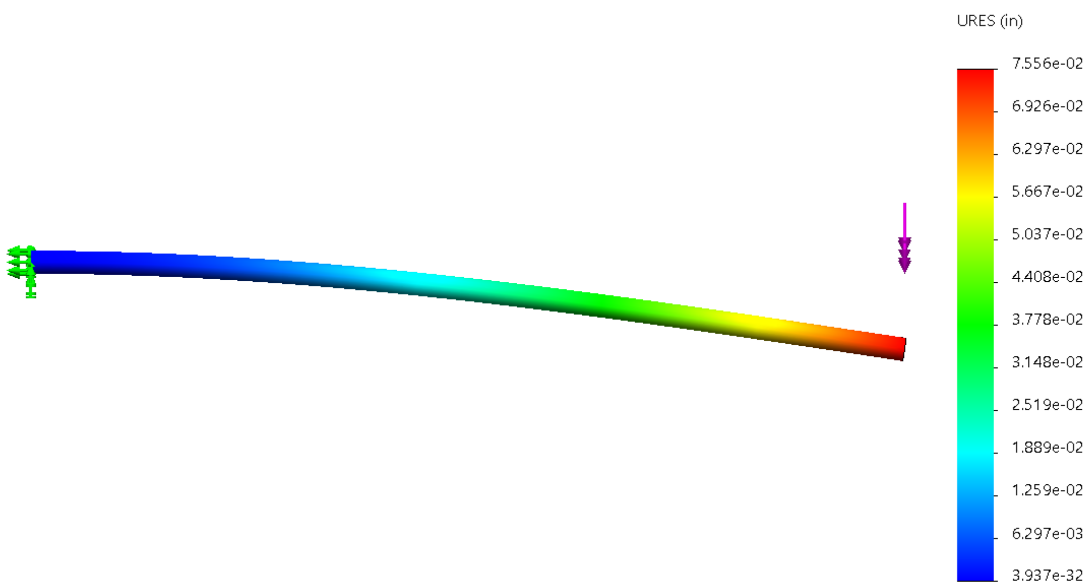


Figure 83: Unthreaded Rod Deflection Test Results

When examining each rod, the maximum possible deflection is .11 in. This is a small amount and should not compromise the ejection of the rover.

Physical Testing 11

Table 44: Rod Deflection (Physical)

Rod Deflection (Physical)	
Objective:	Verify the REA rod will not fail or deflect to the point of rover ejection failure due to the weight of the rover at any point in the ejection process.
Success Criteria:	The rover is successfully transferred from the “packed” position to being fully deployed with no outside interference at least 80% of the time.
Variables:	Position of the rover along the REA rods: varying throughout experiment, causing differing deflection.
Constants:	Rover weight: 2.33 lbs
Step-by-Step Execution:	1. Pack rover with all components into the rocket, correctly threading it onto REA. 2. Command stepper motor to begin ejection process. 3. If rover is completely deployed from the body tube (no longer touching the REA) the test is considered successful. 4. Repeat at least 5 times.
Relevant Safety Concerns:	None.
Status/Results:	Planned.
Rationale: If the rod deflects too much, it may inhibit the stepper motor from successfully pushing out the rover. The stepper motor chosen was specifically done so due to its high torque capabilities. Deflection of the rod should not differ measurably between trials since the rod isnt deforming enough to induce fatigue. By succeeding at least 80% of the time, it is very likely the REA will be successful in deployment. Ideally, 100% success is preferred but needing 80% success allows the team to analyse modes of failure if they occur. This test will be done with the real weight of the rover since this will not be changing at any point of the flight. Also, deflecting the rod too much may induce fatigue over multiple cycles which isn’t favorable and may not be able to be detected.	

Physical Testing 12

Table 45: Threading Integrity

Threading Integrity	
Objective:	To ensure that the threading within the rover and on the rod are robust enough to retain the rover during all points of the flight.
Success Criteria:	Threading can carry the weight of the rover for 24 consecutive hours with no failure or slip.
Variables:	Weight on the threading: 2.33 lbs
Constants:	• Geometry of the threading • Materials ○ PLA plastic on rover interface
Step-by-Step Execution:	1. Correctly “pack” the completed rover into the completed REA. 2. Measure how far the rover is from the REA bulkhead 3. Orient the rods and rover upside down so that the rover could fall off the rods onto the ground. 4. Leave untampered for 24 hours. 5. Measure how far the rover is from the REA bulkhead.
Relevant Safety Concerns:	Rover may fall out of REA - participants may not be within 2 ft of the test during its duration (medium risk)
Status/Results:	Planned.
Rationale: During the ascent of the flight, the rover will be completely contained within the body of the rover. Also due to the acceleration of the launch vehicle, the rover will actually experience a force pushing it into the REA bulkhead. At apogee/deployment of drogue parachute, the opening towards the rover will be facing downward. Due to the acceleration of the vehicle towards the ground, the net force on the rover will be less than the raw weight of the rover at rest. Once the main parachute deploys, the upper body tube will be reoriented with the rover facing upwards. In summary, the rover should never put a force on the treads to be deployed that is greater than its stationary weight if it were turned upside down. So, by testing the weight over a long period of time, it can be proved that the treads should not fail due to the forces imposed by the rover.	

6.1.3. Electronics Test Plans/Status

The electronics team has developed a series of tests to ensure proper operation of electronics occurs before the payload launch, full-scale launch, and competition day launch. Possible problems have been identified and will be developed using a testing plan.

Planned Electronics Tests:

1. Altimeters
2. GPS
3. Pressure Sensor and MPU6050 Calibration
4. RF Communication Post Launch
5. RF Communication Distance
6. Rover Battery Life

Physical Testing 13

Table 46: Altimeters

Altimeters	
Objective:	To ensure altimeters are in working condition to ensure proper deployment of safety parachutes at specified altitudes and storage of flight data for post-flight analysis.
Success Criteria:	Parachutes deploy at specified increments while recording readable data.
Variables:	• Pressure
Constants:	• Volume of Vacuum chamber • Power source • Static Pressure

Table 46: Altimeters

Step-by-Step Execution:	1. Connect LEDs to altimeter's drogue and main chute ports 2. Place altimeter in vacuum chamber and record static pressure readings 3. If static pressure readings are within the limits of the altimeter's specifications, then the altimeter is calibrated 4. Begin testing by reducing the pressure from within the chamber until a pressure comparable to data the pressure obtained during the subscale launch's apogee is comparable 5. Look for the LED of the drogue chute to blink 6. Slowly increase the pressure to static pressure 7. Look for the LED of the main chute to blink 8. Connect to altimeter and analyze data
Relevant Safety Concerns:	• LEDs polarity is reversed and explodes - debris is contained within the vacuum chamber (low risk)
Status/Results:	Completed.
Rationale: The component within the altimeter that is responsible for measuring altitude reads pressure readings, so simulating a flight using a vacuum chamber to alter the pressure ensures the altimeters are in working condition without necessitating a flight. LEDs are used to check if a pulse is sent from the altimeters to eject the parachutes. Recording static pressure readings allows the team to verify the altimeter is calibrated and is reading the correct altitude.	

Physical Testing 14

Table 47: GPS

GPS	
Objective:	To ensure altimeters are in working condition to ensure proper deployment of safety parachutes at specified altitudes and storage of flight data for post-flight analysis.
Success Criteria:	The GPS module is able to be found by team members using Bluetooth Android devices to communicate with the GPS.
Variables:	• Distance • Connectivity
Constants:	• Location of launch vehicle

Table 47: GPS

Step-by-Step Execution:	1. Connect to the GPS using the procedures outlined in the Tiny Telematics Tracker System manual 2. Have a person walk in a random direction for half a mile in an open field with the GPS module a. Testing will not occur in a populous area as this can cause interference with the GPS's signal b. Launch site conditions indicate a flat launch area, so a flat field will be used to conduct the test 3. The other person with the Android device will try and locate the person with the GPS using their device
Relevant Safety Concerns:	None.
Status/Results:	Completed.
Rationale: The launch day field range will be a 0.5 mile radius of flat ground, so testing the GPS in these conditions verifies the GPS will perform as expected during launch day.	

Physical Testing 15

Table 48: Pressure Sensor and MPU6050 Calibration

Pressure Sensor and MPU6050 Calibration	
Objective:	To verify readings obtained by components within the rover ejection assembly are precise with little variation.
Success Criteria:	Readings obtained by the BMP180 and MPU6050 do not vary under static conditions
Variables:	• Component factory settings
Constants:	• Pressure • Temperature • Static movement • Gravity

Table 48: Pressure Sensor and MPU6050 Calibration

Step-by-Step Execution:	1. Components will be properly connected to the Arduino Uno and powered 2. Components will be placed stationary on a flat table 3. Data values will be obtained via the Arduino Uno 4. If both components do not vary, then the components are precise a. Accuracy is not essential for proper operation of the rover ejection assembly
Relevant Safety Concerns:	None.
Status/Results:	Planned.
Rationale: Precision of these data acquisition devices are critical for proper deployment. If values vary wildly, certain parameters within the code may be satisfied, even though they may not have. This can cause premature deployment.	

Physical Testing 16

Table 49: RF Communication Post Launch

RF Communication Post Launch	
Objective:	To verify communication between the rover and driver exists if signal is lost and regained
Success Criteria:	Clear video feedback and operational controls are observed
Variables:	• Connectivity
Constants:	• Distance from rover • Direction of antenna • Carbon fiber body tube interference
Step-by-Step Execution:	1. Connect all RF devices to each other and power them a. Ensure stable feedback is received 2. Place rover electronics within the carbon fiber body tube a. Ensure signal is lost 3. Remove electronics from carbon fiber body tube 4. Check if RF devices are able to communicate with each other as observed before connection was lost

Table 49: RF Communication Post Launch

Relevant Safety Concerns:	None.
Status/Results:	Planned.
Rationale: A concern the team has is loss of connection once the payload has been placed within the launch vehicle. In past years, the team has observed connection issues when transmitting through a carbon fiber medium, such as the launch vehicle's body tube. Testing to see if connectivity is regained after it has been lost ensures the payload will operate as expected for a successful mission.	

Physical Testing 17

Table 50: RF Communication Distance

RF Communication Distance	
Objective:	To verify communication between the rover and driver exists at a length of 0.5 miles.
Success Criteria:	Clear video feedback and operational controls are observed
Variables:	• Connectivity
Constants:	• Distance from rover • Direction of antenna • Flat ground
Step-by-Step Execution:	1. Connect all RF devices to each other and power them a. Ensure clear video feedback and controls are observable 2. Move the rover electronics a distance of 0.5 miles away from the driver 3. Check if RF devices are able to communicate with each other as observed at a close distance
Relevant Safety Concerns:	None.
Status/Results:	Planned.

Table 50: RF Communication Distance

Rationale: A concern the team has is loss of connection at long distances. Antennas have been selected to operate a minimum distance of 0.5 miles with ideal conditions, however, interference can limit the usable communication range between the rover and the driver. The main form of interference can occur from uneven ground and trying to transmit through this ground. Launch day conditions indicate primarily flat field conditions will be observed, but slight discrepancies in elevation can alter the communication range. Testing the rover's RF communication in these conditions ensures proper operation during competition.

Physical Testing 18

Table 51: Rover Battery Life

Rover Battery Life	
Objective:	To verify rover electronics will operate for 3.5 hours on standby and 0.5 hours of mission time
Success Criteria:	Battery lasts 3.5 hours on standby and 0.5 hours of simulated mission time
Variables:	• None
Constants:	• Standby time • Mission time • Battery rating • Electronic current draw and operation
Step-by-Step Execution:	1. Wire all rover electrical components 2. Plug in the battery to the power distribution board and start a timer 3. After 3.5 hours, operate the electronics such that its motors operate at half capacity 4. Measure how long it takes for the battery to fully drain
Relevant Safety Concerns:	None.
Status/Results:	Planned.

Table 51: Rover Battery Life

Rationale: Battery life of the selected Lithium polymer battery is crucial for carrying out the payload mission. The team has set a goal of operation of the rover of 4 hours total to satisfy the 2 hour idle requirement set forth by the Student Launch handbook. A 3.5 hour idle time and 0.5 hour mission time simulates a worst case scenario of a long idle time and a long mission time. Completing this test ensures the rover will be more than sufficiently powered to carry out the mission.

6.2. Requirements Compliance

6.2.1. NASA Requirements Verification

Table 52: NASA Requirements Verification

Requirement	Method of Verification	Verification Plan	Status	Relevant Section
1. General Requirements				
1.1. Students on the team will do 100% of the project, including design, construction, written reports, presentations, and flight preparation with the exception of assembling the motors and handling black powder or any variant of ejection charges, or preparing and installing electric matches (to be done by the team's mentor). Teams will submit new work. Excessive use of past work will merit penalties.	Demonstration	Team has been and plans to continue to continue work needed for competition, excluding tasks requiring a mentor.	In Progress	ALL

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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. Individual subteam leads maintain personnel assignments and checklists relevant to their team. Safety Officer maintains risks, mitigations, and checklists throughout project.	In Progress	6.4 Timeline / 5.3 Safety Hazard Analysis
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 were identified and their information submitted.	Completed	N/A
1.4. The team must identify all team members attending launch week activities by the Critical Design Review (CDR). Team members will include: 1.4.1. Students actively engaged in the project throughout the entire year. 1.4.2. One mentor (see requirement 1.13). 1.4.3. No more than two adult educators	Demonstration	Selected team members as well as team mentor have been submitted to attend launch week.	Completed	N/A

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1.5. The team will engage a minimum of 200 participants in educational, hands-on science, technology, engineering, and mathematics (STEM) activities, as defined in the STEM Engagement Activity Report, by FRR. To satisfy this requirement, all events must occur between project acceptance and the FRR due date and the STEM Engagement Activity Report must be submitted via email within two weeks of the completion of the event. A sample of the STEM Engagement Activity Report is on page 35.	Demonstration	Bearospace at UCLA will partner with SOLES, NSBE, and AISES at UCLA to aid their STEM outreach efforts.	In Progress	N/A
1.6. The team will establish a social media presence to inform the public about team activities	Demonstration	A multi-platform media presence will be established and updated by the social media coordinator.	Completed / In Progress	N/A
1.7. Teams will email all deliverables to the NASA project management team by the deadline specified in the handbook for each milestone. In the event that a deliverable is too large to attach to an email, inclusion of a link to download the file will be sufficient.	Demonstration	All deliverables will be emailed on time to correct personnel.	In Progress	N/A
1.8. All deliverables must be in PDF format.	Demonstration	All deliverables will be in PDF format.	In Progress	N/A

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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	Table of Contents
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	ALL
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	N/A
1.12. All teams will be required to use the launch pads provided by Student Launch's launch services provider. No custom pads will be permitted on the launch field. 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 / Analysis	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 cant will be considered in flight simulations.	In Progress	3.1 Design Verification of Launch Vehicle / 3.4 Mission Performanc e Predictions

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

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2. Vehicle Requirements				
2.1. The vehicle will deliver the payload to an apogee altitude between 3,500 and 5,500 feet above ground level (AGL). Teams flying below 3,000 feet or above 6,000 feet on Launch Day will be disqualified and receive zero altitude points towards their overall project score.	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	3.1 Design Verification of Launch Vehicle / 3.4 Mission Performance Predictions
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 during Launch Week.	Analysis, Demonstration	OpenRocket will be utilized to predict and declare a target altitude. This altitude will be submitted with the PDR.	Completed	3.4 Mission Performance Predictions
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	3.3 Recovery Subsystem

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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 will be designed to be reusable meaning it is designed to be able to withstand flight forces. This will be confirmed on launch day post-launch by examining any damage to vehicle body and defining no damage as reusable.	In Progress	3.1.6. Design Integrity
2.5. The launch vehicle will have a maximum of four (4) independent sections. An independent section is defined as a section that is either tethered to the main vehicle or is recovered separately from the main vehicle using its own parachute.	Analysis, Inspection	Launch vehicle will be designed to have 3 independent sections tethered together.	In Progress	3.1.4. Launch Vehicle Components
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.	In Progress	3.1.4. Launch Vehicle Components
2.5.2. Nosecone shoulders which are located at in-flight separation points will be at least ½ body diameter in length.	Analysis, Inspection	Nose Cone shoulders will be at least 1/2 body diameter in length.	In Progress	3.1.4. Launch Vehicle Components

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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 will be fully completed before launch day and launch readiness checklist will be created to minimize flight preparation time or confusion.	Incomplete	N/A
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.	In Progress	6.1.3. Electronics Test Plans/Status
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.	In Progress	1. Summary of CDR Report
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.	In Progress	N/A

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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.	Completed	1. Summary of CDR Report
2.10.1. Final motor choices will be declared by the Critical Design Review (CDR) milestone.	Demonstration	Motor will be declared at CDR.	Completed	1. Summary of CDR Report
2.10.2. Any motor change after CDR must be approved by the NASA Range Safety Officer (RSO) and will only be approved if the change is for the sole purpose of increasing the safety margin. 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	N/A
2.11. The launch vehicle will be limited to a single stage.	Demonstration	Vehicle will be designed to be single stage.	Completed	3.4. Mission Performanc e Predictions

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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.	Completed	1. Summary of CDR Report
2.13. Pressure vessels on the vehicle will be approved by the RSO and will meet the following criteria:	N/A: No pressure vessels on vehicle.			
2.13.1. The minimum factor of safety (Burst or Ultimate pressure versus Max Expected Operating Pressure) will be 4:1 with supporting design documentation included in all milestone reviews.				
2.13.2. Each pressure vessel will include a pressure relief valve that sees the full pressure of the tank and is capable of withstanding the maximum pressure and flow rate of the tank.				
2.13.3. The full pedigree of the tank will be described, including the application for which the tank was designed and the history of the tank. This will include the number of pressure cycles put on the tank, the dates of pressurization/depressurizatio n, and the name of the person				

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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 will be designed to have a static stability margin above 2.0 at rail exit point. This will be confirmed using simulation software.	Completed	3.4 Mission Performanc e Predictions
2.15. Any structural protuberance on the rocket will be located aft of the burnout center of gravity.	Analysis, Inspection	Vehicle will be designed to meet this criteria. Will be verified post-launch by finding real center of gravity and examination of structural protuberances.	In Progress	3.1 Vehicle Criteria
2.16. The launch vehicle will accelerate to a minimum velocity of 52 fps at rail exit.	Analysis, Test	Vehicle will be designed to complete this. This will be confirmed using simulation software.	In Progress	3.4 Mission Performanc e Predictions
2.17. All teams will successfully launch and recover a subscale model of their rocket prior to CDR. Subscales are not required to be high power rockets.	Demonstration	Team will fabricate and launch sub-scale vehicle before CDR submission.	Completed	3.2 Subscale Flight Results
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.	Analysis, Demonstration	Team will design a subscale vehicle that closely resembles full-scale design. All deviations will be approved by NASA.	Completed	3.2 Subscale Flight Results

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2.17.2. The subscale model will carry an altimeter capable of recording the model's apogee altitude.	Demonstration	Subscale vehicle will carry altimeter to record apogee altitude.	Completed	3.2 Subscale Flight Results
2.17.3. The subscale rocket must be a newly constructed rocket, designed and built specifically for this year's project.	Demonstration	Subscale will be newly fabricated vehicle.	Completed	3.2 Subscale Flight Results
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.	Demonstration.	CDR will include proof of successful subscale flight.	Completed	3.2 Subscale Flight Results
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 8 launch vehicle's stability, structural integrity, recovery systems, and the team's ability to prepare the launch vehicle for flight. A successful flight is defined as a launch in which all hardware is functioning properly). The following criteria must be met during the full-scale demonstration flight:	Demonstration	Team will fabricate and launch full-scale rocket to verify its integrity.	In Progress	N/A

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2.18.1.1. The vehicle and recovery system will have functioned as designed.	Demonstration	Vehicle will have recovery system planned for full-scale vehicle and success will be seen during flight.	Incomplete	N/A
2.18.1.2. The full-scale rocket must be a newly constructed rocket, designed and built specifically for this year's project.	Demonstration	Vehicle will be fabricated from scratch.	Incomplete	N/A
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.	Demonstration	Either payload or mass closely resembling payload will be flown in full scale vehicle.	Incomplete	N/A
2.18.1.3.2. The mass simulators will be located in the same approximate location on the rocket as the missing payload mass.	Analysis, Demonstration	Mass simulations, if used, will be placed so center of masses align with projected payload center of mass.	Incomplete	N/A
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.	N/A: Payload does not have external features or manage total energy of vehicle.			

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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 (such as weather).	Demonstration	Declared motor will be flown at vehicle demonstration or a request waiver will be filed.	Incomplete	N/A
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 same amount of ballast that will be flown during the launch day flight. Additional ballast may not be added without a re-flight of the full-scale launch vehicle.	Demonstration	Full-scale demonstration will be designed to be identical to actual flight, with the exception of the payload	Incomplete	N/A
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).	Demonstration	No components will be modified post-full scale demonstration unless approved by NASA RSO.	Incomplete	N/A
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.	Demonstration	FRR will contain proof of successful flight, including flight data collected.	Incomplete	N/A

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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.	Demonstration	Vehicle demonstration will be planned to take place well in advance of the FRR and data will be included in the FRR.	Incomplete	N/A
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. The following criteria must be met during the Payload Demonstration Flight:	Demonstration	Payload demonstration flight will be planned to occur well before the deadline in the case it must be rescheduled due to weather	Incomplete	N/A

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2.18.2.1. The payload must be fully retained until the intended point of deployment (if applicable), all retention mechanisms must function as designed, and the retention mechanism must not sustain damage requiring repair.	Demonstration, Inspection	Payload will be loaded appropriately into the launch vehicle pre-launch. Post-launch the payload and retention system will be examined for any visible damage.	Incomplete	N/A
2.18.2.2. The payload flown must be the final, active version.	Demonstration	Payload flown will be as discussed in all design reports. Payload will not be flown until fully functional as determined by team leads.	Incomplete	N/A
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.	Demonstration	Payload flight demonstration will be planned to occur well before the deadline in case weather causes rescheduling.	Incomplete	N/A

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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. 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 the vehicle at launch week.	Demonstration	Team will comply if a re-flight is asked for.	Incomplete	N/A
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 the payload at launch week.	Demonstration	Team understands this and plans to complete the payload demonstration appropriately.	Incomplete	N/A
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.	Demonstration	Team will petition for flight of payload if payload demonstration flight is unsuccessful.	Incomplete	N/A

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2.20. The team's name and launch day contact information shall be in or on the rocket airframe as well as in or on any section of the vehicle that separates during flight and is not tethered to the main airframe. This information shall be included in a manner that allows the information to be retrieved without the need to open or separate the vehicle.	Inspection	Team lead or mentor contact information will be listed easily visible on the vehicle prior to the time at launch.	Incomplete	N/A
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	Lithium Polymer batteries will be harboured within bright red 3D printed plastic enclosures to be distinguished as a fire hazard. They will also be sealed from any explosive sources.	Incomplete	N/A
2.22. Vehicle Prohibitions	-	-	-	-
2.22.1. The launch vehicle will not utilize forward canards. 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	Vehicle will not be designed to utilize forward canards.	In Progress	

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2.22.2. The launch vehicle will not utilize forward firing motors.	Inspection	These restrictions are understood by the team and the vehicle has been designed to not include any of these.	Complete	N/A
2.22.3. The launch vehicle will not utilize motors that expel titanium sponges (Sparky, Skidmark, MetalStorm, etc.)				
2.22.4. The launch vehicle will not utilize hybrid motors.				
2.22.5. The launch vehicle will not utilize a cluster of motors.				
2.22.7. The launch vehicle will not exceed Mach 1 at any point during flight.	Analysis, Test	Simulation software is used during the design of the vehicle to ensure maximum speeds is well below Mach 1. Vehicle demonstration will prove this.	In Progress	3.4 Mission Performanc e Predictions
2.22.8. 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.	In Progress	N/A
2.22.9. Transmissions from onboard transmitters will not exceed 250 mW of power (per transmitter).	Analysis, Inspection	All transmitters will be selected with a power rating less than 250 mW.	In Progress	3.3 Recovery Subsystem

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2.22.10 Transmitters will not create excessive interference. Teams will utilize unique frequencies, handshake/passcode systems, or other means to mitigate interference caused to or received from other teams.	Test, Demonstration	All transmitters will communicate to the team using frequency hopping to prevent interference with other teams.	In Progress	3.3 Recovery Subsystem
2.22.11. 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 the design of the vehicle. Only a small amount of aluminum, a lightweight metal, is used for the bottom of the vehicle for strength purposes.	In Progress	N/A
3. Recovery System Requirements				
3.1. The 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 10 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 occuring at apogee and main deployment occuring at some lower altitude as determined by deployment speed and descension time. This will be demonstrated at launch and full-scale verification flight.	In Progress	3.1 Design Verification of Launch Vehicle

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3.1.1. The main parachute shall be deployed no lower than 500 feet.	Analysis, Demonstration	Vehicle will be designed to deploy the main parachute above 500 ft agl. Redundant altimeters will be used to ensure this. This will be demonstrated at the full scale launch.	In Progress	3.3 Recovery Subsystem
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.	In Progress	3.3 Recovery Subsystem
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.	In Progress	3.1 Design Verification of Launch Vehicle
3.2. Each team must perform a successful ground ejection test for both the drogue and main parachutes. This must be done prior to the initial subscale and full-scale launches.	Demonstration	Team mentor will be present at all demonstration flights and will assist with the completion of all tests. These tests will also be included in pre-launch safety checklists to ensure completion.	In Progress	5.4 Launch Concerns and Operation Procedures /Checklists

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3.3. Each independent section of the launch vehicle will have a maximum kinetic energy of 75 ft-lbf at landing.	Analysis, Test, Demonstration	OpenRocket will be utilized to analyze weights of individual tethered sections as well as landing speed to ensure completion of this. Main parachute deployment can be altered to alter speed and kinetic energy at landing. This will be verified during full scale launch.	In Progress	3.4.3. 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	3.3 Recovery Subsystem
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	Incomplete	3.3 Recovery Subsystem
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 push buttons will be used as arming switches. The push buttons will be able to withstand the necessary current and voltage needed to power the altimeters.	In Progress	3.3 Recovery Subsystem

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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.	In Progress	3.3 Recovery Subsystem
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.	Incomplete	3.3 Recovery Subsystem
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.	In Progress	5.4 Launch Concerns and Operation Procedures / Checklists
3.10. The recovery area will be limited to a 2,500 ft. radius from the launch pads.	Analysis, Test, Demonstration	Simulation software will be utilized with varying wind conditions to ensure recovery area complies with this restriction. Full scale demonstration will verify simulation.	In Progress	3.4.5. Drift Calculations

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3.11. Descent time will be limited to 90 seconds (apogee to touch down).	Analysis, Test, Demonstration	Simulation software will be utilized to ensure this. Main parachute deployment time can be altered to comply if needed. This will be verified at full scale demonstration.	In Progress	3.4 Mission Performance Predictions
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.	Incomplete	3.3 Recovery Subsystem
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.	Incomplete	3.3.3. Electrical Components
3.12.2. The electronic tracking device(s) will be fully functional during the official flight on launch day.	Testing, Inspection	Testing of the GPS system will occur before a full-scale launch and connection will be visually verified on launch date.	Incomplete	6.1.3. Electronics Test Plans/Status

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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.	In Progress	3.3 Recovery Subsystem
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.	Incomplete	3.3 Recovery Subsystem
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.	Incomplete	3.3 Recovery Subsystem
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	3.3 Recovery Subsystem

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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.	In Progress	3.3 Recovery Subsystem
4. Payload Experiment Requirements				
4.1. High School/Middle School Division – Teams may design their own science or engineering experiment or may choose to complete the College/University Division mission. Data from the science or engineering experiment will be collected, analyzed, and reported by the team following the scientific method.	N/A			
4.2. College/University Division – Teams will design a system capable of being launched in a high power rocket, landing safely, and recovering simulated lunar ice from one of several locations on the surface of the launch field. The method(s)/design(s) utilized 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.	In Progress	4. Payload Criteria
4.3. Lunar Ice Sample Recovery Mission Requirements	-	-	-	-

Table 52: NASA Requirements Verification

4.3.1. The launch vehicle will be launched from the NASA-designated launch area using the provided Launch pad. All hardware utilized at the recovery site must launch on or within the launch vehicle.	Analysis, Demonstration	Payload will be designed to be retained with all components in the launch vehicle and able to function independent of any additional hardware upon landing. This will be demonstrated at payload demonstration flight.	In Progress	4. Payload Criteria
4.3.2. Five recovery areas will be located on the surface of the launch field. Teams may recover a sample from any of the recovery areas. Each recovery site will be at least 3 feet in diameter and contain sample material extending from ground level to at least 2 inches below the surface.	Demonstration	Payload will be able to identify collection zone and collect sample from it. This will be demonstrated at payload demonstration flight.	In Progress	4. Payload Criteria
4.3.3. The recovered ice sample will be a minimum of 10 milliliters (mL).	Analysis, Test	Payload will be designed to be able to collect and retain more than the minimum of 10mL of sample. This will be verified through testing or collection and retention.	In Progress	4. Payload Criteria / 6.1.2. Payload Test Plans / Status
4.3.4. Once the sample is recovered, it must be stored and transported at least 10 linear feet from the recovery area.	Test, Demonstration	Testing will be done to ensure retention of sample post-collection for the necessary 10ft away from the collection zone.	In Progress	6.1.2. Payload Test Plans / Status

Table 52: NASA Requirements Verification

4.3.5. Teams must abide by all FAA and NAR rules and regulations.	Demonstration	Safety officer will review all team plans to ensure compliance with all federal rules and regulations.	In Progress	5. Safety
4.3.6. Black Powder and/or similar energetics are only permitted for deployment of in-flight recovery systems. Any ground deployments must utilize mechanical systems.	Analysis, Demonstration	Payload will not be designed to utilize black powder for ejection purposes. Ejection system will be completely mechanical. This will be demonstrated during payload demonstration flight.	In Progress	4. Payload Criteria
4.3.7. Any part of the payload or vehicle that is designed to be deployed, whether on the ground or in the air, must be fully retained until it is deployed as designed.	Test, Demonstration	Retention system will be designed that is robust enough to retain payload during the entire duration of the flight. Retention system integrity will be tested during payload flight demonstration.	In Progress	4. Payload Criteria

Table 52: NASA Requirements Verification

4.3.7.1. A mechanical retention system will be designed to prohibit premature deployment.	Analysis, Demonstration	Retention system will be designed so premature deployment is not possible under flight conditions. This will be verified with simulation software and demonstrated during payload flight demonstration.	In Progress	4. Payload Criteria
4.3.7.2. The retention system will be robust enough to successfully endure flight forces experienced during both typical and atypical flights.	Analysis, Test	Retention system will be tested for structural integrity both virtually and physically. It will again be tested during payload flight demonstration.	In Progress	6.1.2. Payload Test Plans / Status
4.3.7.3. The designed system will be fail-safe.	Analysis	Payload subteam as well as safety officer will analyze retention system to find any modes of failure and test that those found are not possible to achieve during flight.	In Progress	6.1.2. Payload Test Plans / Status
4.3.7.4. Exclusive use of shear pins will not meet this requirement.	Demonstration	Payload retention system will not utilize shear pins.	In Progress	4. Payload Criteria

Table 52: NASA Requirements Verification

4.4. Special Requirements for UAVs and Jettisoned Payloads	N/A: Payload is not a UAV or Jettisoned Payload			
4.4.1. Any experiment element that is jettisoned during the recovery phase will receive real-time RSO permission prior to initiating the jettison event.				
4.4.2. Unmanned aerial vehicle (UAV) 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 UAV				
4.4.3. Teams flying UAVs 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).				
4.4.4. Any UAV weighing more than .55 lbs. will be registered with the FAA and the registration number marked on the vehicle.				
5. Safety Requirements				
5.1. Each team will use a launch and safety checklist. The final checklists will be included in the FRR report and used during the Launch Readiness Review (LRR) and any launch day operations.	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.	In Progress	N/A

Table 52: NASA Requirements Verification

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	0.3 Safety Officer
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			In Progress	5.3 Analysis of Failure Modes
5.3.1.2. Construction of vehicle and payload components			In Progress	5.3 Personal Hazard Analysis
5.3.1.3. Assembly of vehicle and payload			In Progress	5.3 Personal Hazard Analysis
5.3.1.4. Ground testing of vehicle and payload			In Progress	5.4 Launch Concerns and Operation Procedures / Checklists
5.3.1.5. Subscale launch test(s)			Completed	5.5 Launch Concerns and Operation Procedures / Checklists

Table 52: NASA Requirements Verification

5.3.1.6. Full-scale launch test(s)			Incomplete	5.5 Launch Concerns and Operation Procedures / Checklists
5.3.1.7. Launch day			Incomplete	5.5 Launch Concerns and Operation Procedures / Checklists
5.3.1.8. Recovery activities			In Progress	5.5 Launch Concerns and Operation Procedures / Checklists
5.3.1.9. STEM Engagement Activities			In Progress	5.2 Personnel Hazard Analysis
5.3.2. Implement procedures developed by the team for construction, assembly, launch, and recovery activities.	Demonstration	Safety officer will be present during all build days and other major events to ensure planned procedures are followed appropriately. Safety officer will be aware of all procedures created by subteam leads through pre-event briefing.	In Progress	5.2 Personnel Hazard Analysis

Table 52: NASA Requirements Verification

5.3.3. Manage and maintain current revisions of the team's hazard analyses, failure modes analysis, 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	5.2 Personnel Hazard Analysis
5.3.4. Assist in the writing and development of the team's hazard analyses, failure mode 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. Safety
5.4. During test flights, teams will abide by the rules and guidance of the local rocketry club's RSO. The allowance of certain vehicle configurations and/or payloads at the NASA Student Launch does not give explicit or implicit authority for teams to fly those vehicle configurations and/or payloads at other club launches. Teams should communicate their intentions to the local club's President or Prefect and RSO before attending any NAR or TRA launch.	Demonstration	Safety officer works with project manager and team mentor to communicate compliance with all rules for all launches. Any problems are addressed if mentor or RSO communicates issue.	In Progress	5. Safety

Table 52: NASA Requirements Verification

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.	Completed / Ongoing	5. Safety

6.2.2. Team Requirements Derivation & Verification

In addition to the requirements presented by the competition, Bearospace at UCLA derived and plans to follow their additional project and engineering constraints. These requirements are proposed to encourage sustainability of the club, minimizing of unnecessary costs, and minimizing unnecessary complexity. Their derivation rationale is listed below in a similar manner as the NASA requirements were presented. They are either entirely separate from the NASA requirements or presented in addendum to them for completion.

Table 53: Team Requirements Derivation

Number	Team Requirement	Reason For Enforcement
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 be on the team at all times to ensure quality and correct work is representing our school.
1.2	Industry relations must be established and at least $5,000 must be received in donations to the team from corporate sponsors.	While the team in the past has sustained itself on grants through UCLA, this funding source is not consistent in amount granted or in timely delivery; it is also usually meant for newly established organizations. As the team continues to expand, constant funding sources must be established as well as connections to industry which our members may find useful for the purposes of career development.
1.3	Social events will be planned and carried out by team leads to encourage membership and team bonding throughout the year.	New member communication with team leads is often lacking due to the level of technicality of the team. Social events where new recruits and leads were both present would help increase communication and retention.

Table 53: Team Requirements Derivation

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.
1.5	Social media coordinator position must be created.	A position for social media coordinator was created and defined to manage accounts on Instagram, Facebook, Twitter, and Flickr. Team leads send relevant content to the coordinator to post where they feel appropriate.
2. Vehicle Requirements		
2.1	Upper and lower body tubes will be a cumulative sum of 5' in length.	This year is a big transitional year in terms of funding. Due to this, team leads are working closely with the finance lead to minimize any material and manufacturing costs. Our team plans on purchasing a body tube from Apogee Rockets, where a 6" diamter 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.
2.2	Payload and retention method will recieve 14" in length within the upper body tube.	This requirement is considered mainly during the early design phase of the manufacturing process. This will avoid crowding later in the manufacturing process as well as resizing if deemed necessary.
2.3	Fins must have a rectangular leading edge.	Fins are generally cut out of flat sheets of material into a shape determined by the stability of the vehicle. By defining them as rectangular, it eliminates any error that may come through trying to reshape the leading edge into an airfoil or some other shape. Furthermore, the material chosen often creates volatile particulates during cutting and this would minimize any health threats to team members.
2.4	All components that launch on or within the vehicle will descent and land either tethered to the vehicle or harbored inside during the duration of the flight.	Multiple components landing individually creates the need for more tracking devices and altimeters to ensure safe landing energy. It also creates the need for multiple recovery systems which increases cost as well as modes of failure.

Table 53: Team Requirements Derivation

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 protubences 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.
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.
3. Recovery System Requirements		
3.1	No recovery hardware or parachutes will be planned to deploy if the vehicle is traveling faster than 90 ft/s	Parachutes deploying at too high a speed could result in failure of the retainment hardware or parachute material itself. Delay in altimeters for any reason can cause for complete failure of deployment if vehicle is descending at too fast a rate.
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.
3.3	Recovery hardware and load-bearing interfaces will be able to take loads expected during flight with a safety margin of 1.5.	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.
3.4	All static interfaces must be reinforced with epoxy.	Reinforcing interfaces with epoxy when possible allows for greater load-bearing capabilities so they will be less likely to fail during deployment.

Table 53: Team Requirements Derivation

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.
4. Payload Experiment Requirements		
4.1	Rover will not exceed 12" in the packed position.	Due to the length restriction placed on the body tubes, the rover length must also be restricted so as to make all components fit within the vehicle during all points of the flight.
4.2	Rover will not contain more than six on board motors.	Due to the size restrictions placed onto the rover, electrical and mechanical components must both be optimized to all fit on the rover body. By limiting the number of motors to six, four may be used for means of navigation, leaving two to be defined for the collection mechanism. This further minimizes failure mechanisms in the collection process. Additionally, most flight controllers are able to control up to a max of 6 motors.
4.3	Ejection system must be able to withstand forces put onto it by the rover without compromising success.	While ejection system may be able to withstand forces during flight with rover in the "packed" position, this does not ensure that it will be able to withstand forces placed onto it upon rover ejection. This is a necessity to successfully deploy the rover so it may complete its mission
4.4	Rover must communicate and provide clear, uninterrupted video feedback to driver within a minimum 0.5 mile radius.	The recovery area is limited to 2500 ft radius(requirement 3.10 in the handbook), which is a little under half a mile. The spectator area is not directly in the center, so a half mile radius minimum is necessary to carry out the mission from any range.
4.5	Payload electronics must endure a minimum 30 minute mission time after deployment.	Once the payload is deployed, it may take a while to find a collection site since the provided camera is low to the ground. A minimum 30 minute requirement ensures the driver has sufficient time to collect samples.

Bearospace at UCLA plans to fulfill these requirements similarly to how they are fulfilling NASA requirements. Below is a table that presents each requirement as well as a method of verification, verification plan, status of fulfillment, and relevant section to where more information about that aspect of the project can be found. For consistency, method of verification is limited to the modes set forth by NASA requirements: tests, demonstration, analysis, and inspection.

Table 54: Team Requirements Verification

Team Requirement	Method of Verification	Verification Plan	Status	Relevant Section
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.	Demonstration	A series of engineering and diversity events will be attended and a general kickoff meeting will be held. In addition, leads will personally reach out to new members to get them more involved in reports and presentations.	In Progress	N/A
1.2 Industry relations must be established and at least $5,000 must be received in donations to the team from corporate sponsors.	Demonstration	Finance lead and project manager will set up a series of meetings with external affairs to get in contact with the dean's industry advisory board. From there, leads will present the team to various sponsors to achieve this goal.	In Progress	6.3 Budget Status
1.3 Social events will be planned and carried out by team leads to encourage membership and team bonding throughout the year.	Demonstration	Project manager will work with all leads as well as parent organization (AISES at UCLA) to plan and carry out these social events.	In Progress	N/A

Table 54: Team Requirements Verification

1.4 Online presence must be established.	Demonstration	Project manager will take applications from potential webmasters and elect one or a team of them to create a website. The project manager will then have periodic meetings with them to stay updated on the progress of the page.	In Progress	N/A
1.5 Social media coordinator position must be established.	Demonstration	Project manager took applications and elected a social media coordinator. Project manager ensures content is sent to them from leads and that posts occur regularly.	In Progress	N/A
2. Vehicle Requirements				
2.1 Upper and lower body tubes will be a cumulative sum of 5' in length.	Demonstration, Analysis	During the design phase, it will be ensured by the structures lead that both body tubes will not exceed 5' in length. During manufacturing phase, only one 5' body tube will be purchased.	Completed	3.1 Design Verification of Launch Vehicle
2.2 Payload and retention method will recieve 14" in length within the upper body tube.	Demonstration, Analysis	During the design phase, it will be insured by the structures lead that this requirement is fulfilled	Completed	3.1 Design Verification of Launch Vehicle
2.3 Fins must have a rectangular leading edge.	Demonstration, Analysis	Structures lead will only consider flat plates of material that may be used for the fins. They will not plan any modification to the leading edge after the fin is cut out of the plate.	In Progress	3.1 Design Verification of Launch Vehicle

Table 54: Team Requirements Verification

2.4 All components that launch on or within the vehicle will descent and land either tethered to the vehicle or harbored inside during the duration of the flight.	Analysis, Demonstration	Structures lead will ensure that all parent components of the launch vehicle are tethered together in a manner that makes failure very unlikely. They will also ensure any structural components within the vehicle will be safely retained during the duration of the flight. Payload lead will ensure that the payload retention system is robust enough to withstand forces during flight. This will be demonstrated during vehicle demonstration.	In Progress	3.3 Recovery Subsystem
2.5 There will be no structural protuberance on the outer frame of the rocket excluding fins and launch lugs.	Analysis, Inspection	The structures lead will ensure that the design of the vehicle has no structural protuberances. They will monitor manufacturing progress to ensure that the design is followed.	In Progress	3.1 Design Verification of Launch Vehicle
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.	Demonstration	Structures lead will ensure that this is not included in the design of the launch vehicle.	Completed	3.1 Design Verification of Launch Vehicle

Table 54: Team Requirements Verification

3. Recovery System Requirements				
3.1 No recovery hardware or parachutes will be planned to deploy if the vehicle is traveling faster than 90 ft/s.	Analysis, Testing	Structures lead will conduct a series of flight simulations to estimate the speed recovery hardware deployment and alter the design as necessary. This deployment speed will then be compared to the experimental speed found at the full scale demonstration.	In Progress	3.3 Recovery Subsystem
3.2 Parachutes will have high-visibility coloring for easy visual tracking.	Demonstration	Structures lead will ensure any parachutes bought or used will have high-visibility coloring (ex. no blue or white parachutes)	In Progress	3.3. Recovery Subsystem
3.3 Recovery hardware and load-bearing interfaces will be able to take loads expected during flight with a safety margin of 1.5.	Testing	Structures lead will plan and execute both virtual and physical testing to ensure hardware can handle this load. Specific load will be found using deployment speed simulations.	In Progress	6.1.1. Vehicle Component Test Plans/Status
3.4 All static interfaces must be reinforced with epoxy.	Demonstration, Inspection	During the manufacturing process, both the structures lead and safety officer will examine the launch vehicle and add epoxy to static load-bearing interfaces if they are not already epoxied.	Incomplete	3.3. Recovery Subsystem
3.5 Altimeter redundancy must be used using two altimeters from two different brands.	Demonstration, Analysis	Electronics lead will ensure that altimeters of two differing brands are bought and used for recovery purposes.	In Progress	3.3.3. Electrical Components

Table 54: Team Requirements Verification

4. Payload Experiment Requirements				
4.1 Rover will not exceed 12" in the packed position.	Analysis, Demonstration	Payload lead will ensure that payload design is within the 12" constraint. Since the rover will be 3D printed, this dimension is secured once it is 3D modeled.	In Progress	4. Payload Criteria
4.2 Rover will not contain more than six on board motors.	Analysis, Demonstration	Electronics lead will utilize 4 motors for transportation of the rover. The payload lead will then ensure that collection method will utilize 2 motors or less while minimizing failure modes.	In Progress	4. Payload Criteria
4.3 Ejection system must be able to withstand forces put onto it by the rover without compromising success.	Testing	Payload lead will lead payload subteam in devising and executing testing plan that can prove both virtually and physically that the ejection system can support the rover at all points of the ejection process.	In Progress	6.1.2. Payload Test Plans / Status
4.4 Rover must communicate and provide clear, uninterrupted video feedback to driver within a minimum 0.5 mile radius.	Testing, Analysis	Components will be bought such that specifications allow the payload to communicate a minimum of 0.5 miles. Numerical analysis will be used to accomplish this. Testing will be conducted on the payload in similar flat ground during the payload launch requirement.	Incomplete	

Table 54: Team Requirements Verification

4.5 Payload electronics must endure a minimum 30 minute mission time after deployment.	Analysis	Payload and electronics lead will analyze power consumption of each component and select an appropriate battery.	In Progress	

6.3. Budget Status

Table 55: 2019-2020 Budget

Bearospace at UCLA **2019-2020 Budget**	
Grand Total	**$6,559**

	Expense	Company	Projected Units	Projected Unit Price	Projected Total Price
Structures	***Totals:***				**$1,830**
	Contingency			10%	$166
	Body Tube	Public Missiles	1	$440	$440
	Rocket Kit	Apogee Components	1	$265	$265
	Subscale Motor	Apogee Components	1	$72	$72
	Full-scale Motor	Cesaroni Technologies	3	$188	$564
	Coupler	Public Missiles	1	$94	$94
	Fiberglass Sheet	McMaster-Carr	1	$17	$17
	Pine Wood Stock	Anawalt Lumber	4	$12	$48
	Motor Mount & Ring/Epoxy	Apogee Components	1	$100	$100
	Phenolic Tube	Apogee Components	1	$15	$15
	RocketPoxy	Apogee Components	1	$49	$49

Table 55: 2019-2020 Budget

	Expense	Company	Projected Units	Projected Unit Price	Projected Total Price
Electrical / Payload	***Totals:***				**$462**
	Contingency			10%	$42
	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

	Expense	Company	Projected Units	Projected Unit Price	Projected Total Price
Recovery	***Totals:***				**$206**
	Steel Eyebolts	McMaster-Carr	4	$3	$11
	Shear Pins	Apogee Components	1	$4	$4
	Main Parachute	Rocketman Enterprise	1	$120	$120
	Shock Cord	Apogee Components	1	$50	$50

	Fire Cloth	Apogee Components	2	$10	$20

	Expense	Company	Projected Units	Projected Unit Price	Projected Total Price
Safety	***Totals:***				**$34**
	Contingency			10%	$3
	Gloves (100 pack)	Fisher Scientific	1	$31	$31

	Expense	Company	Projected Units	Projected Unit Price	Projected Total Price
Travel	***Totals:***				**$4,027**
	Contingency			10%	$366
	Toolbox	UPS	1	$48	$48
	Lodging	Hotel	2	$157	$314
	Rocket Shipping Box	UPS	1	$25	$25
	Uber to LAX	Uber	2	$34	$68
	Car Rental	Enterprise	2	$444	$888
	Gas	Gas Stations	1	$50	$50
	Plane Tickets (Round Trip)	Southwest Airlines	8	$275	$2,200
	Uber to UCLA	Uber	2	$34	$68

Above is the budget plan for the 2019-2020 NASA USLI competition season for Bearospace at UCLA. Incorporated in the Projected Unit Price are estimates on taxes and shipping/handling fees provided in quotes and estimates by market vendors.

Funding via UCLA Groups and Organizations

The first aspect of Bearospace's fundraising plan is to apply for grants and donations from various UCLA groups and organizations. Last year, Bearospace at UCLA applied for and successfully won $650 from the UCLA Engineering Alumni Association (UCLA EAA) for material costs and $1875 from the UCLA Student Organizations, Leadership & Engagement (UCLA SOLE) for travel costs.

This year, Bearospace at UCLA has applied to UCLA EAA again asking for $2800 for covering material expenditures. By the submission of this report, the notification and award is expected to be delivered in at most two weeks' time. In order to maximize this award, manufacturing and testing leadership are advised to not purchase materials unless if significantly necessary, or to limit purchases to small cost items so that more expensive items can be covered by the donation. Should the team not hear back two weeks from the date of this report's submission, material purchasing shall continue regardless of donation notification, as manufacturing and testing becomes an absolute necessity running up to the full-scale rocket vehicle demonstration flight and payload demonstration.

In addition to UCLA EAA, UCLA SOLE grants are also available, though for this competition they may not be as readily applicable as last year. UCLA adheres to the passing of Assembly Bill 1887, which bans state-funded and state-sponsored travel with State General Funds to seven US states for the possession of laws that discriminate based on sexual orientation, gender identity, and gender expression, or to states that have passed a law repealing such protections:

1. Alabama
2. Iowa
3. Kansas
4. Kentucky
5. Mississippi
6. North Carolina
7. Oklahoma
8. South Carolina
9. South Dakota
10. Tennessee
11. Texas

Due to this travel ban, Bearospace leadership must ascertain the exact nature of what constitutes state-funded and state-sponsored travel, ie if any money in a school account is "state-sponsored", if donations through UCLA SOLE are "state-sponsored", what UCLA SOLE grants classify as “state-funded”, etc. Should this become a significant problem for team members looking to be sponsored for competition travel, accommodations could be sought out such as if traveling to a nearby compliant state and then traveling to Alabama is legitimate, or even if UCLA Engineering faculty can vouch and intervene on the team’s behalf.

Funding via Corporate and Industry Sponsorships

One of Bearospace’s major goals this year is to create and retain industry relations and sponsorships. This can be through in-kind donations, such as two 14”x16” cured carbon fiber sheet donations provided by Tencate recently for our project, or through financial support and monetary donations. This second of the two is the most useful, as pure monetary donations are flexible in terms of what they can be spent on, from materials to travel expenditures. The latter of this is the most significant group of expenditures, both in terms of total magnitude of cost and each individual item’s cost.

To reach out to companies, a sponsorship proposal has been developed and will be sent to interested industry representatives, and advertisements will be cold sent to local businesses and companies that align with Bearospace values, such as a focus on engineering interests and under-represented minorities in STEM. Lockheed Martin and VACCO Industries have both expressed interest, and relations are currently being made. Additionally, UCLA External Affairs have reached out on Bearospace’s behalf to aerospace-focused companies on the UCLA Dean of Engineering’s Corporate Advisory Board to gauge interest in sponsoring the only UCLA Engineering technical project focused on under-represented minorities in STEM.

6.4. Timeline

Provided below is the Bearospace at UCLA project timeline, organized by month and denoting milestone development periods and submission dates, project primary phases, and academic breaks and events. Every milestone is given at least a week of early drafting and three days of final editing before submission so as to better address milestone requirements provided in the 2019-2020 NASA SL Handbook.

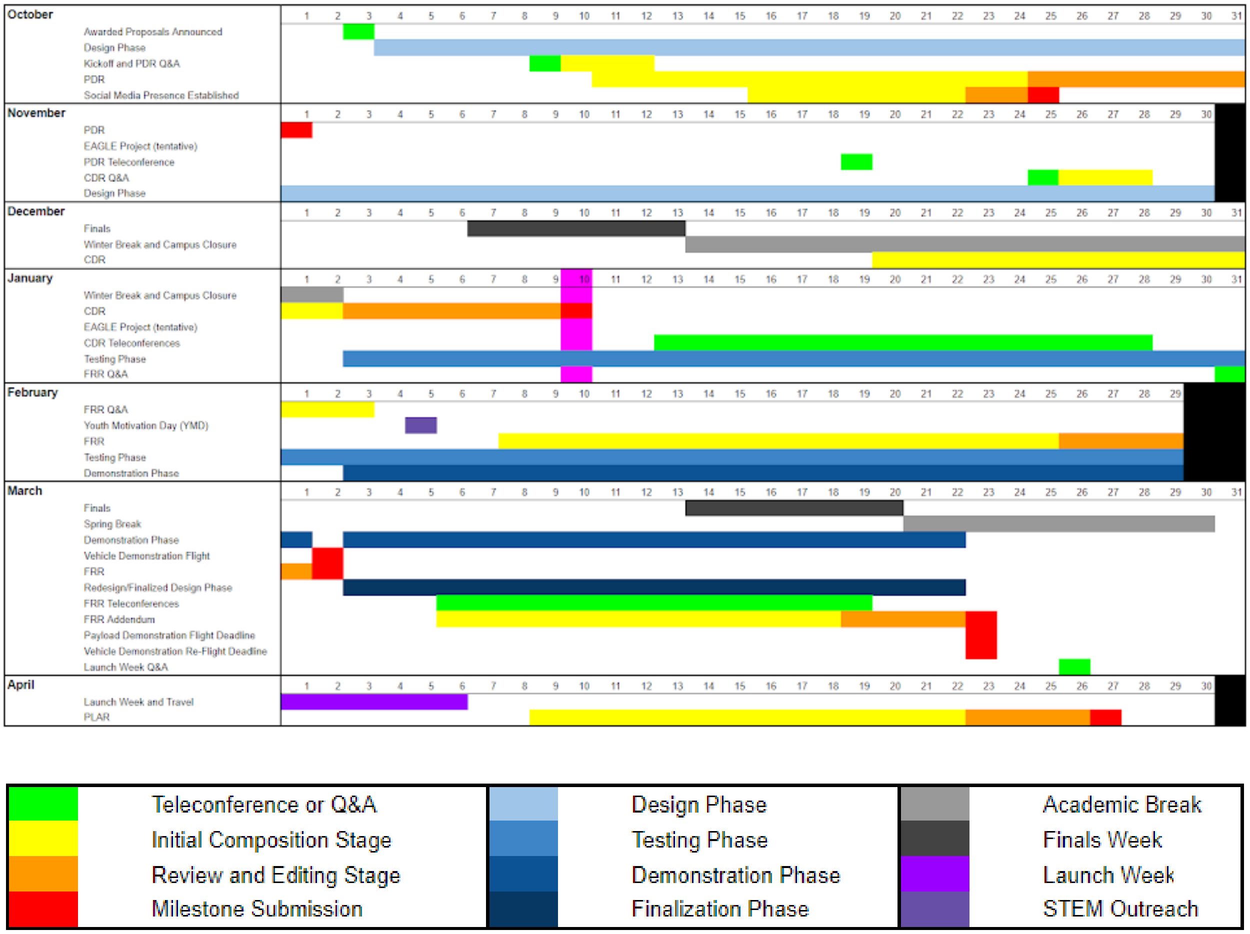

Figure 84: Gantt Chart

Referencing the project schedule, the definitions for the primary phases are as follows:

1. Design Phase (4 Oct - 30 Nov): Following confirmation of an awarded proposal, each subteam will begin designing their respective systems for the entirety of fall quarter. This includes initial sketches and designs of system layouts, as well as sourcing appropriate components and materials. During this time, the PDR will be due.
    a. Structural subteam: host workshops on using power tools, OpenRocket simulation software, and Solidworks software, design structural layout of rocket body, conduct virtual simulations of proposed rocket design, and begin manufacturing rocket structural components.
    b. Electrical subteam: host workshops on Arduino programming and basic soldering, design electrical and recovery systems of the rocket, and source electrical components.
    c. Payload subteam: design the rover payload and its rocket housing, and begin manufacturing rover components.

2. Testing Phase (Jan 3rd - Feb 29th): At the start of Winter Quarter in early January, subteams will progress to finishing up component manufacturing/assemblage and begin system testing. During this time, the CDR will be due.
    a. Structural subteam: finish component manufacturing, practice and ensure proper rocket assemblage with payload and electrical systems, conduct testing of rocket structural integrity, and prepare and launch rocket for demonstration flights.
    b. Electrical subteam: finish component sourcing, conduct tests on antenna system, recovery system, and payload deployment, and prepare recovery and payload deployment systems for demonstration flights.
    c. Payload subteam: finish rover assembly, conduct tests for payload integrity during stresses of launch and landing, and prepare payload for demonstration flights.

3. Demonstration/Finalization Phase (23 Feb - 22 May): This phase runs in conjunction with the Redesign/Finalized Design Phase, to allow results from system demonstrations to inform needed changes of initial and intermediate designs to produce final designs. During this time, the FRR, the Vehicle Demonstration Flight, and the Payload Demonstration Flight will be due.
    a. All subteams: conduct demonstration tests and flights, review results of demonstration tests and flights, and make necessary, informed changes to initial/intermediate design choices to better meet USLI requirements and goals.