Bearospace at UCLA
(LEXS)
Lunar Environment eXcavation Simulation
2019 - 2020 NASA Student Launch
Flight Readiness Review (FRR)

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1. Summary of FRR 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”x6”
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:	12 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 wheels 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 CDR

2.1. Changes to Launch Vehicle

As of the submission of the CDR, several minor changes to the structural layout of the launch vehicle has occurred. These changes have been listed below, and will be addressed in greater detail in 3.1.3.

1. Shifting of the payload, REA, and electronics bay rearward by 1 in
2. Reinforcement of locking mechanism with aluminum sheet
3. Shock cord extension for the REA
4. Resizing of main parachute

2.2. Changes to Payload

Since the CDR, the payload has undergone a few major and minor changes. These changes are listed below and are discussed in greater detail in section 4.1 of the report.

1. Traction system changed from treads to non-differential wheel system
2. Introduction of the DC motor holder and greater motor offset tolerance within chassis
3. Bigger holes within upper ebay for easier wiring
4. Removal of flight controller within electronics system
5. Video camera retention system added to ebay cover

2.3. Changes to Project Plan

As of the submission of the CDR, less focus has been placed into obtaining grants due to the difficulty of being approved to go to a state upon which a California travel ban has been placed, and more on obtaining industry sponsorships. THis approach has been fairly successful, as AErospace Corporation agreed to become Bearospace's first industry sponsor. Bearospace will likely continue using this approach to obtain more sponsorships and make the project more financially stable for future competition seasons.

2.4. CDR Action Items

1. *Increase the safety factor of the locking mechanism. A factor of safety of 4 should be considered a minimum.*

After the CDR, it was decided that load bearing interfaces in the locking mechanism would be reinforced with aluminum which can be seen in section 4.1.4.2 under locking mechanism.

Furthermore the component was tested with only wooden components on the outer ring and metal on the inner ring. An impulse force was then applied onto the load-bearing eyebolt by dropping 50 pounds 10 feet through the use of a shock cord. The wooden ring cracked as expected but the inner component reinforced with aluminum sustained no damage. Though the ring was cracked, the inner component was still retained with the 50 lbs being applied to it. It is expected that, through the reinforcement of the outer ring with aluminum, the component will not fail at all. More about this test is located in section 7.1.1. Vehicle Component Test Plans/Status.

3. Vehicle Criteria

3.1 Design and Construction of 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 Changes Made to Launch Vehicle

The final launch design configuration has not been altered since the submission of the CDR, though several alternative construction and assembly approaches were employed to better reinforce the structural robustness of the rocket, as well as address complications not clearly visible from the simulation perspective or presented by NASA. These alternative approaches are listed below.

1. Relocation of the REA and Electronics Bay Rearward
    a. It was noted during the CDR Q&A Session that there was a concern with the internal volume available for the main recovery harness in the nose cone. As such, the REA (and thus the payload) and the Electronics Bay were shifted rearward to make more internal volume available.
2. Reinforcement of Locking Mechanism with Aluminum Sheets
    a. It was addressed in the CDR Q&A Session that the locking mechanism design employed for accessing the electronics bay, and especially the locking tabs, is the most significant point of possible failure in the entirety of the rocket design. Following this feedback, we determined that it would be prudent to reinforce not

just the tabs, but the outer locking ring as well with aluminum metal so that the interface that applies the recovery deployment isn't just pinewood on pinewood, but aluminum on aluminum, which is then backed by the main pinewood structure.

3. Shock Cord Extension Near REA
    a. Upon manufacturing, it was found to be impossible to attach the quick link to the eyebolt near the REA. Before securing the REA bulkhead, a piece of shock cord was tied to the REA quicklink and the entire assembly was attached to the REA before epoxying. The shock cord extension was then zip tied to the side of the launch vehicle to ensure no tangling with the REA rods.
4. Resizing of Main Parachute from 10 ft to 12 ft
    a. Upon purchasing the main parachute, it was found that the vendor who promised shipping of the parachute actually lacked the desired item, and so shipped the larger 12 ft main parachute for our use. To account for this larger diameter, the parachute was choked slightly so as to increase the descent rate to something approaching that of the 10 ft parachute.

3.1.4 Component Overview

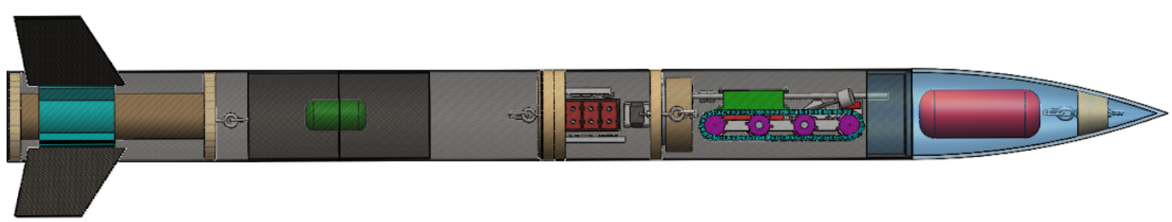

Figure 1: Vehicle Overview

A brief overview of the general components of the launch vehicle will be given here as well as planned dimensions. As- built dimensions and drawings can be found under the construction section.

3.1.4.1 Structural

Components to follow will be reviewed within their harboring parent airframe component. Planned dimensions will also be listed here while actual constructed dimensions will be given in the form of drawings in the construction section.

Nosecone

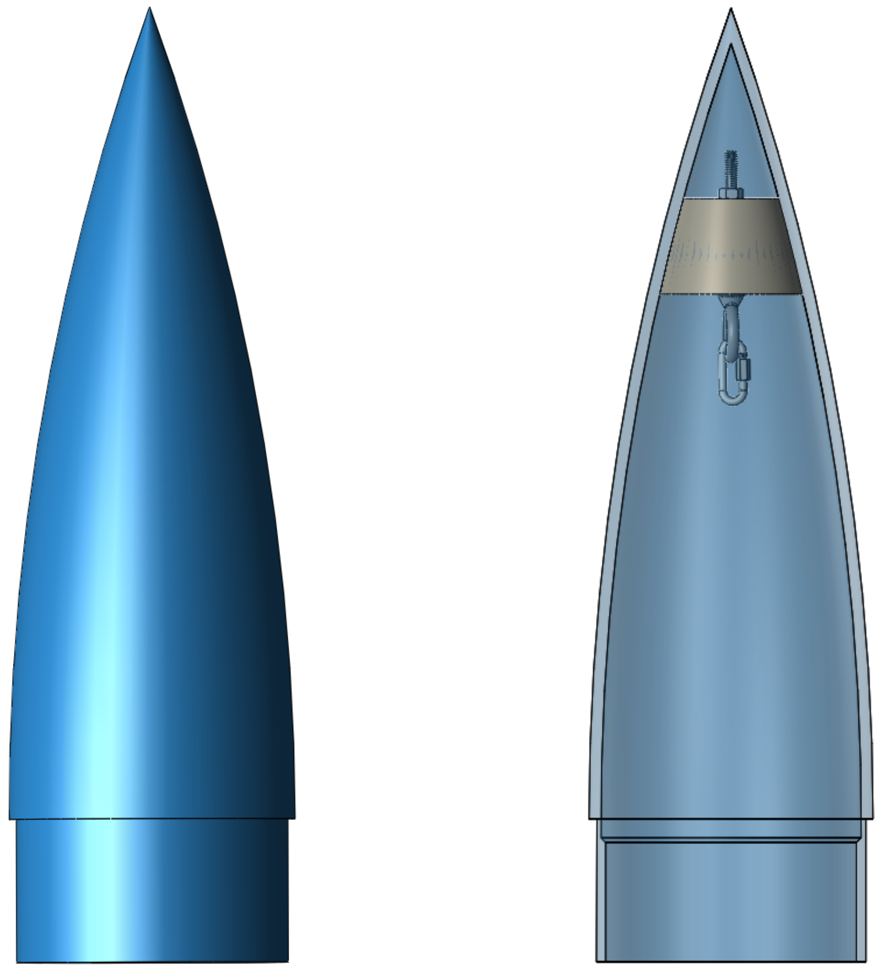

Figure 2: Nose Cone Overview

Rocket Vehicle Section Weight: 1.98 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

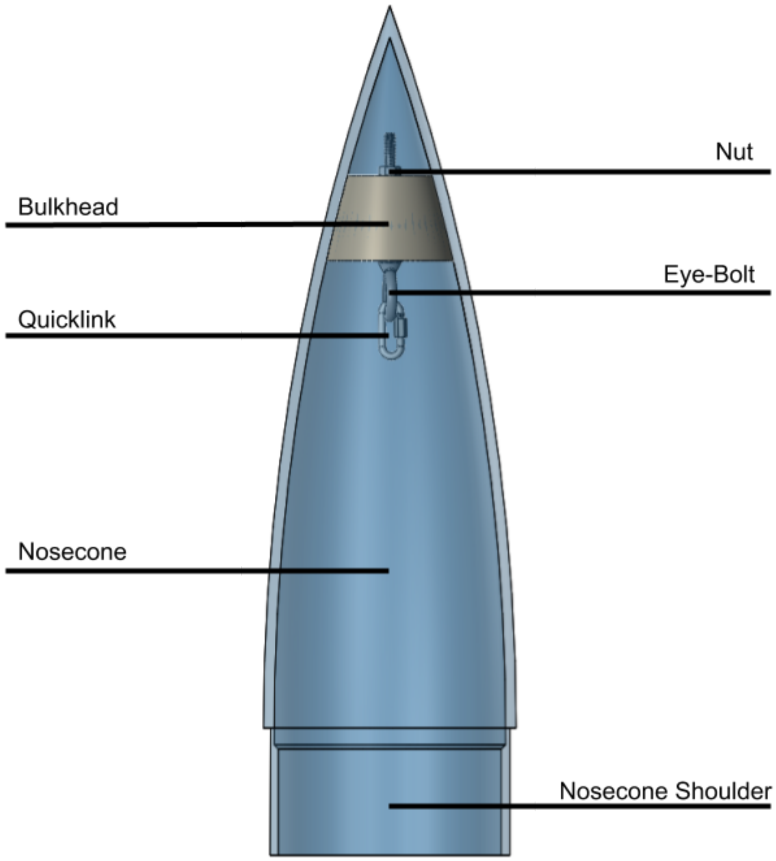

Figure 3: Nose Cone Components

Table 1: Nose Cone Section Components

Component	Material	Dimensions
Nose Cone	ABS Plastic	Cone Length: 17 in. Cone Thickness: 0.2 in. Cone Base Diameter: 5.9 in. Shoulder Length: 3 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.

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.
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	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

	parachute's deployment.	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.

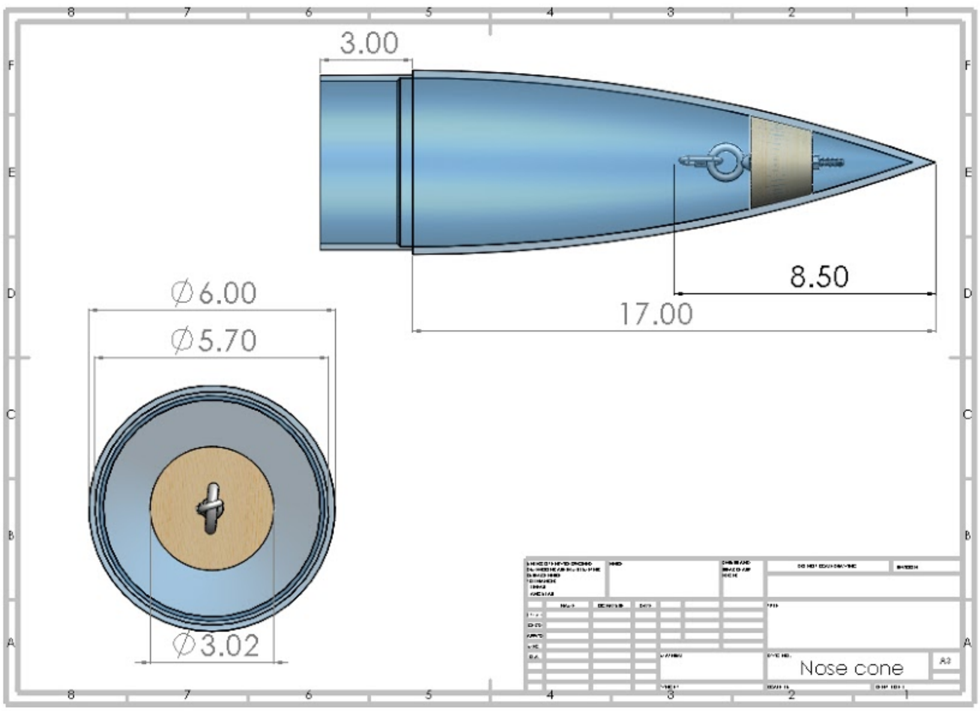

Figure 4: Planned Nose Cone Drawing

Upper Body Tube

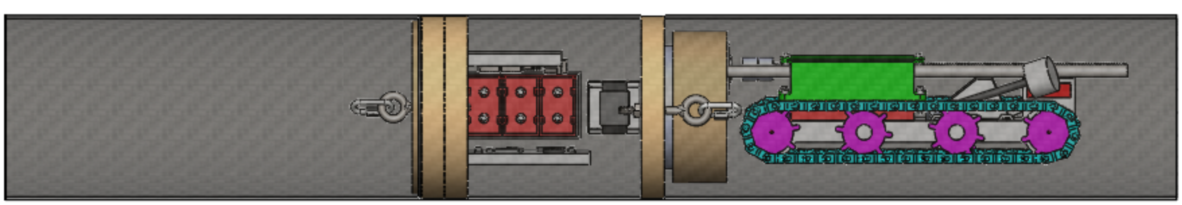

Figure 5: Upper Body Tube Overview

Rocket Vehicle Section Weight: 10.68 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

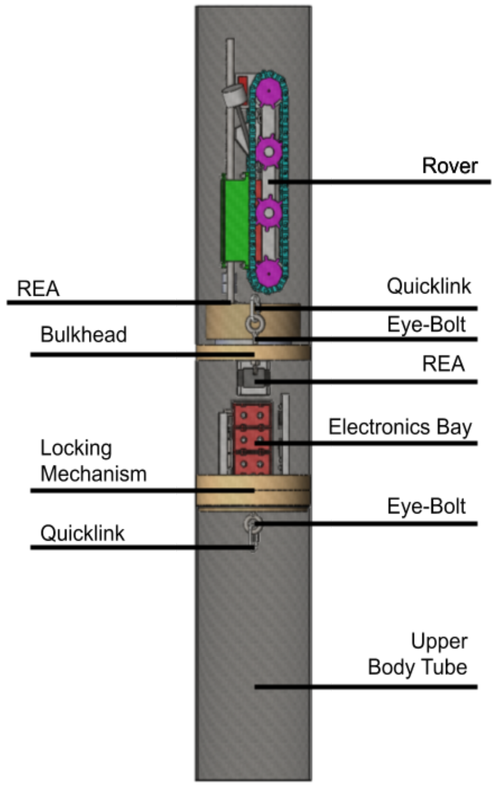

Figure 6: Upper Body Tube Components

Table 2: 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

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 2: 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 within the upper body tube is found below. More detail on the rover and REA will be given in their respective sections to omit repetition.

Lower Body Tube

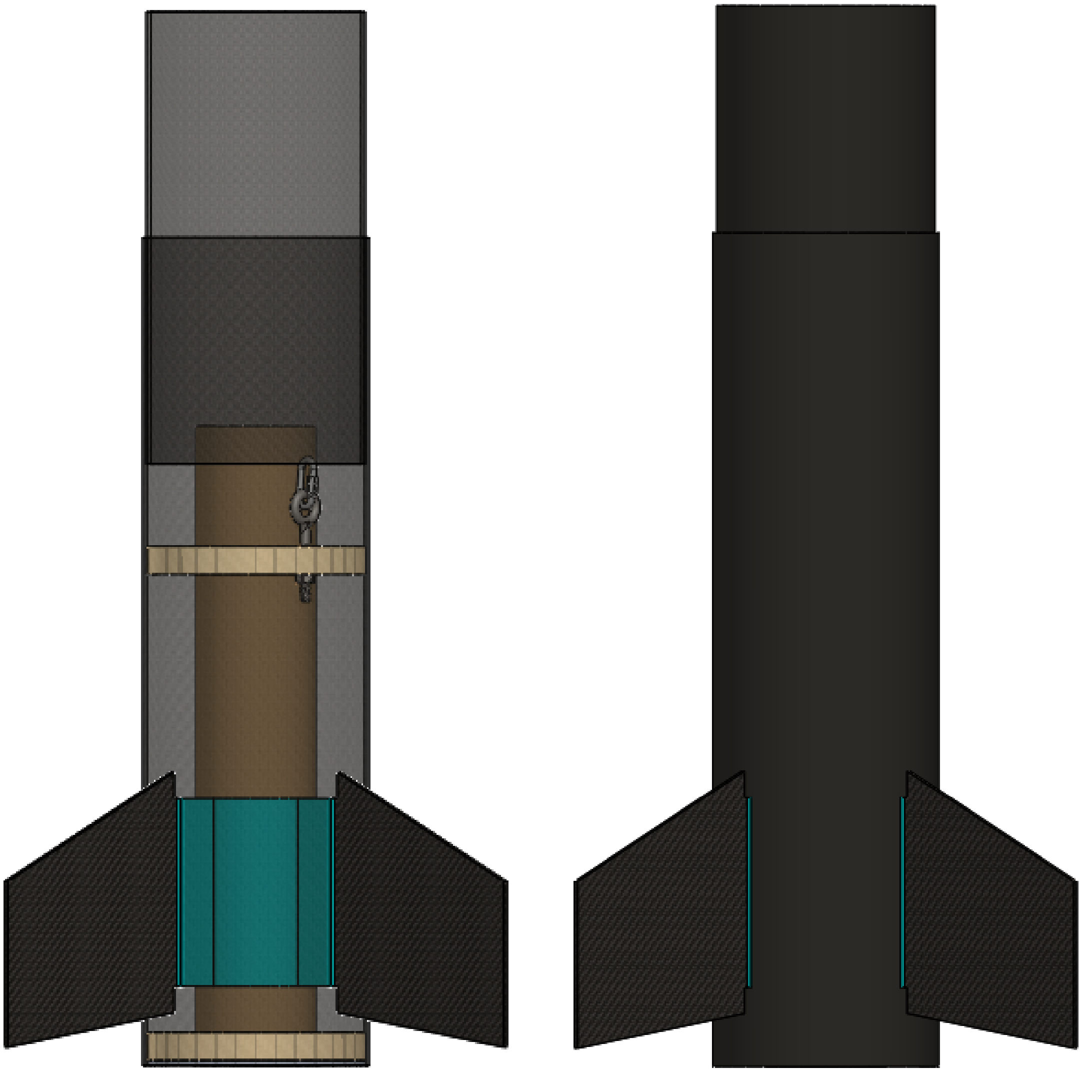

Figure 7: Lower Body Tube Overview

Rocket Vehicle Section Weight (pre-launch): 12.65 lb
Rocket Vehicle Section Weight (post-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
10. The fiberglass coupler, which serves as the interface between upper and lower body tube as well as the in-flight separation point upon drogue parachute deployment.

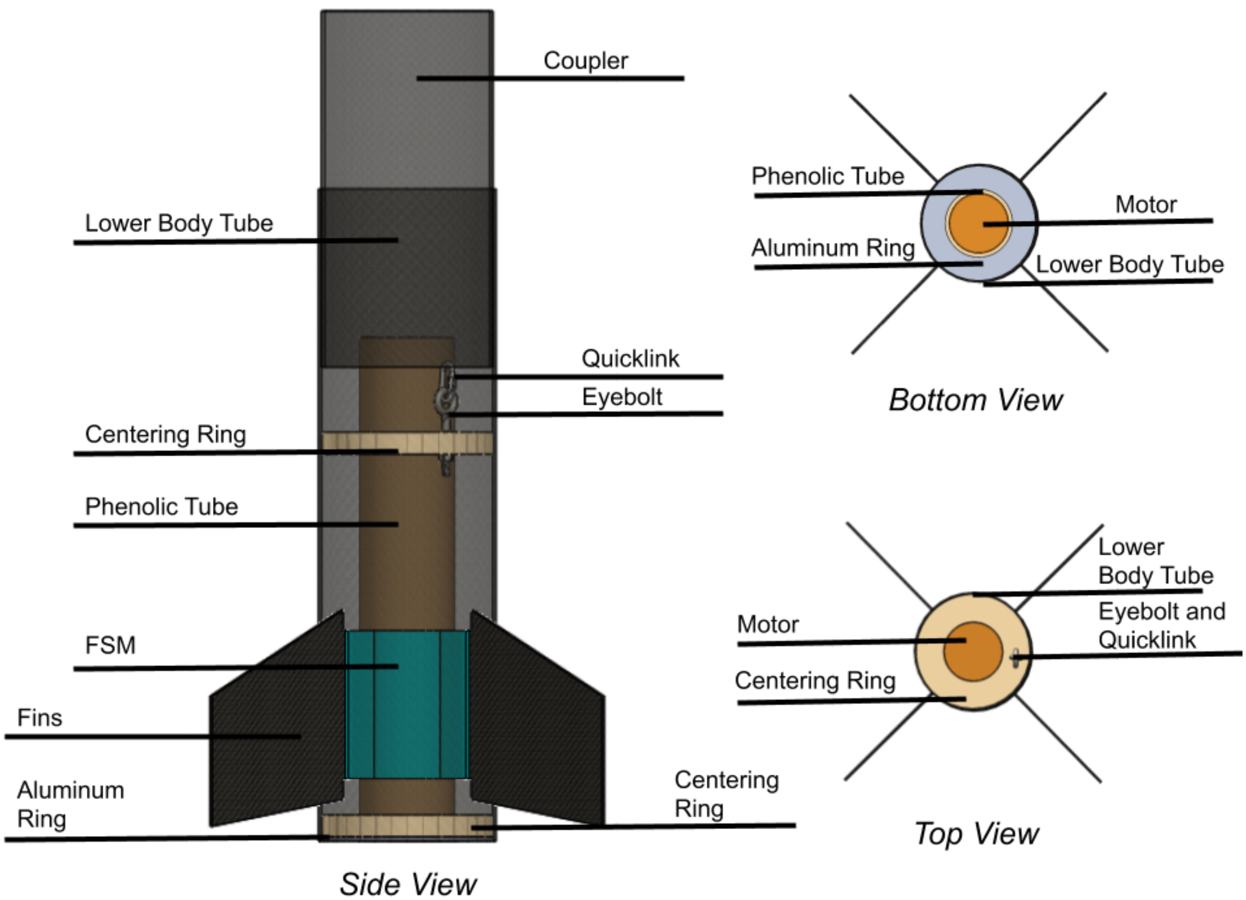

Figure 8: Lower Body Tube Components

Table 3: 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.
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.
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
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.

3.1.4.2 Electrical

Table 4: Launch Vehicle Electronics Overview

	Part	Purpose
Altimeters	Missile Works RRC3 Sports Altimeter	Act as the main altimeter for deployment of drogue and main chute.
	Stratologger SL100 Altimeter	Act as the redundant altimeter for deployment of drogue and main chute.
GPS	Tiny Telematics Tracker GPS System	Allows the team to locate the rocket after launch.
Battery Supply	2x 9V Batteries	Each individual battery powers a single altimeter.

	1S 1200mAh LiPo Battery	Powers the GPS system.
Switches	2x Latching Push Button Switches	Each individual altimeter has a latching push button switch to safely arm the altimeters from outside the launch vehicle.

3.1.5. Flight Reliability Confidence

The mission success criteria are listed below along with their proposed method of solution.

1. Reaching an apogee within 100 ft of 4100 ft.
   Simulations have been run to accurately approximate the expected apogee and assist the structures team in making any vehicle modification in an attempt to ensure this criteria. More can be found in section 3.3 Mission Performance Predictions.
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.
   Altimeters have been programmed to eject recovery hardware at these altitudes as well as utilize redundancy with back up charges in the case of main charge failure. Furthermore, simulations and physical testing have been done on load bearing hardware within the vehicle to ensure that flight forces can be handled. More about these respective issues can be found in section 3.2.3. Redundancy Features and 7.1.1. Vehicle Component Test Plans / Status.
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.
   The REA has been virtually and physically tested as seen in section 7.1.2. Payload Component Test Plans / Status. In addition, a payload flight was attempted and a re-flight is planned to further prove that this will be met.
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.
   ELectrical elements are discussed in section 3.2.2. Electrical Elements where altimeters are described. Furthermore, altimeter data from the full scale launch can be found in section 5.1 Flight 1 and testing of the altimeters can be found in section 7.1.3. Electronic Component Test Plans / Status

3.1.6. Construction

3.1.6.1. Overview

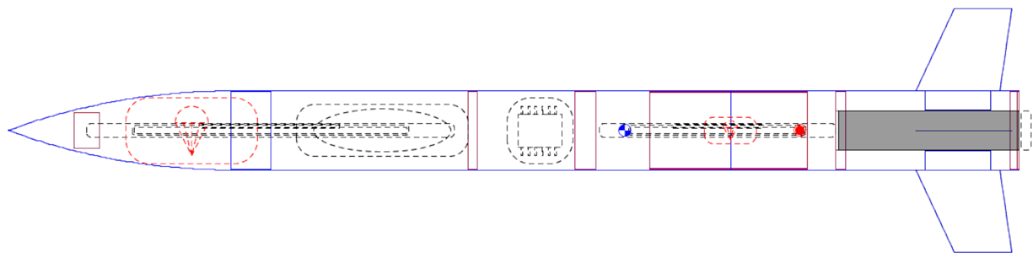

Figure 9: Simulated OpenRocket Rocket Vehicle Layout

As-built, the rocket vehicle length and total weight are presented below.

- Total Length: 77 in.
- Total Pre-Flight Weight: 28.4 lb.

3.1.6.2. Nose Cone Components

Nose Cone

Manufacturing Methodology

1. The nose cone's 3D model is uploaded to a 3D printer, and printed out as four approximately 8 in. parts.
2. The four 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 the nose cone for structural protrusions. If it cannot be appropriately reduced by means of sanding, restart with a 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 a new nose cone.

Construction

Major design requirements of the nose cone components to be printed are the outer and inner faces must be flush post-assembly to decrease drag and create a smooth interface between the nose con and main parachute, and interfaces must allow for small volume for applied epoxy. The first requirement was met by designing each piece with the same nose cone equation and adding a champfer to any protuberances. The second requirement was met by overlapping each interface by 1" and allowing for 1mm between the interface overlap for epoxy. This will be highlighted in the assembly of the nose cone. The stages of the manufacturing process can be seen below. (Note: colors of the nose cone vary due to the iterations of printing and fitting the component.)

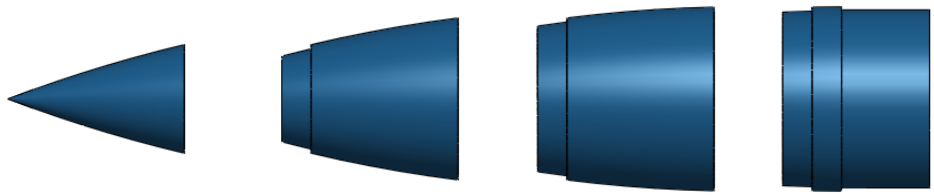

Figure 10: Nose Cone Printing Components

Pieces were 3D printed out of ABS plastic with layering parallel to the shoulder. Upper and bottom most pieces of the nose cone mid-print can be seen below.

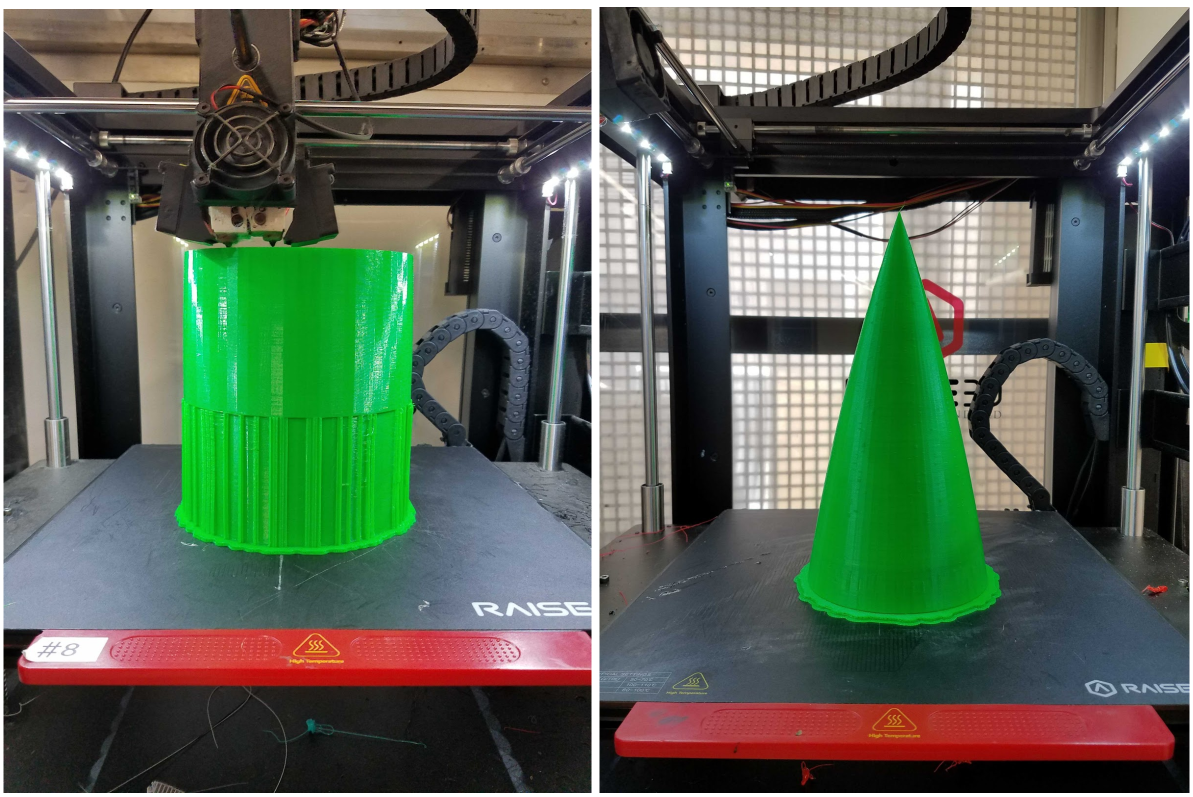

Figure 11: Printing of Nose Cone

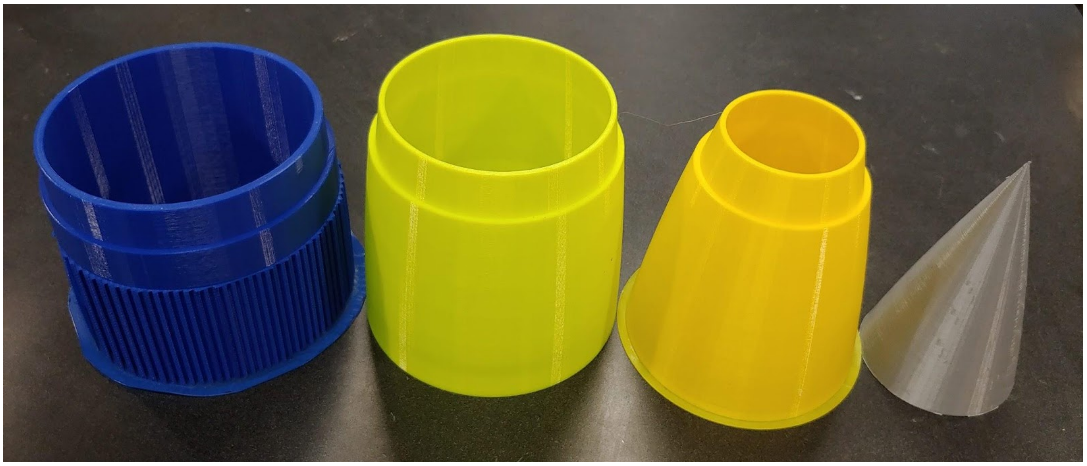

Figure 12: Disassembled Nose Cone Components

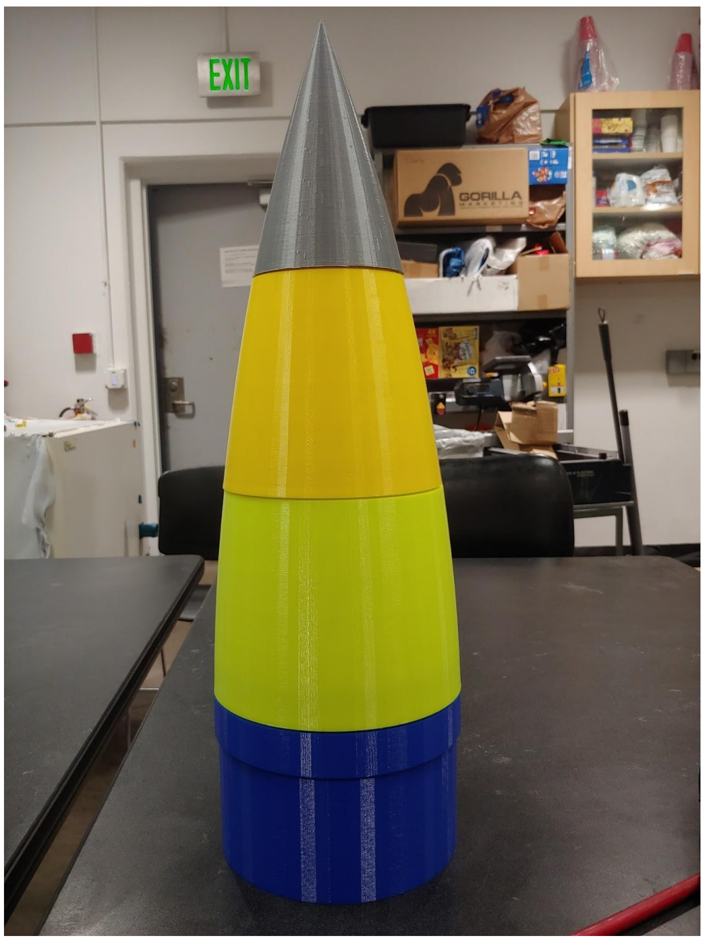

Figure 13: Assembled Nose Cone Components

Bulkhead (Nose Cone)

Manufacturing Methodology

1. Take pine with 0.75 in thickness and prepare 3 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. Anticipated bulkhead diameter found using widest point of nose cone and bulkhead contact.
2. CNC bulkhead layers.
3. Epoxy bulkhead layers together, securing them together with clamps to ensure structural integrity and wiping away excess epoxy.
4. Epoxy eye bolt and nut through all bulkhead layers.
5. Let cure 24 hours.
6. Using a belt sander, sand away sloping sides until it is smooth and comparatively flush to the interior wall of the nose cone.

Construction
CNC footage will be presented in the Lower Body Tube Construction section due to the similarities in construction methods.

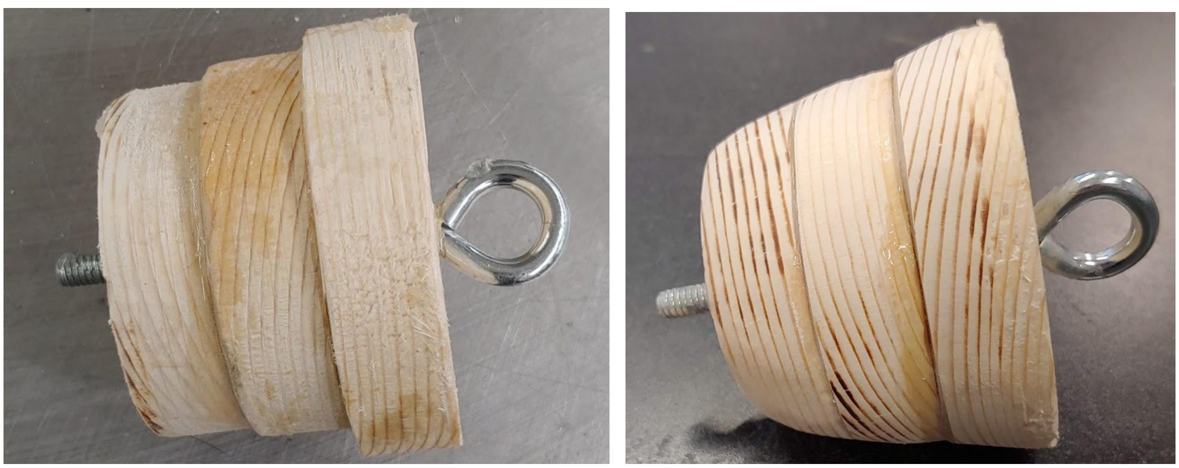

Figure 14: Nose Cone Bulkhead As Cut (Left) and Sanded to Fit (Right)

Figure 15: Nose Cone Bulkhead Sanding Process

Assembly of Nose Cone

1. Epoxy fitted bulkhead into the nose cone so that the outer edge of the bulkhead is continuous with the inner face of the nose cone.

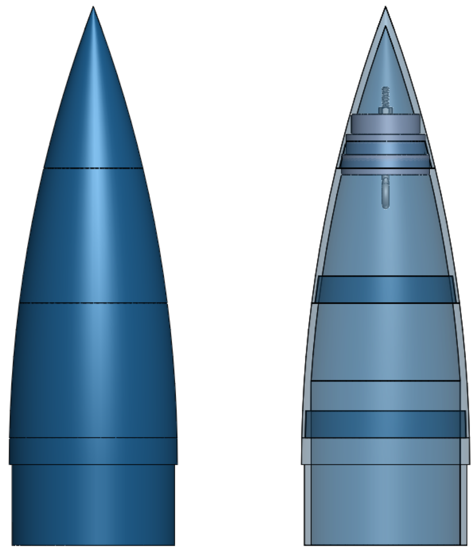

Figure 16: Completed Nose Cone

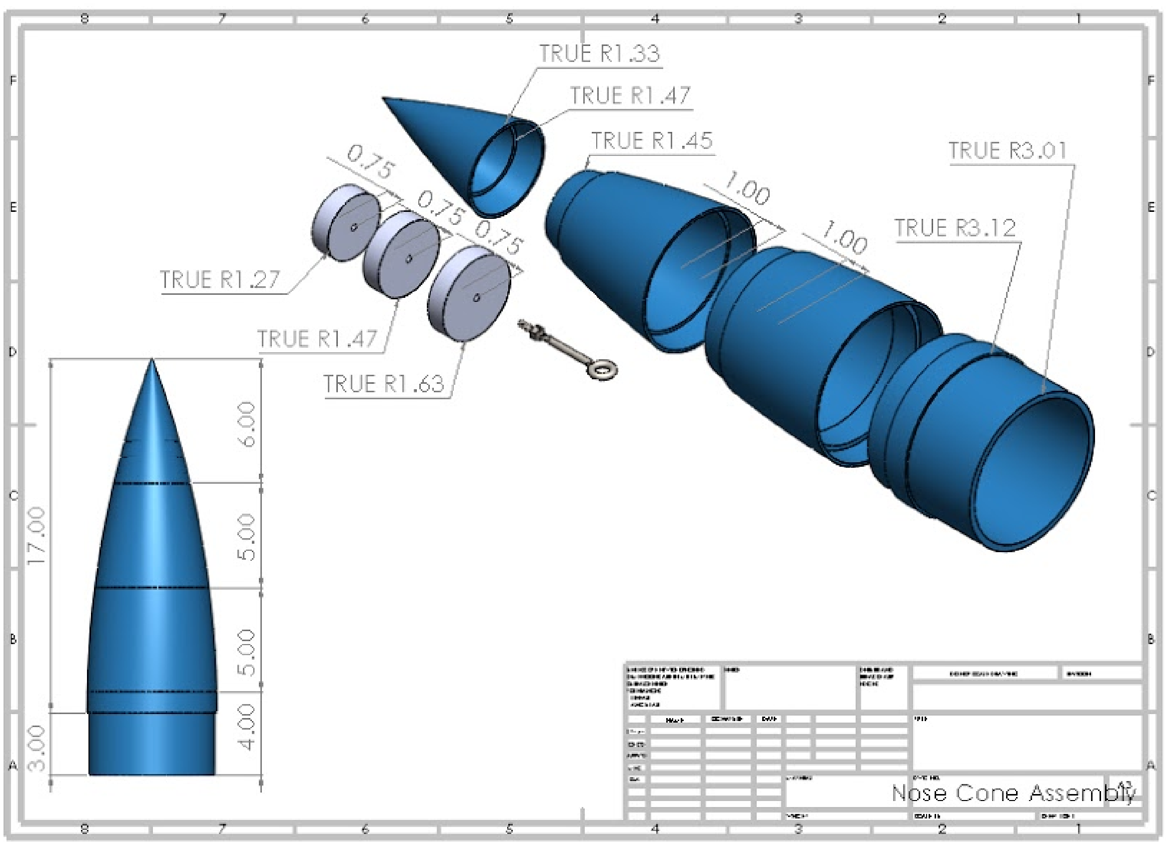

Figure 17: Exploded Dimensional Drawing of Nose Cone Components

Important aspects to note about the image above are the interfaces between the printed portions of the nose cone. Each component has an inner shoulder at its more narrow end and an outer shoulder shoulder at its wider end. As seen with the two narrower components at the top of the image, there is about .02 in between the outer and inner face of the shoulders. This allows for epoxy to fully bond the entire 1in shoulder

3.1.6.3. Upper Body Tube Components

Upper body tube construction includes construction of payload components and the cutting of the tue itself. For completeness, the tube manufacturing will be discussed in Lower Body Tube Components below and the payload fabrication will be discussed in section 4.1.6.

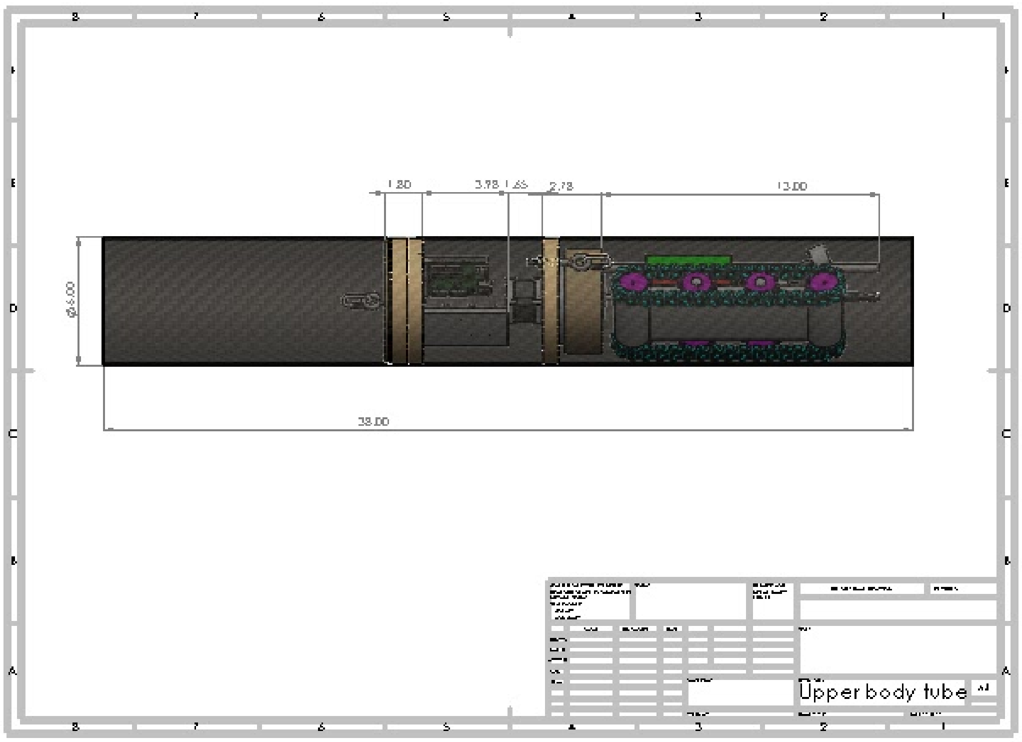

Figure 18: Upper Body Tube Drawing

3.1.6.4. Lower Body Tube Components

Body Tube

Manufacturing Methodology:

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 the 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.

Construction:

Figure 19: Body Tube Manufacturing

To cut both body tubes, masking tape was placed at cutting points as an easy visual marker as where to cut. Below is a dimensional drawing of the component. In grey were the expected dimensions and any dimensions in red signify a change in the as-built vehicle.

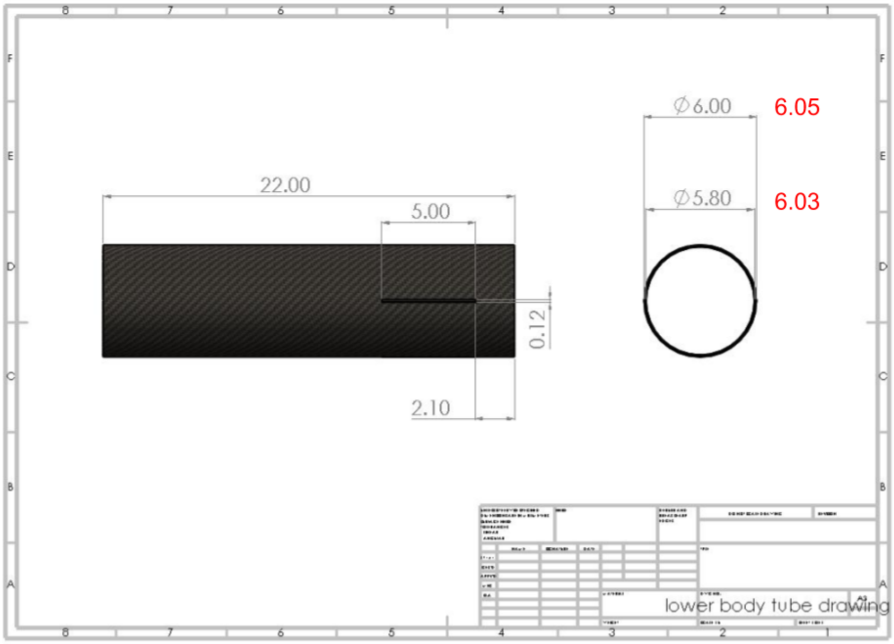

Figure 20: Lower Body Tube Drawing

In this part the only changed dimensions are the inner and outer diameter of the body tube. This is due to a slight imprecision of the manufacturer. This is not a major change to the build and only caused a slight resizing of the bulkheads and centering rings.

Coupler

Manufacturing Methodology:

1. Obtain 12” coupler from vendor.
2. Measure and mark a 12” length portion if longer than 12”.
3. Cut with Dremel with proper PPE.
4. Sand any rough edges.

Coupler was purchased to be the correct size so only installation was needed.

Phenolic Tube

Manufacturing Methodology:

5. Obtain XXX phenolic tube from XXX.
6. Measure and mark a XXX length portion.
7. Cut with Dremel with proper PPE.
8. Sand any rough edges

Construction:

Figure 21: Phenolic Construction

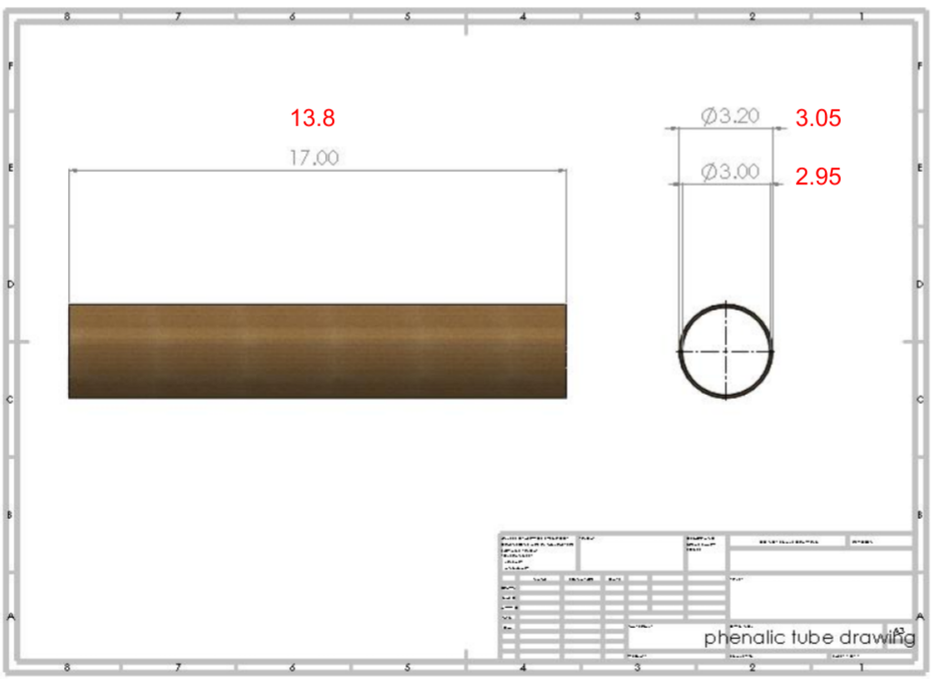

Figure 22: Phenolic Tube Drawing

Changes in the length of the tube is due to a slight design change since CDR. This does not compromise any structural elements. CHanges in the inner and outer diameter of the component are due to the real dimensions of the component not being known from the manufacturer until delivery.

Centering Rings

Manufacturing Methodology

1. Take pine of 0.75 in thickness and prepare 2D drawings on CorelDraw for use on 2D laser cutters.

2. CNC Centering Rings to appropriate dimensions
3. Test fit into the body tube, lightly sanding if too large or recutting larger layers if too small.

Construction

Below is an overview of the CNC process to make the centering rings as well as all other wooden components within the launch vehicle and payload. Precessing what is depicted, parts must be modeled using a computer in CorelDraw. The wood to be used must then be bolted down for the machine to cut. Operation of the CNC was led by Electronics Lead Javier Gomez, who has been certified through UCLA to operate the CNC.

Figure 23: Prepping Wood to be CNCed

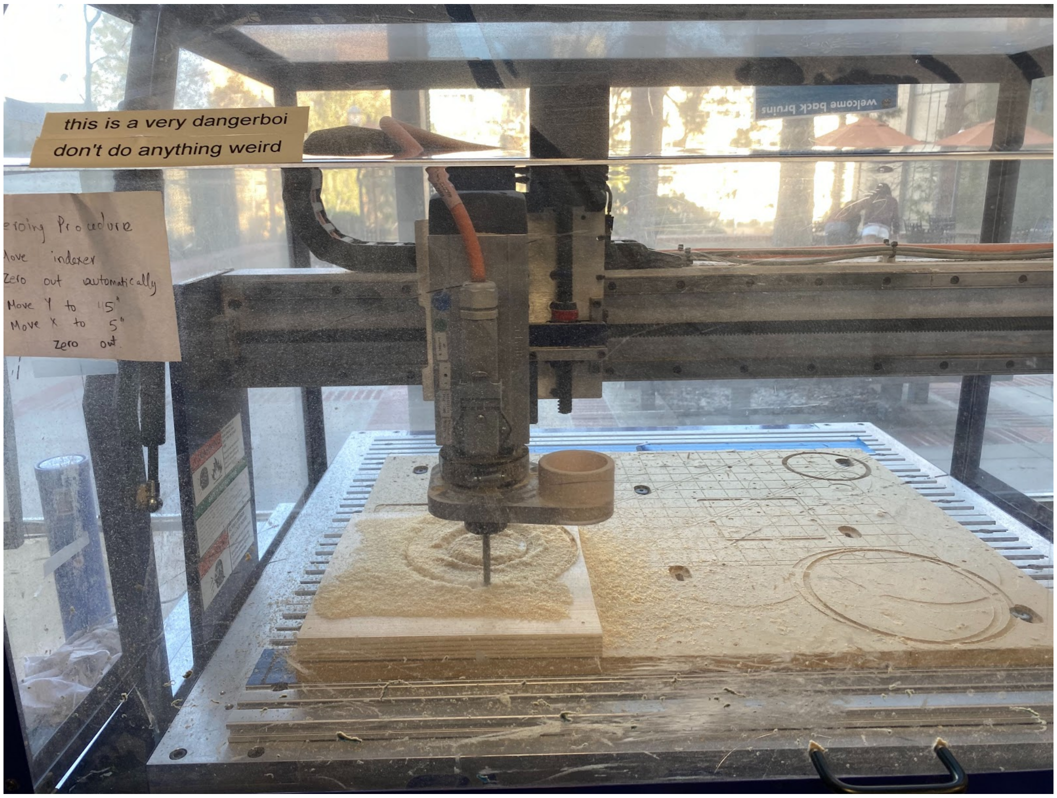

Figure 24: CNC Machining

Figure 25: Detaching Component From Surrounding Wood

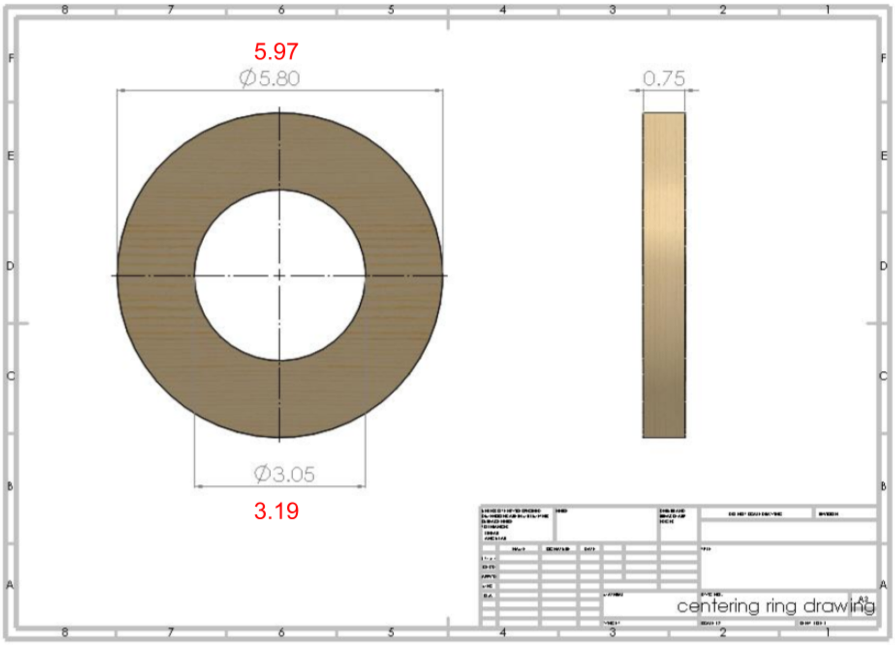

Figure 26: Centering Ring Drawing

The altered real dimensions on the inner and outer diameter of the centering ring are due to the changes in diameter of the phenolic tube and lower body tube.

Aluminum Ring

Manufacturing Methodology

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.

Construction

Due to the nature of the water jet, it can only be operated by trained personnel and no pictures can be taken while it is in use. The trained person who water cut for the team therefore was a UCLA faculty member and therefore there is no documentation of the water cutting process.

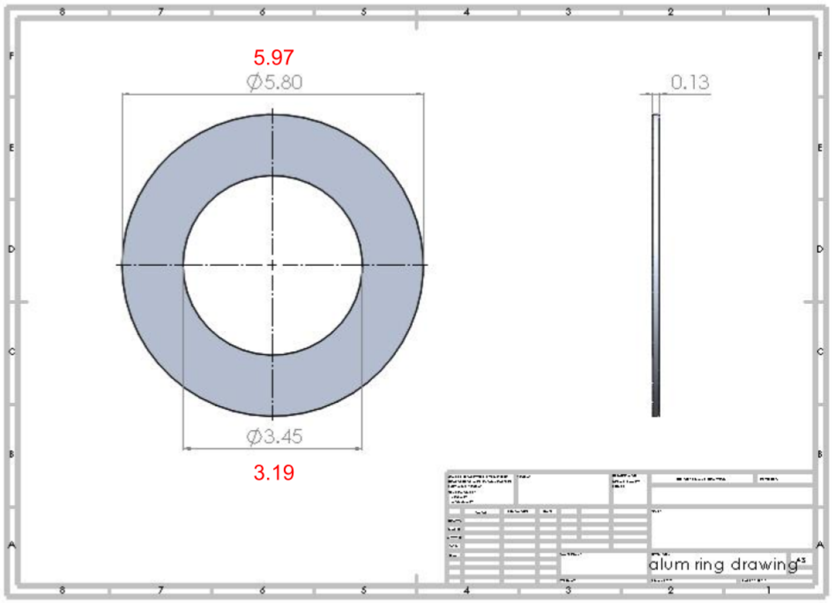

Figure 27: Aluminum Ring Drawing

The discrepancies in the inner and outer diameter are due to the changes in phenolic tube outer diameter and body tube inner diameter. This is a minor change that only had to be taken into consideration during manufacturing.

Fins

Manufacturing Methodology

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.

Construction

Physical construction of the fins is similar to the body tubes in that it is just cutting carbon fiber.

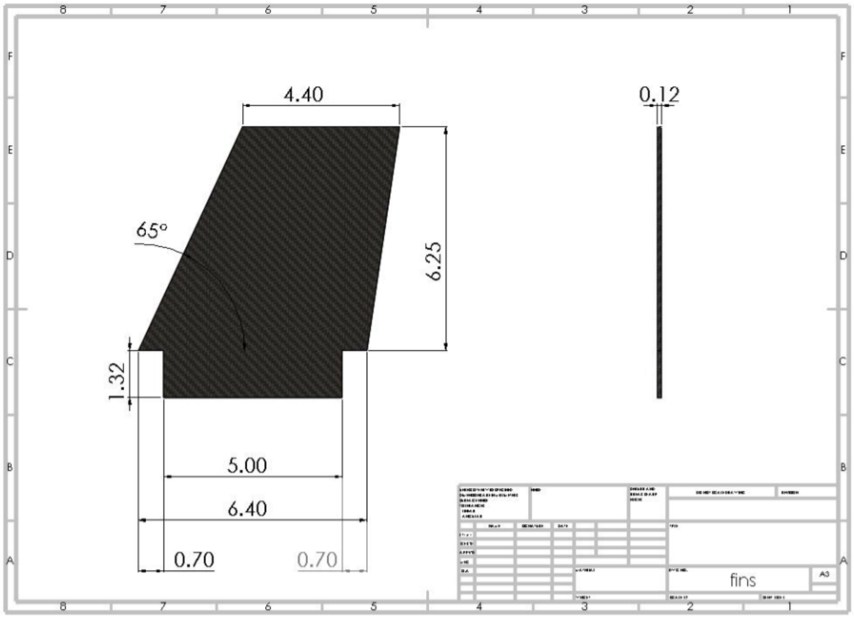

Figure 28: Fins Drawing

While there are some minor errors between different fins due to human manufacturing error, the general dimensions have not been changed from the planned dimensions.

Fin Securing Mechanism

Manufacturing Methodology

1. The FSM's 3D model is uploaded to a 3D printer, and printed out as one whole piece
2. Visually inspect the 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 fits FSM onto a phenolic tube. If it is too small or too large, reprint a new FSM with a different size.

Construction

FSM was printed similar to the nose cone components in that it was made from ABS plastic with layers running perpendicular to the fin slots.

Figure 29: Sanding FSM to Fit

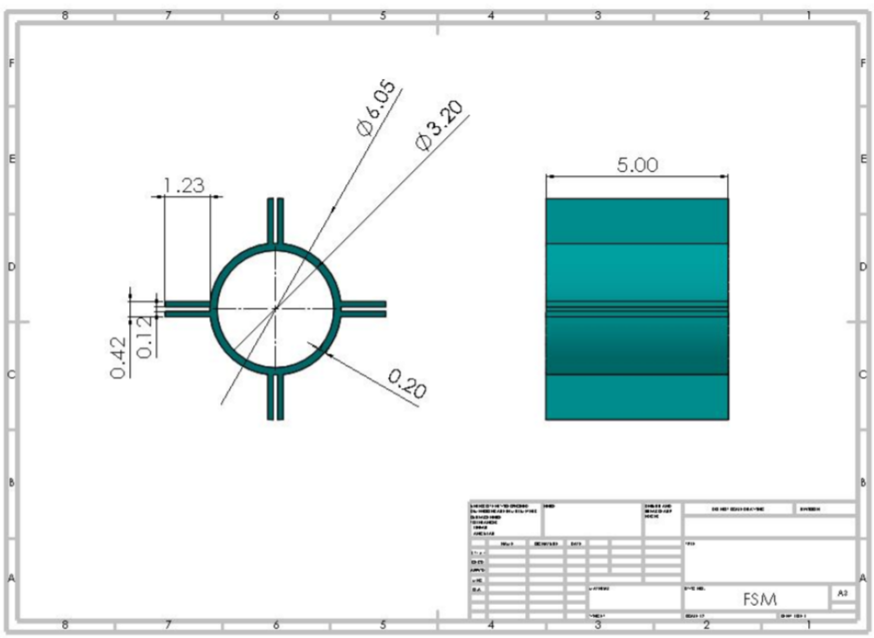

Figure 30: FSM Drawing

Due to the printed nature of the component, dimensions did not drastically change from planned part to manufactured part.

Assembly Methodology

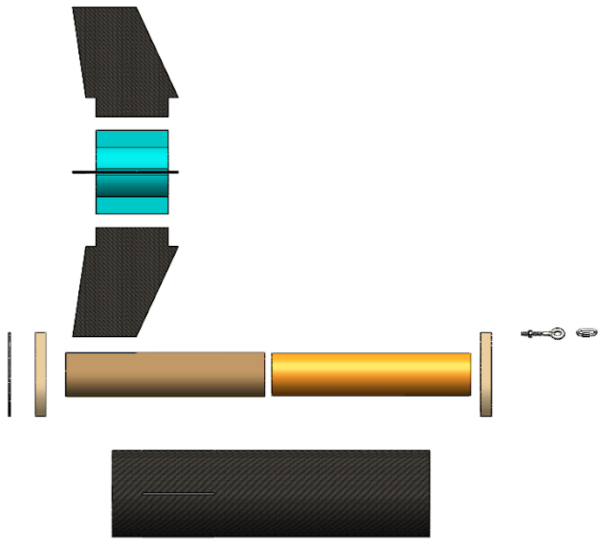

Figure 31: Upper Body Tube Assembly

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 the forward end of the 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.

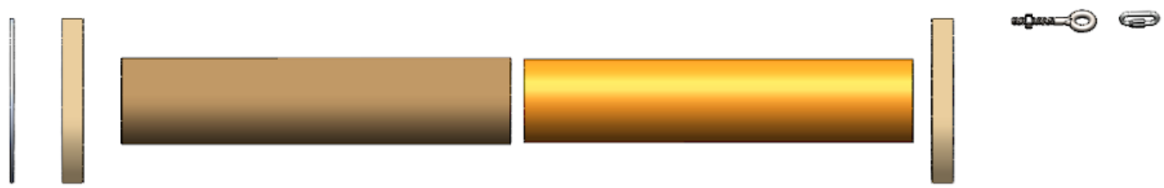

Figure 32: Motor Stabilizing Assembly

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.

Construction

Above methodology was followed and images to assist understanding are shown below.

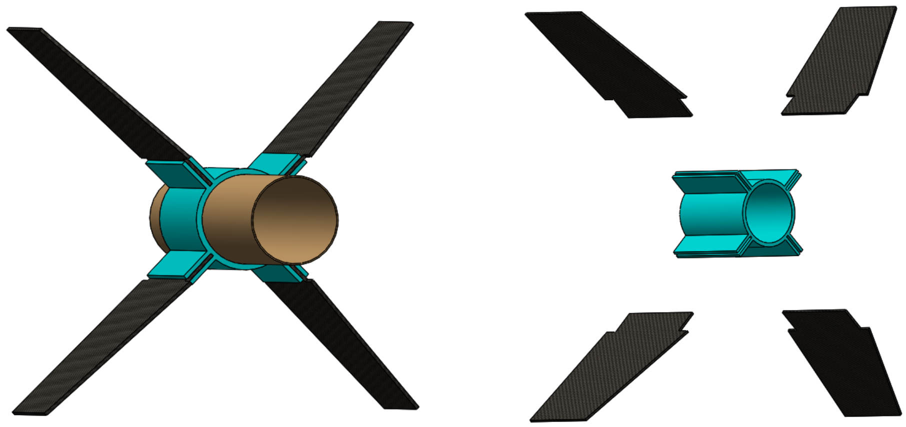

Figure 33: FSM Overview

Steps 7 through 9 of the assembly refer to the installment of the FSM and fins. Above is a diagram showing the interfaces between these two components as well as the phenolic tube. Tabs are fully enclosed within the FSM and constructed version is very similar to above. Due to the nature of placement of the component, it cannot be photographed after placement.

Figure 34: Epoxy Application

Epoxy is applied via wooden sticks after all preparation steps. Above a member is depicted applying the epoxy to the phenolic tube before inserting the bottom centering ring. Epoxying is done in a well ventilated area (hence open door) using gloves and a lab coat.

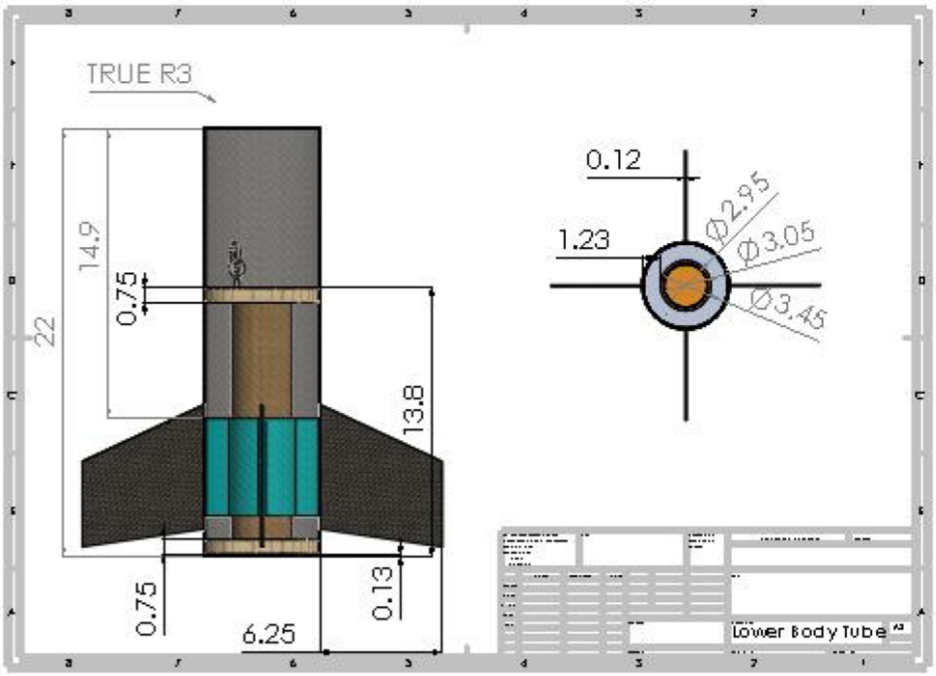

Figure 35: Lower Body Tube Drawing

Above is a drawing of planned dimensions and differing as constructed dimensions (marked in red).

3.2 Recovery Subsystem

The recovery system has been deployed once as part of the full-scale vehicle demonstration launch, and through that and additional impulse testing prior to said launch it has been verified by the team to be adequately robust to justify the continued deployment of the recovery system in future launches.

3.2.1. Structural Elements

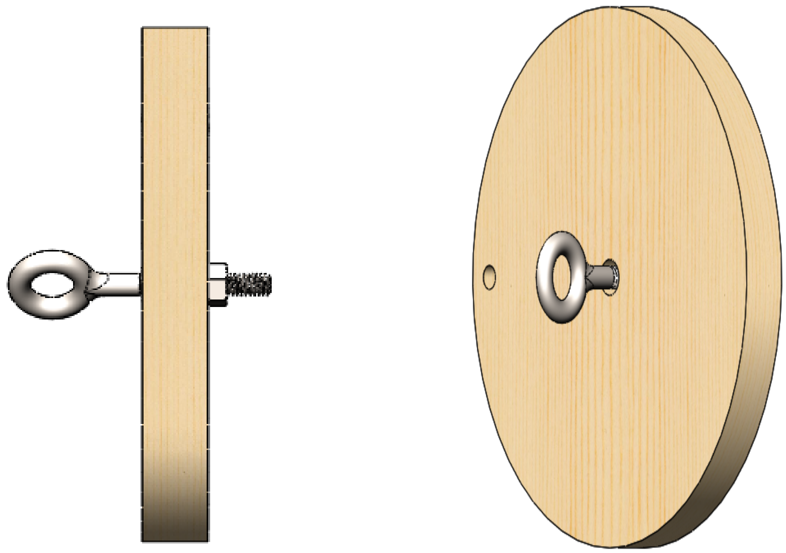

Figure 36: Pine Bulkhead

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.

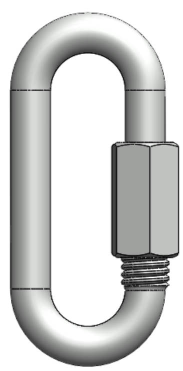

Figure 37: Quicklink

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.

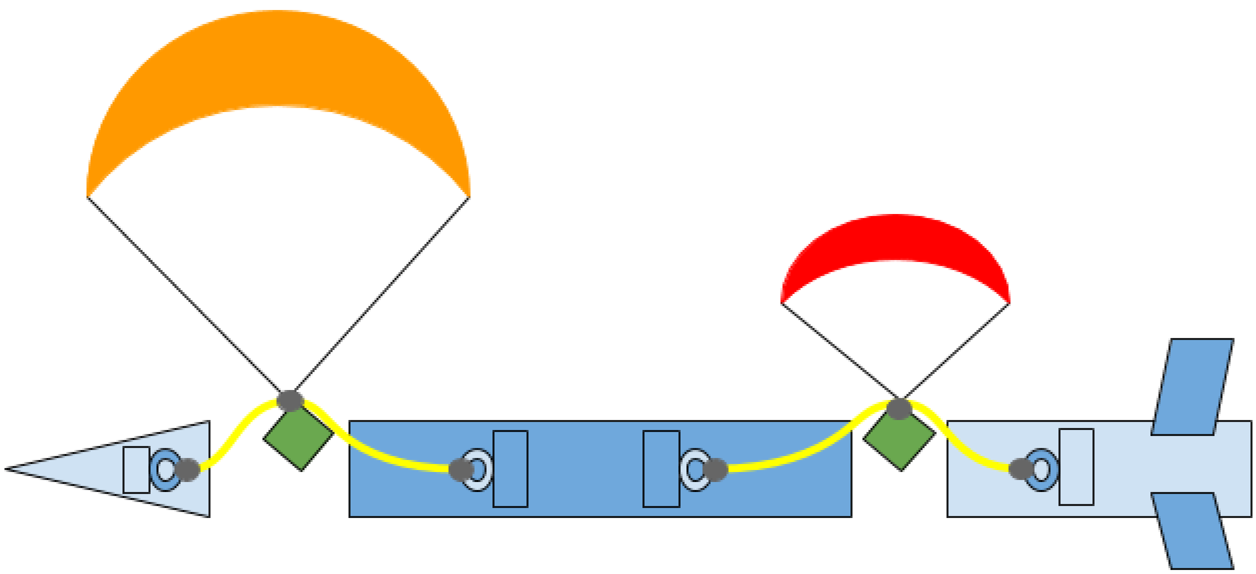

Figure 38: Recovery Component Overview

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.

REA Shock Cord Extension

Due to the size of the rotating portion of the REA, it is not possible to attach a quicklink to the eyebolt post-assembly. For this reason it was decided that a piece of shock cord would be attached to the REA eyebolt that would be permanently attached for easy quick link attachment. Furthermore, to mitigate the risk of the shock cord tangling with the REA rods, the shock cord attachment was ziptied to the inner face of the body tube. Both of these unique aspects can be seen in the as-built images below.

Figure 39: REA Shock Cord Extension

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

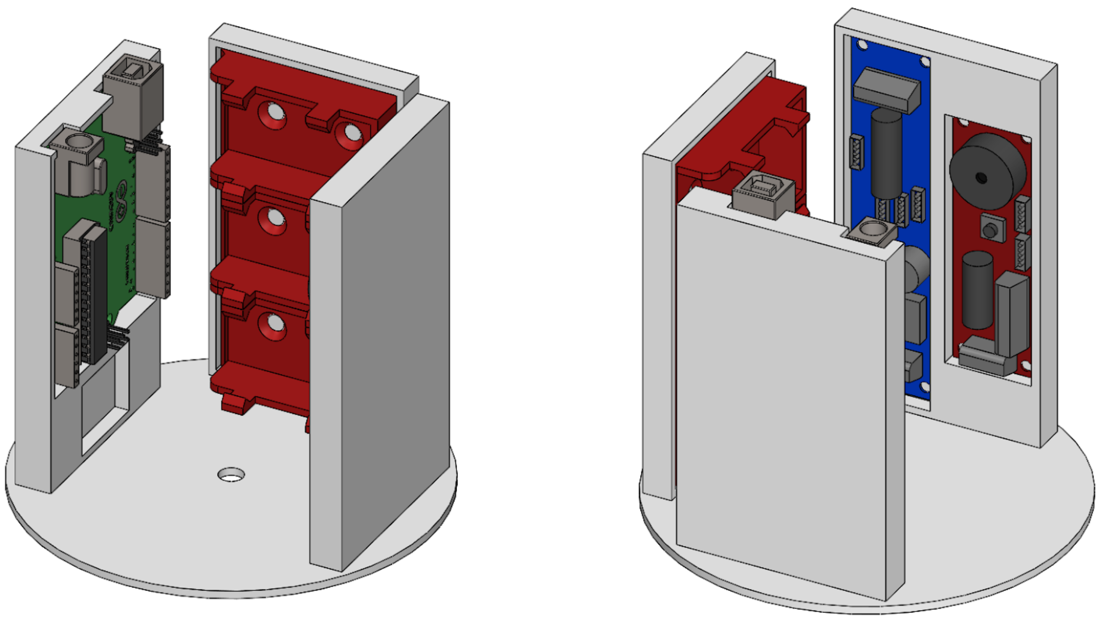

Figure 40: Avionics Sled

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.

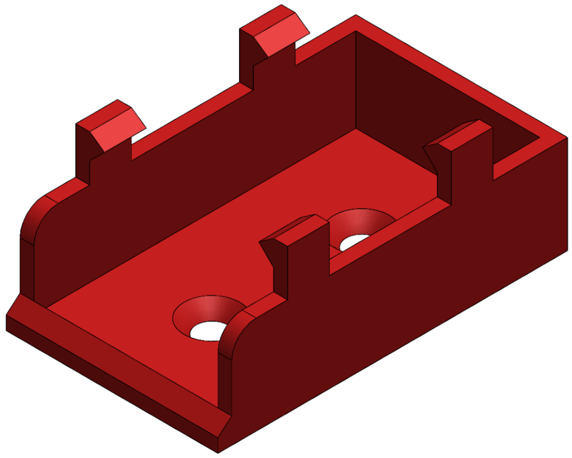

Figure 41: Battery Holder

3.2.2. Electrical Elements

GPS System

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.

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. Bearospace at UCLA 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 GPS 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 T3 GPS will be powered by an alkaline 1S 1200mAh battery and activates using a pair of Anderson Powerpole Connector switches. The current draw of the GPS module onboard the rocket is ~175mA, which means the GPS module will be powered for 6.9 hours. The wiring scheme for the GPS system can be found in section 3.2.5.

3.2.3. Redundancy Features

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.

The Stratologger SL100 and RRC3 Sports altimeter will be selected because they are readily available to Bearospace at UCLA. 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.

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 have its own latching push button as a mechanical switch in order to power them on. The selected latching push buttons are flush with the profile of the rocket and are depressed into the body once activated. The small size of the push buttons make it difficult to be pressed accidentally. A wiring diagram of the altimeters can be found in section 3.2.5.

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:

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

3.2.4. Parachutes

One change implemented was to employ a 12 ft. diameter parachute rather than a 10 ft. diameter parachute of the same coefficient of drag. This was due to the lack of 10 ft. diameter parachutes available from the vendor. As such, a 12 ft. diameter parachute was obtained, wherein the effective diameter and coefficient of drag was reduced by choking the parachute (reducing the length of the shroud lines through tying them in a knot) in an effort to increase descent rate to shorten total descent time.

Table 5: Parachute Sizing and Descent Rates

	Main Parachute	Drogue Chute
Diameter	12 ft	3 ft
Coefficient of Drag	0.97	0.8
Descent Rate (estimated)	14 fps	60 fps
Descent Rate (actual)	18 fps	58 fps

3.2.5. Construction

3.2.5.1 Structural Assemblies

For construction regarding manufactured components, ie bulkheads and centering rings, please refer to Section 3.2.1. The remainder of this section will focus on the assembly of the two recovery harnesses for the main parachute and the drogue chute.

For the main parachute, the first step is to select a point on the shock cord to which the main parachute will affix to. It is recommended that the shock cord for any recovery harness be at least twice the length of the rocket. The shock cord employed by the main parachute is 15.5 ft long, fulfilling this soft requirement. The point is chosen such that it is located at least a nose cone's length away from the center of the cord, so that when the main is deployed, the two attached body sections (in this case the nose cone and the upper body tube) do not hit each other, and are distanced apart due to being attached to two different lengths of shock cord. With this affixation point selected, a series of knots are tied around a quicklink and then wrapped in Gorilla or other duct tape to secure and immobilize the knots. The same is done for the two ends of the shock cords, so that the end result is a shock cord with three quicklinks affixed via a series of knots and duct tape to the shock cord, one at each end and another at least a nose cone's length away from the center. With this prepared, the shorter part of the main recovery shock cord is affixed to the nose cone bulkhead via quicklink and eyebolt, whereas the longer part is affixed to the REA shock cord extension via quicklink. Finally, the main parachute and firecloths are affixed at the main parachute affixation point and at the REA shock cord extension point to protect the main parachute and the payload respectively. Altogether, the main recovery harness has now been assembled and is almost ready for launch, needing only to be folded and packed properly.

The drogue chute harness has the same procedure of preparing the shock cord for affixation, though in this case the shock cord being used is 23 ft long, with the drogue chute affixation point at least a full lower body tube section length away from the shock cord's center, so as to accommodate two longer sections potentially swinging into each other once this recovery harness deploys. Additionally, only one firecloth is needed, as there is only one chute and no payload to protect from recovery ejection charge deployment. After this shock cord has been prepared, it is then attached to the eyebolts in both the upper and lower body tubes.

3.2.5.2 Electrical Assemblies

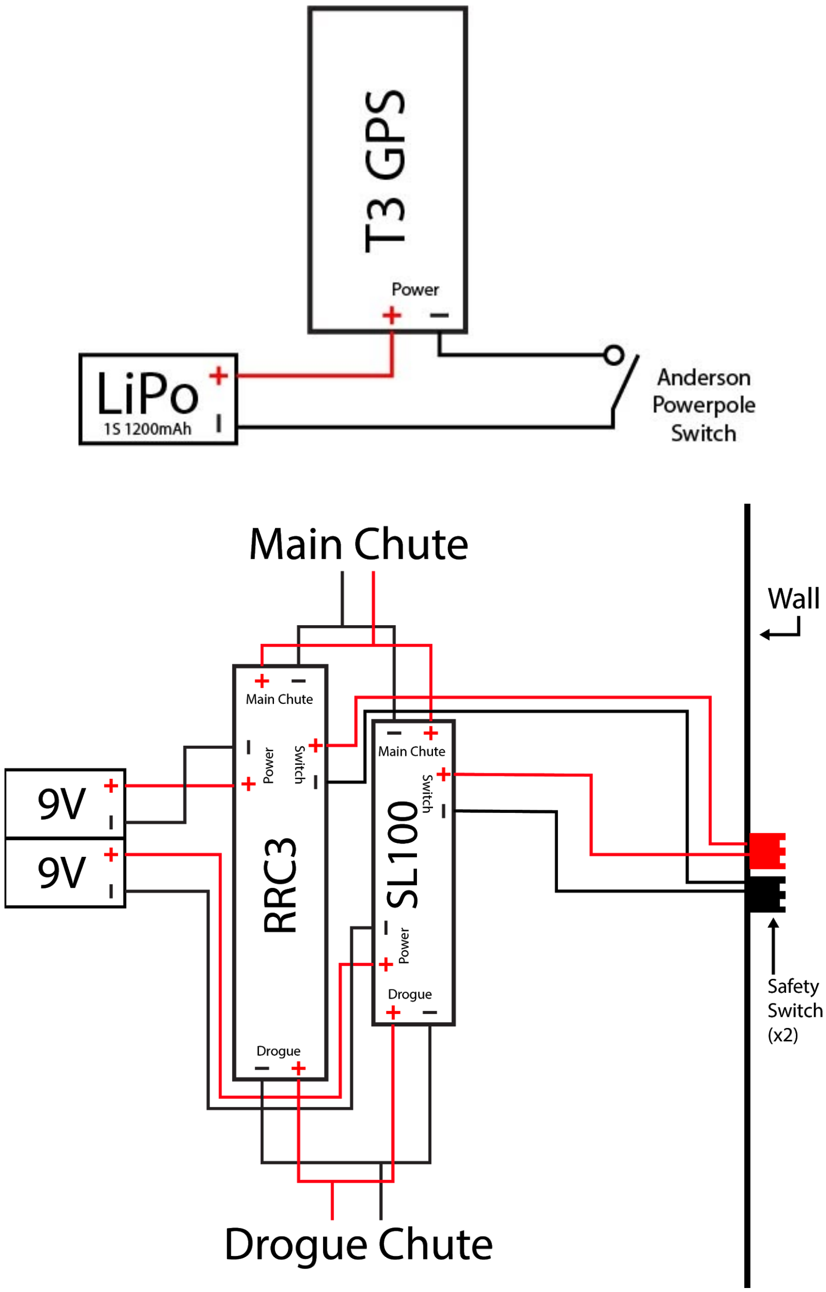

Figure 42: Altimeters and GPS Wiring Schematics

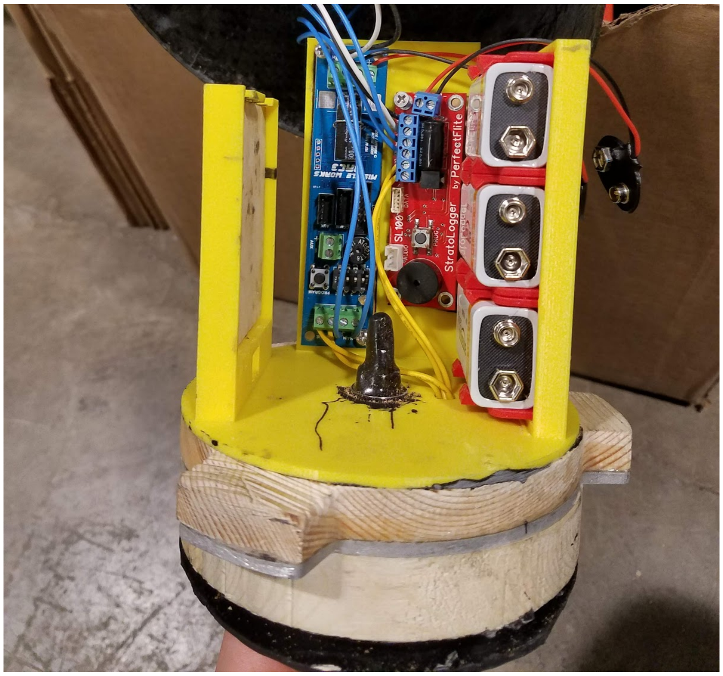

Figure 43: As-Built Avionics Sled with Wired Electronics

3.2.6. Transmitters

Only one rocket locating transmitter exists in the launch vehicle. 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. The transmitter operates on a 250mW power output, which is in compliance with the 250mW limit of all onboard transmitters.

3.2.7. Electromagnetic Sensitivity

In order to prevent interference with critical recovery electronics, an analysis of electrical shielding must be made. Two altimeters, one Arduino Uno, two stepper motor drivers, a stepper motor, and 5 9V batteries are housed within the avionics bay of the launch vehicle. Inside the avionics bay, there is no form of altimeter shielding from the rest of the electrical components, however, none of these devices are meant to generate magnetic fields which can tamper with the performance of the altimeters. The only component that can potentially create a large magnetic field is the stepper motor driver. When activated, the stepper motor driver draws a large current from the 9V batteries. This large change in current creates a magnetic field which can tamper with the altimeter, however, this does not affect the altimeters' ability to deploy the parachutes since the stepper motor driver is only activated after the launch vehicle has landed. By this point, critical operation of the altimeters has passed.

Outside of the avionics bay, there exist two transmitters which can potentially alter the way the altimeters operate. While the GPS transmitter outputs the highest output (250mW) at a lower frequency (which penetrates better through obstacles), the GPS transmitter is located near the nosecone bulkhead, which is ~36in away from the altimeters. Additionally, the altimeters are shielded from the GPS by the locking mechanism, which is composed of two 0.75in slabs of wood and a 0.12in thick sheet of aluminum. The large distance and thick shielding prevent the GPS transmitter from tampering with the altimeters' operation during flight.

The other transmitter onboard the launch vehicle is the video transmitter, which has a frequency of 2.4GHz and operates at 200mW at a distance of ~10in away from the altimeters. While the shielding between this transmitter and the altimeters is a single 0.75in thick wood bulkhead, its lower power output and higher frequency make its effects less detrimental to the altimeters' operation. Additionally, the directional antenna points in the opposite direction of the altimeters, which lessens the potential effect on the altimeters.

3.3 Mission Performance Predictions

3.3.1. Flight Simulations

Using the simulated RockSim as-built rocket vehicle, the following altitude profile was calculated, using weather factors determined from previous Huntsville weather data on the 5th of April, 2019 presented in Table ## and the motor thrust curve for the 2856-L910-CS-0 presented in Figure ##.

Table 6: Huntsville Launch Site Weather Conditions from April 5th, 2019

Time	Temperature	Dew Point	Humidity	Wind Direction
1:53 pm	68ºF	57ºF	68%	Northwest
Wind Speed	**Wind Gust**	**Air Pressure**	**Precipitation Rate**	**Precipitation Accumulation**
8 mph	0 mph	29.39 in.	0.00 in.	0.00 in.

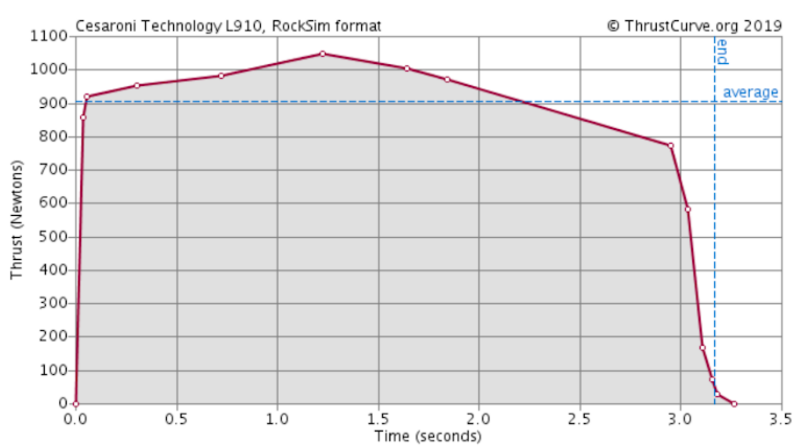

Figure 44: 2856-L910-CS-0 Motor Thrust Curve

With these conditions, the simulations were run ten times to ensure precision of simulation results and detect any possible outliers simulated to be analyzed. During these, care was taken to verify that recovery harnesses were being deployed at proper altitudes and speeds.

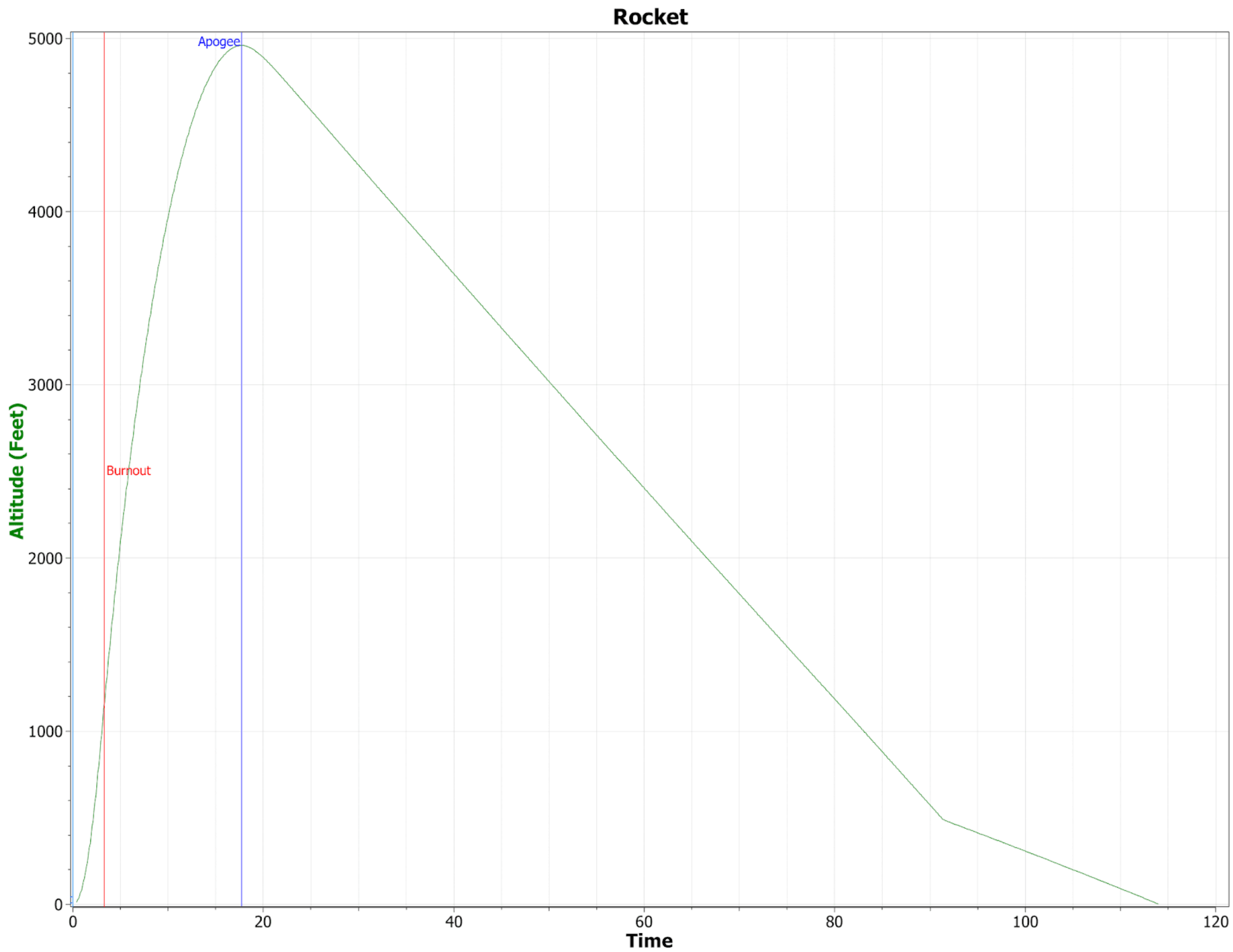

Figure 45: Simulated Altitude Profile for Launch Day

Table 7: Estimate Apogee of As-Built Rocket Vehicle for Launch Day

Trial	Trial 1	Trial 2	Trial 3	Trial 4	Trial 5
Apogee	4959 ft AGL	4959 ft AGL	4959 ft AGL	4959 ft AGL	4959 ft AGL

3.3.2. Vehicle Stability

As the rocket vehicle was constructed and assembled, noting the changes outlined by Section 2, the rocket vehicle's center of gravity (CG) has changed. These changed factors have been directly measured and inputted into the RockSim to more accurately estimate mission performance characteristics. The resulting simulated as-built rocket is provided below in the following figure.

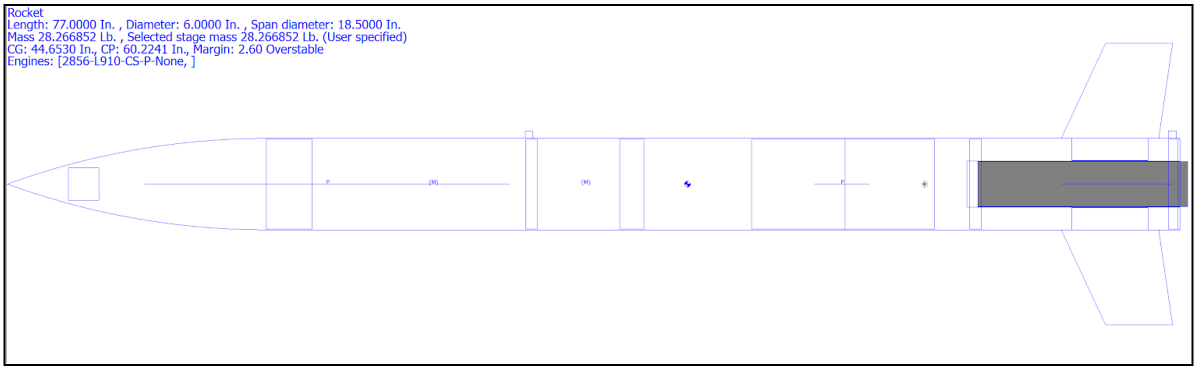

Figure 46: Simulated As-Built Rocket Vehicle

Using this rocket, we can verify the as-built stability hand calculations, where stability is defined as the ratio of the difference between the CP and CG locations measured from the nose cone tip and the outer diameter of the rocket D.

$$Stability = (CP - CG)/D$$

Table 8: Preflight and As-Built Stability Comparison

	Preflight Simulated Rocket	**As-Built Simulated Rocket**
CG Location	46.24 in	44.65 in
CP Location	60.22 in	60.22 in
Stability	2.33	2.60

3.3.3. Kinetic Energy at Landing

Using the main parachute's descent rate determined from the full-scale vehicle demonstration launch outlined in Table ##, the kinetic energy at landing can be calculated for each as-built rocket vehicle section.

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), the main parachute's descent rate determined from the full-scale vehicle demonstration launch outlined in Table ##, the landing kinetic energy of each vehicle section is determined.

$$v_{descent} = 18\,ft/s\ (for\ a\ post-burn\ mass\ of\ 25.35\ lb)$$

$$m_1 = (1.984\ lbf)/(32.2\,ft/s^2)\ \text{–>}\ KE_1 = 0.5 * m_1 * v_{descent}{}^2\ \text{=>}\ KE_1 = 9.98\,ft-lbf\ .$$
$$m_2 = (10.68\ lbf)/(32.2\,ft/s^2)\ \text{–>}\ KE_2 = 0.5 * m_2 * v_{descent}{}^2\ \text{=>}\ KE_2 = 53.73\,ft-lbf\ .$$
$$m_3 = (12.16\ lbf)/(32.2\,ft/s^2)\ \text{–>}\ KE_3 = 0.5 * m_3 * v_{descent}{}^2\ \text{=>}\ KE_3 = 61.18\,ft-lbf\ .$$

Seeing how all the kinetic energies are more that 10 ft-lbf less than the required kinetic energy, all landing sections fulfill the landing kinetic energy requirement by a significant margin. Additionally, simulated landing speed agreed to within 0.2 ft/s of the actual main parachute descent rate (simulated five times), and so the calculations performed with the actual descent rate are presented.

3.3.4. Descent Time

For a predicted apogee of app. 4900 ft AGL and the actual descent rates for the main parachute and drogue chute, the approximate descent time can be calculated, assuming no inclination of the launch rail.

$$v_{main,\,descent} = 18\,ft/s,\ v_{drogue,\,descent} = 58\,ft/s\ (for\ a\ post-burn\ mass\ of\ 25.35\ lb)$$
$$h_{apogee} = 4900\,ft\ AGL,\ h_{main-deploy} = 500\,ft\ AGL$$

$$Descent\ Time = (h_{apogee} - h_{main-deploy})/v_{drogue} + h_{main-deploy}/v_{main}$$
$$Descent\ Time = 103.64\ s$$

To verify these hand calculations, the descent rates were inputted into the as-built RockSim simulation to provide a secondary calculation method.

Table 9: Descent Time Simulations

Trial	Trial 1	Trial 2	Trial 3	Trial 4	Trial 5
Descent Time	96 s	96 s	96 s	96 s	96 s

The notable difference in descent time estimations can be attributed to basic calculations making the assumption that a parachute will instantly catch wing and fully deploy, whereas RockSim can provide an estimation as to the time delay for a parachute to fully open.

3.3.5. Drift

Using the simulated descent time, the amount of horizontal drift of the rocket can be determined for several wind speeds.

Table 10: Drift Relation to Wind Speed

Trial	Trial 1	Trial 2	Trial 3	Trial 4	Trial 5
Wind Speed (0 mph)	0 ft	0 ft	0 ft	0 ft	0 ft
Wind Speed (5 mph)	1137 ft	1692 ft	1438 ft	1543 ft	1113 ft
Wind Speed (10 mph)	1286 ft	1370 ft	1252 ft	1789 ft	1543 ft
Wind Speed (15 mph)	1752 ft	2072 ft	2139 ft	1821 ft	1923 ft
Wind Speed (20 mph)	2126 ft	2098 ft	1909 ft	2276 ft	2317 ft

4. Payload Criteria

4.1 Payload Design and Testing

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” samples, 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 is able to traverse the terrain of the 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. Changes Made to Payload

The primary change to the payload features a wheel traction system, as opposed to the previously mentioned tread system. Fabrication of custom threads using common FDM 3D printers does not achieve the precision necessary for creating accurate treads while being easy to assemble into position. Commercial treads would have to be purchased, which increases the project’s budget. Non-differential steering using custom made wheels improves traction from the previous tread system, reduces the mechanical complexity of the payload, and ensures a timely completion of the rover. The decision to switch from treads to wheels, however, limits the ability of the rover to overcome obstacles due to reduced contact with the ground. The wheel diameter has also been increased by decreasing the wheel/tread thickness from .75” to 0.4”.

Due to limited space within the ebay of the rover, the receiver module for the controls feedback system will be placed on top of the ebay. The selected receiver module is already enclosed to shield sensitive electronics from natural elements, so placing the receiver module in an unprotected location does not jeopardize its functionality.

Additional changes have been made to allow wires and motors to interface better with the rover. Several holes within the ebay have been created and widened for easier mounting of electronics into the payload structure. A section on the top cover of the rover has been updated to contain the payload's camera, which was not previously included in the CDR.

4.1.4. Unique Features

4.1.4.1 Overview

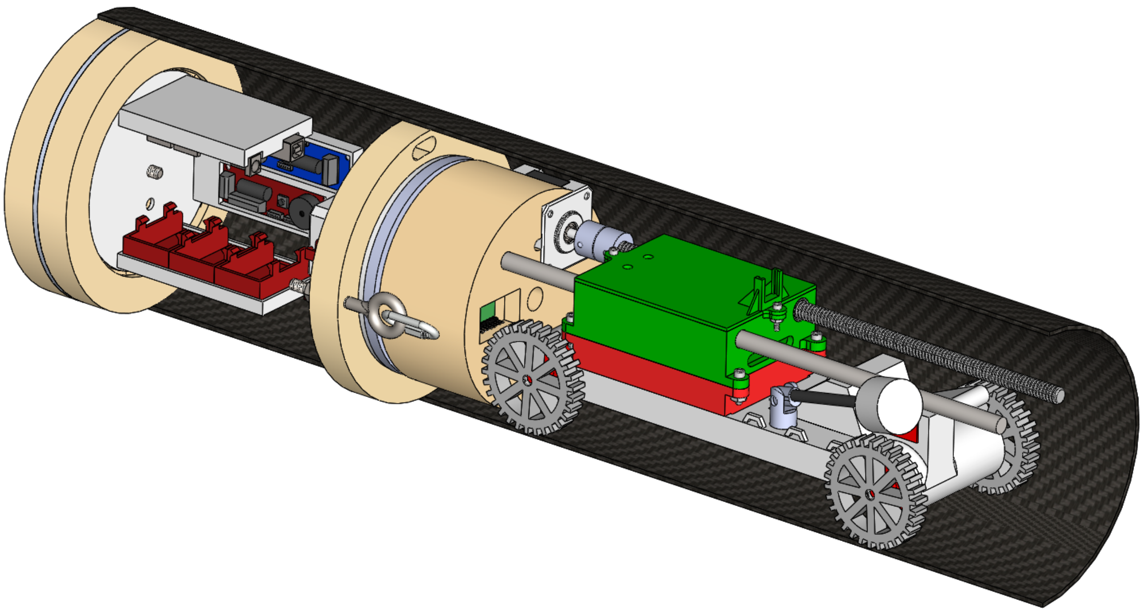

Figure 47: Payload and Rover Ejection Assembly

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.

4.1.4.2 Rover Ejection Assembly

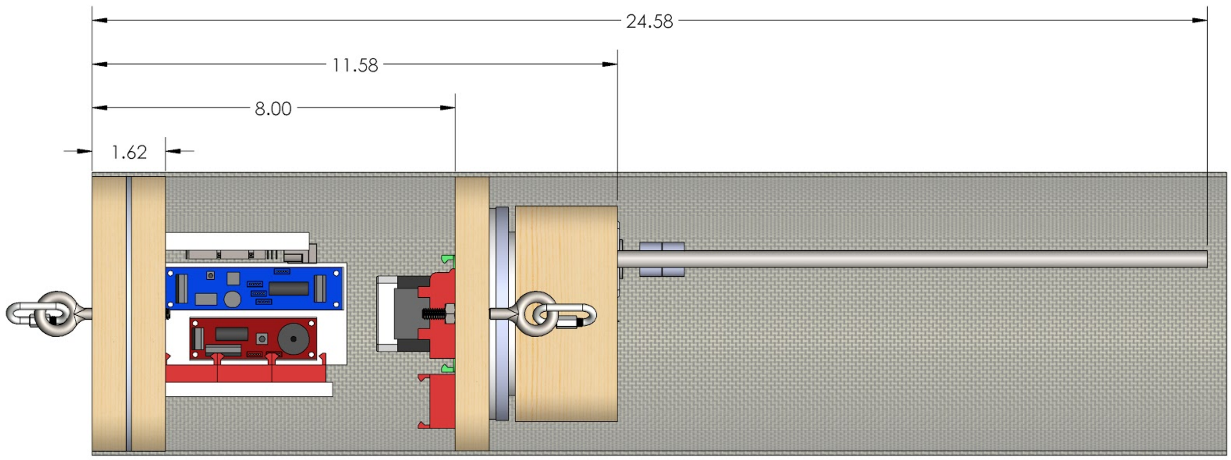

Figure 48: Rover Ejection Assembly

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. Discussion of certain features of the rover deployment mechanism were omitted from this section as their relatively simple geometry can be understood by looking at the drawings provided in section 4.1.6. The rover deployment mechanism contains the following unique features.

ITEM NO.	QTY.	PART NUMBER	/Material
1	2	Eyebolt	Steel
2	1	Locking Mechanism Assembly	Pine
3	1	Avionics Sled Assembly	PLA
4	2	NEMA 17 Stepper Motor	Aluminum, Copper, Steel
5	1	Bulkhead	Pine
6	1	Bearing Ring	Aluminum Alloy
7	1	Circular Block Holder	Pine
8	1	5mm to 10mm Coupling	Aluminum
9	1	0.375-12 x 12 Lead Screw	Carbon Steel
10	1	0.375 x 12 Rod	Carbon Steel
11	2	9V Battery Case Holder	PLA
12	1	Standoff Outer	PLA
13	1	Stepper Motor Interface	PLA
14	1	Standoff Inner	PLA

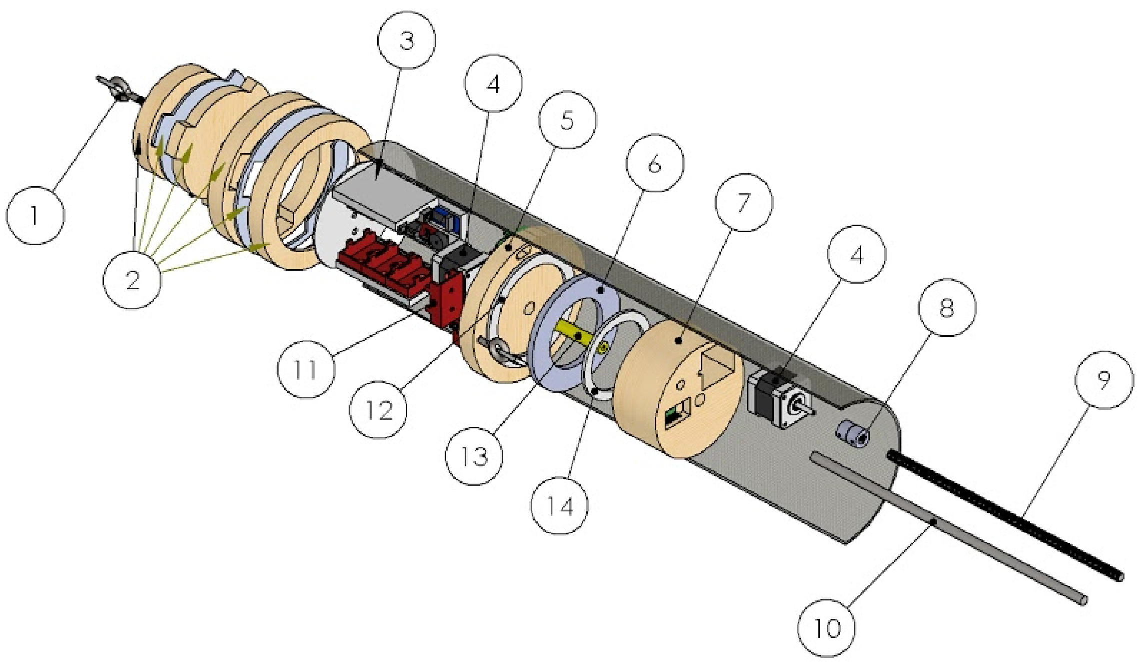

Figure 49: Exploded View of Rover Ejection Assembly

Locking Mechanism

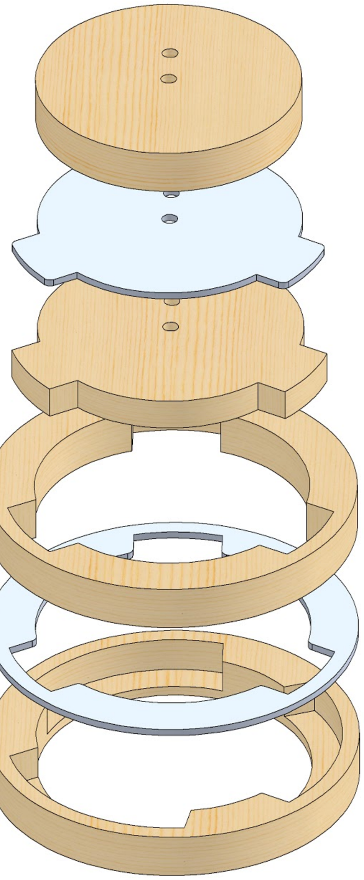

Figure 50: Exploded View of Locking Mechanism

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 and aluminum locking mechanism bulkhead will be implemented. The locking mechanism consists of 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 with an additional aluminum sheet for reinforcement. Wood components were manufactured using a CNC mill and aluminum sheets were cut using a waterjet. The total thickness of the locking mechanism is 1.62in.

Wood and aluminum were used due to their cost and structure. The wooden components form a base on which the aluminum can be attached to the vehicle by providing an increased contact area with the body tube, which increases the amount of epoxy that can be applied for a stronger hold. The thin aluminum sheets add rigidity to the entire structure to reduce the stresses the wooden inner locking mechanism tabs experience once the parachute is deployed.

Dimensions of each part is provided in section 4.1.6.

Avionics Sled

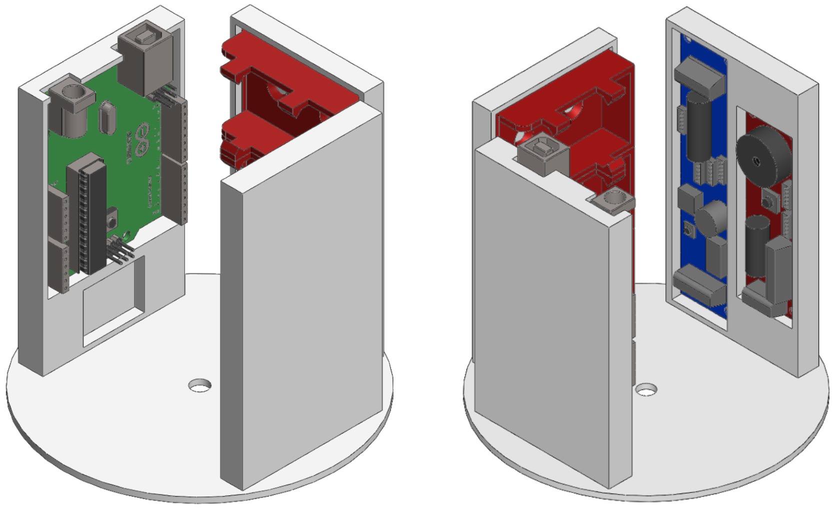

Figure 51: Avionics Sled with Electronics

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 the following figure. Dimensions of the avionics sled are provided in Section 4.1.6.

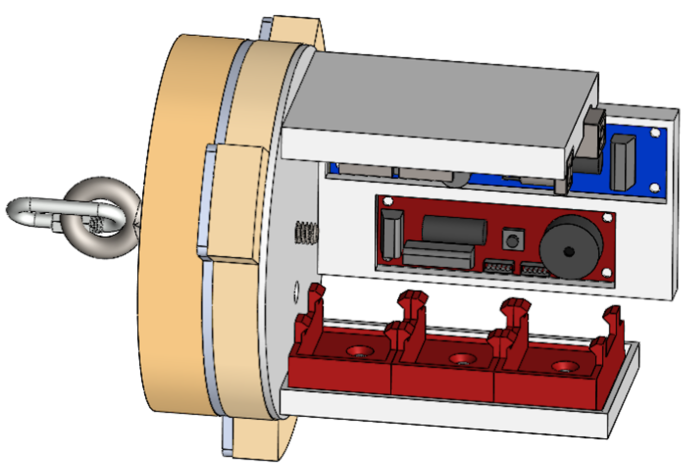

Figure 52: Fully Assembled Avionics Sled with Inner Ring

Rover Deployment Mechanism

In order to deploy the rover after landing, two NEMA 17 stepper motors, a 4.7in diameter ball bearing ring, 3D printed rings to offset the bearing ring, a wooden circular block holder, stepper motor interfacer, shaft coupler, a ⅜”-12 12in long lead screw, and ⅜” 14in long rod are used.

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

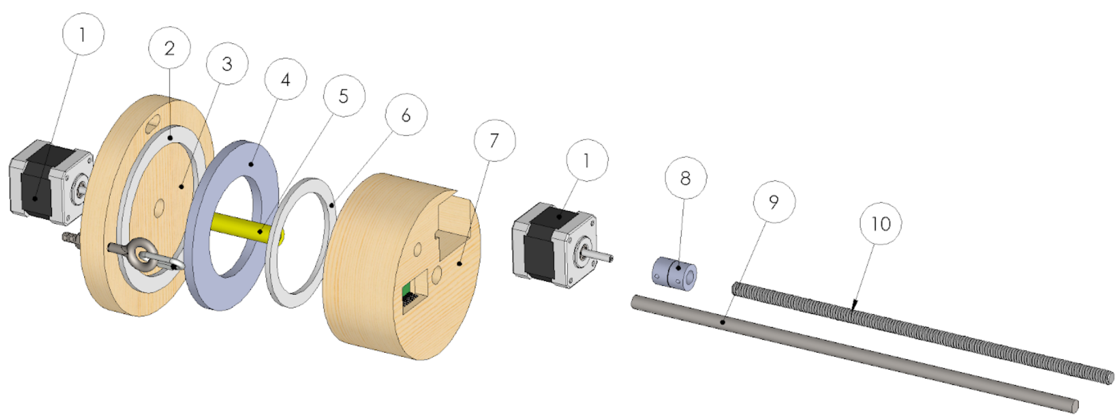

Figure 53: Exploded View of Rover Deployment Mechanism

Using the above figure as reference, the leftmost stepper motor (1) is attached to a bulkhead (3) 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 payload and rods resting on the shaft of the stepper motor. 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. Since the purchased bearing ring is flat, additional 3D printed rings (2 & 6) are placed to offset one rotating ring from the other. These standoff rings interface with the bearing ring and the bulkhead or circular block holder (7). A circular tube (5) will fit around the shaft of the stepper motor and will be epoxied into the large circular block holder (7). The circular block holder acts as a rotating bulkhead for which to attach the rods and additional stepper motor onto. Cutouts for another stepper motor, a gyroscope/accelerometer module, and a steel rod are provided. The unthreaded rod (9) and stepper motor (1) will be epoxied into the designated hole inside the circular block holder. In order to attach the lead screw (10) onto the stepper motor, a

5mm to 10mm coupling (9) 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.

A unique aspect of the rover deployment mechanism is the circular block holder (7). Dimensions of each cut were dictated by the size of the stepper motor, interference with the eyebolt attached to the bulkhead, and size constraints imposed by the rover ebay. A concern with the shape of the circular block holder was its thin wall size for housing the stepper motor compromising the overall strength of the retention system and how protrusion of the stepper motor outside the boundary of the circular block holder outer diameter clashes with the eyebolt if driven the wrong way. The following figure demonstrates the reasoning for the circular block holder.

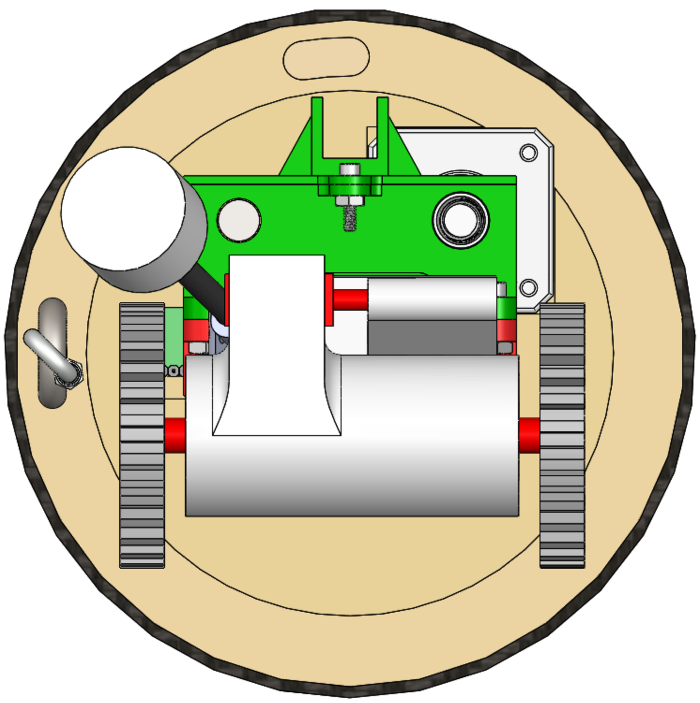

Figure 54: Packed Rover within Launch Vehicle

The diameter of the circular block holder allots space for the leftmost eyebolt, however, this means part of the stepper motor is exposed. If rotated counter clockwise, the stepper motor will interfere with the eyebolt, which jeopardizes the deployment mechanism's ability to orient the rover. Moving the motor and shaft towards the center would mitigate this problem, but would limit the space available for electronics onboard the rover. Dimensions of the circular block holder are provided in section 4.1.6.

Electronics

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 for additional antennas. The individual components are discussed in the following sections.

The Arduino Uno Microcontroller Board will be used to control the operations of all the electrical components involved in the rover ejection assembly. The Arduino Uno will be powered using a 9V battery and will be located on the avionics sled. The Arduino Uno will be powered similar to the onboard altimeters using external latching push button switches to limit excessive current draw. The Arduino Uno is tasked with reading inputs from the pressure sensor, gyroscope/accelerometer, and driving two NEMA 17 stepper motors.

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.

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.

Two A4988 Stepper Motor Driver modules will be used to regulate the current supplied to the two stepper motors. The driver has an operating voltage range 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 from overheating while in service. Two provide a high enough voltage to the stepper motors, two 9V batteries will be placed in series to generate a greater current. To limit the number of batteries within the launch vehicle, two 9V batteries in series will be used to power both stepper motor drivers. Since only one stepper motor will rotate at a given time, the two batteries in series can be used for both stepper motor drivers without compromising voltage draw. MOSFETs will be implemented to act as electronics switches to power individual stepper motor drivers. The MOSFETs will be controlled by the Arduino Uno.

The rover ejection assembly will utilize two NEMA 17 Stepper Motors to drive the mechanical components that eject the rover. The NEMA 17 has a voltage range of 8-36V and a max current of 2A. 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 64 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.

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.

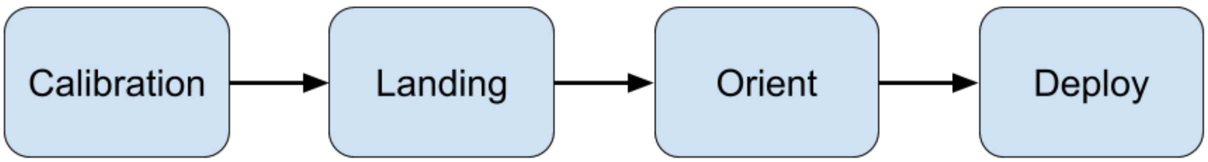

Figure 55: Rover Ejection Assembly Major Events

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.
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.

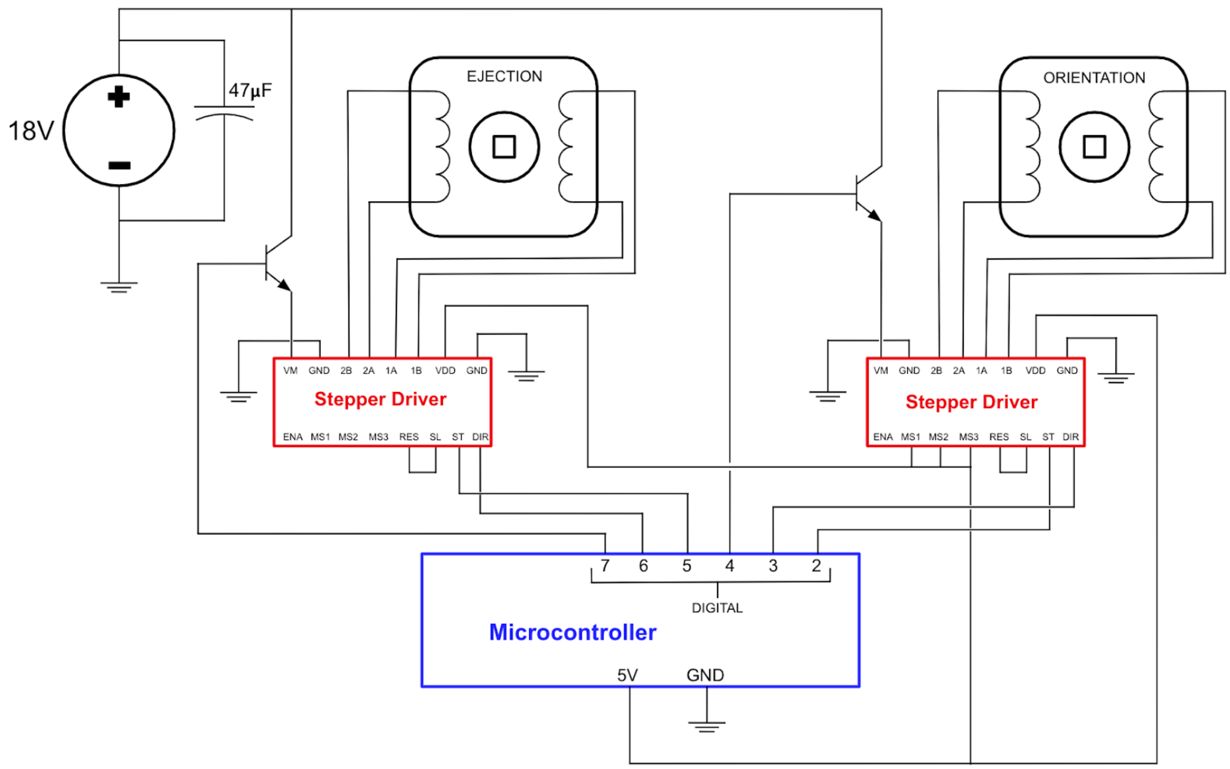

Figure 56: Rover Ejection Assembly Wiring Diagram

All connections will be soldered onto a prototyping PCB (solder board). This board is then attached to the payload bulkhead using a 3D printed enclosure.

4.1.4.3 Rover

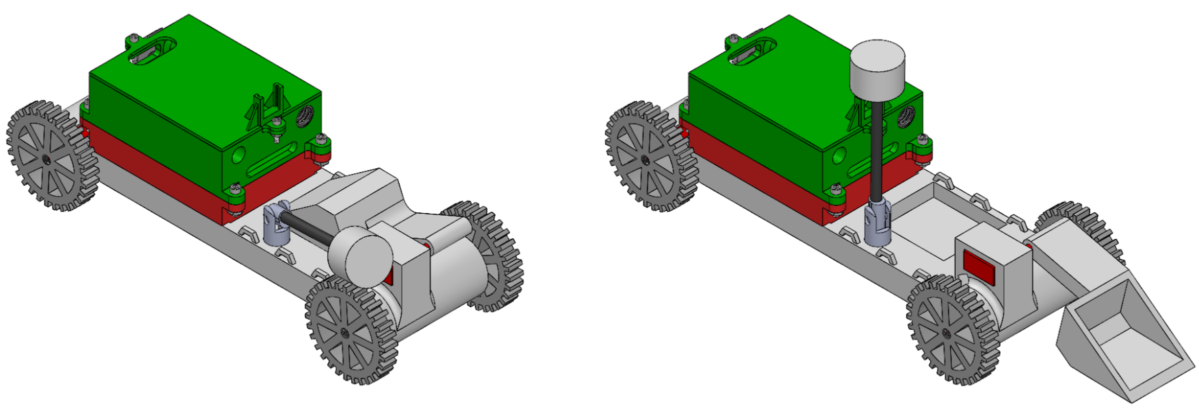

Figure 57: Packed Rover (left) and Unpacked Rover (right)

The payload features an 11.4” x 4.3” x 4.2” 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 wheels instead of treads as its form of movement. While this limits the rover’s ability to overcome obstacles located under its center, the driver will take extra precaution in avoiding sharp peaks in the dirt relative to the size of the rover. The following figure demonstrates the interfaces between each component of the rover. Additional figures of the as-built payload are provided in section 4.1.6.

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

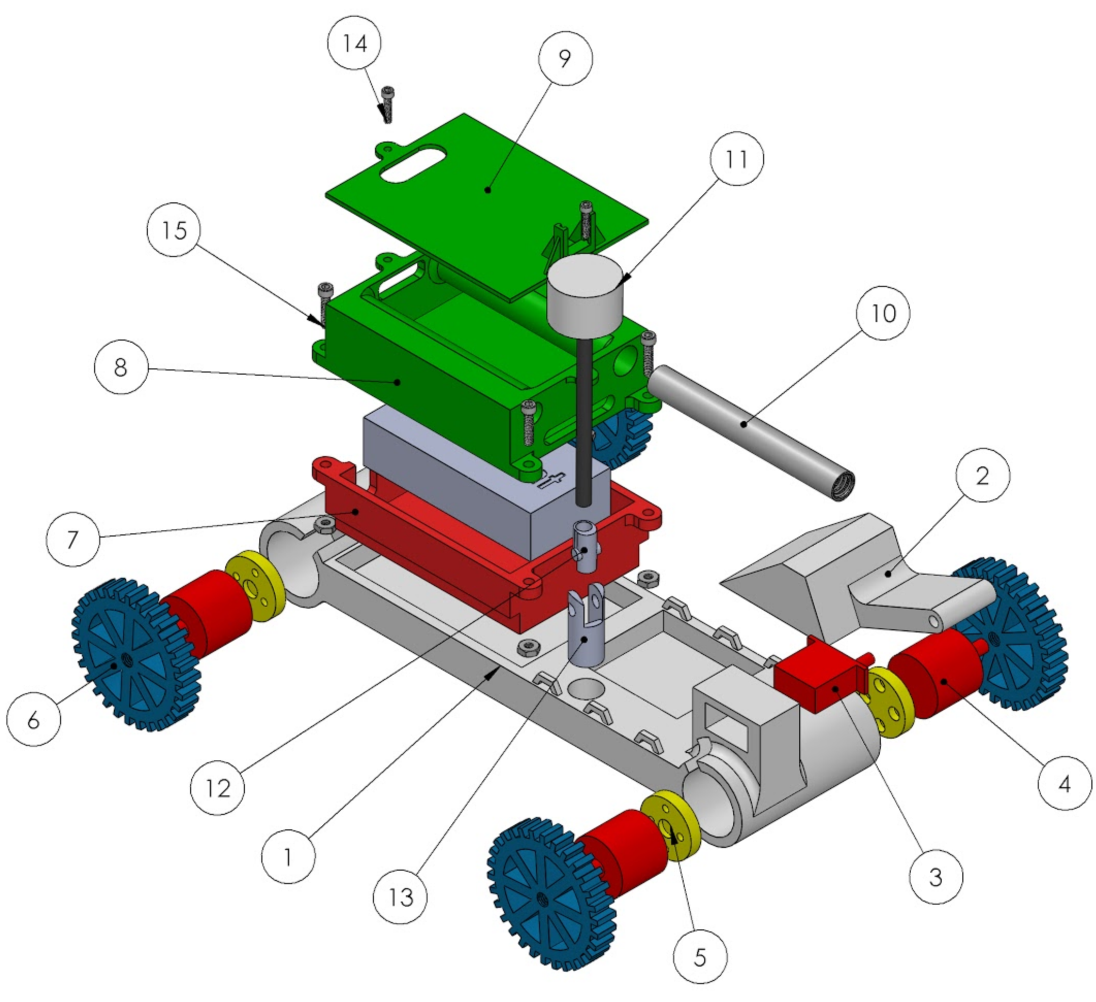

Figure 58: Exploded View of Rover

Discussion of certain features were omitted from this section as their relatively simple geometry can be understood by looking at the drawings provided in section 4.1.6. The payload contains the following unique features.

Antenna Mechanism

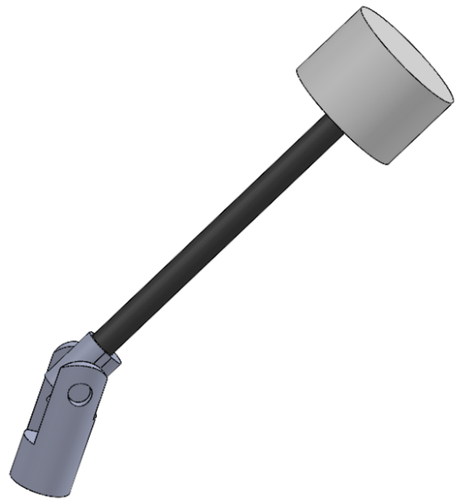

Figure 59: Antenna Mechanism

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. An extension within the part that interfaces with the holder and the antenna will prevent the antenna from moving past its upright position. The size of this tab has been increased since the CDR to prevent the part from breaking.

Electronics Bay

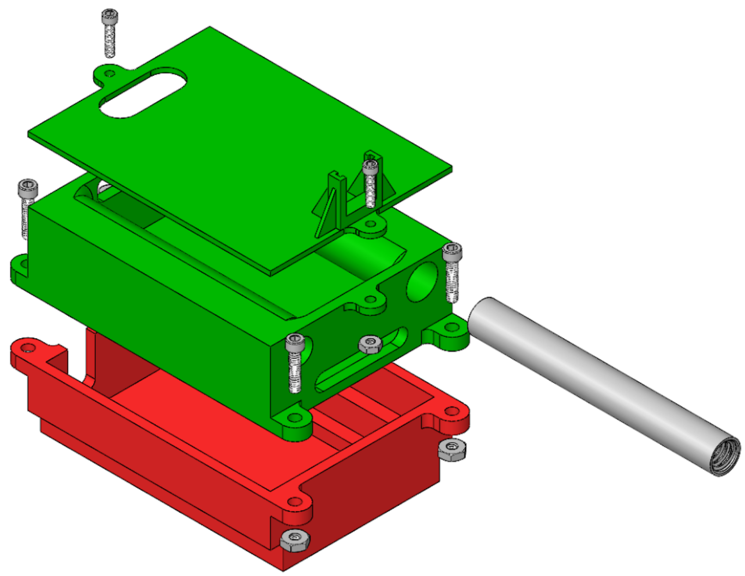

Figure 60: Exploded View of Electronics Bay

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.

Within the electronics bay, a custom 4" long nut is epoxied into the upper ebay section to fasten the rover to the rest of the launch vehicle. The custom long nut is 3D printed and slides smoothly when twisted with the ⅜" threaded rod. This allows the rotational motion of the stepper motor to be translated into lateral motion to deploy the rover.

Motor and Wheel Attachment

During electronic testing, the team noticed that the purchased brushless DC motors are intended for drone usage, so the entire motor casing rotates, as opposed to traditional DC motors where only the shaft rotates and the case is stationary. This imposed a new design challenge as now the DC motor must spin freely within the motor housing in the chassis, must be centered, and must be easy to implement. The solution implemented involved attaching the DC motor to a 3D printed DC motor which contains holes to screw the motors to this component. The DC motor holder has a diameter larger than that of the DC motor so that when the motor is attached to the chassis, the motor will not collide with the chassis hole. By having a DC motor holder, epoxy can be applied to the motor holder instead of the DC motor, which prevents potential motor failure and allows the motor to be used multiple times.

Since the DC motors purchased contain 6mm diameter thread shafts, the wheels have matching female threads to attach to the DC motor. The wheels feature a 2.1” diameter wheel base with 0.15” long protruding treads for a total diameter of 2.4”. The protruding treads are necessary for traversing the terrain since it allows the wheels to sink in and grip the ground. The following figure illustrates the wheel attachment method.

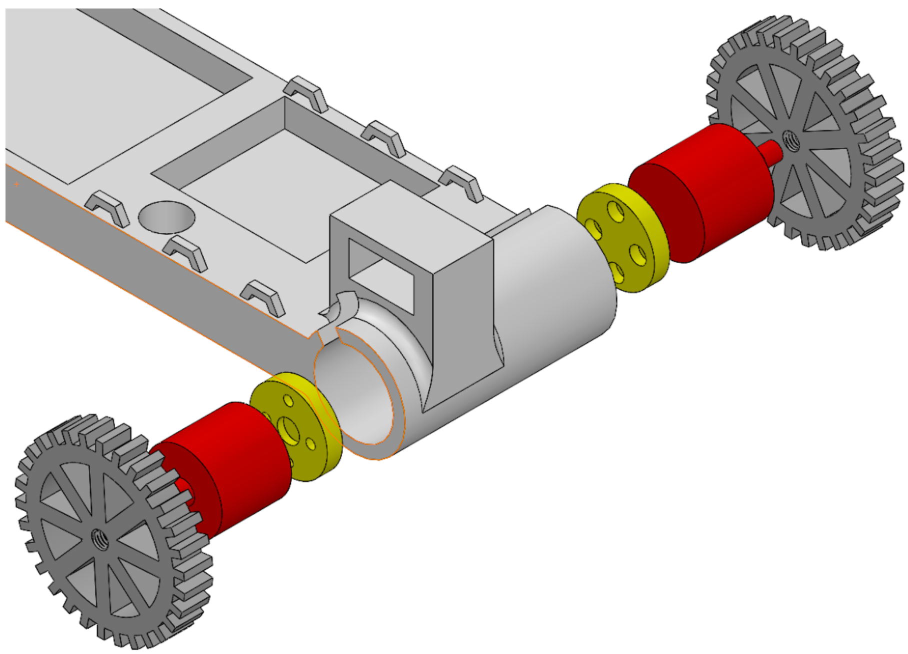

Figure 61: Exploded View of Wheel Attachment Method

Electronics

A major change within the rover electronics is the removal of the CC3D flight controller for programming the rover inputs and a receiver change from the Radiolink R8EF to the FS-iA6B receiver. These changes were necessary due to poor online documentation of the previous transmitter/receiver. The change to a different transmitter/receiver module set permits the motors to be programmed from the transmitter controller, which bypasses the need for the CC3D flight controller. This change is also beneficial since it reduces the internal volume needed for storing all electronics within the ebay and reduces total power consumption of the rover by using less electronics.

The controls transmitter and receiver system operates on a 2.4GHz frequency with a 10 channel Automatic Frequency Hopping Digital System (AFHDS) protocol to prevent interference from other transmitters during competition. Additionally, the FS-iA6B receiver must be paired with the transmitter, which further mitigates interference from other transmitters/receivers.

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.

Unlike the controls receiver/transmitter system, the FuriousFPV Stealth transmitter does not use a frequency hopping protocol to avoid interference from other teams. A compatible frequency between the video transmitter and receiver must be determined and coordinated with other teams. With the selected video transmitter and receiver setup, 4 selectable frequencies can be used during competition.

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 video 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 sets of antennas will communicate with the driver. The antennas used for controlling the rover are limited to factory antennas, which are stock dipole antennas. Since different polarizations are used between the controls transmitter/receiver and video transmitter/receiver, interference between the two signals does not occur.

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 11: 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. After testing the final payload antenna setup, successful transmission across 0.5 miles of flat ground is possible.

The selected motors for maneuvering the terrain post-ejection is the Racestar BR2212 Brushless DC motors. A total of four DC motors will be used for non-differential steering. 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. A drawback of this motor is that the entire casing rotates instead of the shaft, which imposes another payload design challenge.

To control the collection arm, a 360° Micro High Torque Servo will be used. Since the FS-iA6B receiver outputs 5V, the micro servo can be plugged directly to the receiver without needing to connect to an electronic speed controller or power distribution board. This simplifies wiring and programming within the rover.

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 receiver will send the ESC OneShot communication output, which is easily read by the selected ESC. 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 receiver 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.

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 all components of different working voltages to be powered using a single LiPo battery.

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 3380mAh 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 12: 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
	Receiver	5	30	4	120
	Total	-	**5180**	-	**2660**
Video	Transmitter	7.4 - 25.2	90	4	360
	Camera	5	90	4	360
	Total	-	**180**	-	**720**
Final Total			**5360**		**3380**

In accordance with 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.

Testing the battery with all components wired revealed that the battery is able to last for 4 hours with a 30 minute mission time, as desired.

Schematic

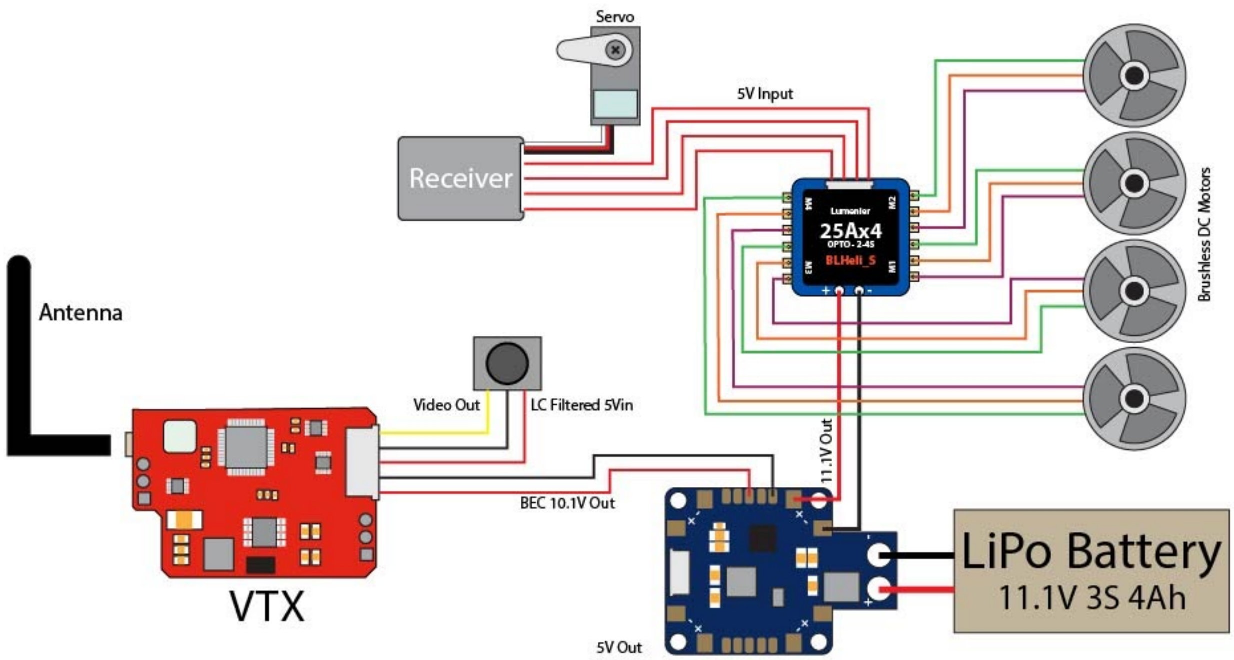

Figure 62: Schematic of Electronics within Rover

4.1.5. Flight Reliability Confidence

Critical design elements of the retention system and payload were identified and tested for reliability. Concerns that were targeted as potential sources of mission failure are the following:

Rover Ejection Mechanism Rod Deflection

A concern with the rover ejection assembly is deflection of both rods caused by their long and narrow geometry. If the rods were to deflect a substantial amount, this could compromise how the rods interface with the allotted holes in the rover and cause a jam if not perfectly aligned.

To counteract this, adjustable rod deflection was desired to allow the rod to deflect where it needed to be. This was done by using a spring-like coupler between the shaft of the stepper motor and threaded rod. This allows imperfections during assembly to be corrected since the threaded rod does not have to be straight.

Rover Ejection Stepper Motor Torque

A crucial aspect of the rover ejection assembly is its ability to rotate the heavy payload system. Stepper motors with high torque were selected to ensure the payload is oriented and deployed successfully. To harness the max torque rating of the stepper motors, a 2A current must be applied to the stepper motors. Two 9V batteries are connected in series to generate a higher voltage, and consequently a higher current.

Testing of the as-built rover ejection assembly with the payload attached confirms that the current setup is capable of functioning as intended.

Rover Custom Long Nut
A unique design aspect of the rover is the incorporation of a 3D printed custom long nut to interact with the commercially machined threaded rod. A concern with creating a 3D printed nut instead of a fabricated nut using a tap is the capability of available 3D printers to generate an accurate thread, the relative ease the nut rotates around the threaded rod, and its ability to withstand flight impulses to safely retain the rover until deployment.

Rover Range on Ground
In order to achieve successful and consistent communication between the rover and driver for the entire field, a 0.5 mile radius is desired for both the video feedback system and controls system. Further testing of the rover antenna system is required, as outlined in section 7.1.

Rover Communication through Carbon Fiber Body Tube
In past years, Bearospace at UCLA has had trouble establishing RF communication within carbon fiber body tubes. In order to justify that an RF communication can be established even after losing connection due to the rover's placement within carbon fiber body tubes, a test was conducted, as outlined in section 7.1. Further testing of the rover antenna system is required.

Rover Battery Life
A derived challenge for the payload is its ability to last for a minimum of 4 hours with a 30 minute mission time. This ensures the payload is able to operate for at least 30 minutes in the case a launch delay of 3.5 hours occurs.

Testing of the rover's battery concluded that the payload is able to operate for longer than 4 hours, as intended.

4.1.6. Construction

Schematics and justifications of changes made since the CDR of each component of the rover ejection assembly and payload are provided in this section.

4.1.6.1 Rover Ejection Assembly

Locking Mechanism
A major change of the locking mechanism since the CDR is the use of an aluminum sheet to reinforce the wooden structure of the inner and outer locking mechanism rings. This adds greater rigidity to ensure the tabs of the bottom inner locking mechanism ring and the top outer locking mechanism ring do not fail. Another major change made since the CDR is the omission of a rubber sheet and wooden cover to provide an airtight seal. Implementation of an airtight cover complicates the locking and wiring process during launch preparations. An easier and temporary alternative is the use of tape to seal any openings.

Dimensions of the locking mechanism have been slightly modified to simplify the manufacturing process. These changes include an increase in outer diameter of the outer ring to better fit within the launch vehicle and an offset increase between the outer and inner locking mechanism components.

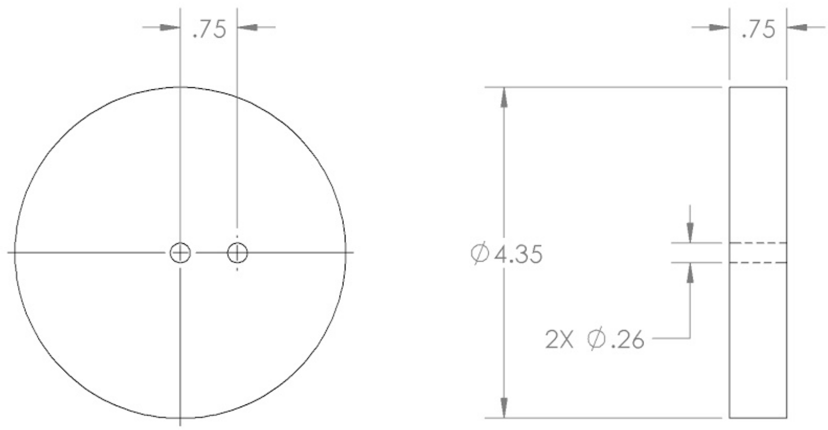

Figure 63: *Locking Mechanism Top Inner Ring Drawing*

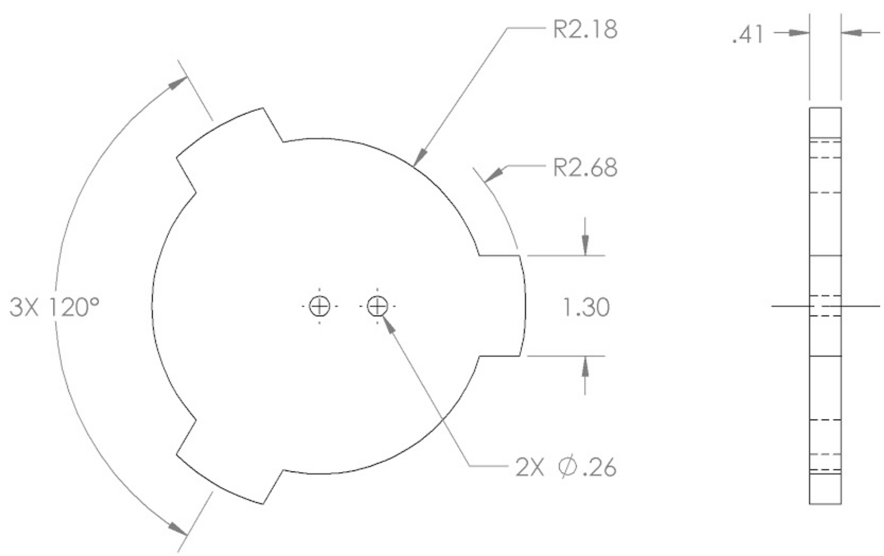

Figure 64: Locking Mechanism Bottom Inner Ring Drawing

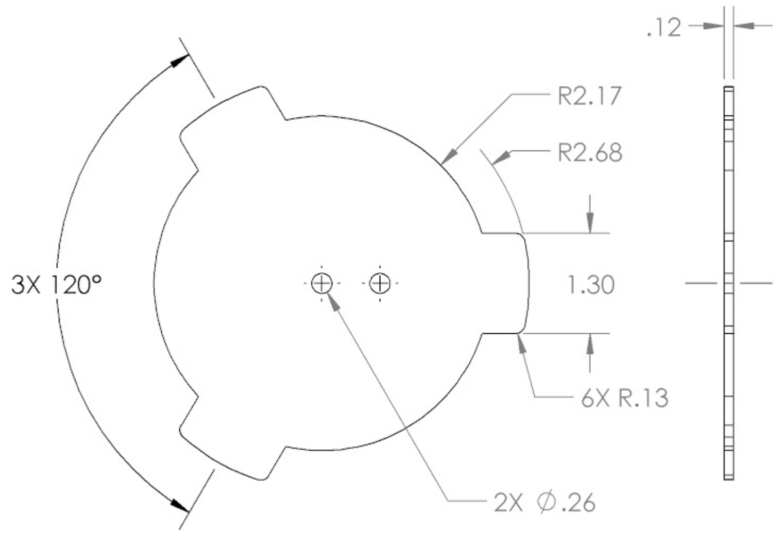

Figure 65: *Locking Mechanism Inner Ring Reinforcement Drawing*

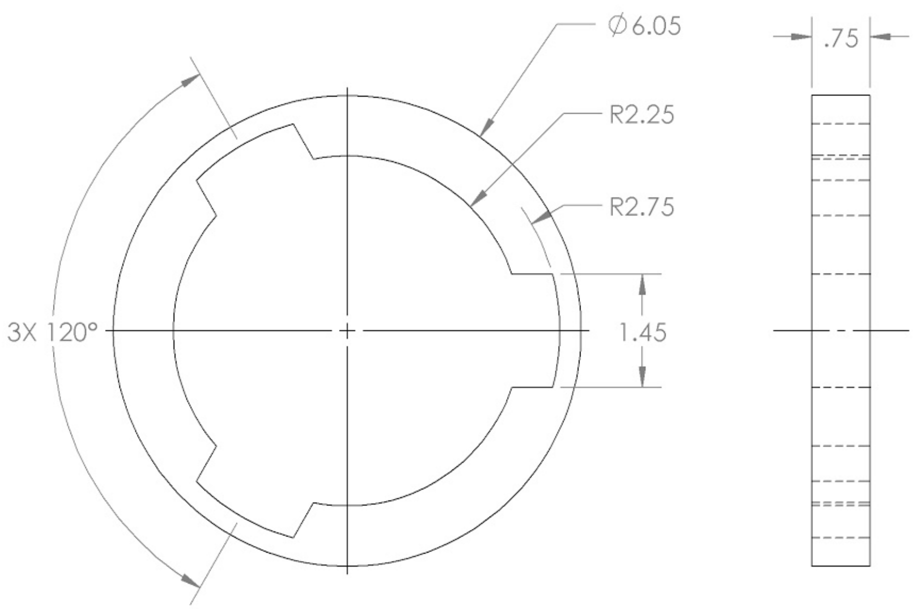

Figure 66: Locking Mechanism Top Outer Ring Drawing

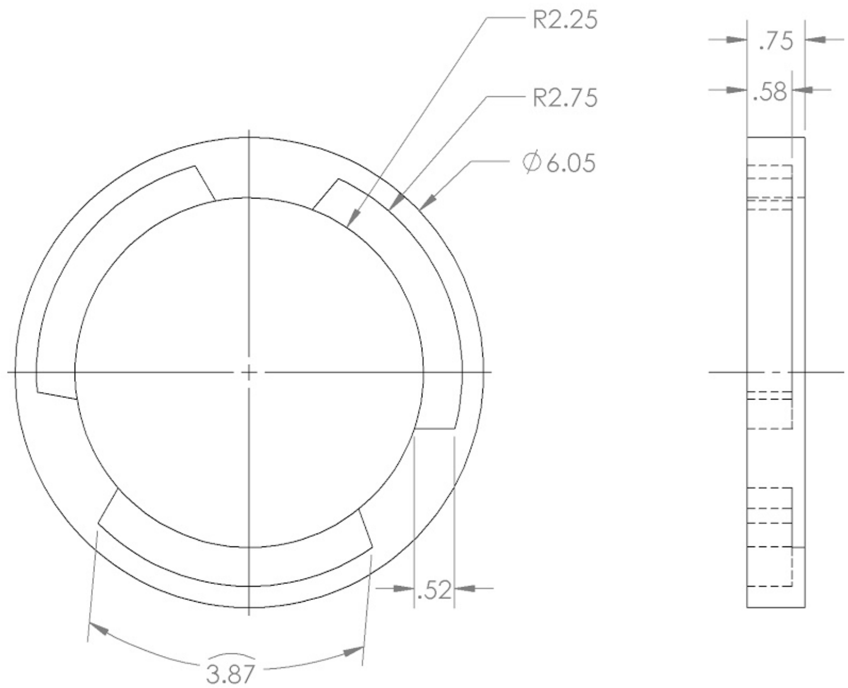

Figure 67: Locking Mechanism Bottom Outer Ring Drawing

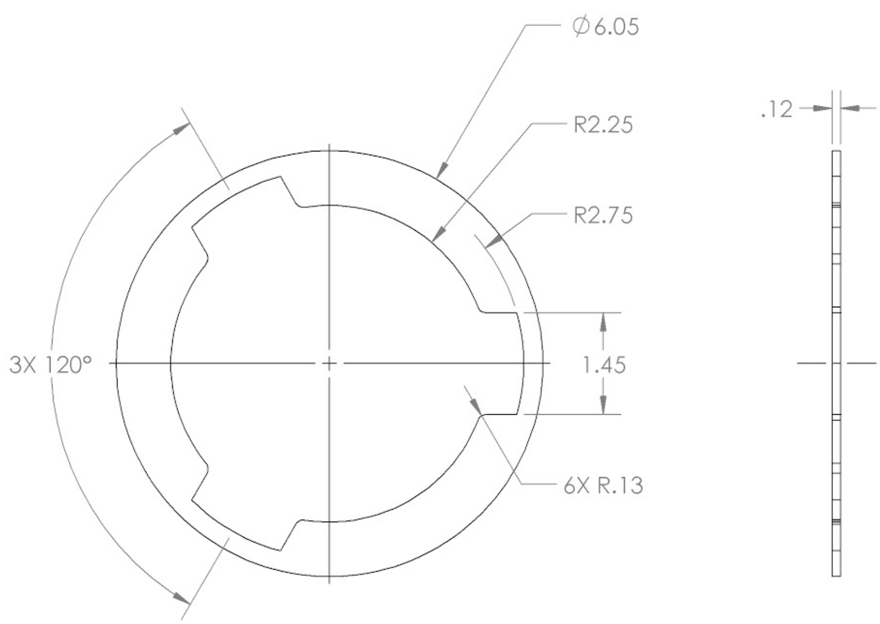

Figure 68: Locking Mechanism Outer Ring Reinforcement Drawing

Below are images of a locking mechanism prototype. The difference between this iteration and the locking mechanism being utilized is the absence of aluminum in the protype. The geometry of the wooden components is consistent between the two models.

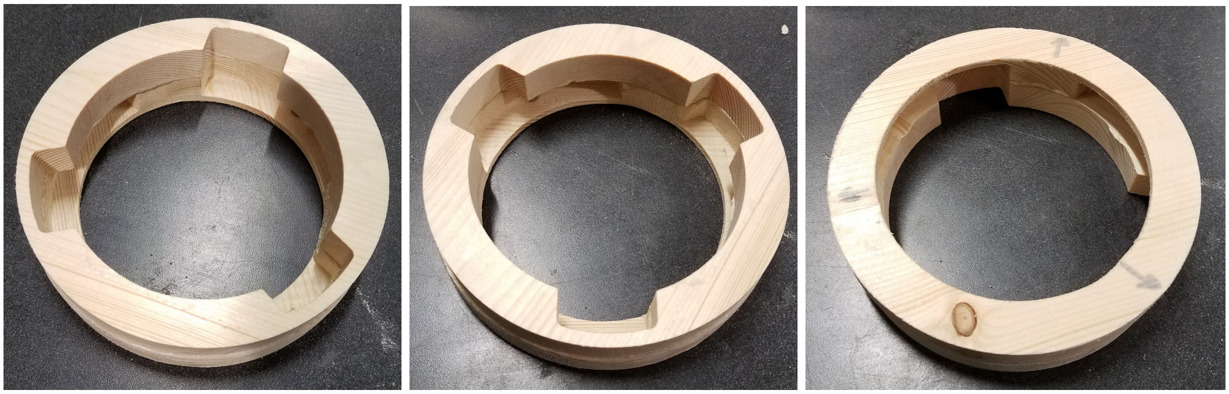

Figure 69: Locking Mechanism Outer Ring

Avionics Sled

Outer diameter of the avionics sled has changed to reflect the changes made to the inner locking mechanism.

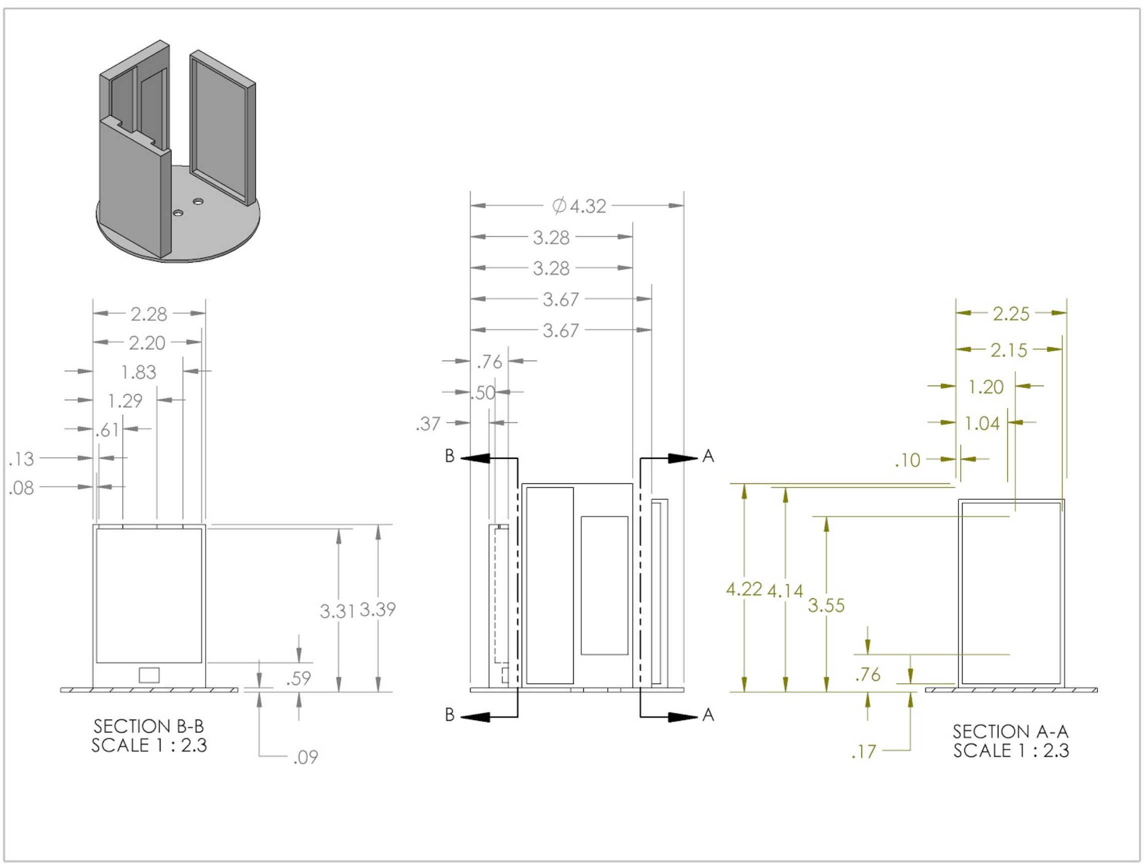

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Figure 70: Avionics Sled Drawing

Circular Block Holder

Outer diameter of the circular block holder has been slightly reduced to prevent unnecessary contact with a neighboring eyebolt. This facilitates the manufacturing process and lessens the torque necessary for rotating the entire payload assembly. However, by reducing the outer diameter, the inserted stepper motor is more likely to break off. An additional semicircular cut has been made to allow wires from the stepper motor to run out of the circular block holder without bending. Hole diameter for rods has been increased due to rod manufacturing error by supplier.

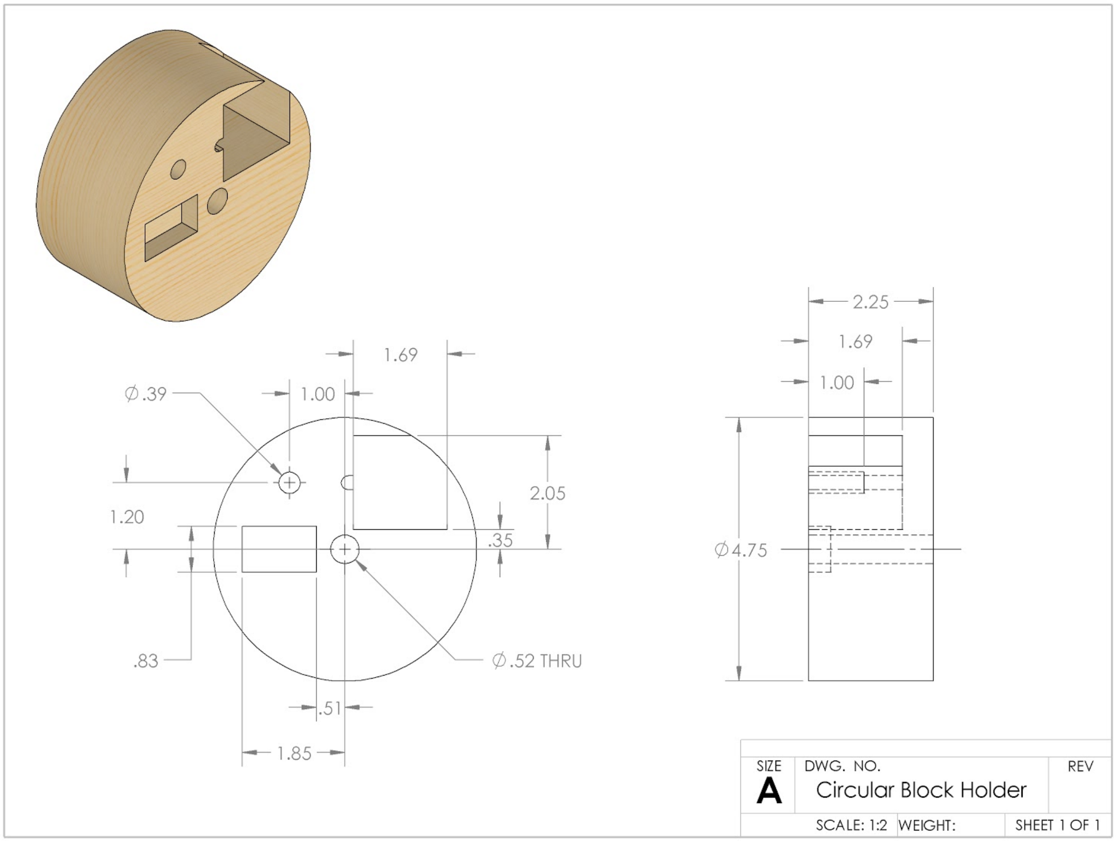

Figure 71: Circular Block Holder Drawing

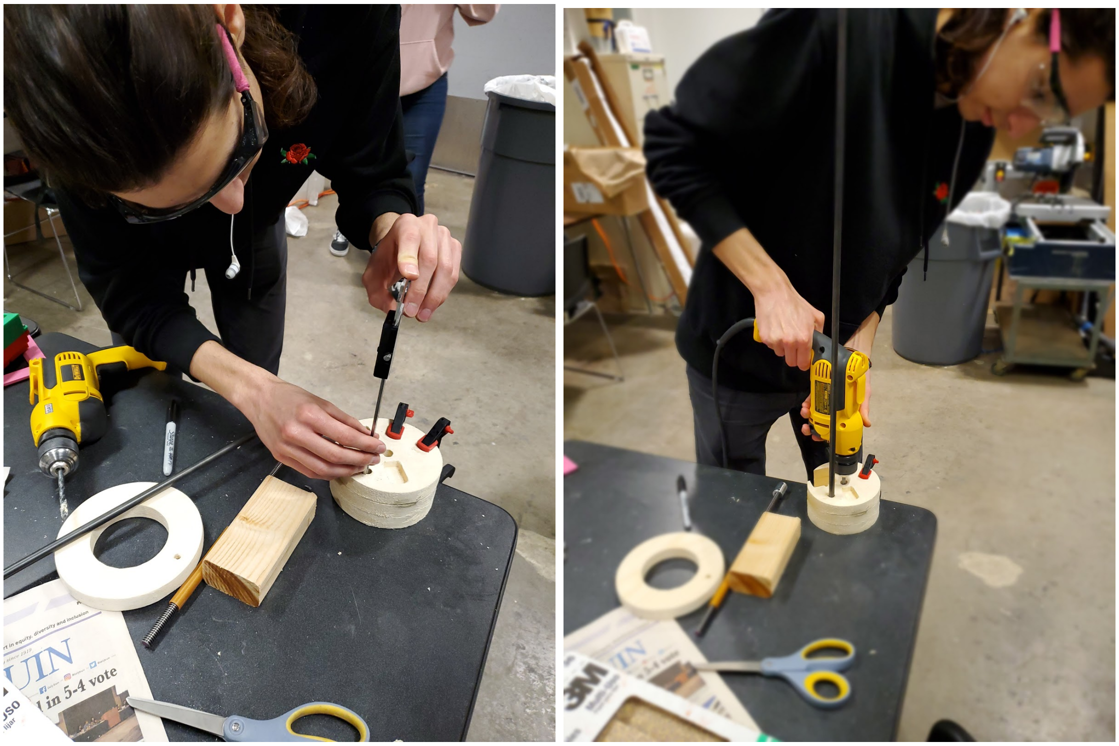

Figure 72: Circular Block Holder Construction

Threaded Rod

The selected threaded rod has not changed since the CDR.

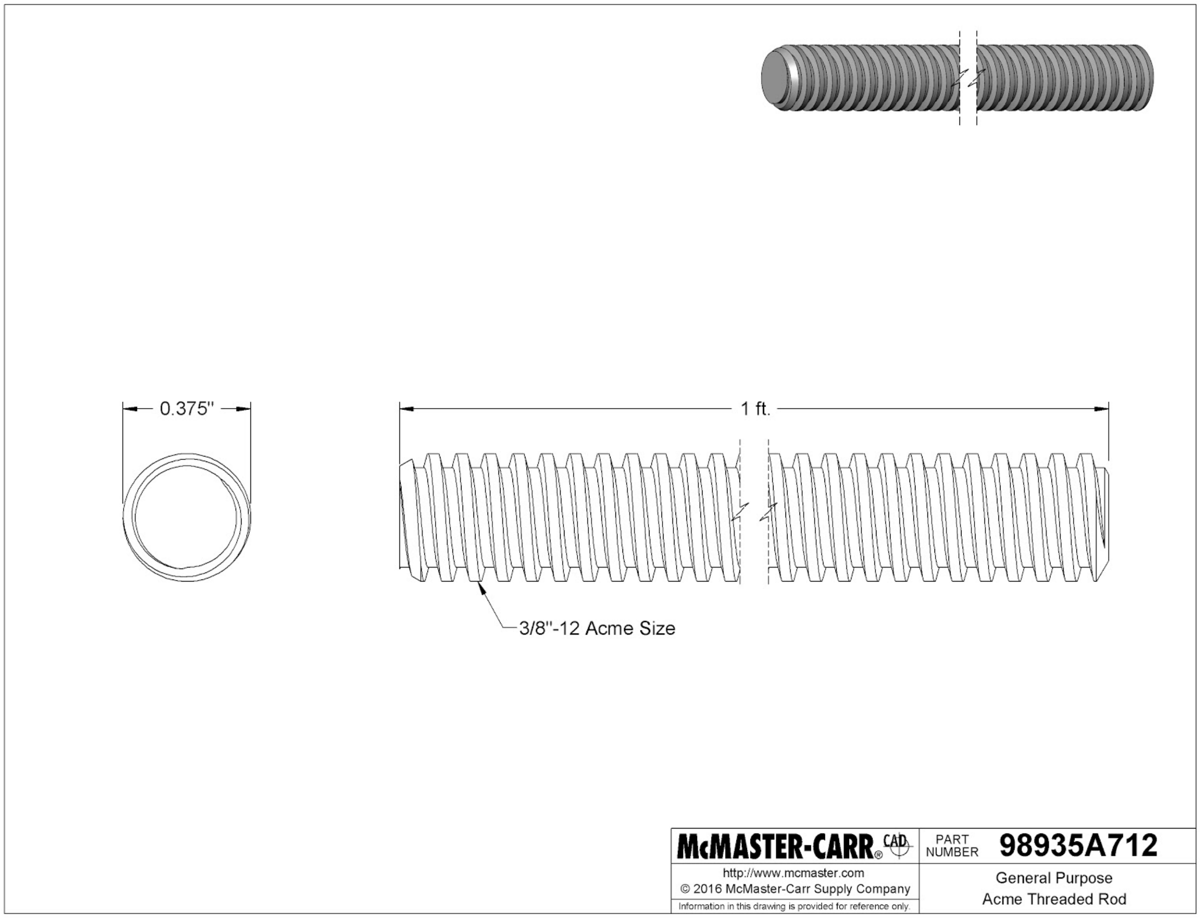

Figure 73: ⅜"-12 x 12in Lead Screw

4.1.6.2 Rover

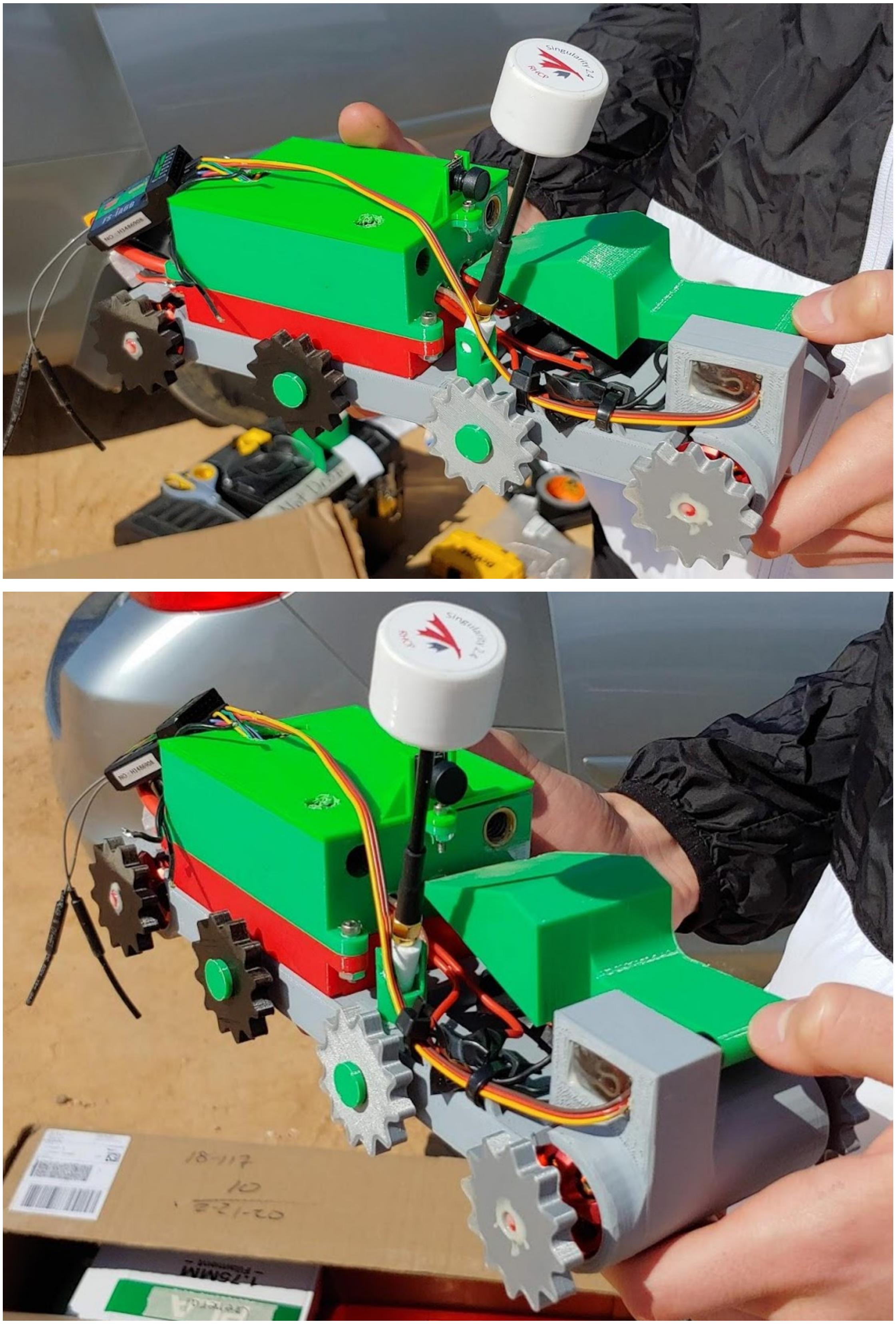

Figure 74: Fully Constructed Rover without Treads

Chassis

The chassis has been modified to better fit the selected brushless DC motors. Additionally, the outer diameter around each motor has been reduced for the rover to better overcome obstacles by increasing the distance between the chassis and the ground. Square cuts around each motor hole have been added so that wires of the DC motors can run through them. Holes for axles have been removed as a tread system will not be used, so intermediate sprockets are not necessary anymore. Between each motor hole is a platform for which to epoxy the motor holders onto.

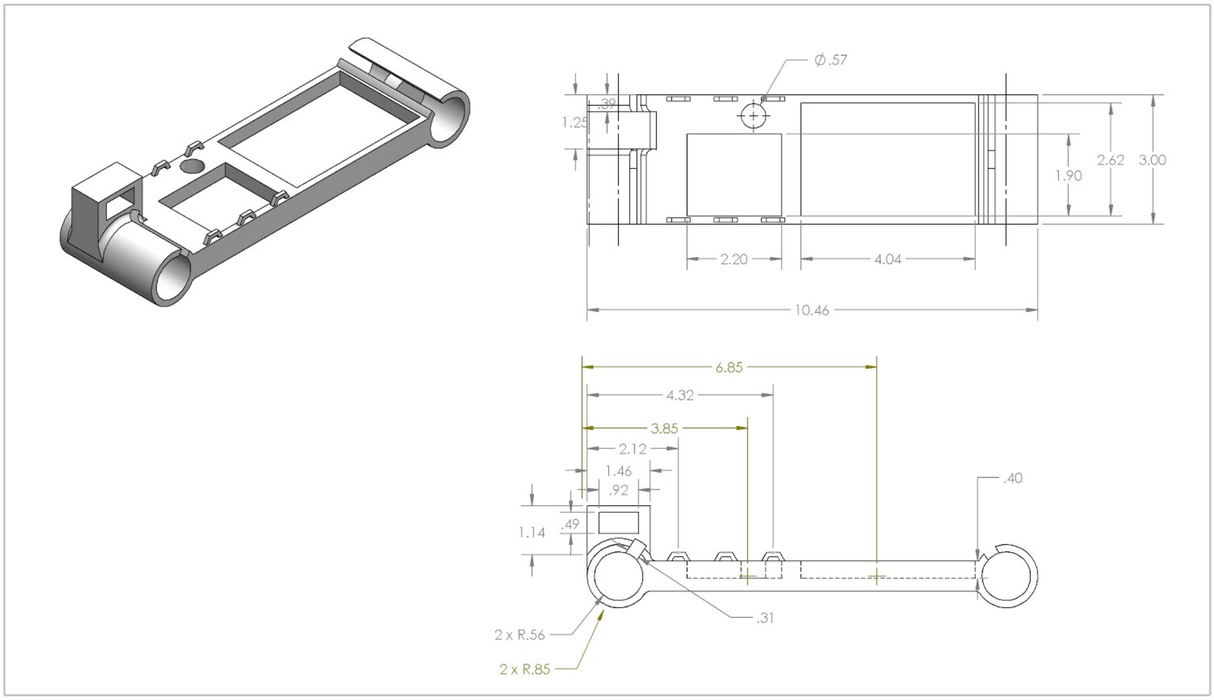

Figure 75: Payload Chassis Drawing

Collection Arm

The collection arm features a shorter shovel length than reported on the CDR to avoid collision with the rover's ebay. The single attachment hole has also been updated to fit the servo's included screw for easier attachment.

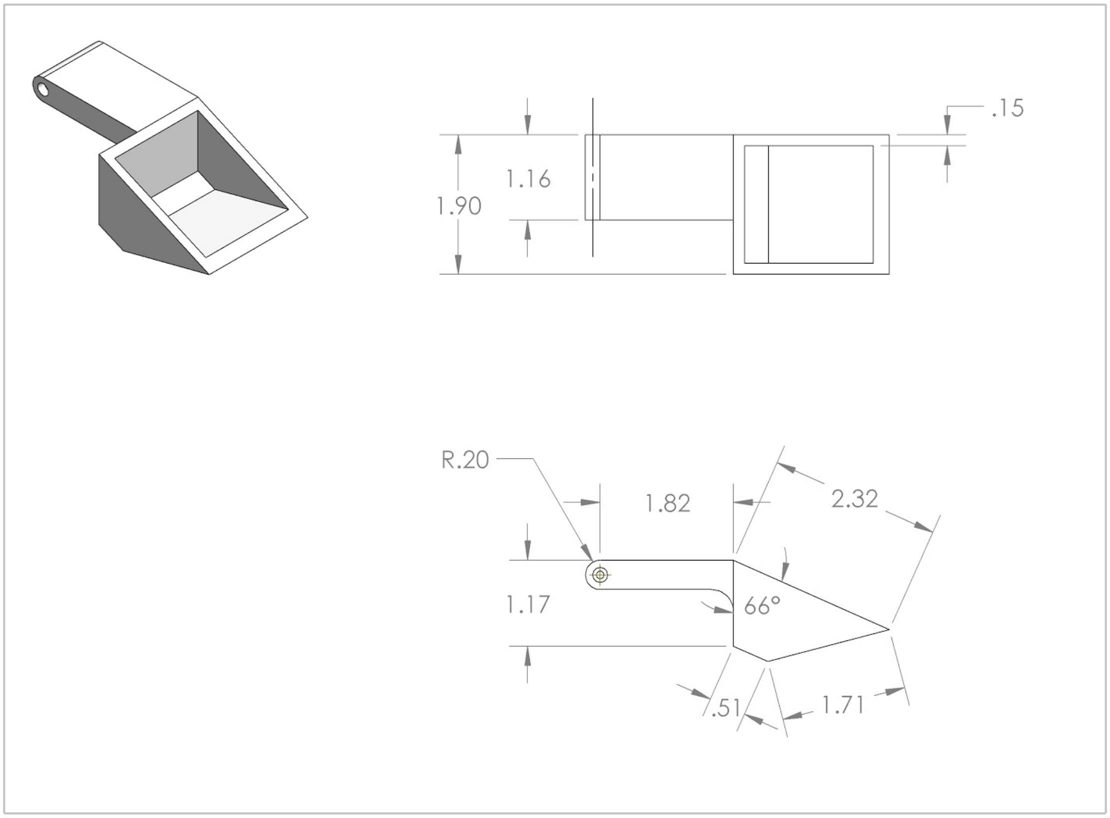

Figure 76: Collection Arm Drawing

Electronics Bay

Several holes within the upper and lower ebay have been created and widened for easier mounting of electronics into the payload structure. A section on the top cover of the rover has been updated to contain the payload's camera, which was not previously included in the CDR.

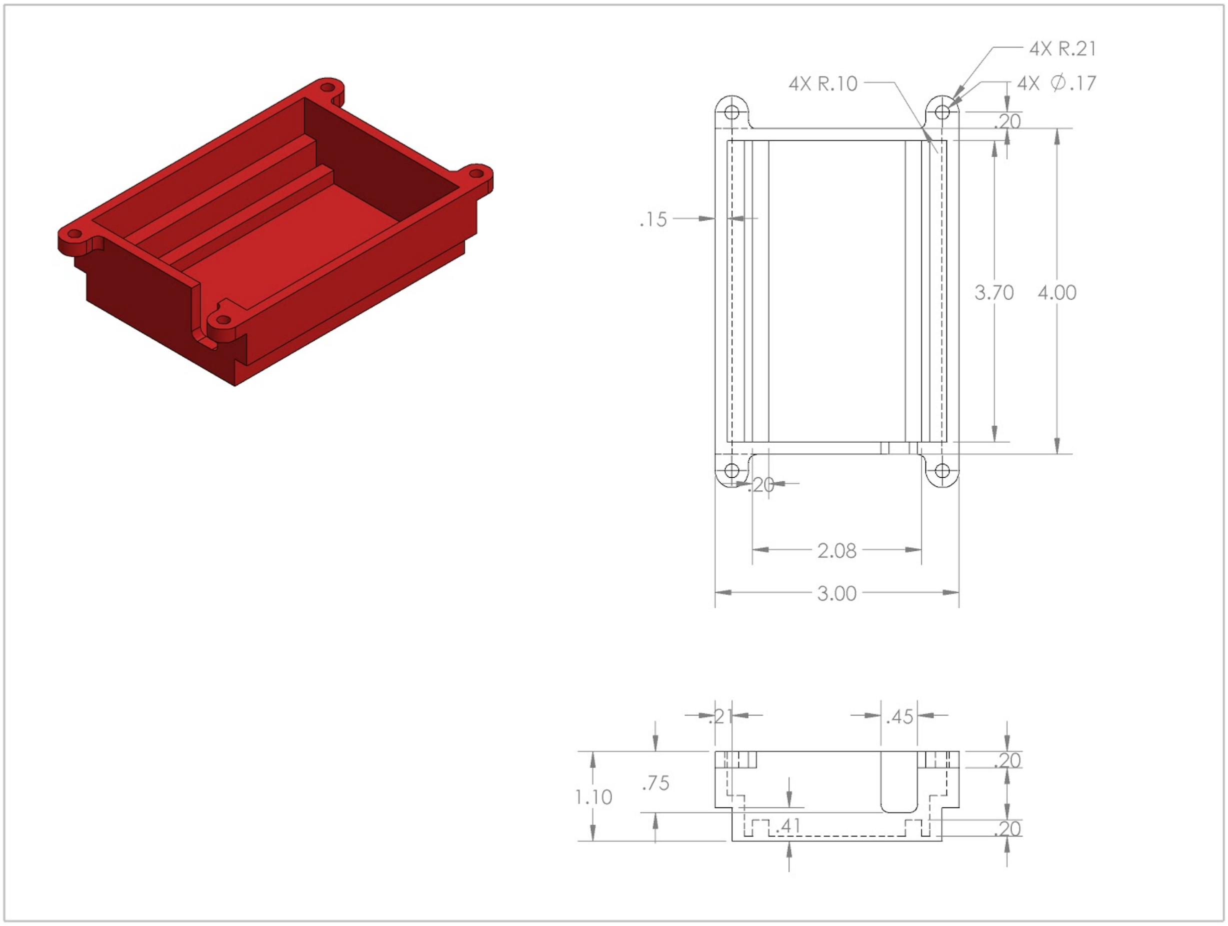

Figure 77: Lower Ebay Drawing

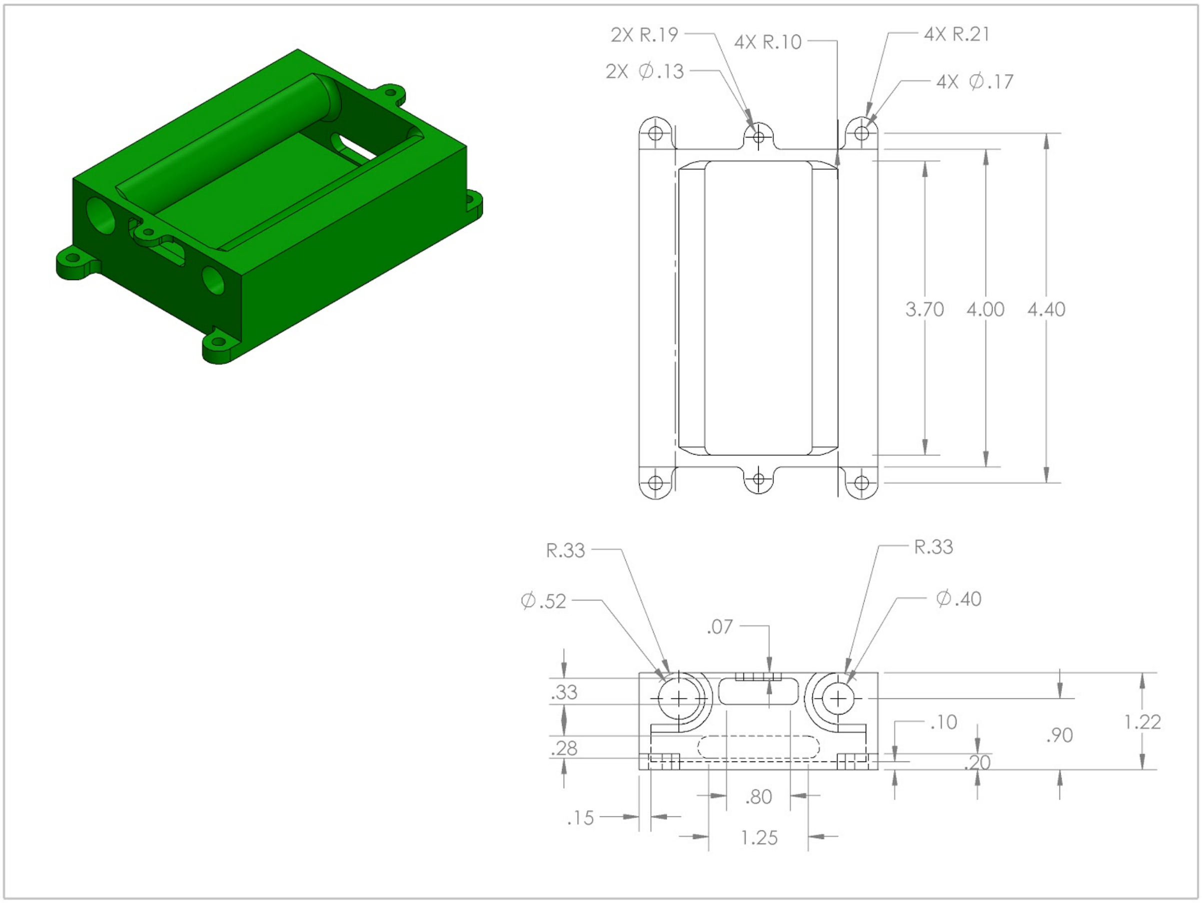

Figure 78: Upper Ebay Drawing

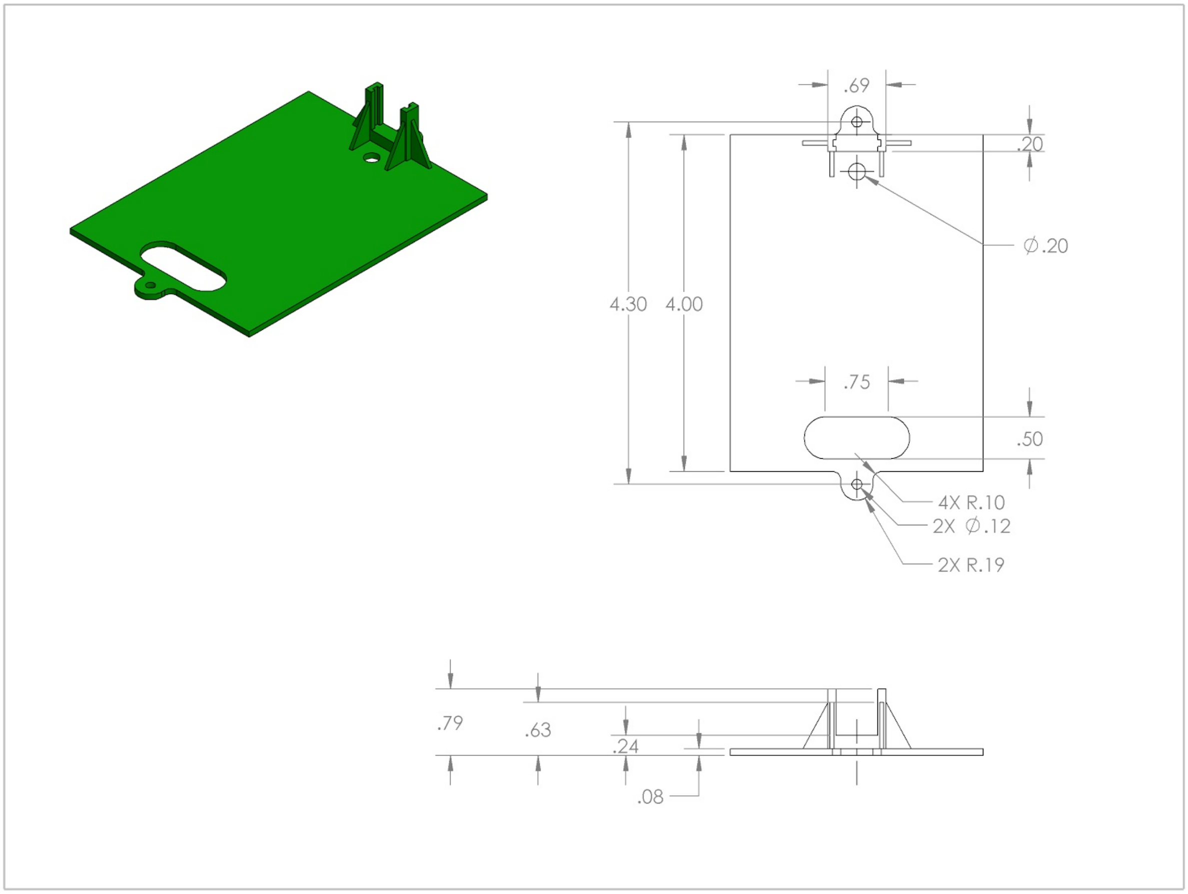

Figure 79: Ebay Cover Drawing

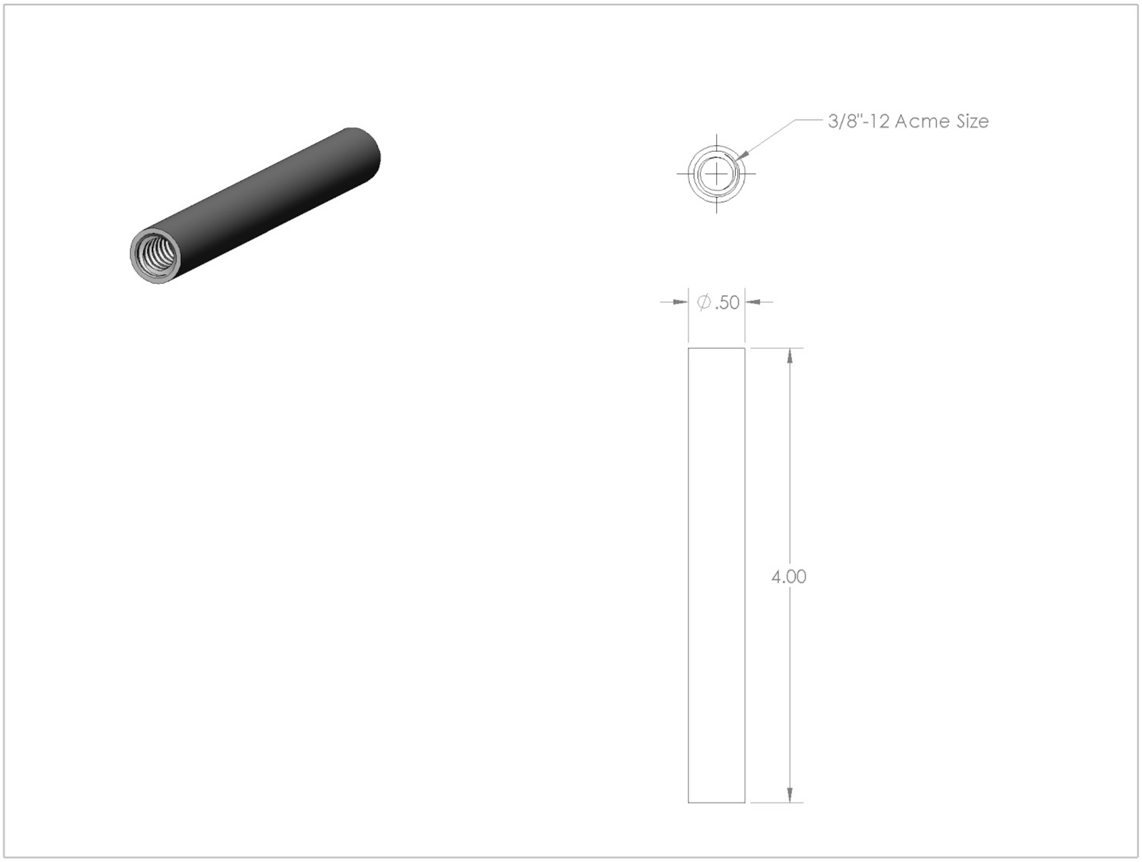

Figure 80: Custom Long Nut

Wheels

As mentioned in the overview of the payload, the previous tread traction system has been replaced with a 4 wheel drive non-differential wheel-based traction system. Non-differential steering using custom made wheels improves traction from the previous tread system, reduces the mechanical complexity of the payload, and ensures a timely completion of the rover. The decision to switch from treads to wheels, however, limits the ability of the rover to overcome obstacles due to reduced contact with the ground. The wheel diameter has also been increased by decreasing the wheel/tread thickness from .75” to 0.4”. An important note about the designed wheels is that they have metric 6mm diameter threads to interface with the threads of the brushless DC motors.

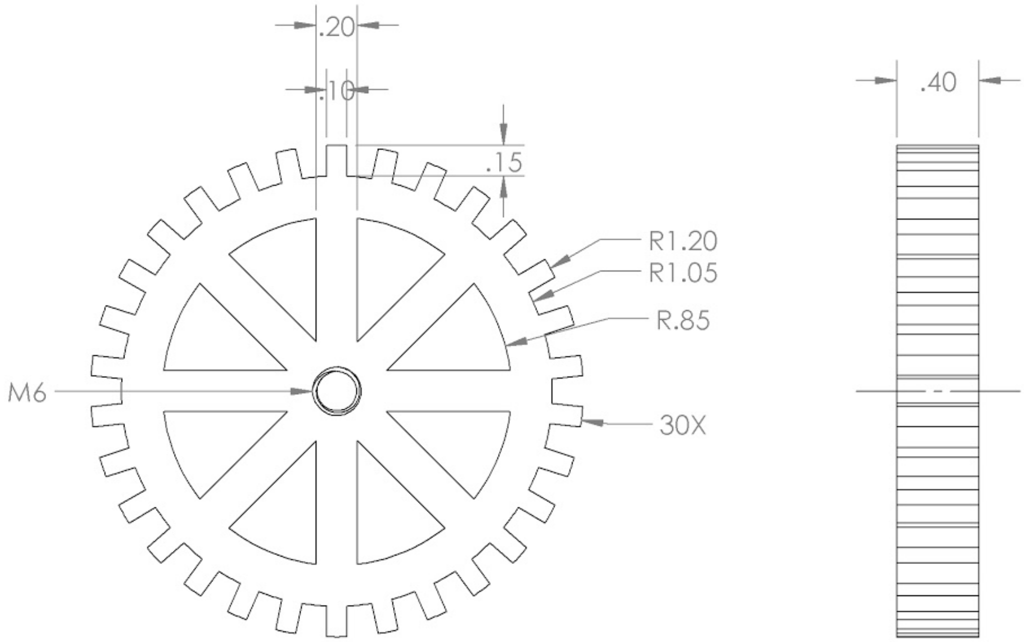

Figure 81: Payload Wheels Drawing

DC Motor Holder

The DC motor holder was incorporated in order to attach the DC motors to the chassis without the case of the DC motor touching the designated holes of the chassis. This component is new since the CDR because of the rotating casing of the DC motor.

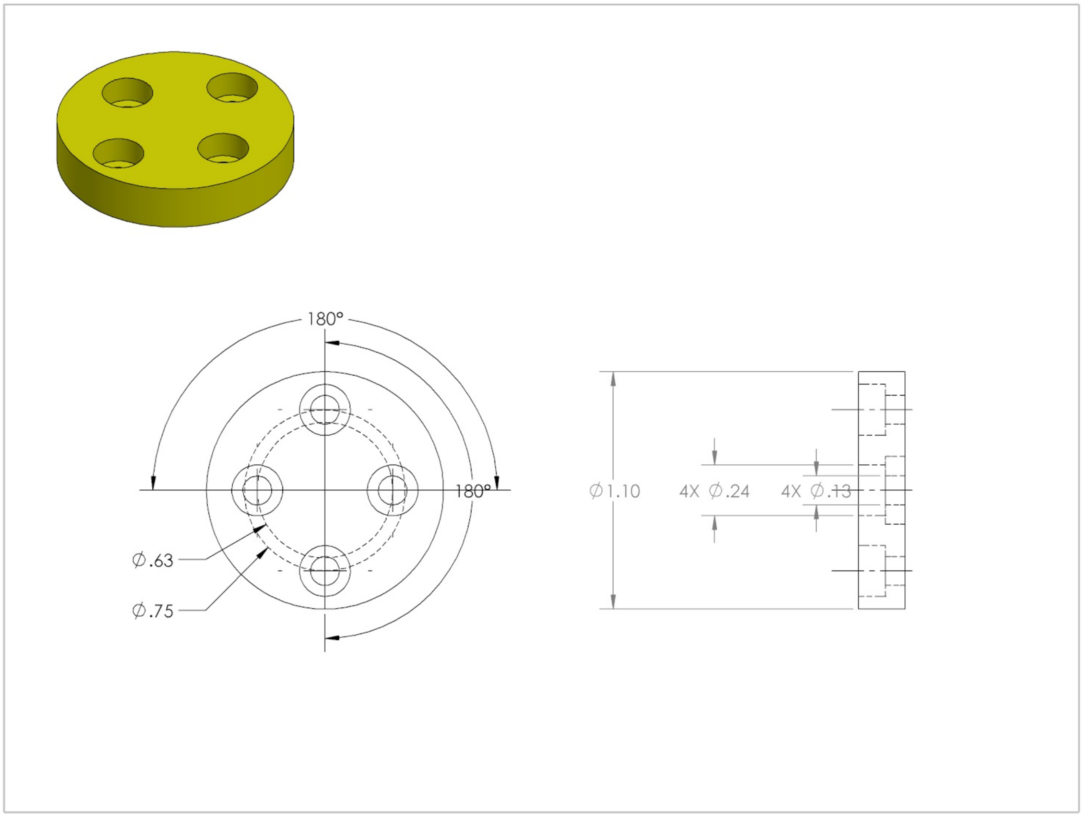

Figure 82: DC Motor Holder Drawing

Antenna Mechanism

The antenna mechanism has been updated to be thicker and longer to allow the 3D printed pieces to snap into position without breaking. Additionally, a longer antenna mechanism is needed to allow sufficient space for the RCA cable that connects to the antenna to bend. This cable is not as easily pliable as other common cables.

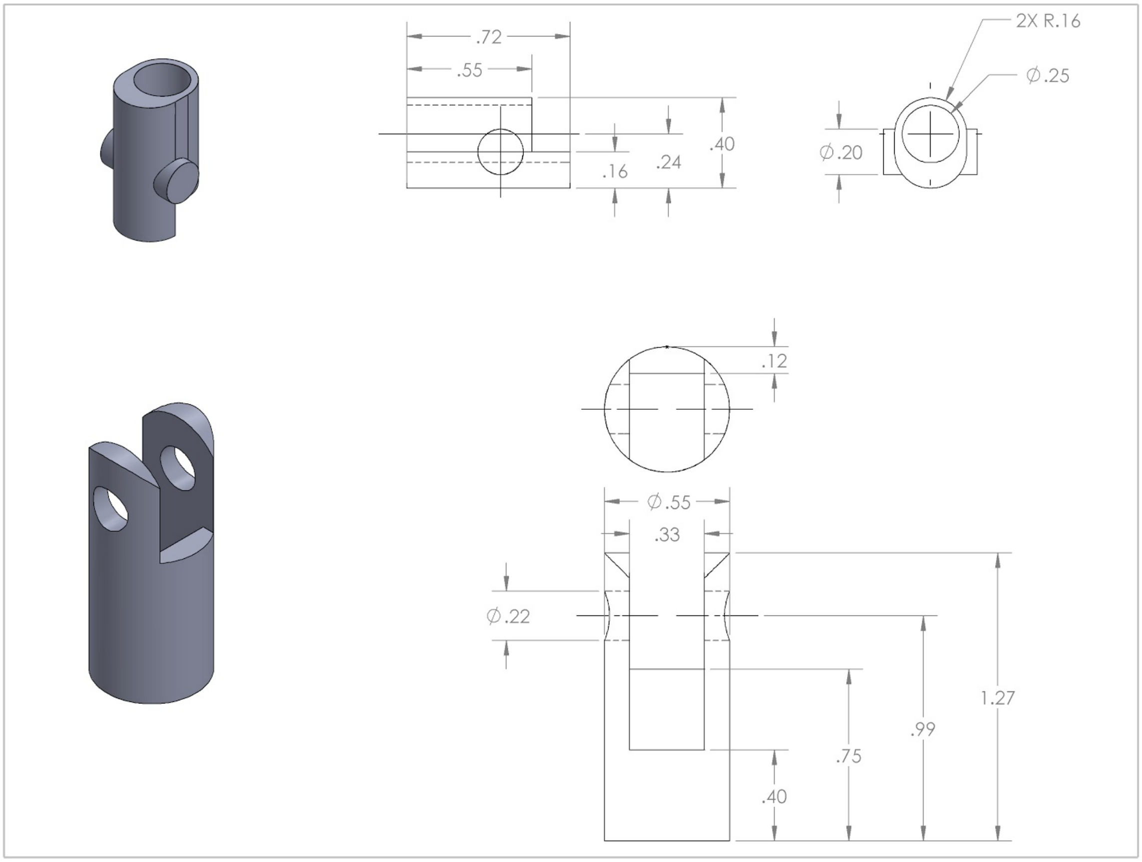

Figure 83: Antenna Mechanism Drawing

4.1.7. Payload Demonstration Flight

4.1.7.1. Date of Flight

Attempt 1

Date:February 22nd, 2020
Location: Mojave Desert Advanced Rocketry Society (MDARS) launch site.
Status: Completed, Reflight Needed

Attempt 2 (Planned)

Date: March 21st, 2020
Location: Friends of Amateur Rocketry (FAR) launch site
Status: Planned

4.1.7.2. Success Criteria

A successful payload demonstration flight is categorized by the payload's ability to complete the following tasks:

1. Safely retain the rover throughout the duration of the flight

2. Properly orient and deploy the rover after touchdown event
3. Establish RF communication with the rover

4.1.7.3. Results of Flight

Attempt 1

During pre-flight packing, a large load was placed on the REA, causing the interface between the REA and the bulkhead attached to the launch vehicle to fail. This load was placed directly on the rover straight out of the body tube. It is also believed to be much larger than the impulse that will be imposed by the 2 pound rover. Since the vehicle still had to be ballasted for stable flight, the RSO was consulted on how to fly the vehicle. They decided the vehicle was still safe to fly if the payload and REA were packed into the body tube with a fire cloth. They and the team understood this mechanism of retention would probably fail but it would properly ballast the vehicle to allow for a successful flight demonstration and failed payload demonstration.

Upon launch, the payload and REA was retained up until main parachute deployment, at which point it fell out as expected. Upon inspection, the custom threaded nut as well as the threaded rod were still connected as packed and the unique rotating bulkhead and unthreaded rod were still intact. Considering these components hit the ground after falling around 500 feet, we don't believe they will fail due to flight forces.

Due to the REA packing failure, the functionality of the REA couldn't be tested, so a re-flight has been scheduled. It should be emphasized that all other components acted as expected and the mode of failure was an unplanned packing error.

4.1.7.4. Retention System Performance

Attempt 1

As said earlier, the REA was not able to be properly tested due to the packing failure. Even so, there is something to be said about the failure that happened during packing.

As said earlier, the packing failure was caused by a load placed directly on the rover, attempting to pull it out of the body tube. The main interface that was expected to possibly fail was between the custom nut and threaded rod. Since this wasn't the interface that failed, that is no longer the interface of concern for the team. The rotating component that failed is now the interface believed most likely to fail. This will the main interface of concern during the payload re-flight.

5. Demonstration Flights

5.1 Flight 1

Date: February 22nd, 2020
Location: Mojave Desert Advanced Rocketry Society (MDARS) launch site.
Requirement Attempted: Vehicle Demonstration Flight AND Payload Demonstration Flight

Objective: Successfully launch full-scale vehicle with launch day motor, while harboring completed payload and payload retention system. Successful launch is quantified by proper recovery hardware deployment, payload retention for the duration of the flight, and rover deployment post-landing.

5.1.1. Launch Conditions

Launch day conditions were recorded by Bearospace members from Edwards AFB Weather Station data (located 20 minutes away from MDARS), available on the website Weather Underground, and are provided below for the time of launch at 2:06 pm on the 22nd of February.

Table 13: MDARS Launch Site Weather Conditions at 2303 ft ASL

Time	Temperature	Dew Point	Humidity	Wind Direction
2:06 pm	57ºF	37ºF	48%	West-Northwest
Wind Speed	**Wind Gust**	**Air Pressure**	**Precipitation Rate**	**Precipitation Accumulation**
8 mph	0 mph	27.51 in.	0.00 in.	0.00 in.

Using this weather data and the properties of the 2856-L910-CS-0 motor used, the launch pad inclination, and final pre-flight data on the rocket, a RockSim rocket launch simulation is performed, which has been provided below in 5.1.4., along with the actual flight results in 5.1.2. for analysis in 5.1.4.

5.1.2. Ground Testing

Ground testing was conducted under the instruction and supervision of the team mentor. It was determined that the main parachute would have a main charge of 7g and the drogue parachute would have a main charge of 6g. Pictures of a team member connecting charge wires to a power source can be seen below.

Figure 84: Ground Testing

5.1.3 Flight Results

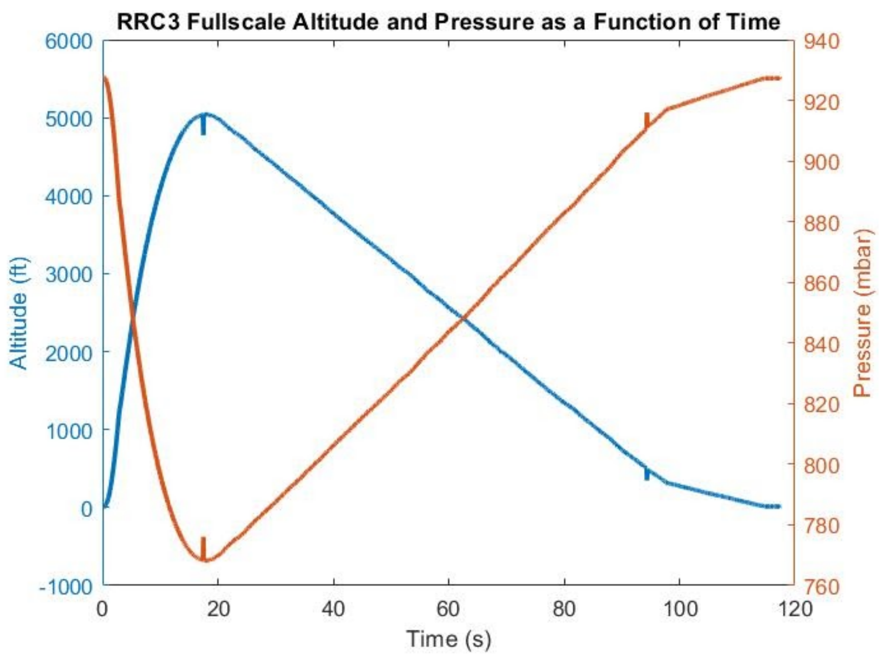

Figure 85: Fullscale Vehicle Demonstration Flight Data from Missile Works RRC3 Altimeter

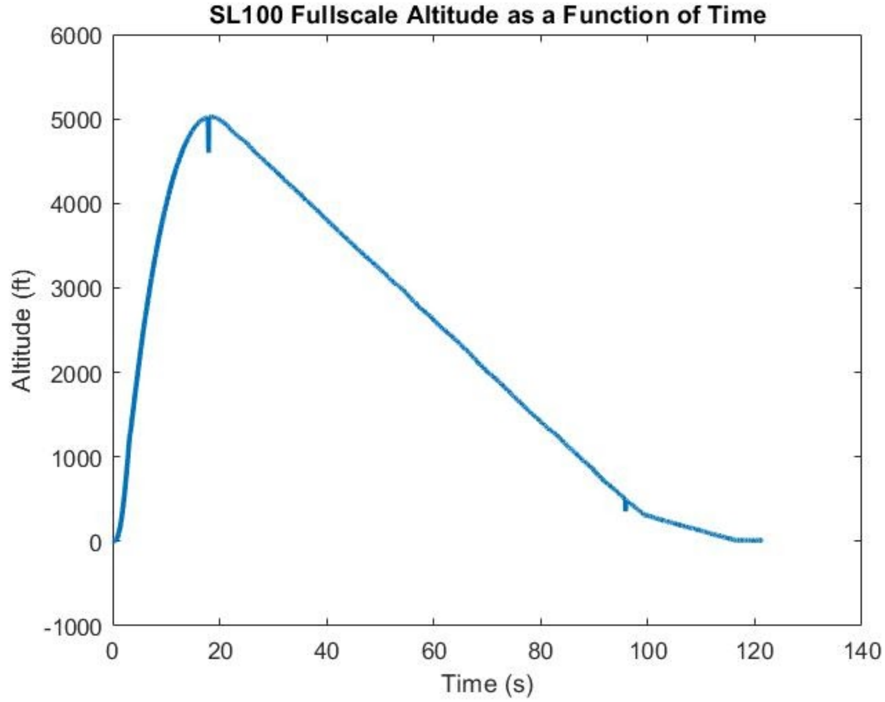

Figure 86: Fullscale Vehicle Demonstration Flight Data from Stratologger SL100 Altimeter

In the figure above, pressure readings of the flight were omitted since the Stratologger SL100 is unable to export pressure data.

The Missileworks RRC3 Sports altimeter recorded a maximum apogee of 5040 feet while the Stratologger SL100 altimeter recorded an apogee of 5025 feet. The discrepancy between the two apogees is attributed to the the different pressure sensor modules each altimeter uses.The Missileworks RRC3 altimeter uses a MSI MS5607 pressure sensor whereas the Stratologger SL100 altimeter does not provide a pressure sensor specification.

5.1.4. Flight Functionality

Payload Flown: Yes, will be discussed in XXX.

5.1.4.1. Successful Functionality

All load bearing hardware and vehicle components functioned as intended. This includes all bulkheads, centering rings, locking mechanism, and airframes. Furthermore, all altimeters functioned as intended and gathered accurate data during flight.

5.1.4.2. Failed Functionality

There was no failure in the launch vehicle. The only failures were in the payload and payload retention hardware which are discussed in section 5.1.6. Payload Retention Performance.

5.1.5 Post-Flight Analysis

5.1.5.1. Altitude

A RockSim simulation of the pre-flight full-scale rocket was performed using the coefficient of drag determined from the subscale demonstration launch, followed by a RockSim simulation performed on the pre-flight full-scale rocket with a coefficient of drag that resulted in a simulated apogee close to that given by the altimeters onboard.

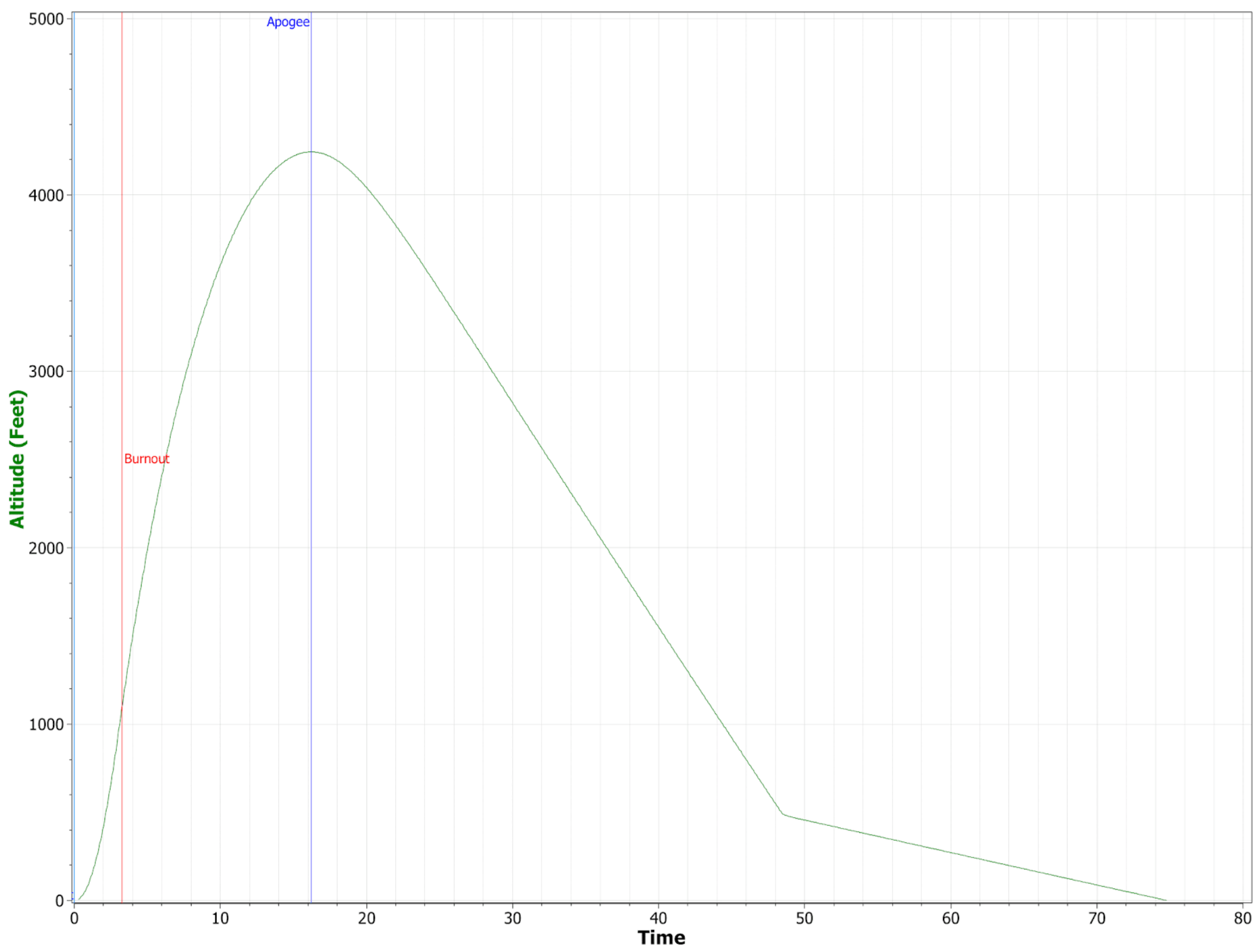

Figure 87: Fullscale Vehicle RockSim Simulation, Coefficient of Drag = 0.63

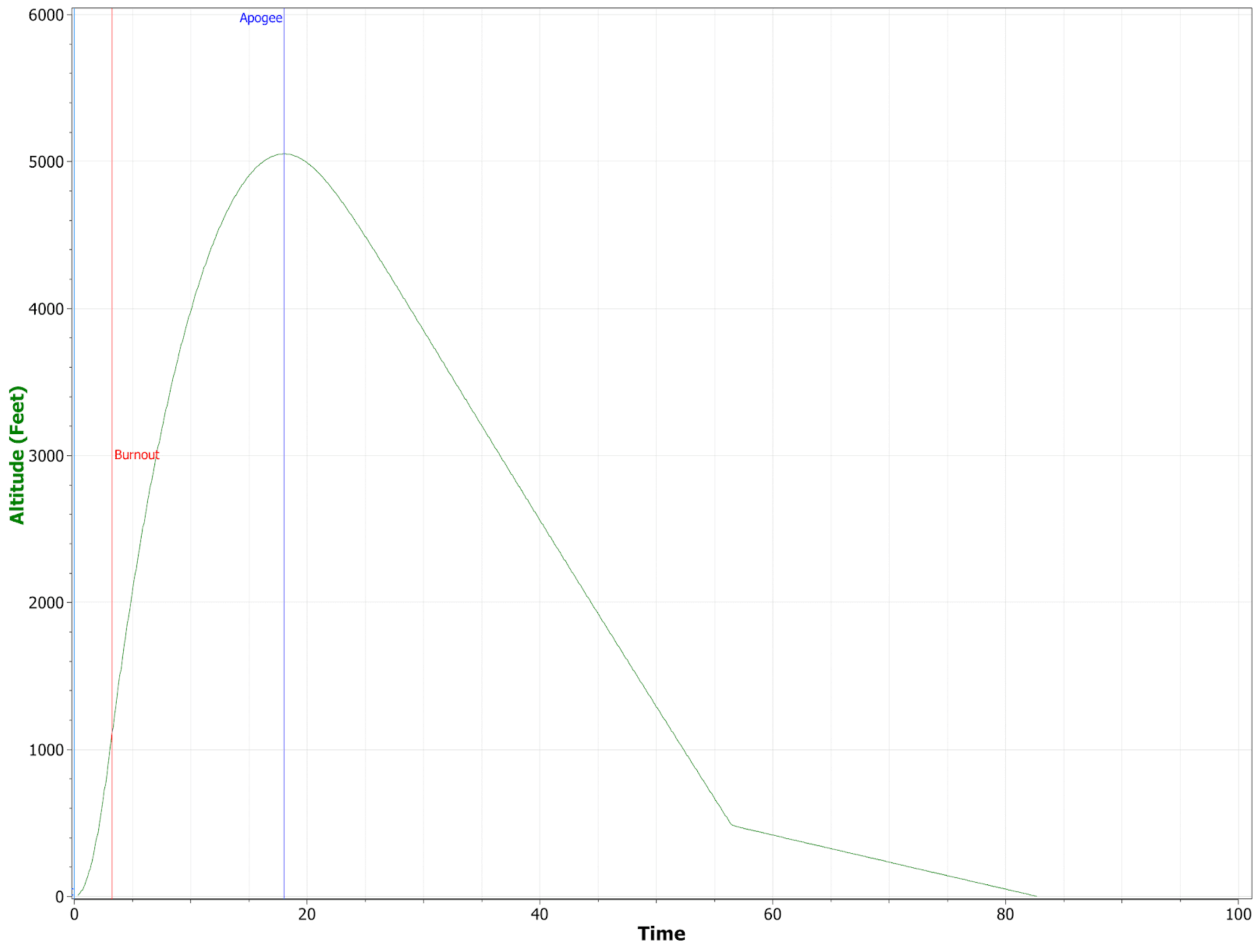

Figure 88: Fullscale Vehicle RockSim Simulation, Coefficient of Drag = 0.39

5.1.5.2. Drag

From comparing the altimeter data presented in 5.1.2 and the pre-flight simulation data, the rocket vehicle coefficient of drag is overridden to determine a single value that will accurately describe the full-scale launch and future full-scale launches.

Table 14: Pre-Flight to Post-Flight Coefficient of Drag Estimation Comparison

Pre-Flight Coefficient of Drag	Post-Flight Coefficient of Drag
0.63	0.39

5.1.5.3. Error

Comparing the drag coefficients determined through RockSim simulations and presented in 5.1.4.2, there is a clear significant difference in the two estimations between the pre-flight status (obtained through the subscale launch) and the post-flight status (obtained through the full-scale launch), an almost 38% reduction in the drag coefficient.

Referring back to the subscale flight analysis in 3.2.4 in the CDR, possible factors contributing to this significant difference in estimation can be reconsidered and reevaluated.

1. Skin Friction Differences in Material Used versus Material Simulated
    a. From CDR 3.2.4: “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.”
    b. Post-Full-Scale Flight Analysis: In comparison to a commercially sold cured carbon fiber body tube, a cardboard tube has seams, can deform readily, and possesses an outer surface that is not as smooth as a cured carbon fiber tube. All of these can possibly explain why the coefficient of drag is higher for the subscale than the full-scale, though not to as extreme a degree as a 38% increase from 0.63 to 0.39. As such, though it is believed to be a contributing factor, it is not believed to be a significant cause.
2. Deformation of Launch Rail During Launch
    a. From CDR 3.2.4: “During launch, it was observed that as the rocket traveled along the launch rail, the rail flexed and bent, 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, it can explain the discrepancy.”
    b. Post-Full-Scale Flight Analysis: As mentioned previously, launch rail deflection and deformation due to loading from motor burn cannot be modeled by either OpenRocket or RockSim (the two rocketry simulation softwares available to Bearospace), and it was noted that there was indeed some deflection in the launch rail during the subscale flight launch. This deflection could have easily increased the friction between the launch rail and the launch lugs (or even the friction between the rail and the body should the rail deflect in that direction, making contact with the body), reducing the kinetic energy of the rocket imparted by the motor burn, resulting in an artificially higher coefficient of drag by way of a reduced apogee. This can be a considerable factor in the 38% increase in the coefficient of drag between the full-scale and subscale launches.

5.1.5.4. Subscale Similarities and Differences

A similarities and differences comparison between the subscale and full-scale flight results is provided below.

1. Subscale to Full-scale Similarities
    a. Recovery System Deployment at Apogee: Both flights successfully deployed their respective chutes once apogee was achieved.
2. Subscale to Full-scale Differences
    a. Estimated Coefficient of Drag: See 5.1.4.2.
    b. Recovery System Deployment Type: The subscale flight was intended as a single chute-deployment flight, where it's main parachute would deploy at apogee. The full-scale flight however is designed as a dual-deployment flight, where the drogue chute is deployed at apogee and the main parachute is deployed at 500 ft AGL.
    c. Apogee: Due to the scaling factors employed for the subscale launch, the apogee reached by the subscale was much lower than that of the full-scale, though this was an anticipated consequence.

5.1.5.5. Damages and Repair Plan

Upon recovery of the rocket vehicle from the landing site, no damage was observed, and so no repair plan for the rocket vehicle itself is planned.

5.1.5.6. Lessons Learned

The lesson learned from this full-scale vehicle demonstration flight is to more carefully consider the factors that can affect or not affect the accuracy of scaling factors employed in a subascale vehicle demonstration flight. Had the launch method been kept constant, ie launch via rail buttons on a launch rail rather than plastic launch lugs on a flexible launch rod, it is possible that a more accurate drag coefficient could have been estimated and accounted for in the CDR to better reach target apogee.

5.1.5.7. Off-Nominal Events

No off-nominal events occured on the launch vehicle during launch.

5.1.6. Payload Retention Performance

5.1.6.1. Successful Functionality

The rover ejection assembly successfully retained the payload throughout the duration of the flight. Flight impulses did not damage the custom 3D printed long nut and was able to manually rotate smoothly, even after touchdown.

5.1.6.2. Failed Functionality

Prior to launch, the electronics team was unable to implement the necessary electrical hardware for deploying the rover onto the launch vehicle due to time constraints. As such, the rover ejection assembly failed to identify a touchdown event, orient the rover, and deploy the rover. This failure was expected as no electrical hardware was wired to the stepper motors responsible for rotating and ejecting the rover.

5.1.6.3. Damages and Repair Plan

The rover ejection assembly suffered no damage caused by the launch. However, the rover ejection assembly will be remanufactured to repair the rod deflection caused by incorrect manufacturing. This implies the creation of an entirely new rover ejection assembly. Previous parts can be reused if salvaged correctly, except for the slabs of wood that were epoxied into place.

5.1.6.4. Lessons Learned

During the launch vehicle's setup, the payload was difficult to position into its desired position, hence the unplanned load that was placed on the rover. To pack the rover into position, the threaded rod must be twisted manually, however, the rover makes it difficult for someone to get their hand behind the rover to twist the rod. The electronics team will develop a button which, upon being pressed, rotates the threaded rod so the rover can be packed into position without having to manually twist the rod.

Another difficulty of the rover ejection assembly was the placement of the unthreaded rod. During manufacturing, the unthreaded rod was epoxied into position without considering the possibility of deflection while the epoxy dried. This resulted in added difficulty when packing the rover since the unthreaded rod was not straight. To prevent this, extra precaution during the re-manufacturing stage will be taken to ensure the rod is straight while the epoxy is drying.

5.1.7. Payload Performance

5.1.7.1. Designed Mission Sequence

In order to automatically deploy the rover, the rover ejection assembly must undergo a series of events to safely and accurately deploy the rover. Details on each step are outlined in section 4.1.4.2. Once the rover ejection assembly has identified a landing event, oriented the payload, and deployed the payload, a mechanical spring system will cause the antenna to be in an upright position for improved video signal transmission once the rover is entirely outside the launch vehicle. At this point, video feedback and control inputs should be fully functional. The driver will then maneuver the rover to the designated collection site and collect simulated lunar ice samples.

5.1.7.2. Successful Functionality

During ground tests at the launch site, the team noticed insufficient ejection charge shielding between the black powder charges and the rover. All electronics within the rover were stripped and replaced with ballast to prevent potential electronic damage. As such, there were no successful payload functions except for payload retention.

5.1.7.3. Failed Functionality

The decision to strip all electronics within the rover meant that the payload failed as expected. None of the designed mission sequence steps were achieved since no electronics were located within the payload.

5.1.7.4. Damages and Repair Plan

The payload suffered minor black powder contamination due to insufficient shielding from ejection charges. The entire payload will be reprinted because of this and to reflect additional design changes outlined in section 4.1. Wiring within the rover must be redone since the decision to remove onboard electronics required wires to be cut.

5.1.7.5. Lessons Learned

An unaccounted design flaw of the demonstration flight revealed that a method of ejection charge shielding is necessary. Even though minor black powder contamination of the rover occured, complete shielding is critical since the attached camera must be clean to operate. Additionally, the team observed that a change from a tread traction system to a wheel traction system is necessary.

5.2 Flight 2

Date: March 21st, 2020 (Planned)
Location: Friends of Amateur Rocketry (FAR) launch site
Requirement Attempted: Payload Demonstration Re-Flight (with full motor to also qualify as Full-Scale Flight Demonstration Re-Flight)

Objective: Successfully launch full-scale vehicle with launch day motor, while harboring completed payload and payload retention system. Successful launch is quantified by proper recovery hardware deployment, payload retention for the duration of the flight, and rover deployment post-landing.

6. Safety and Launch Procedures

6.1 Safety

6.1.1 Student Safety Officer

UCLA's Student Launch Safety Officer has made adjustments 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 7.2.2). 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.
- Fullscale and demonstration launch test analysis and enforcement of all launch operation procedures.
- 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.

6.1.2 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 6.1.3.

Federal Aviation Regulations 14 CFR

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

Code of Federal Regulation 27 Part 55

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

NFPA 1127

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

Table 15: 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.
2. **Materials.** I will use only lightweight materials such as paper, wood, rubber, plastic, fiberglass, or when necessary ductile metal, for the construction of my rocket.	Structures team lead and members will be held responsible for ensuring appropriate materials are utilized in the construction of the rocket as outlined in section two above. MSDS research has been elevated, and materials have been compared to ensure adequate selections for the construction of our launch vehicle and payload.
3. **Motors**. I will use only certified, commercially made rocket motors, and will not tamper with these motors or use them for any purposes except those recommended by the manufacturer. I will not allow smoking, open flames, nor heat sources within 25 feet of these motors.	Motors that are purchased are to be exclusively certified and stored safely, as well as only handled by NAR/TRA personnel. Motors will be solely handled and purchased for our high powered rocket by our team mentor, who possesses Level 2 certification.
4. **Ignition System.** I will launch my rockets with an electrical launch system, and with electrical motor igniters that are installed in the motor only after my rocket is at the launch pad or in a designated prepping area. My launch system will have a safety interlock that is in series with the launch switch that is not installed until my rocket is ready for launch, and will use a launch switch that returns to the “off” position when released. The function of onboard energetics and firing circuits will be inhibited except when my rocket is in the launching position.	The safety officer and team leads will be responsible for proper ignition system installation as outlined in the aforementioned code. All launch pad procedures have been briefed to team leads and the standing safety officer.
5. **Misfires.** If my rocket does not launch when I press the button of my electrical launch system, I will remove the launcher’s safety interlock or disconnect its battery, and will wait 60 seconds after the last launch attempt before allowing anyone to approach the rocket.	The team will collectively ensure that in the case of a misfire, the battery is disconnected and 60 seconds have elapsed before anyone is to approach the rocket. Note that the Range Safety Officer has encompassing final decisions; therefore, alterations may be addressed by the RSO and additional limitations/ regulations may be subject to realization.

6. **Launch Safety.** I will use a 5-second countdown before launch. I will ensure that a means is available to warn participants and spectators in the event of a problem. I will ensure that no person is closer to the launch pad than allowed by the accompanying Minimum Distance Table. When arming onboard energetics and firing circuits I will ensure that no person is at the pad except safety personnel and those required for arming and disarming operations. I will check the stability of my rocket before flight and will not fly it if it cannot be determined to be stable. When conducting a simultaneous launch of more than one high power rocket I will observe the additional requirements of NFPA 1127.	As stated, the team will follow the appropriate launch safety guidelines set forth at the launch site, by the Range Safety Officer, and at a safe distance away from the launch pad. Rocket stability will be checked. Center of gravity and center of pressure will be presumptively identified and labeled on the launch vehicle. In addition, a hard copy of 2020 NASA Student Launch Handbook and Request for Proposal has been obtained for our records. This allows us to have resources such as the minimum distance table on hand.
7. **Launcher.** I will launch my rocket from a stable device that provides rigid guidance until the rocket has attained a speed that ensures a stable flight, and that is pointed to within 20 degrees of vertical. If the wind speed exceeds 5 miles per hour I will use a launcher length that permits the rocket to attain a safe velocity before separation from the launcher. I will use a blast deflector to prevent the motor's exhaust from hitting the ground. I will ensure that dry grass is cleared around each launch pad in accordance with the accompanying Minimum Distance table, and will increase this distance by a factor of 1.5 and clear that area of all combustible material if the rocket motor being launched uses titanium sponge in the propellant.	The team will ensure that the stability of the rocket is safe for launch and that all parameters are approved by the Range Safety Officer for proper flight and that the launch field is properly equipped, maintaining safe distances away. All team members have been briefed on and understand the importance of maintaining a safe distance away from the launch pad before the vehicle is set to launch. To safely comply with the standards of the code, we will ensure that our offset vertical degree amount is well within the 20 degree threshold and is dependent on the wind speeds on launch day and time.
8. **Size.** My rocket will not contain any combination of motors that total more than 40,960 N-sec (9208 pound-seconds) of total impulse. My rocket will not weigh more at liftoff than one-third of the certified average	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

thrust of the high power rocket motor(s) intended to be ignited at launch.	possible design options consider the restrictions and allow for marginal freedom to expand.
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.
11. **Launcher Location.** My launcher will be 1500 feet from any occupied building or from any public highway on which traffic flow exceeds 10 vehicles per hour, not including traffic flow related to the launch. It will also be no closer than the **appropriate Minimum Personnel Distance from the accompanying table from any boundary of the launch site.**	The Safety Officer and team leads will ensure that the launch is positioned away from all persons and property. The launcher will strictly adhere to the launcher location parameters and remain at a safe distance away from the launch pad. All team members have read through the 2020 Handbook and recognize the importance of adhering to the minimum personnel distance as outlined by the regulations.

12. **Recovery System**. I will use a recovery system such as a parachute in my rocket so that all parts of my rocket return safely and undamaged and can be flown again, and I will use only flame-resistant or fireproof recovery system wadding in my rocket.	All team leads and Safety Officer will ensure the rocket is successfully designed with an excellent recovery system that abides to the guidelines set forth. In addition, our recovery system electronics will not be adversely affected by any other on-board electronic devices during flight. It will be physically located in a separate compartment within the vehicle from any other radio frequency transmitting devices.
13. **Recovery Safety.** I will not attempt to recover my rocket from power lines, tall trees, or other dangerous places, fly it under conditions where it is likely to recover in spectator areas or outside the launch site, nor attempt to catch it as it approaches the ground.	The team leads and Safety Officer will collectively ensure that the team safely recovers the rocket by abiding to the preset guidelines. We will collectively wait for approval from the RSO in case of potential hazardous conditions that may be encountered.

6.1.3 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.

6.1.3.1. 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 16: 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%

Consequence

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 17: 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 18: 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 may be completely avoidable. They tend to be rare or 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: either likely or possessing moderate severity. These risks may or may not be acceptable in terms of project success; therefore, 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.

All risks recognized by team members have been recorded, evaluated, and modified by the team safety officer. Although not all risks have yet been encountered up to date, 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. In all following risk assessment tables, each risk is outlined with potential causes, effect on respective section, corresponding mitigation strategies, verification plans of the strategies, and a delineated risk assessment rating for pre- and post-mitigation that are color-coded by level of risk presented above. An updated list since the CDR is presented below, including successful mitigation strategies and experiences through the manufacturing phase. The ultimate goal is to preemptively address as many potential risks and cultivate mitigation strategies that reduce either the likelihood and/or the severity of their effects.

6.1.3.2. Personnel Hazard Analysis

Represented below are potential hazards to personnel working in the lab space and machine shops, including any risks posed by chemicals, machinery, and equipment. Note that the verification will include methods of procession depending on protocols delineated in lab safety guidelines.

Table 19: Personnel Hazard Assessment

Personnel Hazard Risk Assessment						
Risk	**Cause**	**Effect**	**BM**	**Mitigation Strategy**	**Verification**	**PM**
Cuts or lacerations	Improper use of machines or 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.	Consultation of shop safety guidelines. Immediate attention from team leads and Safety Officer to proceed accordingly.	1C
Exposure to chemicals or allergens	Improper handling of chemicals and known allergens	Chemical burns, Epidermal contamination; Cross contamination	3B	Latex gloves will be worn when handling chemicals & known allergens. Proper lab etiquette will be enforced.	PPE enforcement of latex, chemically resistant gloves	3C
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.	Consultation of MSDS before working around powder charges. Must be certified to handle or under Mentor supervision, handling only small amounts.	3A

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.	Required consultation of MSDS prior to use; Respirators and relevant PPE when working with chemical fumes.	3C
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.	Required consultation of MSDS; Eye protection PPE is to be used.	3B
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.	Required consultation of MSDS; An experienced team member will either be performing the epoxy work or supervising it.	3C
Open paint fume inhalation	Improper use of chemical	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.	Every respirator checked for filter cleanliness. Shop safety guidelines are adhered to regarding appropriate fuming location.	3C
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 a consistent, loud sound.	PPE enforcement of ear muffs and/or ear plugs ONLY when working around or with loud machinery.	3C

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.	Consultation of lab safety guidelines. Depending on the location of shock, equipment may cause fire. Fire extinguisher and lab safety kits on hand.	3B
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.	Required shop safety guidelines, proper storage and clean-up. PPE requires clothing covering the full body.	3B
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.	Consultation of shop safety guidelines & proper lab etiquette enforced.	3C
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 the user wears a respirator mask.	PPE enforcement of P100 respirators.	3C
Shop Fire	Chemical cross contaminatio	Moderate to Fatal injuries or	2A	High power circuitry completed with the student safety officer	All lab coats are fire resistant. Fire protocol and	2B

	n & equipment overheating; incorrect wiring; explosion	death; irreparable damage to equipment and lab space		present; fire extinguishers kept in the shop. Always be aware of one's surroundings and be diligent when working in a lab environment.	exit route is included in all lab safety certified courses.	
Caught in a machining equipment	Loose clothing; overhanging jewelry; hair draped over face	Serious personnel injury or death	2B	Those performing machining operations will never wear loose fitting clothing or jewelry. All long hair must be tied back.	Reiteration and consultation of shop safety guidelines. Appropriate clothing worn during work days.	3B
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.	Consultation of lab safety guidelines. PPE requirement of lab coats; all heat producing tools be turned off when not in use.	3C
Structural failure	Excessive sanding, vibration testing	Serious personnel injury	2B	Proper joint tightness, maintain safe distance from test facility during tests. Avoid direct line rocket's fore.	Complete design analysis of vehicle frame; testing procedure strictly adhered to ensure structural stability of system.	3B
Rocket dislodged	Inadequate launch vehicle axial constraint	Serious personnel injury	2B	Monitoring of construction through manufacturing phase. Avoid direct line rocket's fore. Ensure proper vehicle assembly and testing.	Complete design analysis of vehicle frame; testing procedure strictly adhered to ensure structural stability of system.	3B
Contact with flying debris	Operation of or enveloping of large machinery	Epidermal burns, abrasions, irritation of eyes or skin	2B	In addition to PPE worn at all times, all members present during cutting or machine operations will wear eye protection and	Consultation of lab safety guidelines and presence of safety officer and	3B

				remain alert of the environment.	project manager for machine operations.	

6.1.3.3. 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. The table has been updated to delineate experiences from the demonstration flight

Table 20: Environmental Hazard Assessment

Environmental Hazard Risk Assessment: On Environment						
Risk	**Cause**	**Effect**	**BM**	**Mitigation Strategy**	**Verification**	**PM**
Chemical contamination of groundwater	Leakage of battery fluid or excess fuel post landing in the natural body of water.	Electrical components leak toxic chemicals into & contaminate the water & wildlife.	3A	Electrical components provided extra separation from the environment within body tube; rocket recovered quickly to minimize exposure time; launch site chosen away from bodies of water.	Consultation of launch operations procedure before and after launch. Launch is no-go if the body of water is within 2500 feet of the launch pad.	3C
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.	Ensure complete inspection to launch operations procedure & constant visual of launch pad throughout launch.	3B
Explosion of rocket and/or excess powder charge	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.	Complete design analysis of components to ensure withstanding internal forces.	3C

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.	Verify using analysis of expected deployment of parachute time & ejection necessary. Consult launch operation procedures.	1C
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.	Fire extinguisher is on hand & taken to the launch site. Consultation of launch operations procedure during launch.	3C
Untethered hardware blown away	Excessive wind	Littering or contaminati on of surrounding environment	2C	Minimize hardware needed on launch day; proper securement of supplies in labeled boxes.	Consultation of packing checklist and pre-packing inspection.	3C
Harm to environment from litter	Improper disposal	Poison, contaminate or harm animal of wildlife	3B	Designation and deployment of trash bags at the launch site; documentation of all hardware taken to site.	Consultation of packing checklist and pre-packing inspection.	3C
Environmental Hazard Risk Assessment: On Environment						
Risk	**Cause**	**Effect**	**BM**	**Mitigation Strategy**	**Verification**	**PM**
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.	Consultation of launch operations procedure during launch. Fire extinguisher is on hand & taken to the launch site.	3C

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.	Proper procedures on flight conditions. Team members and leads would consult the RSO and establish ways to proceed.	3C
Excess weatherrock ing	Large wind speeds	Increase drift & unexpected vehicle trajectory; vertical stability complication	2A	Ensure the launch vehicle has an ample margin of stability.	Enhanced analysis of vehicle design choice of fins and mass distribution.	2C
Unsafe landing zone; elevated drift	High wind speeds	Increase drift from the launch pad, resulting in unrecoverab le vehicle or land in an area posing additional safety concerns	3B	Continuous monitoring of wind speeds in the vicinity. If the wind is 20 mph, it is possible that the launch will be cancelled. Do not launch in wind speeds larger than 20mph.	Adhesion to procedures on adequate flight conditions. Monitor wind levels and await approval from the RSO.	3C
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.	Monitor wind levels and await approval from the RSO.	3C

Launch pad axial malfunction	Pad offset due to inadequate ground conditions; pad not leveled properly upon setup	Unexpected vehicle trajectory	2B	Ensure launch pad and rails are level to ground and jolt tested.	Consultation of launch operations procedure, verify launch pad condition.	3C
Sealing of vent holes	Below freezing temperatures and precipitation; ice buildup on vehicle	Increased vehicle mass; pressure buildup inside launch vehicle	2B	Vehicle is to be concealed until immediately prior to launch. Sandpaper is to be used on any ice caps that appear.	Adhesion to launch operations procedure and conduction of visual inspection prior to vehicle launch.	3B
Untethered hardware blown away	Excessive wind	Unable to assemble vehicle; results in limited resources	2B	Minimize hardware needed on launch day; proper securement of supplies in labeled boxes.	Consultation of packing checklist and pre-packing inspection.	2C
Structural failure	High temperature; excessive exposure to sunlight	Overheating of electronics; launch vehicle body warp	2A	The launch vehicle is assembled in a shaded area.Time elapsed from launch pad setup to launch is minimized.	Pre-consultation of launch operations procedure; body tube integrity verified and battery temperature tested on immediately prior to launch.	3C

6.1.3.4. Recovery System Failure Modes

Represented below are potential hazards associated with the launch vehicle's recovery system. Most predisposed hazards listed yield detrimental effects on the vehicle's integrity as a whole. Verification for individual mitigation strategies will be embodied holistically as seen below.

Table 21: Recovery System Failure Modes

Recovery System Failure Modes & Risk Assessment						
Risk	**Cause**	**Effect**	**BM**	**Mitigation Strategy**	**Verification**	**PM**
Main parachute deployment failure	Insufficient powder charges; parachute fails to eject	Excessive landing speed and impact damage to or destruction of launch vehicle	2A	Extensive ground-based deployment testing, using the same powder charges as when successfully tested. Redundant charge ejection included.	Consultation of launch operations procedure and adequate ground-testing of chutes prior to initiating launch readiness.	2B
Drogue parachute deployment failure	Insufficient powder charges; parachute fails to eject	High descent rate from apogee; affects main parachute deployment; damage to or destruction of launch vehicle	2A	Extensive ground-based deployment testing, using the same powder charges as when successfully tested. Redundant charge ejection included.	Consultation of launch operations procedure and adequate ground-testing of chutes prior to initiating launch readiness.	2B
Separation failure	Excessive shear pin holding strength; inadequate/failed ejected charge;	Damage to or loss of the launch vehicle	2A	Ground-based deployment testing; proper shear pin sizing/strength and blast charge calculations. Redundant charge ejection included.	Consultation of launch operations procedure and adequate ground-testing of chutes prior to initiating launch readiness.	2B
Low battery of electronics power supplies	Failure to power flight altimeters throughout flight; failure to fire drogue and/or main ejection charges	Excessive landing speed and impact damage to or destruction of launch vehicle	2A	Voltmeter is used to test batteries prior to assembly. Extensive battery testing and replacement (if necessary).	Consultation of launch operations procedure.	2B
Separation	Excessive	Excessive	2A	Main-backup altimeter	Consultation of	2B

failure	shear pin holding strength;	landing speed and impact damage to or destruction of launch vehicle		scheme; individual power supply module for each redundant altimeter; fully ground-based altimeter testing before each flight	launch operations procedure.	
Shock cord failure	Shock cord tear, wear, or fault	Parachute disconnection from vehicle; damage or destruction of launch vehicle	2A	Proper inspection of shock cord before packing parachutes into respective compartments.	Consultation of launch operations procedure.	2B
Parachute tear	Parachute tear, wear, or fault	Decreased parachute performance; potential damage to or loss of rocket	2A	Proper inspection of parachutes before packing parachutes into respective compartments. Parachute repair kit is on-hand in case of repairable damage found.	Consultation of launch operations procedure.	2B
Parachute melts	Improper storage; Improper separation	Decreased parachute performance; potential damage to or loss of rocket	2B	Proper inspection of parachute compartment, ensuring adequate coverage utilizing the fire retardant blanket to shield from ejection charges.	Consultation of launch operations procedure.	2C
Shroud lines or shock cords tangle after deployment	Shock cords too long	Parachute does not fully deploy; damage to launch vehicle	2A	Inspection of folding techniques such that shroud lines or shock cord do not tangle. Ensure cords are length delineated in simulations, in accordance with previous launches.	Consultation of launch operations procedure.	2B
Parachute breakaway	Weak adhesion of recovery	Loss of parachute; Excessive	2A	Inspection to ensure strong retention system and shock absorption;	Consultation of launch operations	2B

	system to launch vehicle	landing speed and impact damage; destruction of launch vehicle		ample ground load testing.	procedure.	
Altimeter failure	Wiring failure; insufficient power	Failure to deploy chutes; deploy parachutes at undesired altitudes	2A	Inspect and ensure that individual power supplies are instituted for each redundant altimeter; fully ground-based test altimeter flight/	Consultation of launch operations procedure.	2B
Arming switch failure	Faulty screw-switch component; miswiring of power supply, switch, and altimeter; short-circuit condition	Failure to activate altimeters; results in failure to deploy parachutes; launch vehicle destruction potential	2A	Ensure ground testing of each arming switch; ground deployment simulation tests prior to launch readiness.	Consultation of launch operations procedure.	2B

6.1.3.5 Vehicle Failure Modes

Represented below are potential hazards associated with the launch vehicle's structure holistically. For additional modes of verification, please consult the launch operations procedures in the following section.

Table 22: Launch Vehicle Failure Modes

Vehicle Failure Modes & Risk Assessment						
Risk	**Cause**	**Effect**	**BM**	**Mitigation Strategy**	**Verification**	**PM**
Premature section separation	Shear pins implemented are too small; altimeter	Recovery failure and loss of vehicle	2A	Appropriate shear pins selection and implementation; ground-based deployment and altimeter testing.	Adequate altimeter testing using computational means.	3A

	malfunction					
Launch pad/ rail failure	Issues concerning the stability of launch pad and rail	Unpredict-able rocket trajectory	3A	Inspect launch pad and rail prior to ensure minimum level of stability.	Consolidation of NAR safety guidelines and launch operations procedures	3C
Malfunction in electronics	System failure; cross wiring; overheating	Failure to deploy/ collect data/ operate as intended	2B	Vigorous testing of separate functions within each part. Electronics Operation Checklist thoroughly completed.	Electronics operation checklist thoroughly completed.	3B
Fin failure or weakness	Damaged material; previous landing from testing	Flight stability at risk; unreliable trajectory	2B	Proper inspection prior to every flight of the launch vehicle body and fins; evaluation of structural integrity before and after each launch; ensure well-adhered with epoxy.	Verify fin choice; adequate testing of fiberglass strength, consultat launch operations procedures.	2C
Nosecone damage	Prior flight damage; shipment to launch site	Unstable flight	3B	Evaluation of structural integrity before and after each flight.	Adequate inspection and adhesion to launch operations procedures.	3C
Bulkhead failure	Incorrect calculation of forces that bulkheads can support	Insecure internal parts; possible explosion, payload and recovery system damage, and destruction of vehicle	1B	The accuracy of calculations using OpenRocket software is tested physically using ground tests of strength of materials, prior to assembly.	Consultation of launch operations procedures.	3B
Motor retention failure	Drogue chute applies a force great enough to	The motor may be lost as it detaches	3A	Ensure centering rings have been well epoxied to the inner walls of the body tube.	Ample ground testing of motor retention system Consult launch	3C

	push out motor	completely from the launch vehicle			operations procedures and pre-launch checklist.	
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.	Consultation of launch operations procedure and pre-launch checklist.	3C
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; possible explosion	3A	Simulations are conducted virtually and physically, checked against one another for redundancy.	Verify with and consult simulations; adhesion to launch operations procedures.	3C

6.2 Launch Operations Procedures

The Launch Operations Procedures have been broken up into component preparation spanning from the day before launch to post-launch. These have been divided into a series of tables that should be read as the following:

Table 23: Sample Procedures Checklist

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

The middle column labeled "Completed Substeps" has a single blue box that should be checked if the vehicle passes the requirement with no modification necessary. If success criteria is not initially met and troubleshooting must be done, each yellow box must be checked next to each troubleshooting step to ensure completion. The blue initial box to the left should be initiated by a required personnel listed at the beginning of each section only in the event where either the first light blue box of “COmpleted Substeps” is checked or each yellow box under “completed substeps” is checked. The red initials box next to the warning should also be initiated by a required personnel to ensure that the importance of the step is understood and risks added if failure of step completion occurs.

6.2.1. Pre-Packing Inspection

Purpose: Identify any damage or abnormalities in the launch vehicle or payload BEFORE packing vehicle to go to launch. To be conducted the night before launch.

6.2.1.1. Structural Components

Required Personnel: Project Manager and Structures Lead

Table 24: Structural Pre-Packing Inspection

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

		After allowed cure time, ensure epoxy is dry to touch.
		Sand seal until the epoxy is flush with the rest of the component.
		Reimspect component for imperfections. If there are no further imperfections, the requirement is fully completed.
	Warning: Failure to complete could result in failure of body.	
		Visual Inspection of fin-lower body tube contact point for gap in epoxy application. If no gaps at any point in interface on any fin, mark as completed.
		PPE REQUIRED: Gloves
		Apply two-tube epoxy to the gap and smooth to be flush with the rest of the epoxy interface. (This epoxy used for fast cure time.)
		Wait 1 hour for full cure at room temperature. (Wait 1.5 hours if the temperature is below 60 degrees F.)
		After allowed cure time, ensure epoxy is dry to touch.
		Sand seal until the recently applied epoxy is flush with previously applied epoxy.
		Reinspect interface for imperfections. If there are no further imperfections, the requirement is fully completed.
	Warning: Failure to complete could result in fin detachment from the launch vehicle during flight or on landing.	
		Visual Inspection of the internal interface between nose cone and nose cone bulkhead, internal interface between nose cone bulkhead and eyebolt attached to it, external interface between coupler and lower body tube, internal interface between centering ring closest to the shoulder and the lower body tube, and internal interface between that centering ring and the eyebolt attached to it for gap in epoxy application. If no gaps at any point in either interface, mark as completed.
		PPE REQUIRED: Gloves
		Apply two-tube epoxy to the gap and smooth to be flush with the rest of the nose cone. (This epoxy used for fast cure time.)
		Wait 1 hour for full cure at room temperature. (Wait 1.5 hours if the temperature is below 60 degrees F.)
		After allowed cure time, ensure epoxy is dry to touch.
		Sand seal until the recently applied epoxy is flush with previously applied epoxy.
		Reinspect interfaces for imperfections. If there are no further imperfections, the requirement is fully completed.
	Warning: Failure to complete could result in recovery hardware failure.	

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

		the passing or failing of the requirement.
		If Nosecone falls out of body tube with force of gravity alone.
		Apply painters tape to the coupler in a fashion where there is an even layer covering the entire coupler. Continue adding even layers until friction fitting defined above is met.
		Return back to definition of friction fitting above, perform the test, and classify the passing or failing of the requirement.
	Warning: Failure to complete could result in pre-deployment or failure to deploy recovery hardware.	
		Visual Inspection to ensure main parachute and drogue parachute have no holes or rips within the fabric (including next to the shroud line interfaces). If no imperfections are detected, requirement is fully completed
		Lay the damaged parachute on the ground fully unfolded so it forms an unwrinkled circle on the ground.
		Apply Rip-Stop Parachute tape to both sides of any rips or holes in parachutes in a way where no wrinkles in the parachute are caused when laying flat.
		Reinspect both parachutes for rips or holes. If no others are found, the requirement is met.
	Warning: Failure to complete will result in a change in the expected coefficient of drag, causing faster descent time and larger Kinetic Energy at landing or failure of parachute at full deployment.	
		Visual Inspection of all shock cords and shroud lines used in recovery subsystem for tears. If there are no visible tears, the requirement is fully completed.
		Discontinue use, use replacement of this component. Inspect new components and other components, if no further tears are found on any components, requirement is passed.
	Warning: Failure to complete will result in a change in the expected coefficient of drag, causing faster descent time and larger Kinetic Energy at landing or failure of parachute at full deployment.	
		VIsual Inspection of main parachute and drogue parachute for knot containing all shroud lines about 2" from end of shroud lines to prevent tangling of shroud lines.
		Lay unknotted parachute flat on the ground with shroud lines untangled on top of the parachute fabric.
		Pinch centers of each shroud line and lift off the ground.
		Tie one overhand knot containing all shroud lines about 2" from the pinched point.
		Tighten the knot as much as possible.

		Repeat for other parachute if needed. Otherwise, the requirement is completed.
	Warning: Failure to complete can result in recovery deployment failure.	
		VIsual Inspection of main parachute's (XXX ") shroud lines tied to the middle of the XXX shock cord. If knot is tied and tight, this requirement is met.
		Thread shock cord through the loop made with the ends of the main parachute's shroud lines between the middle of the lines and the knot containing all lines made prior.
		Continue to thread until the main parachute is at the approximate midpoint of the shock cord.
		Tie an overhand knot in the shock corn where it interfaces the shroud line loop, therefore containing the loop within the knot.
		Tighten the knot.
		If the shroud line loop cannot move relevant to the interface with the shock cord, requirement is met.
	Warning: Failure to complete can result in recovery deployment failure.	
		VIsual Inspection of drogue parachute (XXX ") shroud lines tied to the middle of the XXX shock cord. If knot is tied and tight, this requirement is met.
		Thread shock cord through the loop made with the ends of the drogue parachute's shroud lines between the middle of the lines and the knot containing all lines made prior.
		Continue to thread until the drogue parachute is at the approximate midpoint of the shock cord.
		Tie an overhand knot in the shock corn where it interfaces the shroud line loop, therefore containing the loop within the knot.
		Tighten the knot.
		If the shroud line loop cannot move relevant to the interface with the shock cord, the requirement is met.
	Warning: Failure to complete can result in recovery deployment failure.	
		Shear pin holes should be drilled and marked with one alignment marking per interface.
		PPE Required: Safety Goggles
		Draw two arrows pointing to each other in silver sharpie, one on each parent component facing each other on either side of the interface.
		Drill 3 holes with 1/16” drill bit equally spaced around the upper body tube about 2" from the interface.
		Draw circles around each hole with a silver sharpie.
		Mark as completed when all holes are drilled and marked (6 total).
	Warning: Failure to complete can result in recovery deployment failure.	

6.2.1.2. Electrical Components

Required Personnel: Electronics Lead and Project Manager

Table 25: Electrical Component Pre-Packing Inspection

		Four wires should be coming out of the REA, and four out of the locking mechanism, all securely connected to the altimeter for the purposes of setting off ejection charges.
		If any wires are missing, alert electronics lead and locate missing wire.
		Inspect altimeters to find which wire is missing. An empty pin on the altimeter denotes which wire is missing
		Cut new piece of wire and slide the wire through the designated wiring hole and connect to the altimeter
		All drogue chute wires should go through the locking mechanism and all main chute wires should go through the payload bulkhead
		Mark as completed when there are a total of 8 wires protruding from the electronics bay but still within the upper body tube. 4 wires should be protruding from each side.
	Warning: Failure to complete can result in recovery deployment failure.	
		Interface between ejection charge wiring and bulkheads surrounding electronics bay should be air tight by means of an epoxy seal.
		PPE Required: Gloves
		Put quick-setting epoxy onto the interface to completely cover it.
		Allow a 1- hour cure time, 1.5 hours if the temperature is below 60 degree fahrenheit.
		Repeat for other interface if it is not deemed airtight.
		Mark as completed once all interfaces have been deemed completely sealed.
	Warning: Failure to complete could result in damage of altimeters from ejection charges, causing main parachute deployment failure and hardware destruction.	
		Main ejection charge wiring should be marked differently than the back up charge wiring by means of black tape.
		Open mDACs software (for RRC3, which is the main altimeter) and connect the altimeters to the laptop being used.
		Twist ends of two LEDs together, ensuring the positive terminal of one is twisted with the negative terminal of another
		Connect each end of the LED circuit to two random wires and set off an "ejection charge" for the wiring that is being tested (either main or drogue chute) in the software.

		If one LED lights up with the charge, the two wires connected to the LEDs will be marked with black tape as the main charge wiring. If there is no light, try a different combination of wires and continue until two wires allow for an LED to light up.
		No further testing is required since the other set of wires is for the backup altimeter.

Table 26: Payload Component Pre-Packing Inspection

		Ensure LiPo batteries for rover and video receiver are fully charged.
		PPE Required: Eye protection
		Make sure all LiPo batteries are unplugged from all other devices.
		Plug LiPo cell battery balancer connector to the mating balancer port on the battery charger. **Only one LiPo battery can be charged at a time.**
		Set the charge rate to predefined rates as specified by the cover of the selected LiPo battery. Make sure that prior to charging, LiPo battery mode has been selected and **LiPo BALANCE** has been selected. **Choosing LiPo CHARGE will cause the battery to malfunction and burn.**
		Start the charging procedure. Make sure someone is **always** present to monitor the battery.
		The process may take up to more than an hour. If at any point swelling of the battery or the battery combusts, unplug the charger from its wall plug socket.
	Warning: Failure to complete could result in damage to batteries and people in the vicinity. A partially charged battery can also result in an unsuccessful mission.	
		Ensure all wires are properly soldered to their respective boards
		Tug the wires attached to each board. If a wire comes loose or is close to coming loose, unsolder the pad the wire is on.
		Solder the wire back on using a soldering iron and solder.
		Tug on the wire again and make sure a sturdy connection is made.
		Repeat for all wires.
	Warning: Failure to complete could result in an unsuccessful mission.	
		Make sure all transmitters/receivers are on the desired frequency and are in working condition
		Make sure all wires are properly attached and all connections are correct as specified by the wiring diagrams.
		Connect the 3S 1200mAh LiPo to the video receiver and turn on the receiver. Connect component cables to their appropriate colors to the USB adapter.
		Open OBS software on the computer and make sure the USB adapter is being read.

		Power the entire rover by plugging the 3S 4Ah battery into the power distribution board, making sure the motors do not beep after their initial powerup sequence. If the motors start sporadically spinning, unplug the battery on the distribution board and try again.
		Check the computer for video feedback. If a signal is not being read, the frequency will have to be changed such that the video receiver and video transmitter frequency are equal. This can be done by referring to the manuals of each component and changing the frequencies accordingly. Manuals are physically located in the electronics box or online in the team's Google Drive.
		Once proper video feedback has been obtained, turn on the controller.
		Move the control sticks on the controller to activate each motor.Visually inspect each motor moves as programmed.
		Unplug everything once done.
	Warning: Failure to complete could result in an unsuccessful mission.	
		Check that the ebay is properly assembled and packed and that all electronics are in position
		Place 3S 4Ah LiPo battery into the lower ebay. Place all other rover electronics in the top ebay.
		Obtain 6-32 screws and nuts to attach to the lower ebay and upper ebay. This is relatively difficult as there is not much space to work with in the rover. Make two people are working on this at a time.
		Using angled pliers, hold the nut below the thru hole while another person inserts the bolt through the hole. Start twisting the bolt clockwise using an allen wrench.
		Do not tighten all the way yet. Make sure all bolts are in place before fully tightening.
		Once all bolts are in position, tighten each bolt all the way.
		Place the camera in its allocated slot and place a small piece of tape over the top. Make sure the tape does not cover the lense of the camera.
	Warning: Failure to complete could result in an unsuccessful mission and possible rover detachment from its retention system.	

6.2.2. Packing Checklist

Purpose: To be followed the day before launch and morning of launch to ensure all needed materials are brought to the launch site.

Structural Components

- ❏ Nose cone
    - ❏ Should contain nosecone bulkhead and eyebolt
- ❏ Upper body tube

- ❏ Should contain ejection assembly, static portion of locking mechanism (to be talked about in payload component section)
- ❏ Removable portion of locking mechanism
    - ❏ Ebay (discussed in electronic components)
    - ❏ Eyebolt
- ❏ Lower body tube
    - ❏ Should contain centering rings (one with eyebolt), coupler, phrenalic tube, fins, aluminum plate, static portion of motor retainer
- ❏ Removable portion of motor retainer
- ❏ 4 quicklinks
- ❏ 1 12’ main parachute
- ❏ 1 3’ drogue parachute
- ❏ 2 20’ shock cords
- ❏ 3 green octogonal 1’ fire cloths
- ❏ 20 shear pins
- ❏ Motor
    - ❏ Motor casing

Structural Equipment

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

Electrical Components

- ❏ Electronics Bay
    - ❏ Avionics sled
    - ❏ Two altimeters (RRC3 and SL100)
- ❏ 5 9V Batteries (ensure full voltage with voltmeter)
- ❏ 2 stepper motors with stepper motor drivers
- ❏ Fully assembled stepper motor prototyping PDB

Electrical Equipment

- ❏ Wire Strippers

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

Payload Components

- ❏ Rover
    - ❏ Chassis
    - ❏ Ebay (upper, lower, cover, and custom nut)
    - ❏ 4 Wheels with DC motors
    - ❏ Antenna holder and antenna interfacer
    - ❏ 3S 4Ah LiPo battery
    - ❏ Controls receiver
    - ❏ Power distribution board
    - ❏ 4-in-1 ESC
    - ❏ Rubber bands
- ❏ 3S 1200mAh LiPo battery
- ❏ Video receiver
- ❏ RCHP Antennas
- ❏ SMA to MMCX adapters
- ❏ SMA female to SMA-RF female adapters
- ❏ USB SMI Grabber
- ❏ AV to component cables

Payload Equipment

- ❏ Screw driver set
- ❏ Angled pliers
- ❏ Quick-dry epoxy
- ❏ Tape
- ❏ Battery charger unit

6.2.3. Pre-Flight Inspection

Preform visual inspections of exterior components in pre-packing inspection to ensure no damage to components was sustained during transportation. These are re-stated below and should be re-signed

6.2.3.1. Structural Components

Table 27: Pre-Packing Structural Inspection

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

		Apply two-tube epoxy to the gap and smooth to be flush with the rest of the epoxy interface. (This epoxy used for fast cure time.)
		Wait 1 hour for full cure at room temperature. (Wait 1.5 hours if the temperature is below 60 degrees F.)
		After allowed cure time, ensure epoxy is dry to touch.
		Sand seal until the recently applied epoxy is flush with previously applied epoxy.
		Reinspect interface for imperfections. If there are no further imperfections, the requirement is fully completed.
	Warning: Failure to complete could result in fin detachment from the launch vehicle during flight or on landing.	
		Visual Inspection of the internal interface between nose cone and nose cone bulkhead, internal interface between nose cone bulkhead and eye bolt attached to it, external interface between coupler and lower body tube, internal interface between centering ring closest to the shoulder and the lower body tube, and internal interface between that centering ring and the eyebolt attached to it for gap in epoxy application. If no gaps at any point in either interface, mark as completed.
		PPE REQUIRED: Gloves
		Apply two-tube epoxy to the gap and smooth to be flush with the rest of the nose cone. (This epoxy used for fast cure time.)
		Wait 1 hour for full cure at room temperature. (Wait 1.5 hours if the temperature is below 60 degrees F.)
		After allowed cure time, ensure epoxy is dry to touch.
		Sand seal until the recently applied epoxy is flush with previously applied epoxy.
		Reinspect interfaces for imperfections. If there are no further imperfections, the requirement is fully completed.
	Warning: Failure to complete could result in recovery hardware failure.	
		Visual Inspection to ensure main parachute and drogue parachute have no holes or rips within the fabric (including next to the shroud line interfaces). If no imperfections are detected, requirement is fully completed
		Lay the damaged parachute on the ground fully unfolded so it forms an unwrinkled circle on the ground.
		Apply Rip-Stop Parachute tape to both sides of any rips or holes in parachutes in a way where no wrinkles in the parachute are caused when laying flat.
		Reinspect both parachutes for rips or holes. If no others are found, the requirement is met.
	Warning: Failure to complete will result in a change in the expected coefficient of drag,	

	causing faster descent time and larger Kinetic Energy at landing or failure of parachute at full deployment.	
		Visual Inspection of all shock cords and shroud lines used in recovery subsystem for tears. If there are no visible tears, the requirement is fully completed.
		If the tear is less than a quarter of the width of the shock cord: tie a tight knot so that the tear is contained within the knot. Once a knot is tied, if no further tears are found on any components, requirement is passed.
		If the tear is greater than a quarter of the width of the shock cord: discontinue use, use replacement of this component. Inspect new components and other components, if no further tears are found on any components, requirement is passed.
	Warning: Failure to complete will result in a change in the expected coefficient of drag, causing faster descent time and larger Kinetic Energy at landing or failure of parachute at full deployment.	
		Visual Inspection of all shock cords and shroud lines used in recovery subsystem for tears. If there are no visible tears, the requirement is fully completed.
		If the tear is less than a quarter of the width of the shock cord: tie a tight knot so that the tear is contained within the knot. Once a knot is tied, if no further tears are found on any components, requirement is passed.
		If the tear is greater than a quarter of the width of the shock cord: discontinue use, use replacement of this component. Inspect new components and other components, if no further tears are found on any components, requirement is passed.
	Warning: Failure to complete will result in a change in the expected coefficient of drag, causing faster descent time and larger Kinetic Energy at landing or failure of parachute at full deployment.	
		VIsual Inspection of main parachute and drogue parachute for knot containing all shroud lines about 2" from end of shroud lines to prevent tangling of shroud lines.
		Lay unknotted parachute flat on the ground with shroud lines untangled on top of the parachute fabric.
		Pinch centers of each shroud line and lift off the ground.
		Tie one overhand knot containing all shroud lines about 2" from the pinched point.
		Tighten the knot as much as possible.
		Repeat for other parachute if needed. Otherwise, the requirement is completed.
	Warning: Failure to complete can result in recovery deployment failure.	

6.2.3.2. Electrical Components

Since most electronic wiring is contained within the upper body tube, full inspection is not necessary. Visual inspection of components that could be damaged during transportation will be listed here.

Table 28: Pre-Flight Electronics Checklist

Initial	Completed Substeps	Task
		Main ejection charge wiring should be marked differently than the back up charge wiring by means of black tape.
		Open mDACs software (for RRC3, which is the main altimeter) and connect the altimeters to the laptop being used.
		Twist ends of two LEDs together, ensuring the positive terminal of one is twisted with the negative terminal of another
		Connect each end of the LED circuit to two random wires and set off an "ejection charge" for the wiring that is being tested (either main or drogue chute) in the software.
		If one LED lights up with the charge, the two wires connected to the LEDs will be marked with black tape as the main charge wiring. If there is no light, try a different combination of wires and continue until two wires allows for an LED to light up.
		No further testing is required since the other set of wires is for the backup altimeter.
	Warning: Failure to complete will result in failure of ejection charges ignition.	
		Ensure that three push buttons are still secured on the face of the upper body tube so that the pushed button is flush with the component.
		If pushbutton somehow got dislodged during transportation, gorilla tape will be used to secure it rather than epoxy due to there not being adequate time to cure.
		Gorilla tape the outside and inside of the interface between the upper body tube and push-buttons.
		Mark as completed once the feature is secured enough to sustain itself during flight.
	Warning: Failure to complete can result in incorrect altimeter data.	

6.2.3.3. Payload Components

All connections except for battery connections should already have been done as specified in the pre-packing inspection. The following list outlines the steps that should be taken prior to launch.

Table 29: Pre-Flight Payload Preparation

		Check that the ebay is properly assembled and electronics are working
		Ensure 3S 4Ah LiPo battery is in lower ebay and other electronics are in upper ebay.
		Plug LiPo battery to power distribution board and listen for DC motor startup beeps. Check if video feedback is being provided and move the controller to test if connectivity is established to control motors.
	Warning: Failure to complete could result in an unsuccessful mission.	
		Make sure all transmitters/receivers are on the desired frequency and are in working condition
		Connect the 3S 1200mAh LiPo to the video receiver and turn on the receiver. Connect component cables to their appropriate colors to the USB adapter.
		Open OBS software on the computer and make sure the USB adapter is being read.
		Power the entire rover by plugging the 3S 4Ah battery into the power distribution board, making sure the motors do not beep after their initial powerup sequence. If the motors start sporadically spinning, unplug the battery on the distribution board and try again.
		Check the computer for video feedback. A signal should be read. If not refer back to pre-flight checklist
	Warning: Failure to complete could result in an unsuccessful mission.	
		Place packed payload within the launch vehicle
		Place antenna and collection arm in its packed position by manually moving components to their desired positions.
		An external button on the launch vehicle rotates the deployment stepper motor in the opposite way
		Press this button to load the rover on the retention mechanism. Make sure the threaded rod catches the threads of the custom long nut.
		Continue pressing the button until the payload is **CLOSE** to the end of the threaded rod
		Cover the rover exit with fire cloth to ensure the rover does not experience blast forces from the ejection charges
	Warning: Failure to complete could result in an unsuccessful mission and rover detachment from its retention system.	

6.2.4. Payload Preparation

No additional payload preparations must be taken after the pre-flight inspection has been completed, as outlined in section 6.2.3.3.

6.2.5. Recovery Preparation

Table 30: Pre-Flight Recovery Preparation

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

	Warning: Failure to complete could result in altered coefficient of friction or delayed deployment of parachutes.	
		Main parachute should be attached to the quicklink in the middle of the main shock cord and the drogue parachute should be attached to the quicklink in the middle of the drogue shock cord.
		Locate the quicklink that the parachute in question must be connected to.
		Thread centers of all shroud lines of that parachute through open quicklink.
		Close quicklink.
		Repeat for other parachute if necessary. Step is completed when both parachutes are properly threaded.
		Both parachutes should be properly folded.
		Required Personnel: Structures Lead
		Structures lead will instruct how parachutes should be folded and ensure proper packing.
		Shock cords should be taped to ensure lowered shock upon deployment.
		The following must be done to each segment between quicklinks.
		Start at one side of the segment.
		Fan-fold 9inch folds of the shock cord, starting with 3 folds.
		Tape two loops of masking tape around the center of the fan-fold.
		Repeat with an incrementing number of folds for the remainder of the segment.
		Repeat with each segment of the recovery system (4 segments total).
		Mark as done when all sections are properly taped.
	Warning: Failure to complete could cause violent shock, causing load-bearing interface failure.	
		Black powder should be loaded into XXX canisters.
		PPE Required: Safety goggles.
		Personnel Required: Team Mentor
		Team mentor will measure out needed black powder amounts and load into canisters.
		Team mentor will place ignitor into canister and gorilla tape over the canister to seal it.
		Team mentor will repeat this for each canister (4 total).
	Warning: Failure to complete will result in deployment failure.	
		Ignitors must be connected to altimeter wiring.

		PPE Required: Safety Goggles
		Main canisters and wiring will be marked with black tape. If not marked, alert electronics lead or project manager to conduct wiring matching. The process for this will be in XXX.
		Match wiring for main and backup charges to corresponding canisters.
		Rub wiring together to ensure no charge going through wiring.
		Connect one wire to each side of the igniter or corresponding main or backup charges.
		Repeat for all wiring for nose cone and lower body tube charges.
		Mark is completed when all igniters are connected to corresponding altimeter wiring.
	Warning: failure to complete will result in deployment failure.	
		Payload must be completed packed.
		Pause in the build process until the payload team has finished the packing process.
		Mark as completed once the payloads lead and project manager was approved.
	Warning: failure to complete will result in deployment failure.	
		Packed parachute facing the ejection charge must be wrapped in fire cloth.
		PPE Required: Safety Goggles
		Portion of the main parachute facing the tip of the nose cone should be wrapped in firecloth to completely cover the exposed cross section.
		Portion of the drogue parachute facing the locking mechanism should be wrapped in firecloth to completely cover the exposed cross section.
		Mark as completed once both parachutes are properly wrapped.
	Warning: Failure to complete will result in parachute destruction.	
		Main parachute should be packed and nose cone shoulder placed into the upper body tube.
		PPE Required: Safety Goggles
		Put parachute into the nose cone with the fire-cloth covered portion going in first.
		Fold remaining shock cords losely and place into the nose cone shoulder and upper body tube atop the REA.
		Put the nose cone shoulder within the upper body tube next to the REA ensuring full insertion by checking that none of the shoulder is visible. If a portion of it is still visible, alert structures lead or project manager.
		Mark is completed when the nose cone is completely inserted and contains the main parachute.

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

6.2.6. Motor Preparation

Required Personnel: Team Mentor

With team mentor, follow motor preparation instructions that came with motor.

6.2.7. Launch Pad Procedure

Required Personnel: Team Mentor

Table 31: Launch Pad Procedure

Initial	Completed Substeps	Task
		All parent components should be fully interfaced with shear pins.

		If not completed, refer to the Recovery Preparation Table.
	Warning: If not completed, recovery hardware could pre-maturely deploy.	
		Launch buttons should be interfaced with the launch rail and vehicle should be at the bottom of the rail.
		Starting at the far end of the launch rail, slide the two rail buttons onto the rail, ensuring that they interface completely.
		Roll the vehicle to the bottom edge of the rail.
		Have mentor or RSO move the rail to the upright position.
		Once the vehicle is free-standing on the launch rail by means of the launch buttons, the procedure is finished.
	Warning: If not completed, launch would fail and be unsafe for bystanders	
		Altimeters must be armed.
		All three push buttons on the side of the vehicle should be pressed.
		Sound should be emitting from both altimeters.
		Electronics lead or team members appointed and verified by the electronics lead will be next to the vehicle listening to the sound and ensure that the correct arming tune is emitted from each altimeter.
		XXX arming cycle
		Once the arming sound has been emitted from each altimeter, the member will alert the RSO and other participants near the launch vehicle during on-pad preparations and the requirement will be marked as finished.
	Warning: If not completed, ejection charge deployment will not occur and deployment of recovery hardware will fail.	
		Ignitor must be placed within the motor.
		PPE Required: Safety Goggles
		Ignitor wiring will be attached to the launch pad wiring.
		Members will slide the ignitor into the open portion of the motor nozzle and push it up into the motor as far as it will go.
		Once pushed all the way up, A portion of the wire will be taped to the side of the vehicle to secure it.
		The remainder of the wiring will be wrapped away from the vehicle body as wanted by the RSO.
		Once ignitor is fully inserted and accepted by the RSO step is complete.
	Warning: If not completed, the motor will not ignite and no launch will occur.	
		Team will move to viewing area and RSO will initiate a countdown and launch.
		Once the vehicle is fully loaded, the team will relocate to the viewing area.
		RSO will decide the launch protocol on who counts down and pushes the

		launch button.
	Warning: If not completed, serious injury could occur to team members.	

6.2.8. Launch Procedure

The following does not need to be initiated, however it is the responsibility of the project manager to ensure that all team members present at launch are aware of the launch procedure and follow it.

Table 32: Launch Procedure

Initial	Completed Substeps	Task
		Entire team should be in the viewing area.
	Warning: Failure to complete could result in injury.	
		Upon launch, entire team should be following vehicle with their eyes and pointing to vehicle upon descent
	Warning: Failure to complete could result in loss of vehicle.	
		Two events should be witnessed; drogue deployment at apogee and main deployment at 500 ft agl. If an event fails, the recovery system had a failure.
	No Warning	
		Upon landing, team members should draw an arrow in dirt to where they believe the vehicle landed in the case the vehicle is hard to locate.
	Warning: Failure to complete could result in loss of vehicle.	
		When declared safe by the RSO, the team should go locate their rocket, taking care to watch any other launches happening at the site. GPS can be used to aid in location of the vehicle.
	Warning: Failure to complete could result in loss of vehicle.	

6.2.9. Post-Flight Inspection

Table 33: Post -Flight Inspection

Initial	Completed Substeps	Task
		Upon approach to the vehicle, altimeters should be making high-pitched whining sound. This is a location feature that also signals that the component is still being powered and was powered during the duration of the flight.
		Personnel Required: Electronics Lead

		If no whining is occurring, electronics lead will disarm altimeters and inspect component using the appropriate altimeter software
	Warning: Failure to complete could result in future altimeter failure.	
		Vehicles should be disassembled on the ground with the following components visibly separated from each other and connected by shock cord: lower body tube, drogue parachute, upper body tube, main parachute, nose cone.
		PPE Required: Safety Goggles
		If components are not disassembled, this be a product of either ejection charges not going off or not enough black powder being used.
		Vehicle should be taken back to team mentor with no members walking or standing in the trajectory of the vehicle's components in the case that ejection charges go off unexpectedly.
		Mentor will examine black powder charges and safely disconnect black powder from any ignition source.
	Warning: Failure to complete could result in serious injury from spontaneous combustion leading to burns.	
		Parachutes should not have new tears or holes sustained during flight.
		If damage was sustained by the parachute during flight, it is most likely a sign of insufficient fire cloth sizing
		If another flight is planned, a bigger firecloth must be utilized in place of firecloth on that shock cord.
	Warning: Failure to complete could result in damage to recovery hardware.	
		Altimeter data must be transferred from vehicle avionics to a laptop with appropriate reading software.
		Personnel Required: Electronics Lead
		Electronics lead should remove locking mechanism and disconnect any cords that are no longer necessary.
		Electronics lead will properly connect altimeters to a computer with appropriate software able to read altimeter data and save for further examination.
		Step will be marked done with data from both altimeters have been overviewed and the data saved onto the altimeter or computer for further examination.
	Warning: Failure to complete could result in no flight data.	

6.2.10. Payload Post-Mission Inspection

Table 34: Payload Post-Flight Inspection

		Ensure collected samples are accounted for scoring
		Approach rover and unscrew ebay cover to access battery connector
		Disconnect battery from power distribution board
		Wait for a judge/official to acknowledge collected samples
	Warning: Failure to complete could result in accidental activation of DC motors.	
		Visually inspect all rover components for signs of defects
		Inspect the custom nut for any signs of cracking or warped threads
		Inspect the collection arm for any signs of cracks
		Inspect the lower and upper ebay tabs for any signs of cracking
		Check the computer for video saved feedback.
	Warning: Failure to complete could result in failure of the mission.	

7. Project Plan

7.1 Testing

7.1.1. 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 on a very small scale. Physical testing success criteria will be individually presented.

Virtual Testing 1

Table 35: 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 the 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 the outer edge of the 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.
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:

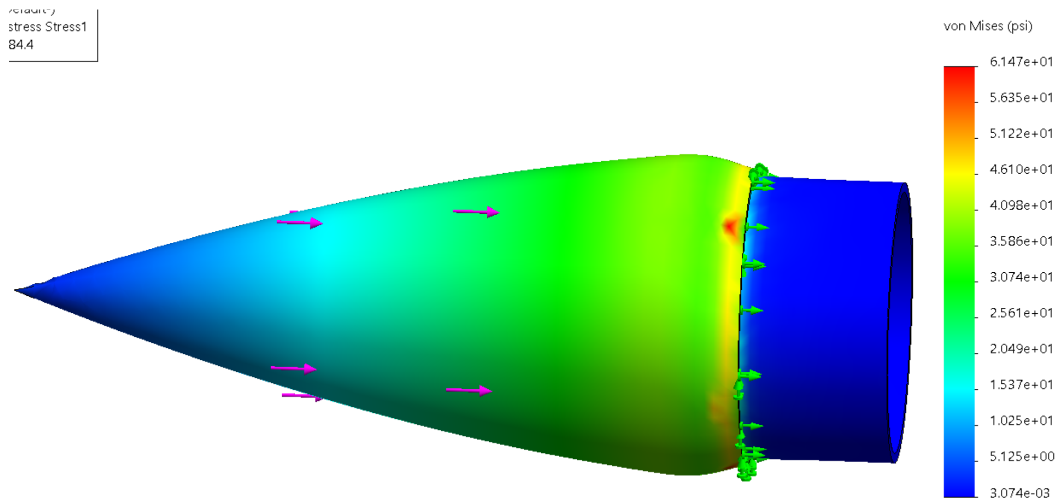

Figure 89: Nose Cone Normal Stress Test Results

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:

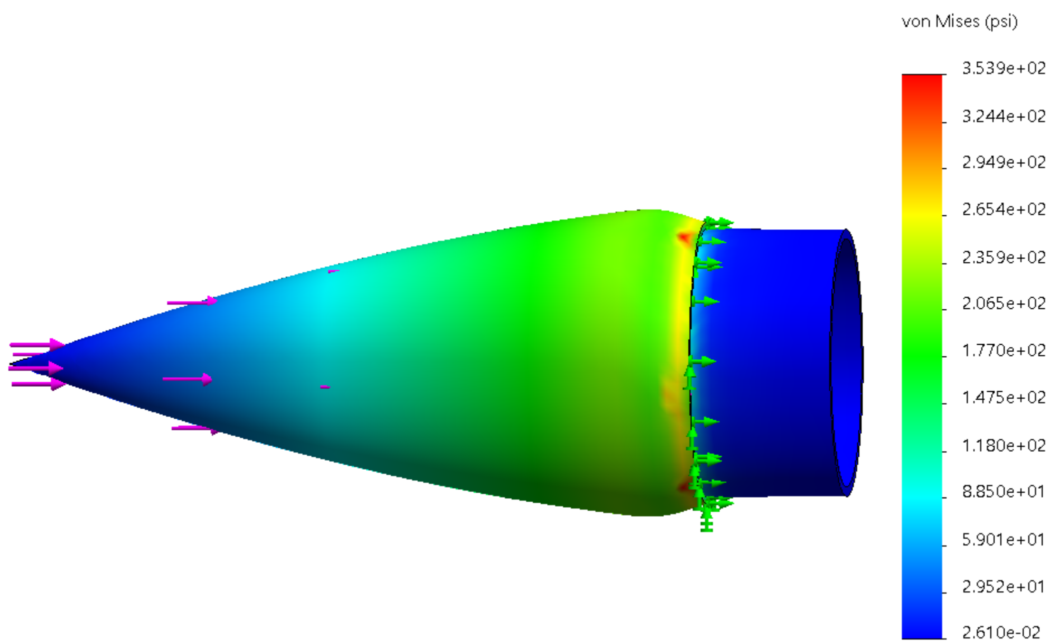

Figure 90: Nose Cone Shear Stress Test Results:

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 36: 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

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):

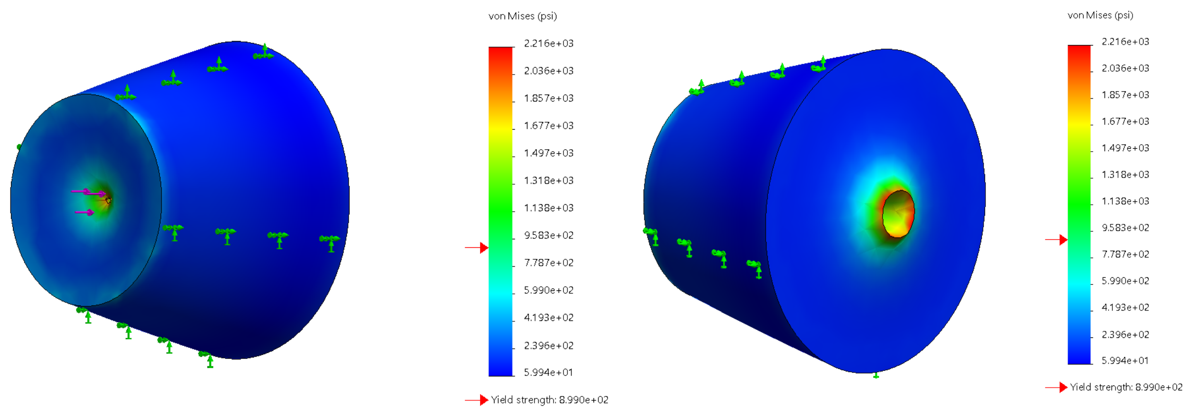

Figure 91: Nose Cone Bulkhead Shear Stress Test Results

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 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 37: 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: 8 lbf This was found using the weight of the nosecone assembly (2 lbs) and enforcing a factor of safety of 4.0.
Constants:	• Nose Cone geometry: discussed in vehicle section • Bulkhead geometry • Adhesive material: Epoxy • Testing hardware:
Step-by-Step Execution:	1. Brace shoulder against a grated balcony rail.

	2. Thread XXX shock cord through a grate and fasten it to the nosecone bulkhead as though a launch were occuring. 3. Tie 8 pound weight to the other side of the shock cord hanging over the balcony. 4. Drop weight over the balcony, imposing impulse on the bulkhead. (Weight should not hit the ground.) 5. Inspect bulkhead and interface for any visible damage.
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:	Completed.
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 the 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.	

Status/Results: (if completed):

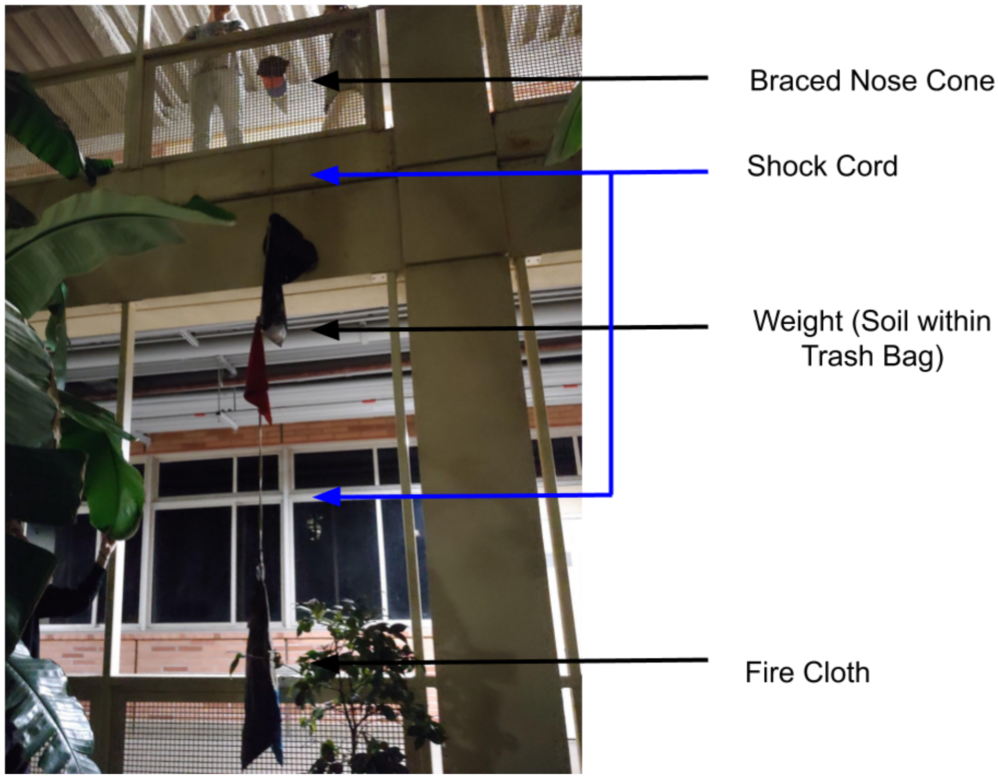

Figure 92: Nose Cone Testing Post - Drop

Images of the nose cone testing pre and post drop of the weight can be seen above. Upon inspection, no visible damage was sustained by the nose cone, bulkhead, or interface. Test was successful.

Virtual Testing 3

Table 38: 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 the 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: 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):

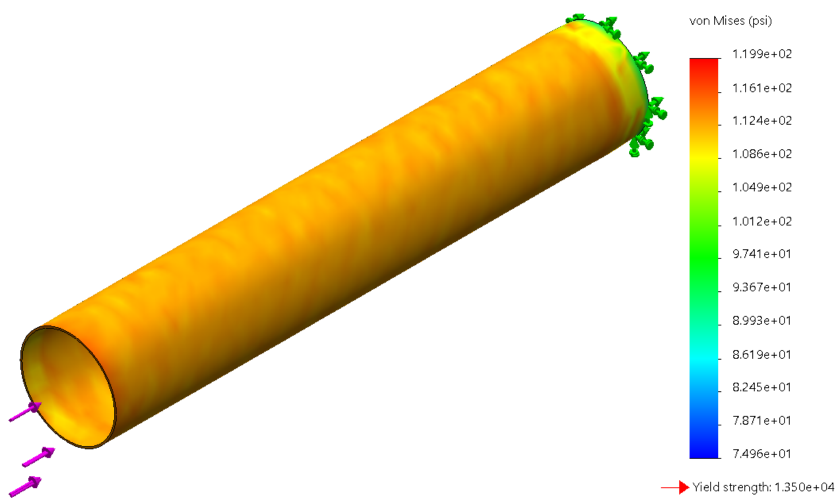

Figure 93: Upper Body Tube Normal Stress Test Results

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 39: 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.
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):

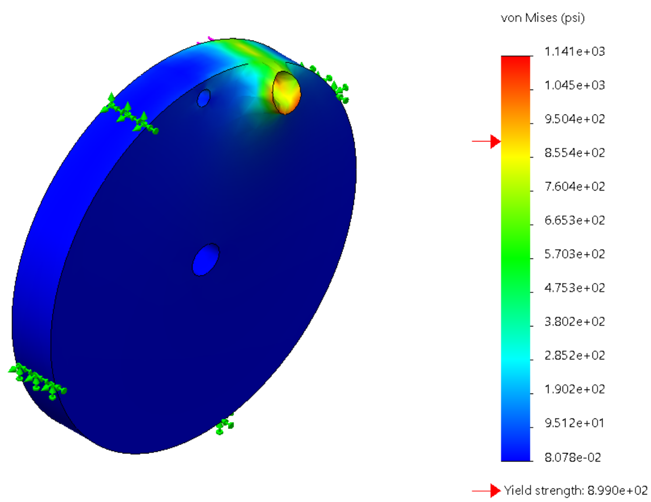

Figure 94: Bulkhead Shear Stress Test Results

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 40: 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: 50 lbf
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 components.
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:	
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.	

Status/Results: (if completed):

No failure was detected in this component. It was tested similarly to the locking mechanism that is discussed more in depth below in locking mechanism physical testing.

Virtual Testing 5

Table 41: 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
Step-by-Step Execution:	Tabbed component: 1. Fix outer edge of mechanism. 2. Impose force on the center of the mechanism where the 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:

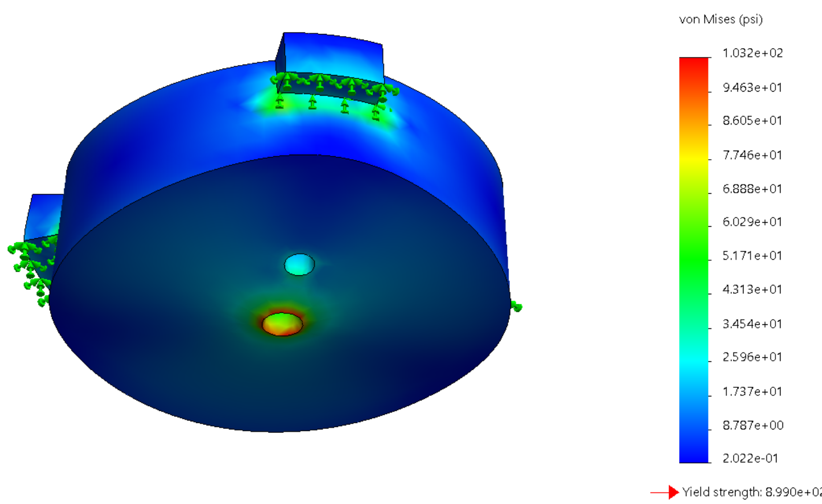

Figure 95: Locking Mechanism Stress Results - Upper Component

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:

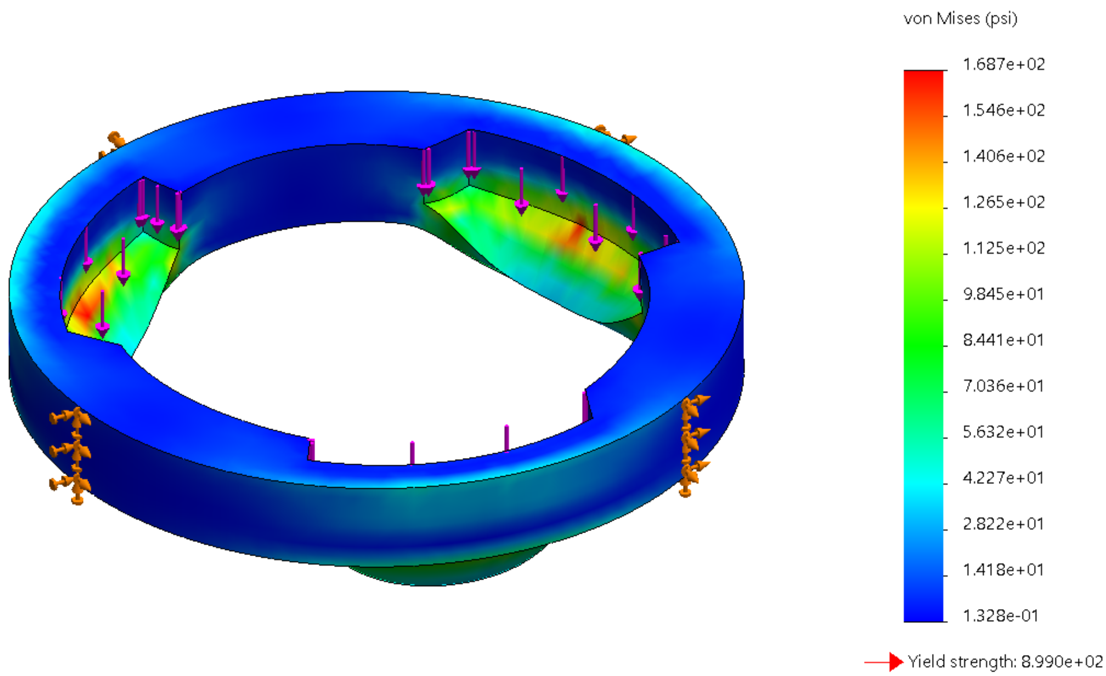

Figure 96: Locking Mechanism Stress Results - Lower Component

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 42: 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: 50 lbs
Constants:	Geometric Relation.

Step-by-Step Execution:	1. Locking mechanism will be fabricated at the full scale size with aluminum enforcement in the inner component but not the outer ring. 2. A heavy object will be tied on a shock cord about 10 ft from one end. THis object should weigh roughly 50 lbs. 3. The end of the shock cord should then be secured on to the locking mechanism. 4. Brace the locking mechanism on a gridded balcony rail. 5. Drop heavy object over the size. 6. Allow the object to hang over the edge for one minute. 7. Inspect locking mechanism for cracks and failure as well as if it was retained during drop.
Relevant Safety Concerns:	• Rope failure resulting in freefalling object - participants will wear protective eyewear (medium risk). See Section 6.1.3. • 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 6.1.3.
Status/Results:	Completed.
Rationale: Locking mechanism must support upper body tube once the main parachute is deployed. WHen choosing a weight to be dropped the team wanted to maximize the weight without posing a large safety risk of possibly flying debris. The upper body tube is an as-built weight of about 10 lbs with the payload fully packed. For this reason, 50 pounds was chosen to be put into freefall for 10 ft to impose an impulse force on the locking mechanism. This introduced a safety factor of about 5.0.	

Status/Results: (if completed):
The set up of the test can be seen below.

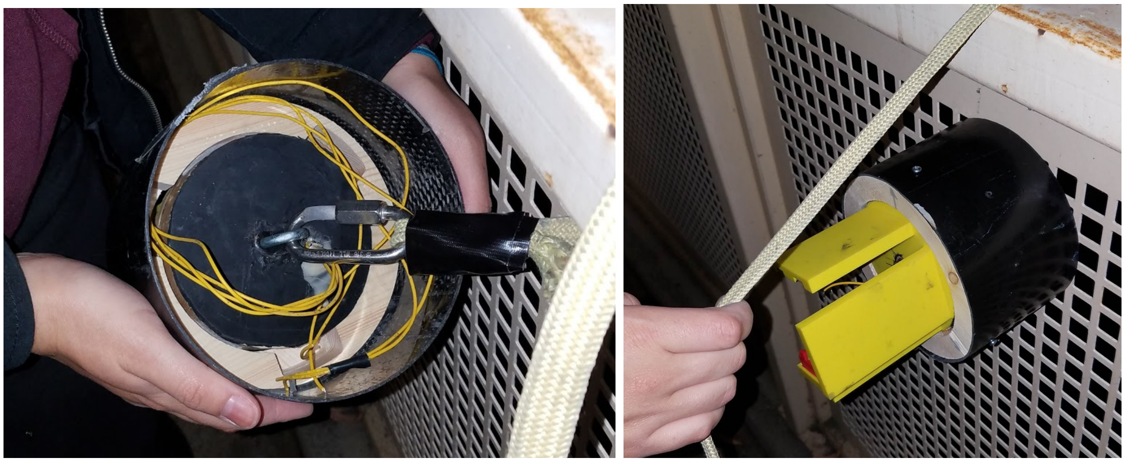

Figure 97: Recovery Hardware Attachment and Load Preparation

A 50 pound object was made up of a trash bag carrying 35 pounds worth of dirt and a 5 gallon bottle carrying 15 pounds of water. These were both attached to the shock cord and dropped at the same time. During the drop, the locking mechanism detached from the grid then slammed back onto it, causing a plastic component to break off. Results are seen below.

FIgure 98: Inner Component Post Testing

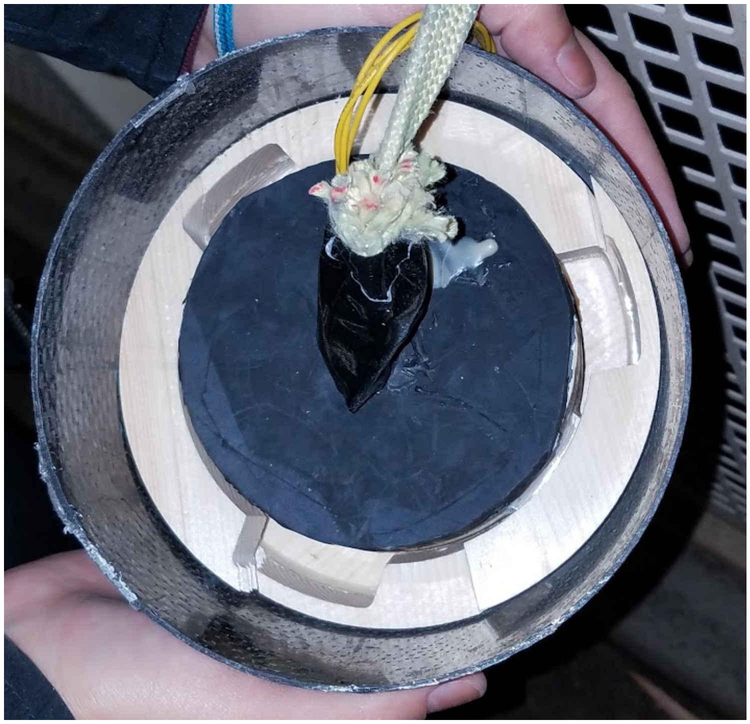

Figure 99: Locking Mechanism Assembly Post Testing

An important thing to note from the figures above is that the inner component is undamaged, with the exception of the electronics bay, which was damaged from the metal gridding and nature of the test. The outer ring sustained some cracking, but was not reinforced with epoxy or the aluminum ring components and continued to retain the inner component.

Since the outer ring did not completely fail and the inner component did not fail at all, it is expected that the addition of the aluminum ring to the body tube will strengthen the component to not fail at all.

Virtual Testing 6

Centering Ring Structural Integrity (Virtual)

Table 43: 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 is 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):

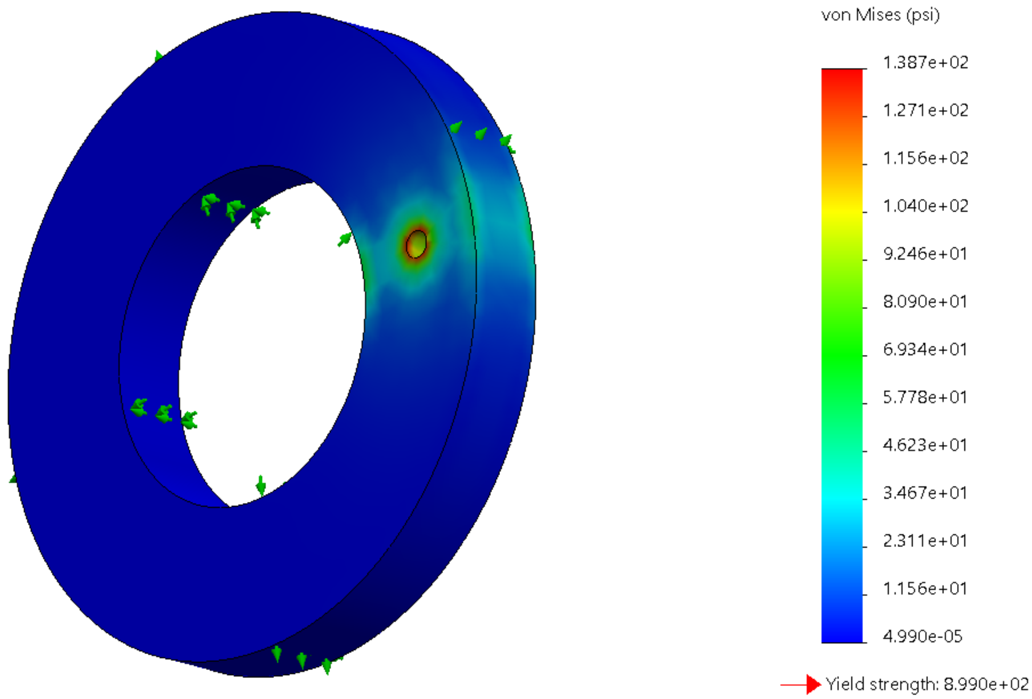

Figure 100: Centering Ring Shear Stress Test Results

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 44: 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.
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 the 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):

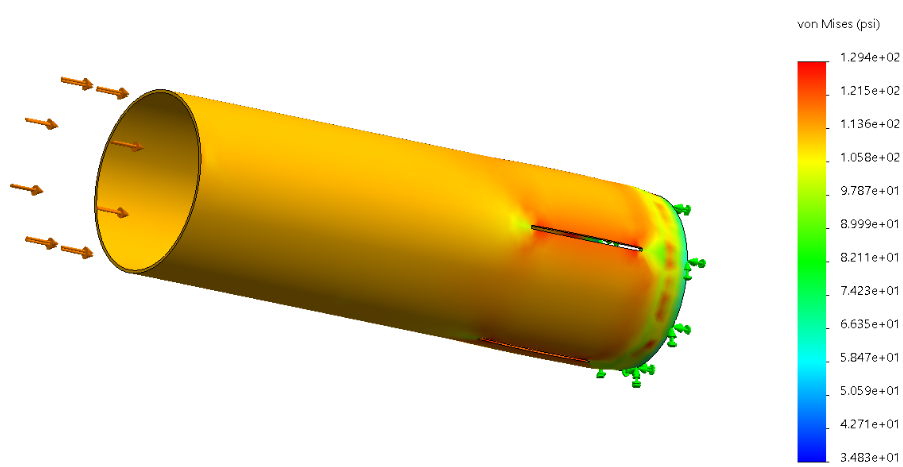

Figure 101: Lower Body Tube Normal Stress Test Results

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.

7.1.2. 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 (Cancelled)
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 45: 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
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:	Completed.
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.	

Status/Results: (if completed):

No visible deformations were sustained by any part of the rover, so the test was passed.

Physical Testing 5

Table 46: 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 samples.
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)
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.	

Status/Results: (if completed):

No visible deformations were sustained by any part of the rover, so the test was passed.

Physical Testing 6

Table 47: 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.
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:	Cancelled
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.	

Status/Results: (if completed):

Due to treads being removed from the payload design, this test was voided as not needed.

Physical Testing 7

Table 48: 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.
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 the collection bin of the 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:	Completed.
Status/Results:	Completed.
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.

Status/Results: (if completed):

Test was successful, a full 20mL was contained during all testing.

Physical Testing 8

Table 49: 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
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 the 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:	Completed.
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.	

Status/Results: (if completed):

No deformation recorded and no visible cracks were found, the test was successful.

Physical Testing 9

Table 50: Body Integrity

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

Status/Results: (if completed):

No deformation was recorded and no visible cracks or other deformations were visible for any weight applied, the test was successful.

Physical Testing 10

Table 51: 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.
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.	

Status/Results: (if completed):

No deformation was recorded and no visible cracks were found for any weight applied, also no slip was recorded on the rod. The test was successful.

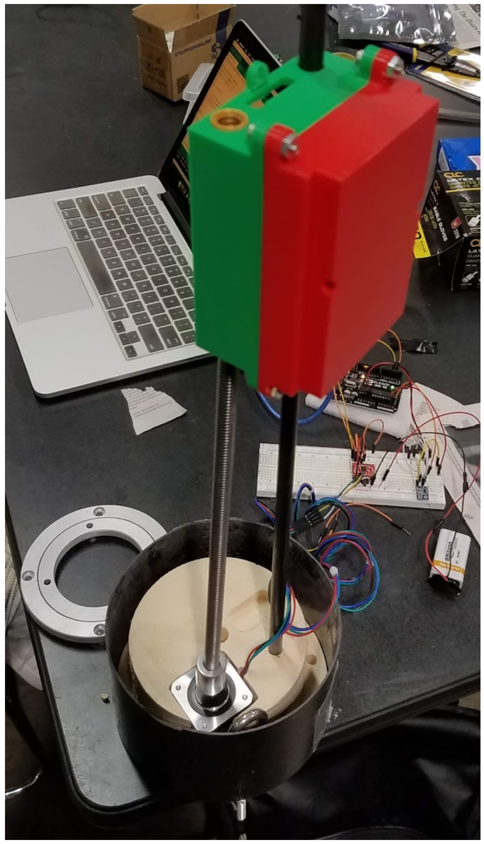

Figure 102: Loaded Payload Onto REA Rods

Virtual Testing 8

Table 52: 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)

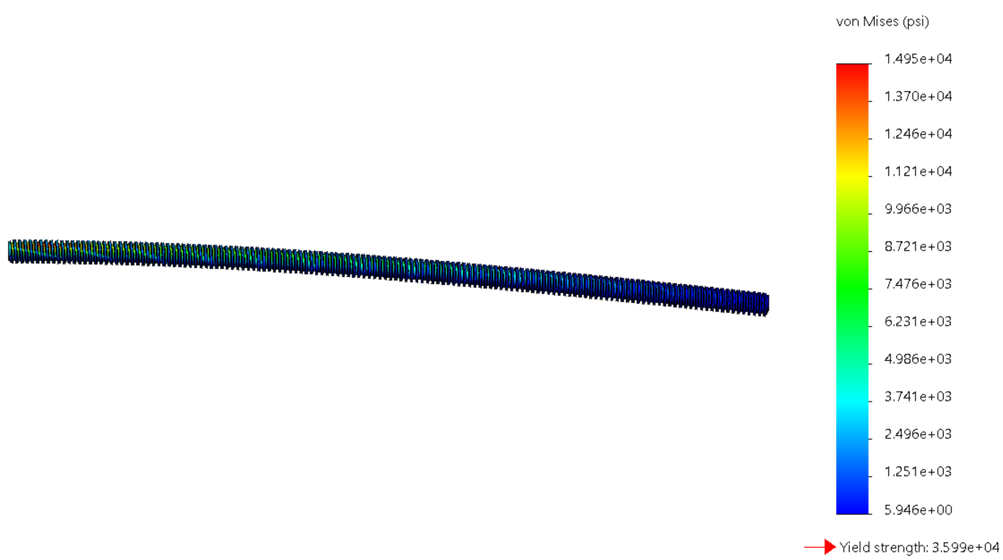

Figure 103: Threaded Rod Stress Results

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

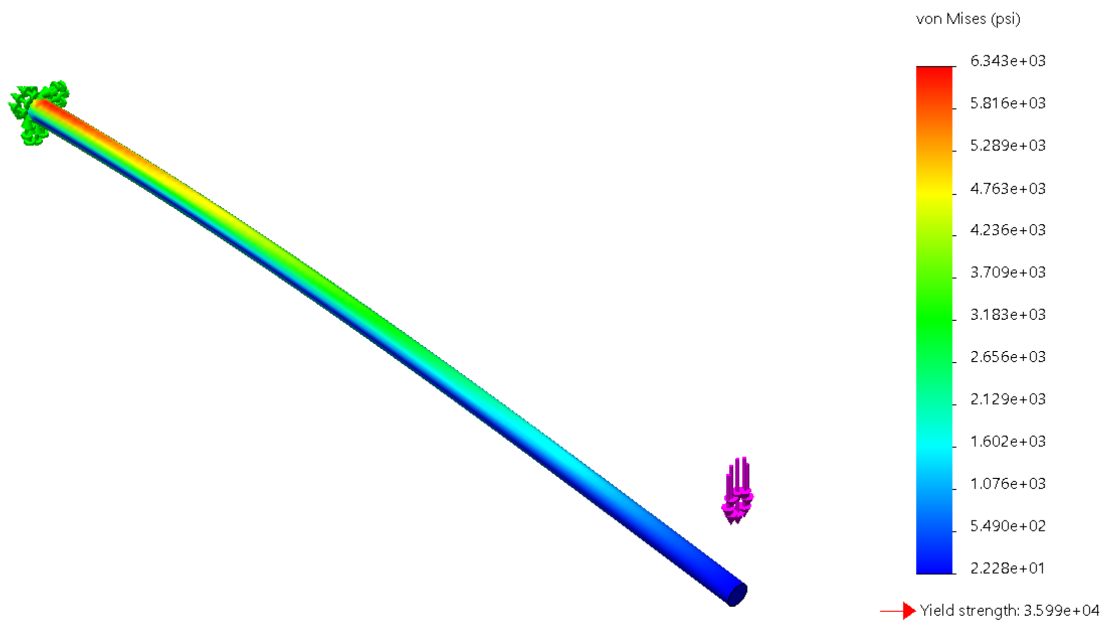

Figure 104: Unthreaded Rod Stress Results

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.

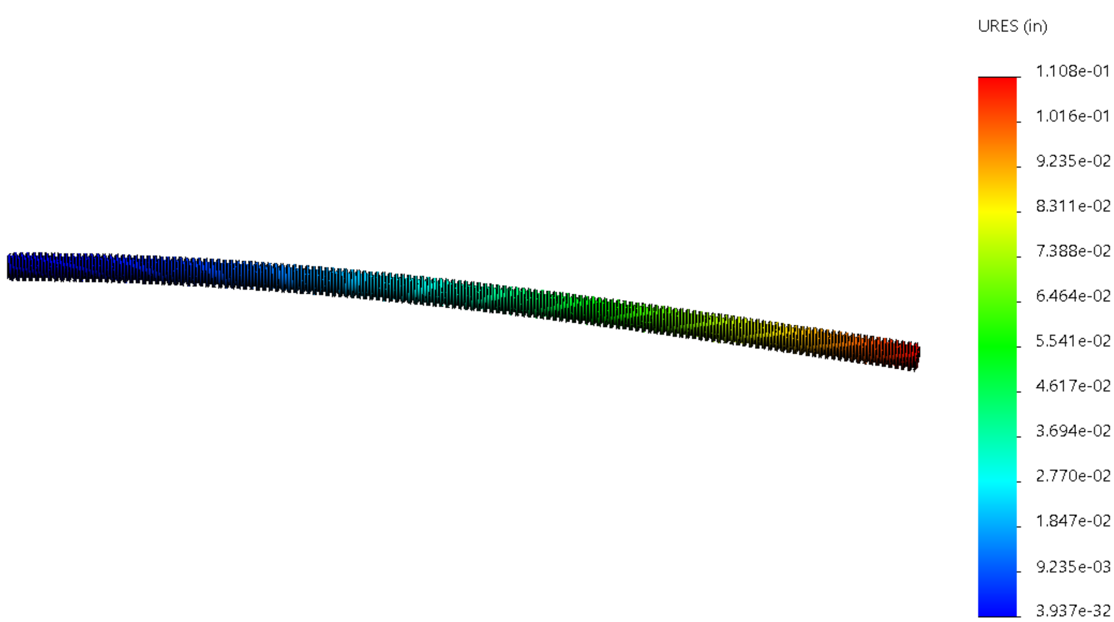

Figure 105: Threaded Rod Deflection Test Results

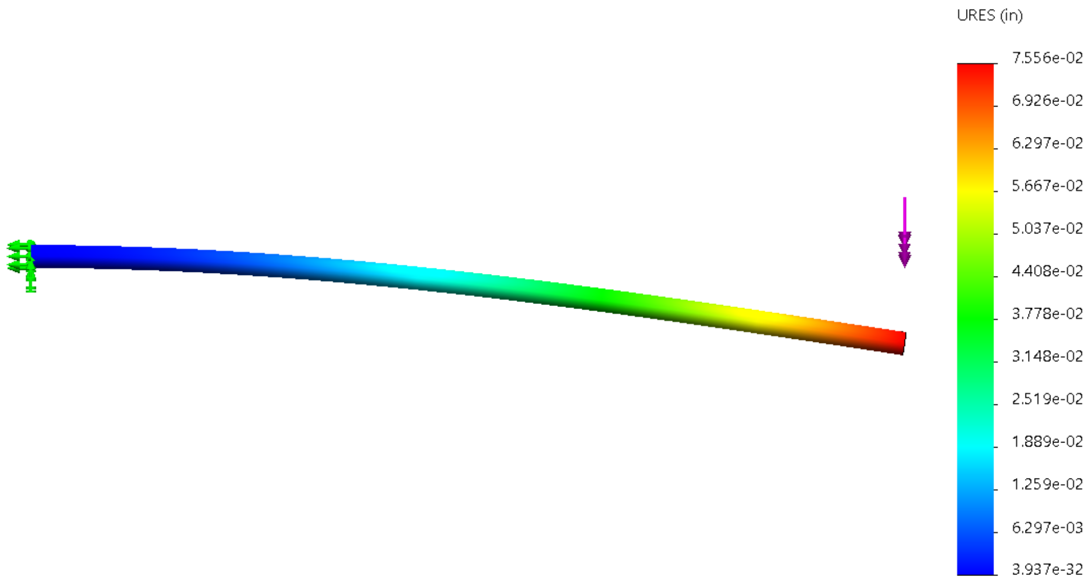

Figure 106: Unthreaded Rod Deflection Test Results

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 53: 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:	Completed.
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.	

Status/Results: (if completed):

Test was completed both outside and within the body tube. Due to the change in the attachment hardware of the threaded rod, that component's interface now deflects with weight. This serves as an advantage since it is easier to pack and doesn't affect the deployment of the rover. Rover was deployed for every test iteration that was completed. Test is successful.

Physical Testing 12

Table 54: 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:	Completed.
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.	

Status/Results: (if completed):

No slip or deformation was recorded or visible, the test was passed.

7.1.3. 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 55: 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
Step-by-Step Execution:	1. Connect LEDs to altimeter's drogue and main chute ports 2. Connect to altimeters using the included USB adapters 3. Begin testing by firing simulated charges using the appropriate altimeter program 4. FIre the drogue chute 5. Look for the LED of the drogue chute to blink 6. Fire the main chute 7. Look for the LED of the main chute to blink
Relevant Safety Concerns:	● LEDs polarity is reversed and explodes - debris is contained within the vacuum chamber (low risk)
Status/Results:	Completed.
Rationale: a pressure chamber is not readily available to the team, so testing the connectivity of the ejection charges is sufficient. This ensures black powder charges will activate when the altimeter dictates they need to be fired. LEDs are used to check if a pulse is sent from the altimeters to eject the parachutes.	

Status/Results: (if completed):
All drogue and main chute ports are functioning as intended and all LEDs lit up as expected.

Physical Testing 14

Table 56: 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
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.	

Status/Results: (if completed):
Suggested Android application and GPS system correctly identified the location of the person to a satisfactory degree.

Physical Testing 15

Table 57: 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
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:	Completed.
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.	

Status/Results: (if completed):
Both modules operated successfully as intended. As mentioned before, accuracy of both modules is not necessary as long as they consistently read the same wrong values.

Physical Testing 16

Table 58: 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
Relevant Safety Concerns:	None.
Status/Results:	Needs more testing.
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.	

Status/Results: (if completed):
Failure. Testing occurred at Santa Monica beach at a distance of 0.5 miles. Connectivity was established successfully for 0.1 miles and was lost. The team believes this is caused by power lines which were placed at intervals along the beach to power lifeguard towers. Previous unofficial testing revealed a further connection is possible to establish. Testing will occur again, but in a more remote location with no signal interference. The following picture shows the connection location and distance attempted.

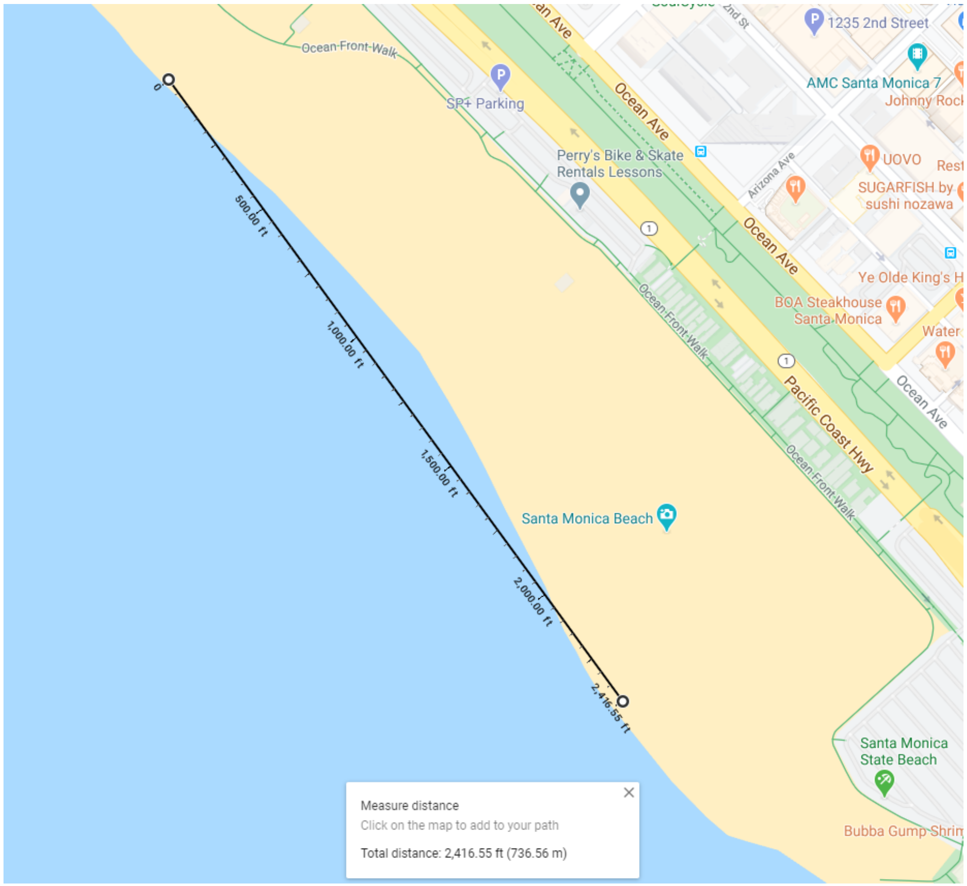

Figure 107: Attempted RF Communication Distance

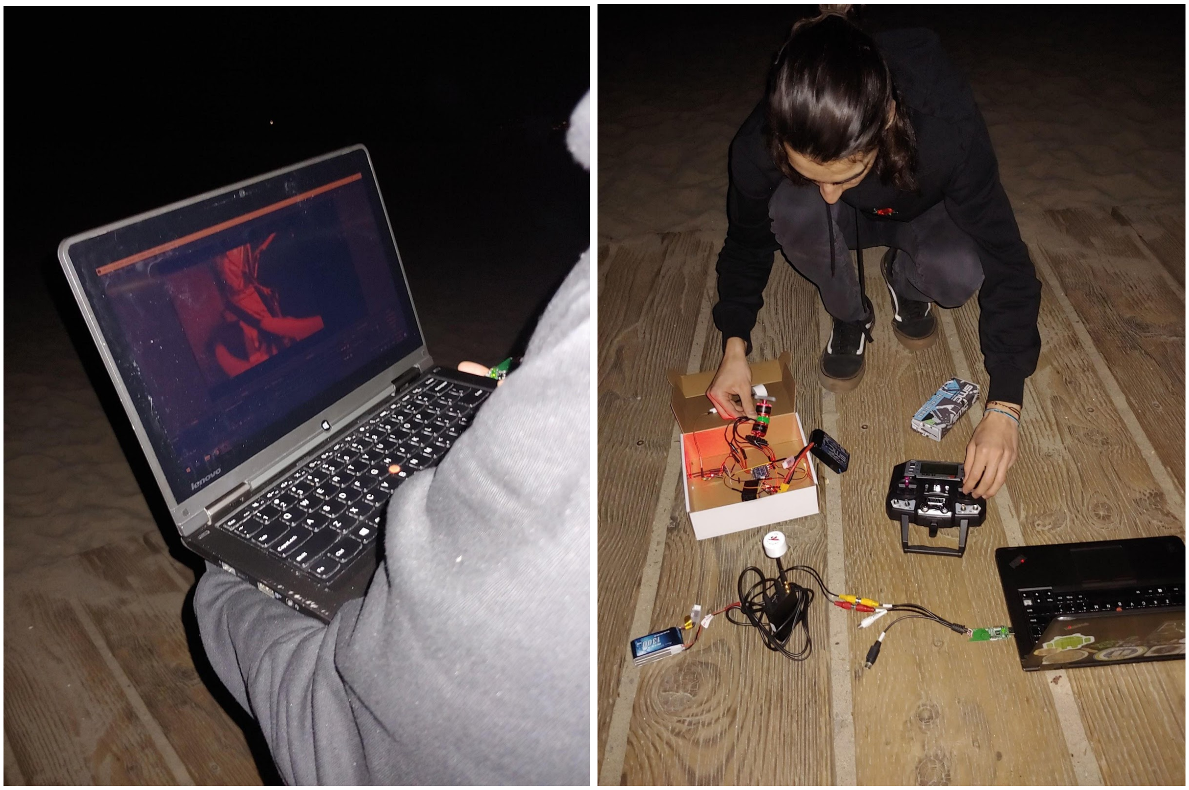

Figure 108: Establishing Video Feedback

Physical Testing 17

Table 59: 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:	Needs further testing.
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.	

Status/Results: (if completed):
Failure. Testing occurred at Santa Monica beach at a distance of 0.5 miles. Connectivity was established successfully for 0.1 miles and was lost. The team believes this is caused by power lines which were placed at intervals along the beach to power lifeguard towers. Previous unofficial testing revealed a further connection is possible to establish. Testing will occur again, but in a more remote location with no signal interference.

Physical Testing 18

Table 60: 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:	Completed
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.	

Status/Results: (if completed):
Successfully completed. The rover operates for 3.5 hours on standby and 0.5 hours while being operated continuously at low speeds, which the speed the rover will operate at competition.

7.2 Requirements Compliance

7.2.1. NASA Requirements Verification

Table 61: 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.	Completed/ On Going	ALL

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 the project.	Completed/ On Going	7.4 Timeline / 6. Safety
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
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.	Demonstration	Bearospace at UCLA will partner with SOLES, NSBE, and AISES at UCLA to aid their STEM outreach efforts.	Completed/ On Going	N/A

A sample of the STEM Engagement Activity Report is on page 35.				
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/ On Going	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.	Completed/ On Going	N/A
1.8. All deliverables must be in PDF format.	Demonstration	All deliverables will be in PDF format.	Completed/ On Going	N/A
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	Completed/ On Going	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.	Completed/ On Going	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.	Completed/ On Going	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.	Planned Completion (On Launch Day)	3.3 Mission Performance Predictions

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
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.	Completed in Flight Demo / Planned Completion on Launch Day	3.1 Design Verification of Launch Vehicle / 3.3 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	Completed	3.3 Mission Performance Predictions

		will be submitted with the PDR.		
2.3. The vehicle will carry one commercially available, barometric altimeter for recording the official altitude used in determining the Altitude Award winner. The Altitude Award will be given to the team with the smallest difference between their measured apogee and their official target altitude on launch day. This altimeter may also be used for deployment purposes (see Requirement 3.4)	Inspection	The vehicle will contain two different commercially available altimeters for redundancy.	Completed in Flight Demo / Planned Completion on Launch Day	3.2 Recovery Subsystem
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.	Completed	3.1.4.Component Overview
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.	Completed	3.1.4. Component Overview
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.	Completed	3.1.4. Component Overview
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 1 body diameter in length.	Completed	3.1.4. Component Overview

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 the launch readiness checklist will be created to minimize flight preparation time or confusion.	Completed in Flight Demo / Planned Completion on Launch Day	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.	Completed in Flight Demo / Planned Completion on Launch Day	7.1.3. 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.	Completed in Flight Demo	1. Summary of FRR 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.	Completed in Flight Demo	N/A
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 FRR 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 FRR 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.	Completed (Not Needed)	N/A
2.11. The launch vehicle will be limited to a single stage.	Demonstrati on	Vehicle will be designed to be a single stage.	Completed	3.3. Mission Performance Predictions
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, Demonstrati on	Motor choice will be L-class impulse or lower.	Completed	1. Summary of FRR 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/depressurization, and the name of the person or entity administering each pressure event.				

2.14. The launch vehicle will have a minimum static stability margin of 2.0 at the point of rail exit. Rail exit is defined at the point where the forward rail button loses contact with the rail.	Analysis, Test	Vehicle will be designed to have a static stability margin above 2.0 at the rail exit point. This will be confirmed using simulation software.	Completed	3.3 Mission Performance 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 these criteria. Will be verified post-launch by finding the real center of gravity and examination of structural protuberances.	Completed	3. 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.	Completed in Flight Demo / Planned Completion on Launch Day	3.3 Mission Performance 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 a sub-scale vehicle before CDR submission.	Completed	CDR REPORT: 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	CDR REPORT: 3.2 Subscale Flight Results
2.17.2. The subscale model will carry an altimeter capable of recording the model's apogee altitude.	Demonstration	Sub-scale vehicles will carry an altimeter to record apogee altitude.	Completed	CDR REPORT: 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	The Sub-scale will be a newly fabricated vehicle.	Completed	CDR REPORT: 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	CDR REPORT: 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 (i.e. drogue chute at apogee, main chute at the intended lower altitude, functioning tracking devices, etc.). The following criteria must be met during the full-scale demonstration flight:	Demonstration	Team will fabricate and launch a full-scale rocket to verify its integrity.	Completed	5.1 Flight 1
2.18.1.1. The vehicle and recovery system will have functioned as designed.	Demonstration	Vehicle will have a recovery system planned for a full-scale vehicle and success will be seen during flight.	Completed	5.1 Flight 1
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.	Completed	5.1 Flight 1
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.	Completed (Not Needed)	5.1 Flight 1
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 the center of masses align with projected payload center of mass.	Completed (Not Needed)	5.1 Flight 1
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 the total energy of the vehicle.			
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.	Completed	5.1 Flight 1
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 exception of the payload	Completed	5.1 Flight 1
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.	Completed / On Going Through Launch Day	5.1 Flight 1
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.	Completed	5.1 Flight 1

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.	Completed	5.1 Flight 1
2.18.2. Payload Demonstration Flight - All teams will successfully launch and recover their full-scale rocket containing the completed payload prior to the Payload Demonstration Flight deadline. The rocket flown must be the same rocket to be flown on launch day. The purpose of the Payload Demonstration Flight is to prove the launch vehicle's ability to safely retain the constructed payload during flight and to show that all aspects of the payload perform as designed. A successful flight is defined as a launch in which the rocket experiences stable ascent and the payload is fully retained until it is deployed (if applicable) as designed. The following criteria must be met during the Payload Demonstration Flight:	Demonstration	Payload demonstration flight will be planned to occur well before the deadline in the case it must be rescheduled due to weather	Attempted, Reflight Necessary (In Progress)	5.1 Flight 1
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.	Attempted, Reflight Necessary (In Progress)	5.1 Flight 1

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.	Attempted, Reflight Necessary (In Progress)	5.1 Flight 1
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 scheduled to occur well before the deadline in the case weather causes rescheduling.	Incomplete / Planned	5.2 Flight 2
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 plans to submit FRR Addendum due to Payload Re-Flight.	Incomplete / Planned	5.2 Flight 2
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 / Planned	5.2 Flight 2
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	Demonstration	Team will petition for flight of payload if the payload demonstration	Incomplete / Planned	5.2 Flight 2

will not be granted if the RSO or the Review Panel have any safety concerns.		re-flight is unsuccessful.		
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 / Planned	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.	Complete	4.1.4. Unique Components
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.	Complete	N/A
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.	Completed in Flight Demo / Planned Completion on Launch Day	3.3 Mission Performance 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.	Completed	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.	Completed	3.2 Recovery Subsystem
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.	Completed	3.2 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 light weight metal, is used for the bottom of the vehicle for strength purposes.	Completed	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 descent time. This will be demonstrated at launch and full-scale verification flight.	Completed in Flight Demo / Planned Completion on Launch Day	3.1 Design and Construction of Launch Vehicle
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.	Completed in Flight Demo / Planned Completion on Launch Day	3.2 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.	Completed in Flight Demo / Planned Completion on Launch Day	3.2 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.	Completed	3.1 Design and Construction 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.	Completed	5.1.2. Ground Testing

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.	Completed in Flight Demo / Planned Completion on Launch Day	3.3.3. 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	3.2 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	Complete	3.2 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.	Complete	3.2 Recovery Subsystem
3.7. Each arming switch will be capable of being locked in the ON position for launch (i.e. cannot be disarmed due to flight forces).	Test, Inspection	Pushbuttons will be selected such that when pressed (turned on), the button is no longer protruding from the body of the launch vehicle.	Complete	3.2 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.	Complete	3.2 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.	Completed in Flight Demo / Planned Completion on Launch Day	6.2.5. Recovery Preparation
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.	Completed in Flight Demo / Planned Completion on Launch Day	3.3.5. Drift
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.	Completed in Flight Demo / Planned Completion on Launch Day	3.3 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.	Complete	3.2 Recovery Subsystem
3.12.1. Any rocket section or payload component, which lands untethered to	Inspection, Demonstration	All rocket components and payload will land	Completed in Flight Demo /	3.1.4.2. Electrical

the launch vehicle, will contain an active electronic tracking device		tethered with a main tracking device.	Planned Completion on Launch Day	
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 full-scale launch and connection will be visually verified on launch date.	Planned Completion on Launch Day	7.1.3. Electronics Test Plans/Status
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.	Completed in Flight Demo / Planned Completion on Launch Day	3.2 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.	Complete	3.2 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.	Complete	3.2 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	Demonstration	Besides wires carrying current between low-amperage electronic devices, no magnetic-field	Complete	3.2 Recovery Subsystem

avoid inadvertent excitation of the recovery system.		producing devices will be used, so no additional shielding is required.		
3.13.4. The recovery system electronics will be shielded from any other onboard devices which may adversely affect the proper operation of the recovery system electronics.	Demonstration	Recovery electronics will be adequately shielded within the avionics bay and will be tested for functionality.	Complete	3.2 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 the original design to fulfill the challenge. Safety officer will analyze any safety or legal concerns. These will be reviewed by NASA RSO.	Complete / Ongoing	4. Payload Criteria
4.3. Lunar Ice Sample Recovery Mission Requirements	-	-	-	-
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	Planned for Launch Day	4. Payload Criteria

		at payload demonstration flight.		
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 the collection zone and collect sample from it. This will be demonstrated at payload demonstration flight.	Planned for Launch Day	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.	Planned for Launch Day	4. Payload Criteria / 7.1.2. 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.	Planned for Launch Day	7.1.2. Payload Test Plans / Status
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.	Verified, Planned for Launch Day	6. Safety and Launch Procedures
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. The Ejection system will be completely mechanical. This will be demonstrated during the payload demonstration flight.	Completed, Planned for Launch Day	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.	Planned for Payload Re-Flight Demonstration and Launch Day	4. Payload Criteria
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.	Completed, Pending Payload Demonstration Re-Flight	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.	Completed, Pending Payload Demonstration Re-Flight	7.1.2. 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 the retention system to find any modes of failure and test that those found are not possible to achieve during flight.	Completed, Pending Payload Demonstration Re-Flight	7.1.2. 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.	Completed	4. Payload Criteria
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.	Completed	N/A
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 will work 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	-	-
5.3.1. Monitor team activities with an emphasis on safety during:			-	-
5.3.1.1. Design of vehicle and payload			Completed	6.1.3. Hazard Analysis
5.3.1.2. Construction of vehicle and payload components			Completed	6.1.3. Hazard Analysis

5.3.1.3. Assembly of vehicle and payload		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.	Completed	6.1.3. Hazard Analysis
5.3.1.4. Ground testing of vehicle and payload			Completed	6.1.3. Hazard Analysis
5.3.1.5. Subscale launch test(s)			Completed	6.1.3. Hazard Analysis
5.3.1.6. Full-scale launch test(s)			Completed / Pending Re-Flight	6.1.3. Hazard Analysis / 5. Demonstration Flights
5.3.1.7. Launch day			Planned	6.2 Launch Operations Procedures
5.3.1.8. Recovery activities			Completed / On Going	6.2 Launch Operations Procedures
5.3.1.9. STEM Engagement Activities			Completed / On Going	N/A
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.	Completed / On Going	6.1.3. Hazard Analysis

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.	Completed / On Going	6.1.3. Hazard Analysis
5.3.4. Assist in the writing and development of the team's hazard analyses, failure modes analysis, 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.	Completed / On Going	6. 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 the issue.	Complete / Ongoing	6. Safety
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	6. Safety

7.2.2. 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 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 62: 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.
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" diameter and 5' length body tube costs roughly $600. By limiting the purchase to just one of these, our team is saving a considerable amount of funds.

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 descend 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.
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 ## ft/s	Parachutes deploying at too high of a speed could result in failure of the retainment hardware or parachute material itself. Delay in altimeters for any reason can cause a complete failure of deployment if the vehicle is descending at too fast a rate.
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 4 for physical testing.	When failure testing, it is better to be conservative in estimating to ensure failure will not occur. A 1.5 safety margin will be added to loading calculations to ensure that no element of the recovery hardware will fail upon deployment. This includes both hardware and any interfaces including screw

		links, nuts, and any epoxied surfaces.
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.
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	The 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 restriction 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	The Ejection system must be able to withstand forces put onto it by the rover without compromising success.	While the 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 the driver within a minimum 0.5 mile radius.	The recovery area is limited to a 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.

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 63: 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.	Completed / On Going	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.	50% Completed	7.3 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.	Completed / On Going	N/A
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.	On Going	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.	Completed	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 the manufacturing phase, only one 5' body tube will be purchased.	Completed	3.1.4. Component Overview
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	3.1.4. Component Overview
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.	Completed	3.1.4. Component Overview
2.4 All components that launch on or within the vehicle will descend 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.	Completed Design, Pending Payload Re-Flight	3.2 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.	Completed	3.1.4. Component Overview
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	3.1.4. Component Overview
3. Recovery System Requirements				
3.1 No recovery hardware or parachutes will be planned to deploy if the vehicle is traveling faster than ## 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.	Completed in Flight Demonstration / On Going to Launch Day	3.2 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)	Completed	3.2. Recovery Subsystem
3.3 Recovery hardware and load-bearing interfaces will be able to take loads expected during flight with a safety margin of 4 for physical testing.	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.	Completed	7.1.1. 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.	Completed	3.2. 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.	Completed	3.2.2. Electrical ELements
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.	Completed	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 the collection method will utilize 2 motors or less while minimizing failure modes.	Completed	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 will a factor of safety of at least ##.	Completed / Pending Payload Re-Flight	7.1.2. 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.	Completed	7.1.2. Payload Test Plans / Status
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.	Completed / Pending Payload Re-Flight	7.1.2. Payload Test Plans / Status

7.3 Budget Status

Table 64: Bearospace at UCLA Total Expenditures

Bearospace at UCLA ***2019-2020 Budget***	
Grand Total	**$8,394**

Table 65: Rocket Vehicle Components Expenditures

	Vendor	Items	Date of Purchase	Price
Rocket Vehicle	***Totals:***			$2,070.88
	Giant Leap Rocketry	Missileworks USB IO Interface Module	11.20.2019	$30.74
	Hobbyclinic	Subscale Rocket Kit	12.03.2019	$264.99
	Apogee Components	AEROTECH G75J-10A 29/180 Reload Kit	12.04.2019	$83.17
	Chris's Rocket Supplies	L910 Motor Reload Kit	01.17.2020	$217.17

	McMaster-Carr	Eyebolts, Quicklinks, Aluminum	01.23.2020	$66.95
	Apogee Components	6" Coupler, Rocketpoxy, Shear Pins, Shear Pin Drill and Tap, 75mm Retainer	01.24.2020	$252.11
	Anawalt Lumber	Pine Wood, Drill Bit, Dremel Saws	01.25.2020	$27.71
	McMaster-Carr	Rubber, Javi Stuff	01.29.2020	$24.55
	Adafruit Co.	Servo, Cutters, LiPo, Soldering Iron	01.29.2020	$98.42
	Public Missiles	3" CF Body Tube	02.03.2020	$268.90
	McMaster-Carr	Steel Rods, Screws	02.12.2020	$18.05
	Anawalt Lumber	Pine Wood, D. Saw Bit, Extension Cords	02.14.2020	$57.31
	Rocketman Enterprises	12' Parachute	02.14.2020	$150.00
	Sunward	Pro75 2G Motor Casing	02.17.2020	$157.94
	Public Missiles	6" CF Body Tube	02.17.2020	$430.90
	Sunward	Refund	02.18.2020	-$157.94
	Anawalt Lumber	Pine Wood, Extension Cords, etc.	02.20.2020	$79.91

Table 66: Electronic/Payload Components Expenditures

	Vendor	Items		Price
Electrical / Payload	***Totals:***			$997.90
	McMaster Carr	Carbon Steel Acme Lead Screw		$11.78
	Gas Station	Subscale Launch Gas		$30.00
	Anawalt Lumber Co	1/2 x 4 F/H Screws		$1.52
	Friends of Amateur Rocketry	Entrance fee for 3		$30.00
	Friends of Amateur Rocketry	Rocket motor from John		$10.00

	DronesVision Inc	VRX	$44.79
	GetFPV	VTX	$54.89
	GetFPV	2x 2.4GHz Antennas	$64.88
	GetFPV	4in1 25A ESC	$49.89
	ReadyToFlyQuads	CC3D Flight Controller	$19.50
	Superior Matching Concept	11.1V 4000mAh LiPo	$57.45
	Denau Hobby Supplies	SL Data Transfer Kit	$36.90
	Amazon	NEMA 17 Stepper Motor, 360 Degree Servo Motor, 4x Latching Push Buttons, Wire Stripper, 5x10mm Diameter Couplers, SMA Female to RP-SMA Male, 2.4GHz VX/TX	$134.16
	Amazon	Adafruit LSM9DS1, Multimeter, 9V Battery (Pack of 8), SMA Female to MMCX Male Adapter, Jumper Wire Cable Assortment, 9V Battery Connectors	$65.44
	Amazon	18AWG Wires, 11.1V 1300mAh LiPo, Prototype PCB Pack, Heat Shrink Tubing, Soldering fan, iron, and tips, LiPo Battery Charger, 4x Racestar DC Motor, Stepper Motors	$278.46
	Amazon	Stepper Motor Drivers, A23 12V Batteries, Hobbymate PDB, Color Sensor/Detector, 4in Lazy Susan Ring, FPV Camera, Distance Sensors, 6x MPU6050, 3x BMP180	$108.24

Table 67: Travel Budget Expenditures

	Expense	Vendor	Projected Units	Projected Unit Price	Projected Total Price
Travel	***Totals:***				$5,324.94
	Contingency			10%	$484.09
	Toolbox	UPS	1	$48	$48.00

	Lodging	Hotel	1	$1,332	$1,331.85
	Rocket Shipping Box	UPS	1	$25	$25.00
	Uber to LAX	Uber	2	$34	$68.00
	Plane Tickets (Round Trip)	Southwest Airlines	12	$275	$3,300.00
	Uber to UCLA	Uber	2	$34	$68.00

Above is the budget plan for the 2019-2020 NASA USLI competition season for Bearospace at UCLA. All material for the Electronics and Structures teams have been purchased with no further foreseen expenditures for the current competition season, though travel expenditures have yet to be spent (except for the hotel reservations). 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 January 15th, Bearospace was awarded $2000 for material expenditures, with a presentation score 2 points below the highest achieved score of the funding season.

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 this competition season 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.

A sponsorship proposal was made and sent to members of the Dean's Corporate Advisory Board, with Aerospace Corporation offering a monetary donation of $2500 for any kind of expenditure and a desire to continue contributing donations in the future. Bearospace will continue reaching out to these entities as well as expanding upon its new relationship with Aerospace Corporation to solidify a more permanent relationship.

7.4. 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.

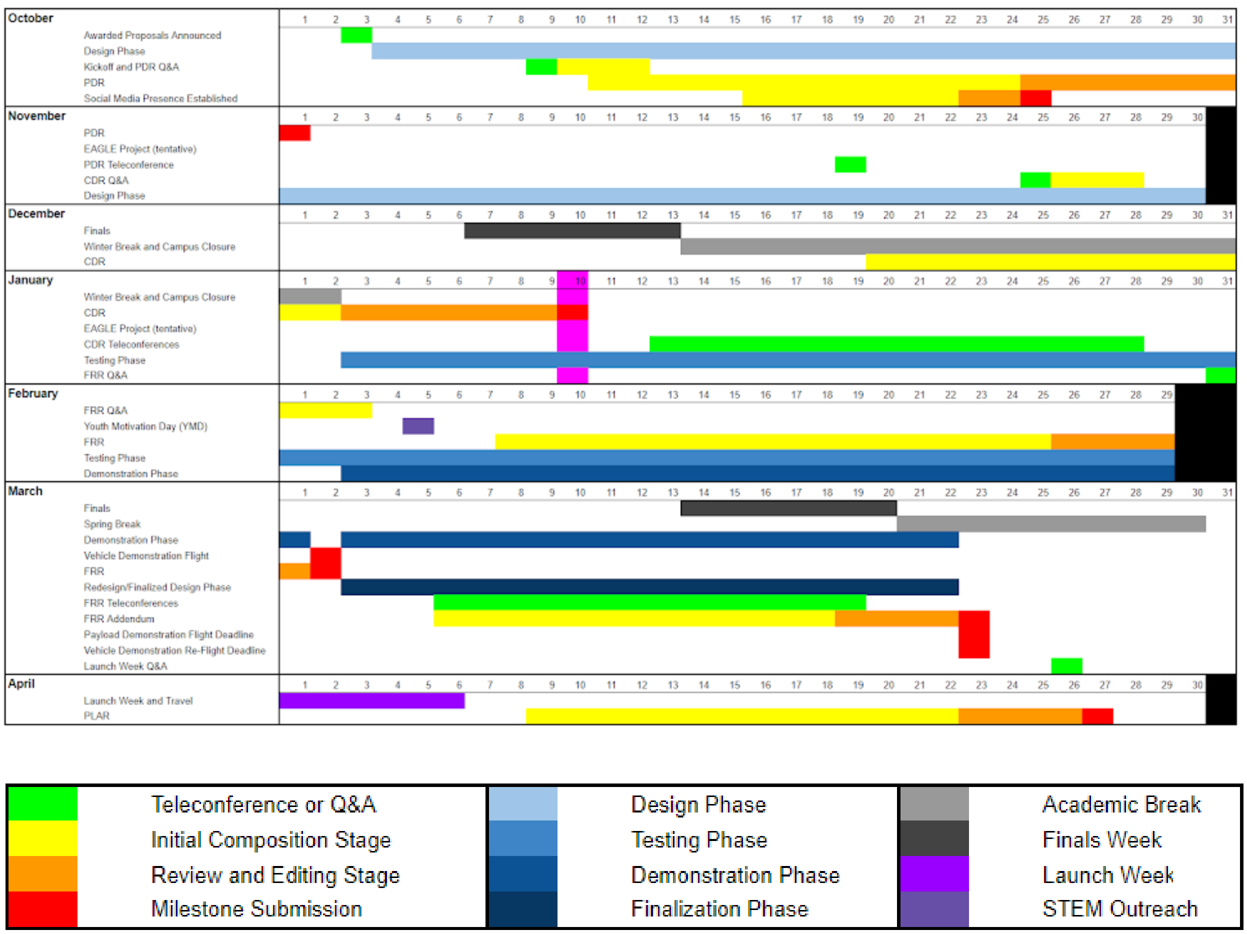

Figure 109: Gantt Chart

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.