UCLA Bearospace
(LEXS)
Lunar Environment eXcavation Simulation
2019 - 2020 NASA Student Launch
Preliminary Design Review (PDR)

University of California, Los Angeles

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0. General

0.1 Adult Educators

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0.2 Student Leader

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0.4 Team Structure

Since UCLA is on the quarter system, instruction does not start until September 26, so recruitment this year has not happened yet. UCLA Bearospace consists of a select number of people who have participated in rocketry competitions in the past. Through strategic and dedicated recruitment, the team is expected to grow from the current 7 member team to 15. Below is a flowchart of current members and the subteam(s) they are committed to.

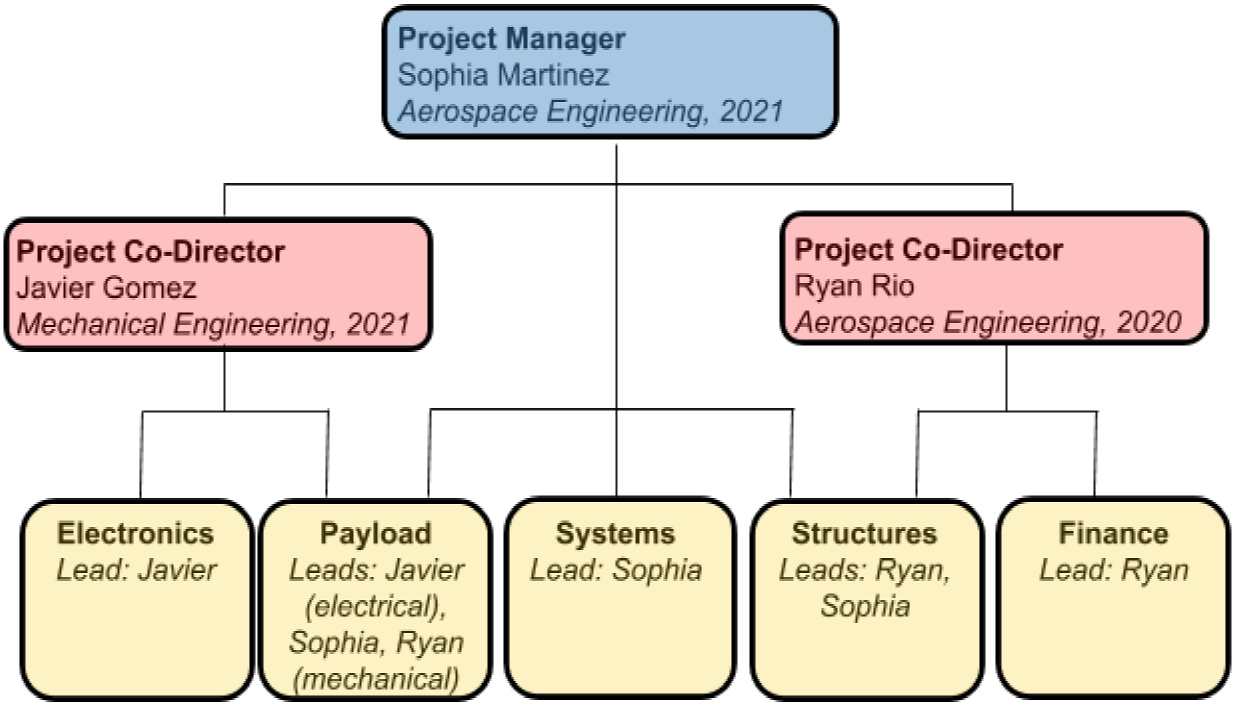


Figure 1: Current Team Structure

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

Table 1: Subteam Purposes

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

UCLA Bearospace

0.5 Team Member List

Table 2: Team Member List

Member Name	Degree	Role
Sophia Martinez	Aerospace Engineering, B.S. 2021	*Project Manager*, Systems Team Lead, Payload Team Co-lead
Ryan Rio	Aerospace Engineering, B.S. 2020	*Project Co-Director*, Finance Team Lead, Structures Team Lead
Javier Gomez	Mechanical Engineering, B.S. 2021	*Project Co-Director*, Electronics Team Lead, Payload Team Co-lead
Andy Muratalla	Aerospace Engineering, B.S. 2021	*Safety Officer*
Andres Cruz	Computer Science, B.S. 2023	*Webmaster*
Eduardo Ramirez Torres	Computer Science, B.S. 2023	*Webmaster*
Jaime Perez	Computer Engineering, B.S. 2023	*Webmaster*
Anais Hernandez	Aerospace Engineering, B.S. 2023	*Media Coordinator*
Jasmine Gomez	Aerospace Engineering, B.S. 2021	*General Member*
Juan Silva	Materials Science and Engineering, B.S. 2021	*General Member*
Rossana Rico	Mechanical Engineering, B.S. 2020	*General Member*
Achille Hebert	Aerospace Engineering, B.S. 2020	*General Member*
Mitchell Rivas	Aerospace Engineering, B.S. 2022	*General Member*
Karina Ballesteros	Aerospace Engineering, B.S. 2020	*General Member*
Karla Bonilla	Aerospace Engineering, B.S. 2023	*General Member*
Elijah Bratcher	Aerospace Engineering, B.S. 2023	*General Member*
Armando Rendon	Electrical Engineering, B.S. 2022	*General Member*
Marcus Vidaurri	Aerospace Engineering, B.S. 2023	*General Member*
Damian Meza	Aerospace Engineering, B.S. 2023	*General Member*

Jason Salgado	Electrical Engineering, B.S. 2023	*General Member*
Justin Lopez	Aerospace Engineering, B.S. 2023	*General Member*
Miranda Diaz-Infante	Bioengineering B.S. 2023	*General Member*
Jorge Roji	Aerospace Engineering, B.S. 2023	*General Member*
Fredy Gochez Gonzalez	Aerospace Engineering, B.S. 2020	*General Member*

0.6 NAR/TRA Partner

Rick Maschek
Director, Sugar Shot to Space
ROC (Rocketry Organization of California)
MDARS (Mojave Desert Advanced Rocketry Society)
TRA # 11388
Level 2

1. Summary of PDR Report

Team Name:	UCLA Bearospace
Mentor:	Rick Maschek TRA #11388 Level 2
Rocket Dimensions:	77.915 in 478oz
Preliminary Motor Choice:	**2856-L9 10-CS-0**
Target Altitude:	4500 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.
Payload Title:	Lunar Environment eXcavation Simulation (LEXS)
Payload Summary:	Payload will deploy in the proper orientation using a rover ejection assembly embedded into the launch vehicle. The rover will be operated manually via radio telecommunication using feedback provided from an on-board camera. Radio telecommunication will be used as the primary means of travel if autonomy is not developed in time. The driver will operate 5 motors: 4 DC motors to drive the treads and 1 servo motor to move the collection arm. The collection arm and collection bin contains a volume greater than 10 mL as specified in the NASA Student Launch Handbook. The rover will be 11"x5"x4".

2. Changes Made Since Proposal

During pre-proposal design, the team criteria of only Aerotech brand motors would be used was imposed. It was found that these motors would either barely allow the vehicle to reach an acceptable altitude (as seen in the proposal) or the lengths of the motors would not allow enough space for the payload and keep to the team requirement of keeping both body tubes to a combined maximum of 5’ in length. It was decided that moving forwards, different brands of motors could be considered for more optimal flight trajectories. The leading design option is discussed in section 3.3.1.2 with a rationale as to its choice in section 3.3.2.

The rover ejection assembly has changed from a scissor jack deployment method to a lead screw deployment method. The specifics of each design is outlined in section 4.4.1. All other electronics on board have remained the same. The structure and interface with electronics of the payload have been left unchanged. The rover itself has remained unchanged since the proposal. Several design alternatives have been considered before final decision and are discussed in section 4.2 but none were chosen as a better design than the proposal version.

There have been no changes to the project plan.

3. Vehicle Criteria

3.1 Mission Statement

A launch vehicle will be made entirely from scratch that harbors a payload to an apogee of between 3500 and 5500 feet, deploy parachutes at major events, and land safely. Furthermore, minimizing cost will be at the focus of design and manufacturing stages.

3.2 Mission Success Criteria

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

1. Reaching an apogee between 3500 and 5500 feet
2. Deploying recovery hardware at the correct altitudes and landing safely
3. Maintaining an undamaged payload for the duration of the flight
4. Avionics collecting and retaining useful and precise data

3.3 Launch Vehicle

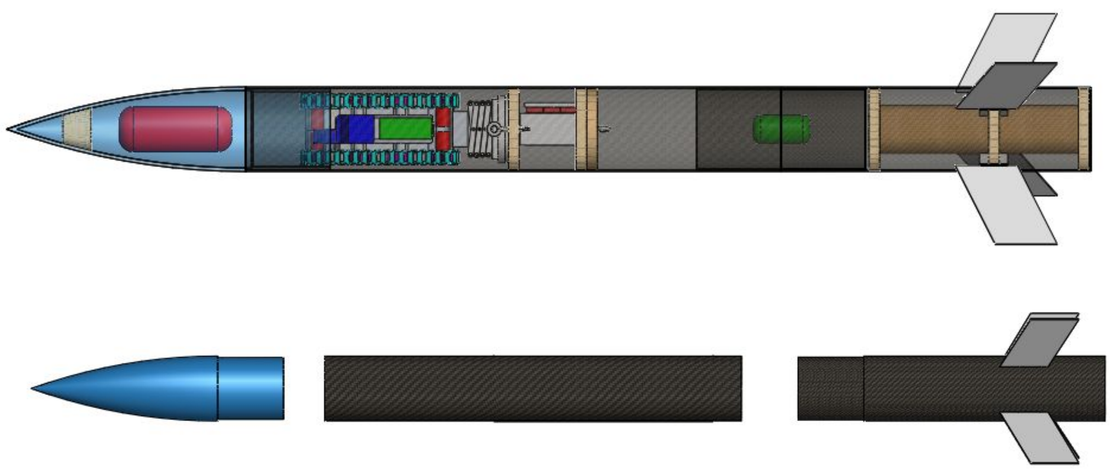


Figure 2: Overall Rocket Vehicle Layout

While exact dimensioning of the vehicle and components within it change, overall layout remains relatively consistent. There are three parent components, the nose cone, upper body tube, and lower body tube. These components must contain avionics, motor and motor retention system, and recovery hardware.

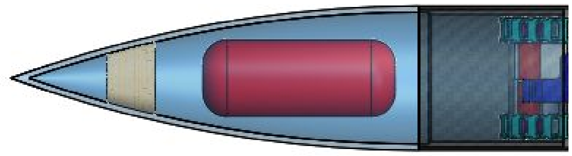
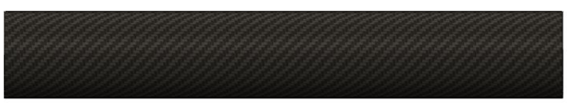


Figure 3: Nose Cone Layout

The nose cone serves as the first interface of our rocket during launch. The exact type of nose cone is dependant on the amount of drag the designer would like to create on the vehicle. The two types of nose cones that have been considered in the designing process are ogive and ellipsoid. An ogive nose cone is popular due to its low drag force and ease of design. The curvature of the nose cone can be found using the following formula where R is the radius of the body tube and L is the desired length of the nose cone.

$$\rho = (R^2 + L^2) / 2R$$

The ellipsoid nose cone is popular when a higher coefficient of drag is desired and is designed by creating an ellipse with the desired length and bluntness of the nose cone. The nose cone itself will also have a shoulder attached to it so as to easily fit into the top body tube. During the duration of the launch it will harbor recovery hardware as well as a bulkhead attached internally where that recovery hardware will be tethered.



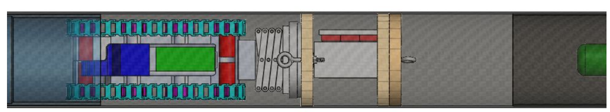


Figure 4: Upper Body Tube and Payload Layout

The upper body tube harbors the avionics necessary for events during flight, scientific payload, and some recovery hardware. Recovery hardware mainly consists of a bulkhead, similar to the nose cone, on either end of the avionics compartment. The avionics contain a series of sensors that can record altitude during flight and deploy recovery hardware when it was programmed to do so.

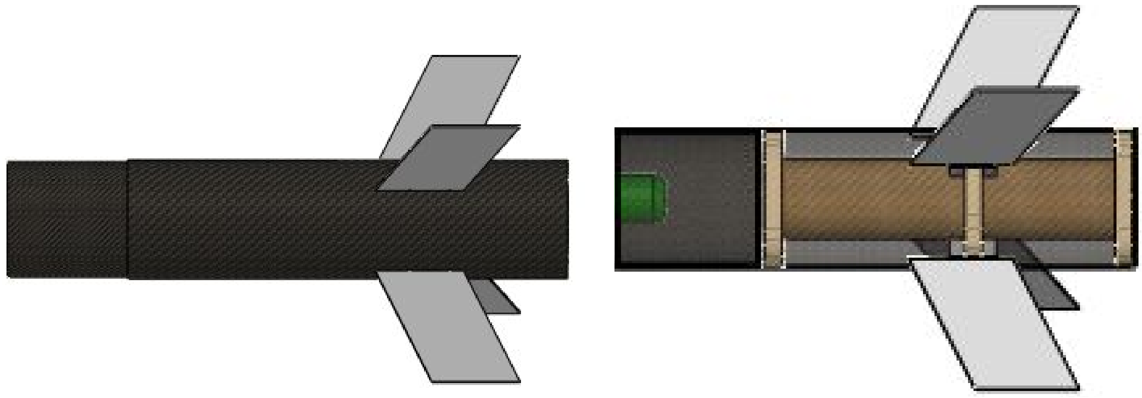


Figure 5: Lower Body Tube Layout

The lower body tube harbors the motor, fins, recovery hardware, and the coupler. The motor is encased in a phrenalic tube and held within the rocket using a motor retention system. To keep it steady for the duration of the launch, the phenolic tube is supported by three centering rings, the top of which also serves the same purpose as a bulkhead and tethers recovery hardware to this portion of the rocket. The middle centering ring also acts as the fin securement method where slots are placed to keep the fins stable during flight. The main purpose of fins is to keep the rocket stable and balanced for the duration of the flight. The coupler is attached to the top of the lower body tube and its purpose is to fit the two body tubes together.

3.3.1 Alternative Designs

When creating vehicle designs, on top of general rocket components that must be included, a series of competition and team requirements had to be met. A listing of all of them can be seen below.

Table 3: Competition and Team Requirements

Restriction	**Purpose**
Vehicle will deliver the payload to an apogee altitude between 3,500 and 5,500 feet AGL	Competition Requirement
Launch vehicle will have a maximum of four independent sections	Competition Requirement
Motor cannot exceed 5,120 Newton-seconds (L-class)	Competition Requirement
Launch vehicle will have a minimum static stability margin of 2.0 at the point of rail exit	Competition Requirement
The launch vehicle will accelerate to a minimum velocity of 52 fps at rail exit	Competition Requirement
The sum of upper and lower body tubes lengths will not exceed 5’	Team Requirement
Payload will recieve 14” and 9 lbs in the upper body tube above the electronics bay, facing the nose cone.	Team Requirement
Upper and lower body tubes will both have an outer diameter of 6”	Team Requirement

When designing, the biggest obstacles were the restrictions on total body length and space allotted for the payload. Since most L class motors are over 20 inches in length, the strategy taken by the team was to research shorter L-class motors then customize the vehicle to fit it and the payload. Fins and nose cone would then be altered to meet the stability requirements and simulations would ensure appropriate apogee and rail exit velocity, resulting in multiple alternative designs of a rocket vehicle that differed in only nose cone design, fin design, and motor selection

The stability of the vehicle is dependant on the distribution of mass and area along it. Before construction, distributions are calculated using OpenRocket. This program takes material densities and projected sizes to produce a mass distribution, and uses surface area to create an area distribution. The center of gravity and pressure are then calculated using the respective distributions. An example will be shown below for center of gravity, where x_{cg} is the center of gravity (mass), N is the number of mass components, i is the component in consideration, m_i is the mass of the component being considered, x_i is the position of the center of mass of that component relative to the tip of the nose cone, and M is the total mass of the vehicle; the center of pressure is calculated the same way but considering area instead of masses.

$$x_{cg} = \sum_{i=1}^{N} m_i x_i \div M$$

Once the centers of mass and pressure are calculated, stability can be calculated using the formula below where x_{cp} is the center of pressure, and d is the diameter of the launch vehicle, and S is the stability at rest.

$$S = (x_{cp} - x_{cg}) \div d\,.$$

This calculation was repeated for major motor events (pre-launch, launch rod clearance, and motor burnout) and recorded below. All x_{cp} and x_{cg} values were calculated using OpenRocket flight simulations and measured from the tip of the nose cone.

For all alternative designs, carbon fiber tubing is being used for body and coupler elements due to its lightweight, durable, and heat resistant aspects. This will be purchased from a commercial supplier. Purchasing a body tube also minimizes health risks to the team and increases precision on simulations and real launch.

3.3.1.2 Alternative Design 1

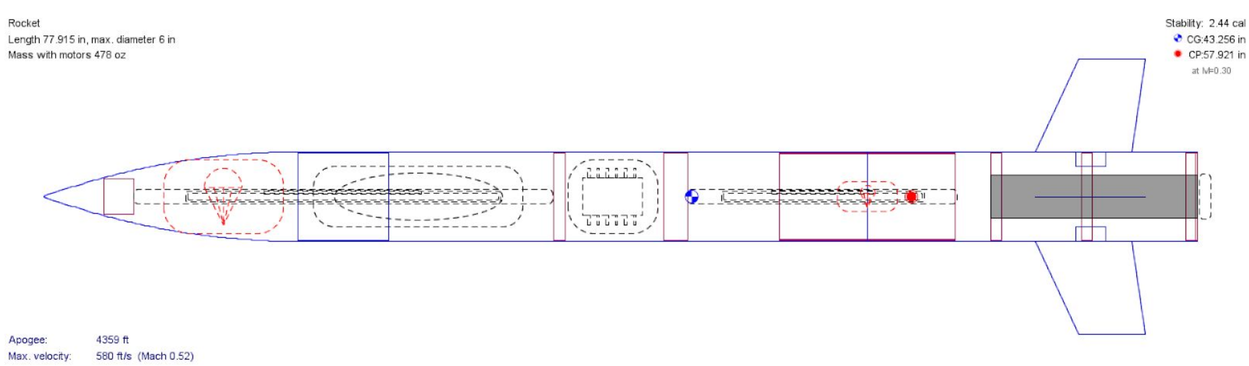


Figure 6: Alternative Design 1

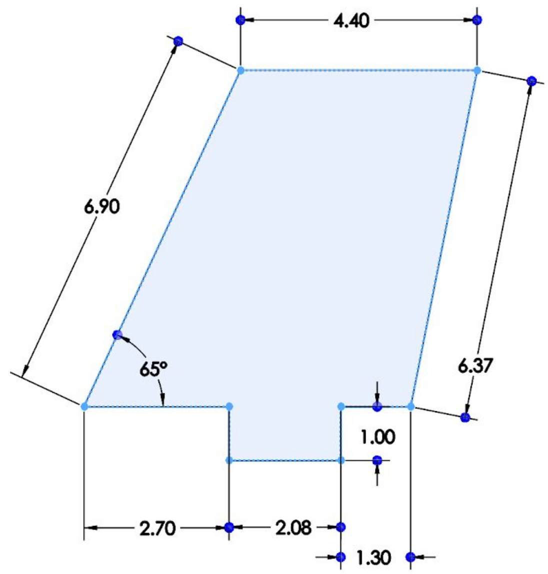


Figure 7: Alternative Design 1 Fin Layout

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

Table 4: Alternative Design 1 Characteristics

Overall Vehicle Characteristics		**Nose Cone Characteristics**	
Total Vehicle Length (in)	77.915	Total Length (in)	17.0
Total Weight on Rail (oz)	478	Component Weight (oz)	13.12
Static Stability	2.44	Wall Thickness (in)	0.079
Average Thrust-to-Weight Ratio	6.822	Shoulder Length (in)	6.0
Motor	2856-L910-CS-0	Material	ABS Plastic
Upper Body Tube Characteristics		**Lower Body Tube Characteristics**	
Total Component Length (in)	38	Total Component Length (in)	22
Component Weight (oz)	241.56	Component Weight (oz)	196.22
Wall Thickness (in)	0.079	Wall Thickness (in)	0.079
Material	Carbon Fiber	Material	Carbon Fiber

3.3.1.3 Alternative Design 2

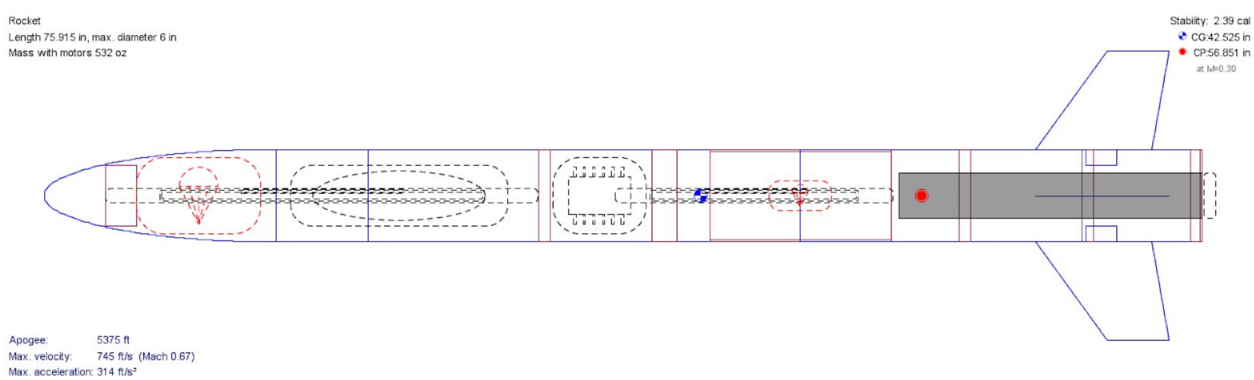


Figure 8: Alternative Design 2 Layout

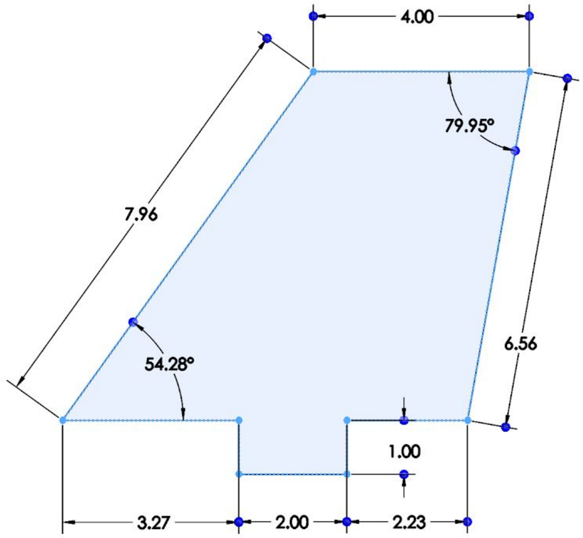


Figure 9: Alternative Design 2 Fin Layout

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

Table 5: Alternative Design 2 Characteristics

Overall Vehicle Characteristics		**Nose Cone Characteristics**	
Total Vehicle Length (in)	75.915	Total Length (in)	15
Total Weight on Rail (oz)	532	Component Weight (oz)	18.2
Static Stability	2.29	Wall Thickness (in)	0.079
Average Thrust-to-Weight Ratio	10.358	Shoulder Length (in)	6
Motor	L1482-0	Material	ABS Plastic
Upper Body Tube Characteristics		**Lower Body Tube Characteristics**	
Total Component Length (in)	34	Total Component Length (in)	26
Component Weight (oz)	235.46	Component Weight (oz)	251.72
Wall Thickness (in)	0.079	Wall Thickness (in)	0.079
Material	Carbon Fiber	Material	Carbon Fiber

3.3.1.4 Alternative Design 3

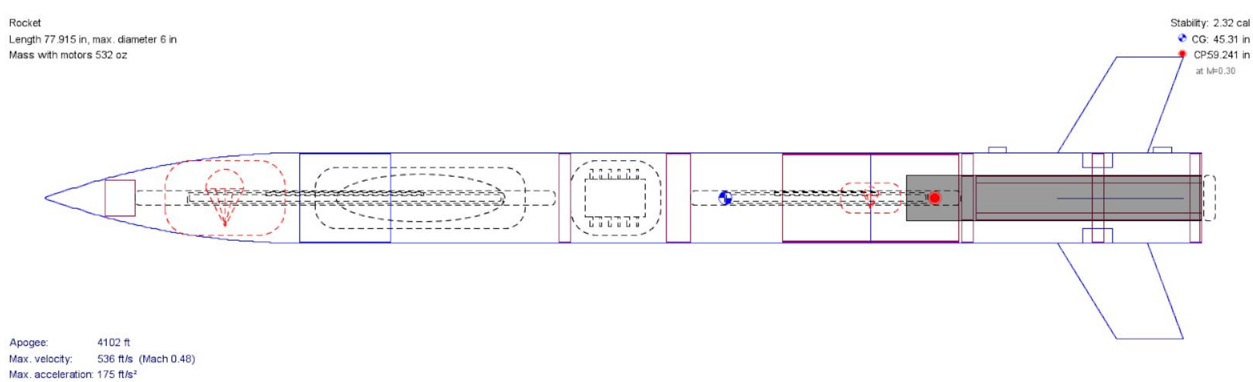


Figure 10: Alternative Design 3 Layout

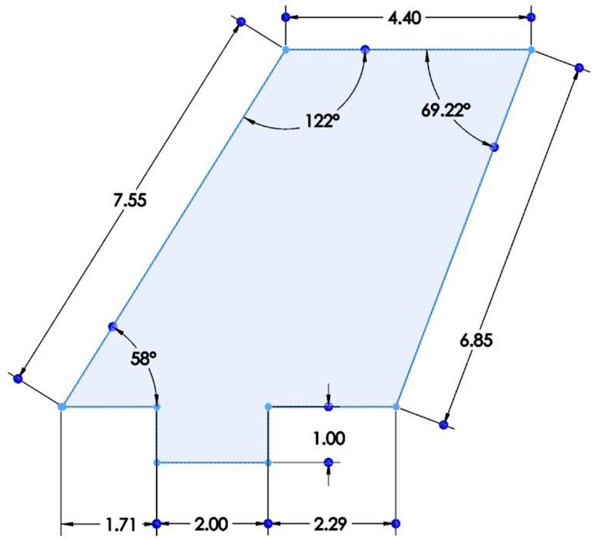


Figure 11: Alternative Design 3 Fin Layout

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

Table 6: Alternative Design 3 Characteristics

Overall Vehicle Characteristics		Nose Cone Characteristics	
Total Vehicle Length (in)	77.915	Total Length (in)	17
Total Weight on Rail (oz)	532	Component Weight (oz)	13.12
Static Stability	2.33	Wall Thickness (in)	0.079
Average Thrust-to-Weight Ratio	5.399	Shoulder Length (in)	6
Motor	L780-SF-0	Material	ABS Plastic
Upper Body Tube Characteristics		**Lower Body Tube Characteristics**	
Total Component Length (in)	38	Total Component Length (in)	22
Component Weight (oz)	241.56	Component Weight (oz)	226.72
Wall Thickness (in)	0.079	Wall Thickness (in)	0.079
Material	Carbon Fiber	Material	Carbon Fiber

3.3.2 Leading Design Choices

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

3.3.3 Motor Alternatives

3.4 Recovery Subsystem

The recovery subsystem is responsible for ensuring the completion of three major events, deployment of drogue chute at apogee, deployment of the main chute at 50 ft AGL, and touchdown.

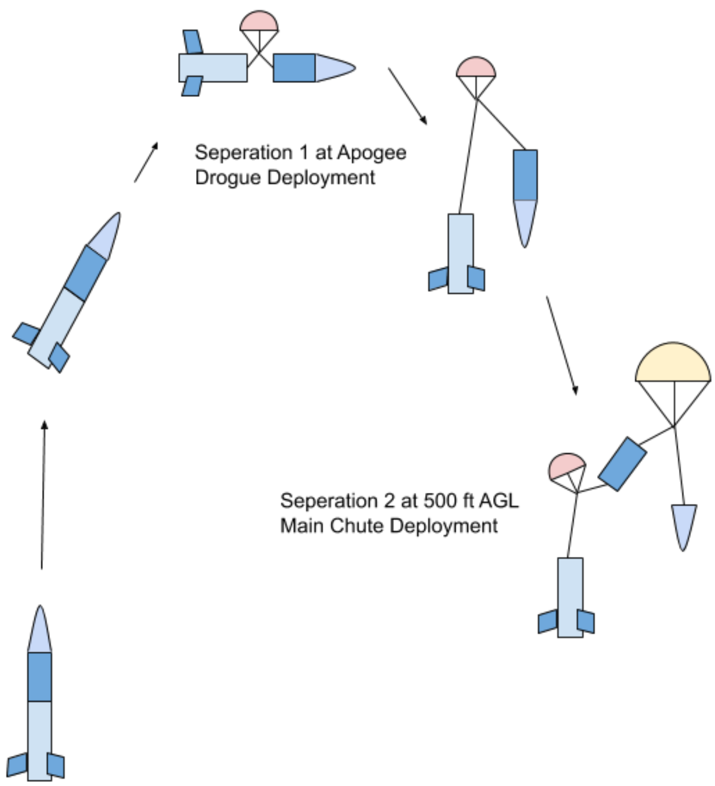


Figure 12: Dual Deployment System

3.3.1 Alternative Designs

When creating alternative recovery designs, the most important aspects are material strength, weight, and cost. The material used for the locking mechanism was either between carbon fibre or epoxied pine. As seen by previous uses, pine is less prone to release of particulates when cut to specific dimensions. Carbon fibre may hold some advantages with an estimated strength to weight ratio of 2457 kN*m/kg while oak (similar to pine) has a strength to weight ratio of 87 kN*m/kg. The rigidity of carbon fibre is about 20 times stronger than pine.

Young's Modulus: Pine Wood (along grain) : 8.963 GPascal
Carbon Fiber Reinforced Plastic: 181 GPascal

Weibull Modulus: Carbon fiber in a laminate: 1600 MPa
Pine wood (parallel to grain): 40 MPA

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

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

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

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

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

Table 7: Resin Properties

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

The pine wood applied with the epoxy resin has an overall lower density than the one where polyester was the resin. The epoxy and polyester resin had the overall similar effects on the strength of the pine. In addition, the epoxy resin provided a greater hardness and minimal elongation occurs during failure. The minimal elongation is preferred, specifically for the locking mechanism as it will hold a pull of force for a longer period of time and should resist strain applied. Overall, pine wood with epoxy resin was chosen for the locking mechanism, it has held its properties of being stiff and resists elongation. Epoxy is slightly more expensive than polyester resin, but the greater hardness and resistance to elongation is preferred.

3.3.1.1 Hardware

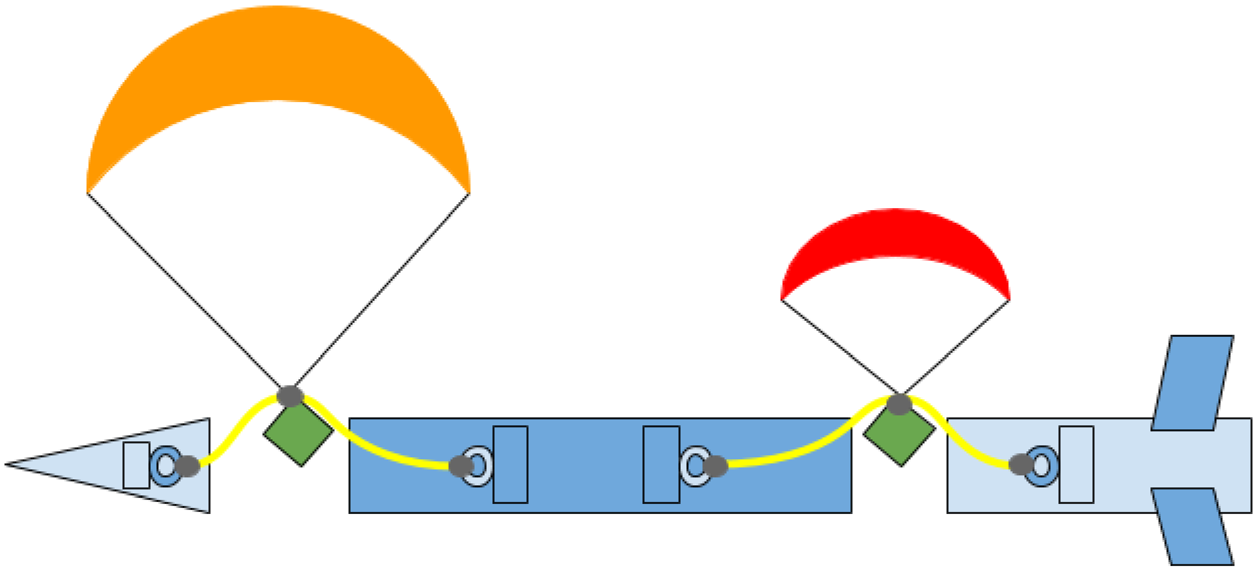


Figure 13: Parachute Locations within Rocket

Apart from the parachutes themselves, the components in the recovery system that must be analyzed are the retainment structures adhered to the vehicle, the tethering material, and the connection between the two.

The retainment structures are essentially thick pieces of material adhered to the inner perimeter of the body tube of nose cone to which recovery hardware can be attached to retain the launch vehicle during descent. Shown below are two options of these structures, called bulkheads.

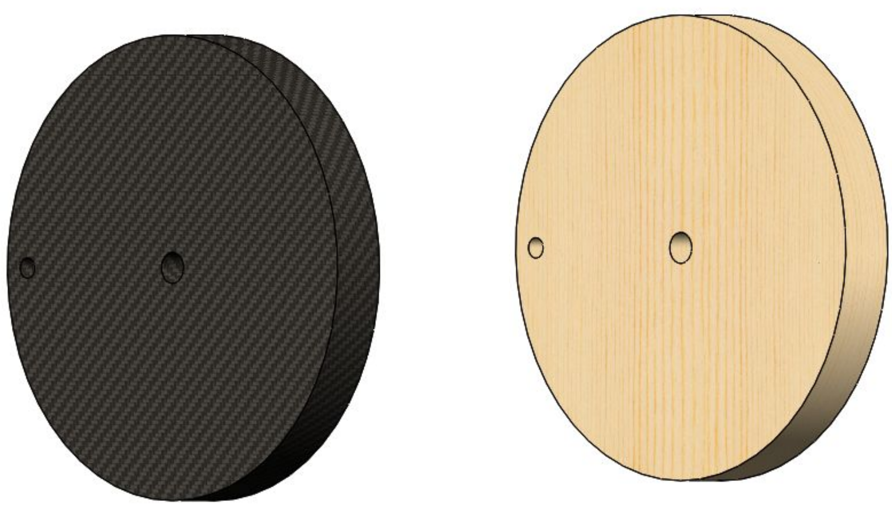


Figure 14: Retainment Structures

Since this is an integral part of the design, the only discrepancy is what material to make it out of. The options were sheets of carbon fiber or pine. While carbon fiber is stronger, it is more expensive and creates toxic particulates when manufactured. It also does not show fatigue after testing, which would cause unforeseen failure. Pine is much easier to manufacture since it can be easily cut using a CNC or laser cutter and can be sanded down with ease for post processing.

Connected to the bulkheads is normally some metal attachment that is both screwed into the bulkhead as well as epoxied onto either face. The two attachments that were considered were U-bolts and eyebolts (both models taken from McMaster-Carr, a part supply company).

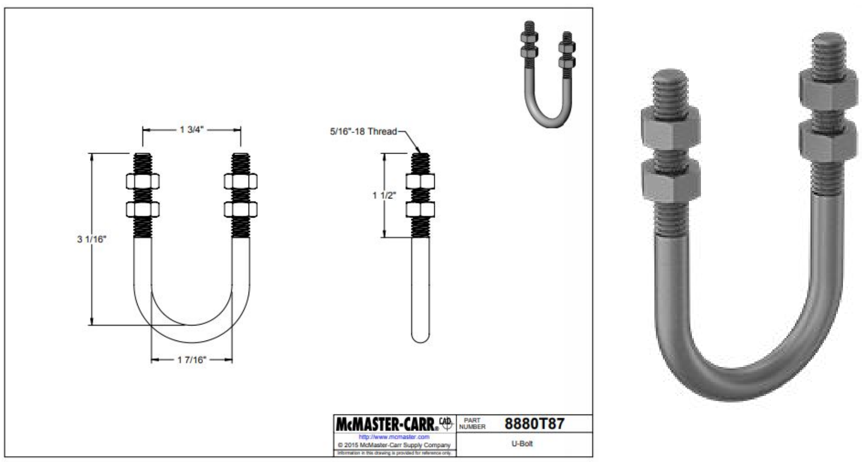


Figure 15: U-bolt

While a u-bolt would provide double the interface with the bulkhead, decreasing the chances of it being ripped out on recovery system deployment, it is not very strong. This particular u-bolt can only hold 600 lbs of force with no factor of safety.

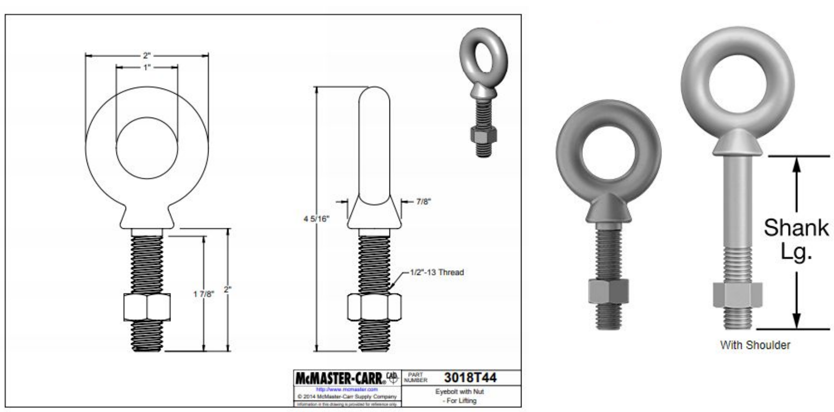


Figure 16: Eye-bolt

Eye Bolts only have one interface with the bulkhead so they are more likely to be ripped out the vehicle. Other than this, its vertical capacity is 2,100 lbs, far exceeding the force that will be seen by the vehicle during flight. This supplier also labels this eyebolt specifically for lifting, which gives the team further reassurance that it will remain in the launch vehicle.

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

Figure 17: 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.

3.3.1.2 Locking Mechanism

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

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

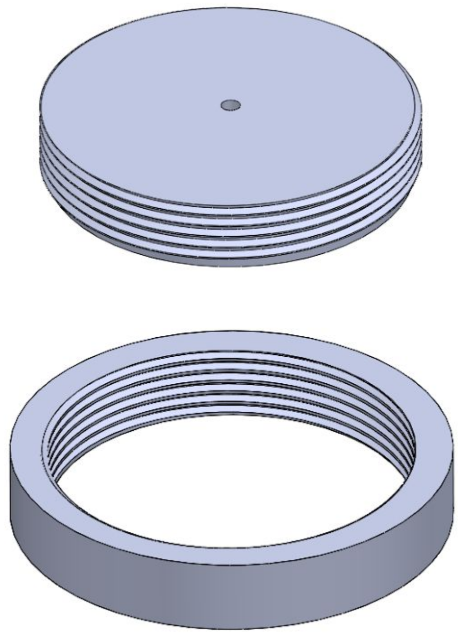


Figure 18: Threading Mechanism

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

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

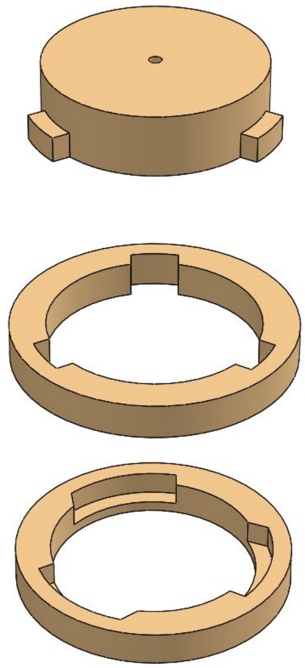


Figure 19: Locking Mechanism

Because the geometry of the assembly is simple, component manufacturing is also simplified. This simple, yet robust design permits a greater variety of materials to be used. Primarily, wood and metals can be CNC'd to specification. A double layered wooden locking mechanism can be implemented. The inner ring of the locking mechanism can be manufactured using two 0.75" slabs of wood as well as the outer ring.

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

3.3.1.3 GPS Tracker

In order to keep track of the rocket's position, a GPS tracker will be placed inside of the rocket. The tracker was located inside of the carbon fiber body tube in previous years which caused some issues with the signal being lost. To prevent this, the GPS will be located inside of the nose cone which is made out of PLA plastic. Due to space limitations, a small GPS tracking device is preferred.

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

Another option is the NEO-6M GPS Module for Arduino, which costs a little over $10. While it is cost-efficient and about the same size as the T3, it does not come with a strong enough antenna to meet the desired range of the rocket.

3.3.2 Preliminary Parachute Sizing Analysis

Parachute sizing for each alternative rocket vehicle design is determined by the maximum landing kinetic energy allowed. Per the NASA Student Launch Statement of Work (SOW), the maximum kinetic energy any rocket component can experience is 75 ft-lbf. From this, using the kinetic energy equation given below, the maximum landing velocity for the heaviest rocket component (as the heaviest component will have the most kinetic energy as can be clearly seen in the kinetic energy equation) can be determined.

$$KE_{max} = 75\,ft * lbf = 0.5 m_{max} v_{max}{}^2$$
$$v_{max} = \sqrt{2m_{max}/KE_{max}}\,.$$

Using this equation, the maximum landing velocity of each alternative designs heaviest component is determined.

$$m_{1,max} = 241.56\,oz \;{->}\; v_{1,max} = 17.88\,ft/s\,.$$
$$m_{2,max} = 235.46\,oz \;{->}\; v_{3,max} = 18.11\,ft/s\,.$$
$$m_{3,max} = 241.56\,oz \;{->}\; v_{3,max} = 17.88\,ft/s\,.$$

With this maximum landing velocity, a parachute sizing that lowers the landing velocity to below the minimum is determined. Through simulations through OpenRocket, a 12’ parachute services all alternative designs well enough to lower the landing velocity below their respective maxima.

$$v_{1,12"} = 16.4\,ft/s < v_{1,max} = 17.88\,ft/s\,.$$
$$v_{2,12"} = 16.3\,ft/s < v_{2,max} = 18.11\,ft/s\,.$$
$$v_{3,12"} = 16.3\,ft/s < v_{3,max} = 17.88\,ft/s\,.$$

To reinforce the initial results produced through OpenRocket, simulations were repeated 10 times and the highest landing velocity is taken for additional safety measures, rather than the average. Using the highest landing velocity, the kinetic energy of each mass component . To supplement OpenRocket simulations, calculations were made by hand using the kinetic energy equation and the parachute diameter equation to determine a minimal parachute diameter, which would be rounded up to the nearest even-numbered foot. The corresponding landing velocity to the rounded up parachute diameter is then used to calculate the landing kinetic energy of each rocket component.

insert kinetic energy equation and parachute diameter equation
insert hand calculations, rounding, new velocities, and new kinetic energies

$$D = \sqrt{8m_{rocket}g/(\pi\rho C_d v_{rocket})}\text{ , } where\ \rho = 0.0238\ slug/ft^3\text{ , } C_d = 0.8\text{ , } and\ g = 32.2\ ft/s^2\text{ .}$$

$$m_{rocket,1} = 478\ oz,\ \ v_{1,max} = 17.88\ ft/s\ -> D = 11.19\ in\ -> D = 12\ in$$
$$m_{rocket,2} = 532\ oz,\ \ v_{2,max} = 18.11\ ft/s\ -> D = 11.66\ in\ -> D = 12\ in$$
$$m_{rocket,3} = 532\ oz,\ \ v_{3,max} = 17.88\ ft/s\ -> D = 11.81\ in\ -> D = 12\ in$$

$$KE = 0.5m_{rocket,component} =$$

3.3.3 Leading Design Choices

Since vehicle design one is the leading vehicle design choice, all parachute sizing is relevant to that model.

3.3.3.1 Hardware

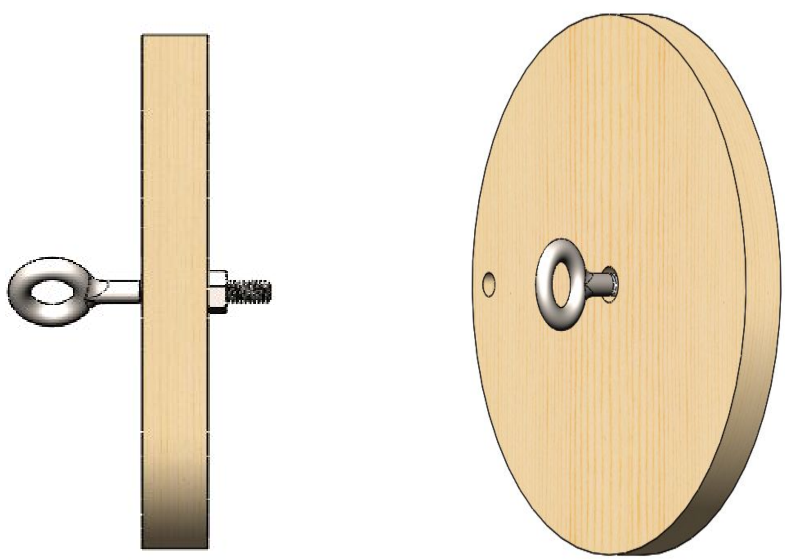


Figure 20: Pine Bulkhead

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.

3.3.3.2 Locking Mechanism

The goal of the avionics is to securely house all onboard electronics from hazards during flight to ensure proper usage of the safety electronics. To do this, a locking mechanism will be implemented to facilitate electronic integration into the launch vehicle. The locking mechanism will also serve as a bulkhead from which to attach the parachute and must resist blast forces from ejection charges. Since the locking mechanism will endure harsh conditions, the design of the locking mechanism must be durable and robust.

The locking mechanism chosen will be the simple slide-and-lock mechanism. Although its design is clunky and limits usable area for the avionics sled, its robustness and simplicity make it a better selection than the 3D printed threaded locking mechanism. The slide-and-lock's simple geometry allows it to be manufactured with a greater number of materials. In past years, pine has been selected for the locking mechanism and no signs of cracking or deformation are seen on the wood after launch. SLA 3D printers have resins rated with higher strength, but they may not be durable enough for applications within a high powered rocket. Selecting a durable resin would also incur further testing to see if this material is viable for its application.Pine is simple to CNC mill and is sufficiently strong to endure all forces during flight and parachute deployment. Analysis on pine as the choice material for the locking mechanism will be conducted throughout the project's timeline.

To ensure an airtight lock, a thin rubber sheet and wood cover will attach to the inner ring of the locking mechanism. The rubber sheet will have a diameter as the inner diameter of the body tube of the launch vehicle and the wood cover will have a smaller diameter than the rubber sheet. A rubber sheet of durometer 40A will be selected to press against the inner wall of the body tube without being too difficult to manipulate. A harder durometer will create a tighter seal, but will also make it difficult to slide and rotate the locking mechanism into position. The wooden cover will provide rigidity for the rubber sheet so that it does not detach and will be the component that is exposed to the black power charges during parachute deployment. The diameter of the wood cover is smaller than that of the rubber sheet so that the rubber sheet folds up, pressing snugly against the walls of the body tube. This creates an airtight seal for the avionics compartment, which is crucial for electronics that depend on pressure readings for operation, such as the altimeters (discussed in section 3.3.4) and BMP180 (discussed in section section 4.4.2).

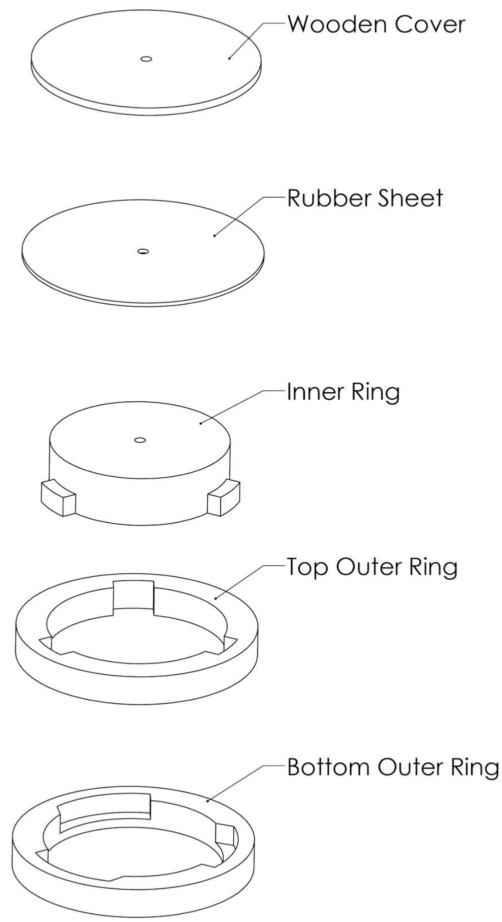


Figure 21: Locking Mechanism Assembly

3.3.3.3 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

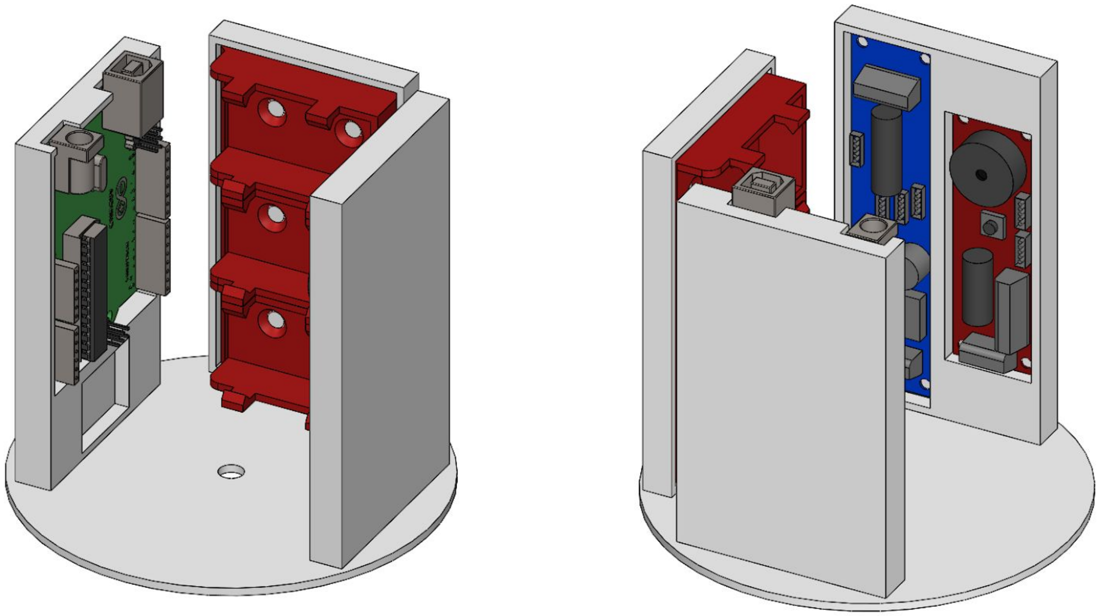


Figure 22: Electronics Sled

Multiple electronic components will be housed within the avionics bay, so space management is crucial. All electronics will face inwards to prevent wires from getting caught with the locking mechanism when trying to place the sled. Inward facing electronics will cause all wires to be localized within the sled, which prevents wires from getting stuck with the locking mechanism. The sled features an empty central volume for wire accessibility and space for the rover ejection assembly's orientation motor (discussed in section 4.4.1.1). 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.

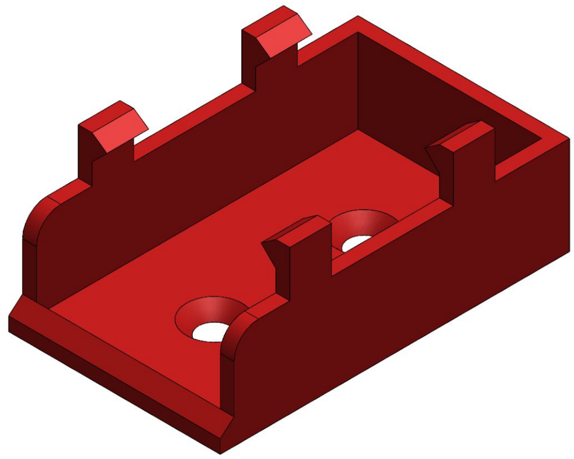


Figure 23: Battery Holder

3.3.3.4 Avionics 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:

$$SinglePort\ Diameter = Volume\ of\ EBay\ /\ 400$$

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

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

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

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

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

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

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

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

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

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

3.3.3.5 GPS Tracker

UCLA Bearospace has participated in high powered rocketry competitions in the past using commercial GPS trackers and other equipment.To reduce costs of the launch vehicle, some of these devices from previous years will be reused.

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

The operational voltage of the T3 is 3.5 volts to 7.4 volts using a 1S Li-Po battery. The power consumption is about 175 mA.

3.3.4 Redundancy

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

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

- Must be dual deployment
- Ease of programmability
- Size

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

Table 8: Altimeters

Altimeter	Dual Deployment	Dimensions (LxWxH)	Programming
Entacore AIM Altimeter	Yes	2.56" x 0.98" x 0.59"	-Software included -Requires an additional USB dongle
Stratologger SL100 Altimeter	Yes	2.75" x 0.90" x 0.50"	-Software included -Requires an additional USB dongle
RRC3 Sports Altimeter	Yes	3.92" x 0.92" x 0.46”	-Software included using an additional USB dongle -Alternative plug in LCD Terminal

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

Both altimeters will be programmed to deploy at apogee and 500 feet AGL with no delays to accomplish a safe and timely descent.

3.3.4.1 Switches

In order to safely and efficiently power the altimeters from outside the launch vehicle, Anderson Powerpole connector switches will be used. Anderson Powerpole switches are easy to connect, lock tightly to each other, and have a low cross-sectional area, so additional drag effects from the Anderson Powerpole switches are negligible. These switches will be accessed from outside the avionics bay and will be connected on the launch pad to power all electronics only once they are needed. As a result, power consumption will not occur while the launch vehicle is being transported to the launch pad, which maximizes battery life during flight. Another advantage of using Anderson Powerpole switches is that they arm the altimeters from inside the avionics bay. In the case a malfunction within one of the altimeters occurs and an ejection charge accidentally goes off, the explosion will be contained within the rocket to prevent personal injury.

Standard 9V alkaline batteries will be used to reduce costs. Lithium ion polymer (LiPo) batteries were considered for their higher energy density than alkaline batteries, but were not used due to their tendency to be flammable if mishandled. If anything were to happen to the launch vehicle during flight, it is imperative that the safety features of the rocket deploy.

A wiring diagram for various recovery components inside the avionics bay is seen below.

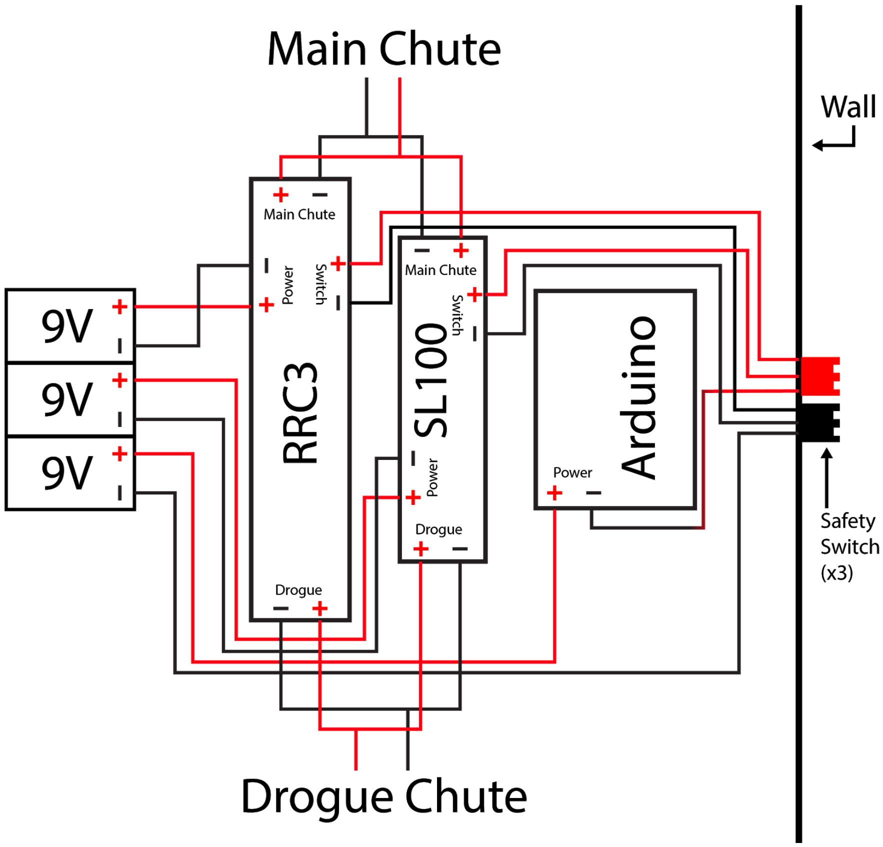


Figure 24: Recovery System Layout

An Arduino Uno is included in Figure 24 since it is within the avionics compartment. The Arduino Uno plays no role in the safe recovery of the launch vehicle but will still use an Anderson Powerpole connector switch to operate. More information on the Arduino Uno in section 4.4.4.1. The altimeters connect to the black powder charges of each parachute, not the parachute itself.

3.5 Mission Performance Predictions

3.5.1 Official Target Altitude

The official target altitude is set to 4100 ft AGL exactly, based off of the estimated apogee of the leading rocket vehicle design simulations and probable additional loss in apogee height through other actors such as launch rail friction.

3.5.2 Flight Simulations

To ensure compliance with rocket vehicle safety requirements set forth by NASA, the CP locations, CG locations, and stability margin calibers were estimated and plotted throughout the duration of flight. These charts are reproduced below, accounting for the range of inclination that the launch rail could be within, depending on ambient conditions.

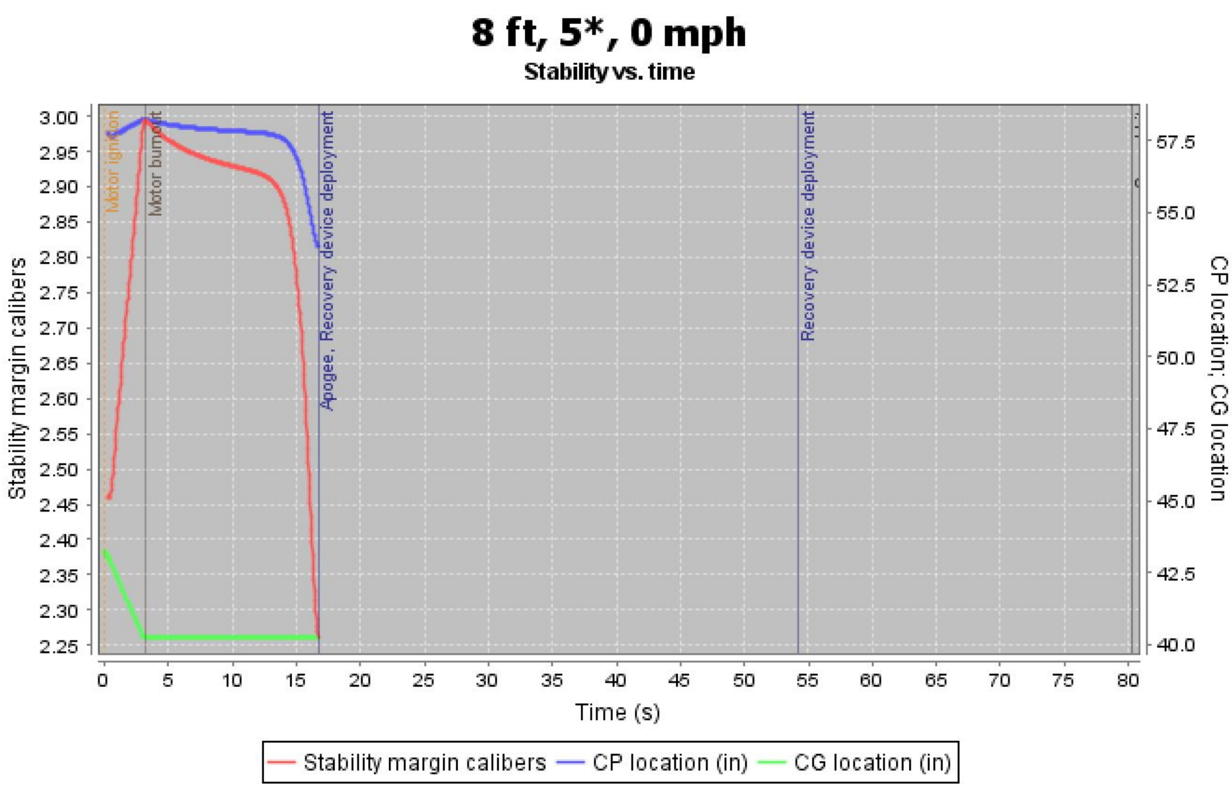


Figure 25: Stability over Time, 5 degree Inclination

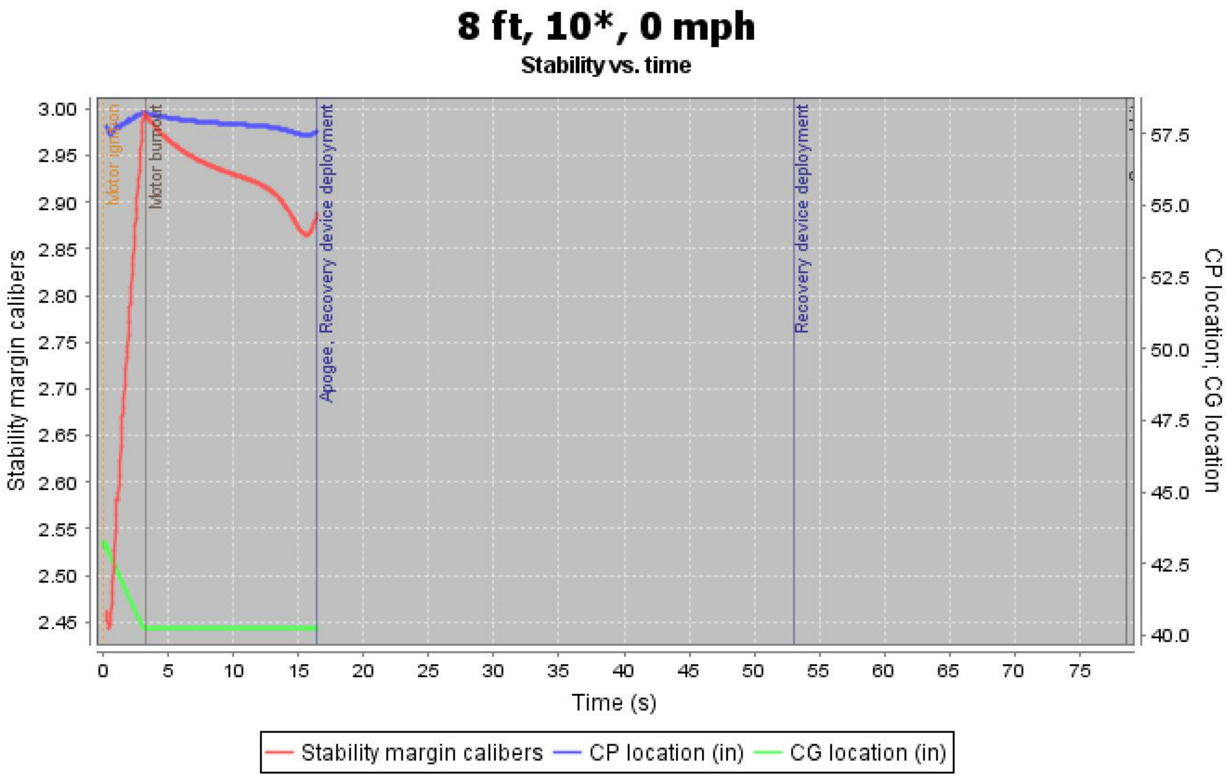


Figure 26: Stability over Time, 10 degree Inclination

Given below is the motor thrust curve for the Cesaroni Technologies 2986-L910-CS-0, the motor selection for the leading alternative design.

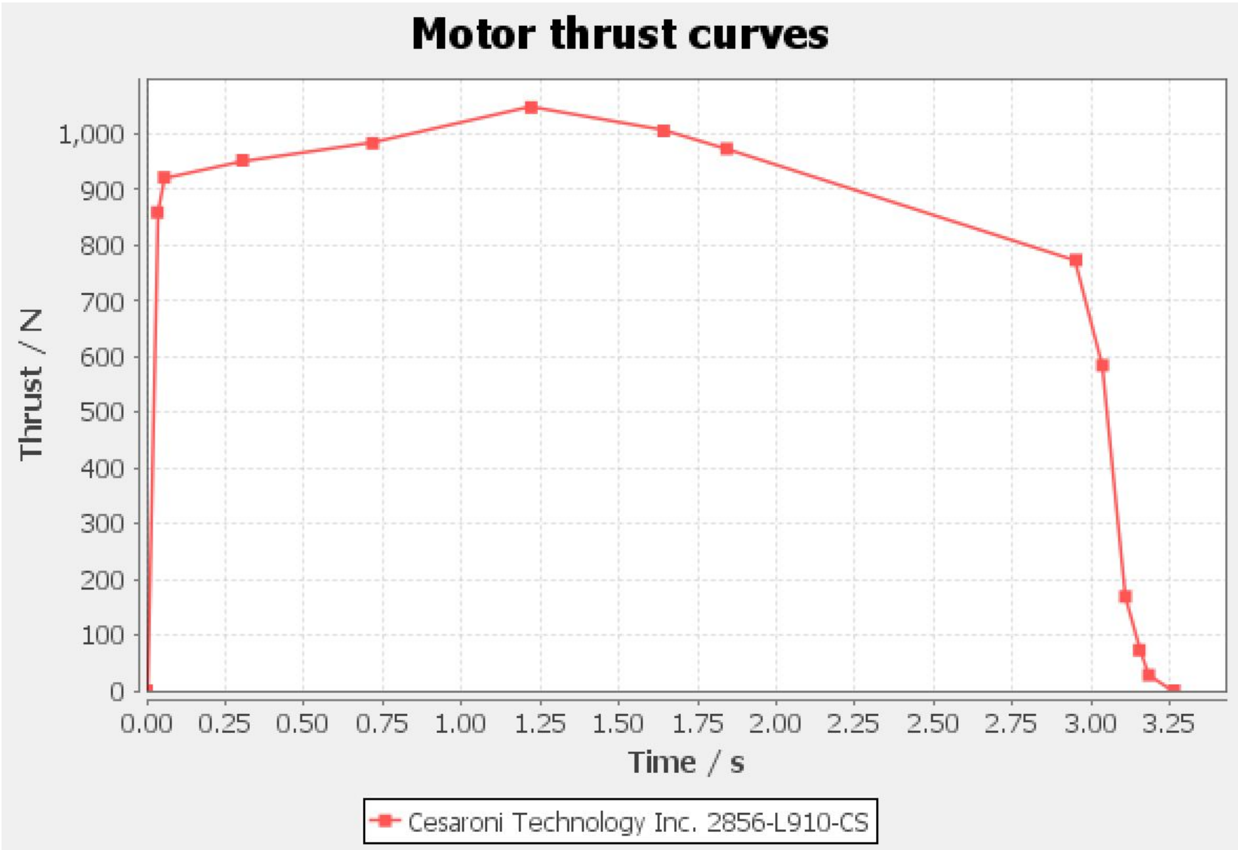


Figure 27: Motor Thrust Curve for 2856-L910-CS-0

With this motor selected, the resulting lateral drift of the rocket, its landing speed, and landing kinetic energy of each rocket vehicle component can now be determined.

3.5.3 Recovery Simulations

Referring back to section 3.3.2 and the landing velocities computed using a 12 ft parachute, the kinetic energies of all the tethered rocket vehicle components of the leading rocket vehicle design can be determined.

$$KE_{component} = 0.5 m_{component} v_{landing}^{2}, \ where\ v_{landing} = 16.4\ ft/s$$

$$m_{nose\ cone} = 13.12\ oz \ \text{->}\ KE_{nose\ cone} = 2.96\ ft-lbf$$

$$m_{upper\ body\ tube} = 241.56\ oz \ \text{->}\ KE_{upper\ body\ tube} = 57.29\ ft-lbf$$

$$m_{lower\ body\ tube} = 148.02\ oz \ \text{->}\ KE_{lower\ body\ tube} = 35.1\ ft-lbf$$

Note that the highest kinetic energy, that of the upper body tube, is more than 20 percent less than the maximum allowable rocket vehicle component landing kinetic energy, 75 ft-lbf. This provides a measure of contingency in the event of weight gain during the design and manufacturing process, as weight gain contributes to a proportionally higher landing kinetic energy. Further simulations in OpenRocket accounting for 5-10 degree inclinations of the launch rail as well as 0-20 mph wind speeds show that a landing speed of 16.4 ft/s is actually the upper bound to the rocket vehicle landing speed spread, with the lower bound being as low as 14.8 ft/s, meaning a component's kinetic energy, depending only on launch conditions, will always be less than the estimate produced above.

3.5.4 Drift Estimate

Drift is determined through OpenRocket simulations, where drift from apogee to landing is the only lateral distance being considered, making the assumption that a rocket reaches apogee directly above the launch site. Different rail inclinations are also factored into the drift calculations, using the minimum and maximum inclinations set forth in the requirements (5 degrees and 10 degrees respectively) to form a resulting drift window depending on rail length, rail inclination, and wind speed.

Table 9: Drift and Descent Time Estimates

Rail Length (ft)	Rail Inclination downwind (degrees)	Wind speed (mph)	Drift (ft)	Descent Time (s)
8	5	0	215.9	63.6
8	5	5	547.3	64.7
8	5	10	782.3	63.6
8	5	15	365.1	64.7
8	5	20	132.8	64.2
8	10	0	374.9	62.3
8	10	5	760.7	64.8
8	10	10	1118.5	65.5
8	10	15	1499.6	65
8	10	20	1660.5	64.6

3.5.5 Simulation Verification

The structures team is in the process of writing a code in Matlab that can verify the calculations stated in this report. The team believes OpenRocket to be a very reliable source but will not proceed to the manufacturing stage until simulations are verified.

4. Payload Criteria

4.1 Payload Objectives

The scientific payload is designed to correctly deploy itself, maneuver across unknown terrain, and collect simulated lunar ice samples from designated collection areas. The payload will involve a remotely operated rover with treads and a collection arm. Payload success is defined by its ability to collect, store, and transport 10mL of lunar ice samples a distance of 10 linear feet from the collection site.

4.2 Alternate Designs

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

In the design, electronics are contained in a green box for the electronics team to further size as they obtain physical parts and wire them. The main concern when designing the wheel system is traction. Considering the terrain would be some sort of soil (loose or packed), the wheels would have to be able to go over this terrain without sinking into it. The team first considered a simple set of geared wheels but was concerned that they would not be able to go over any major debris such as fallen foliage. Because of this, the team modeled the wheels after tank treads.

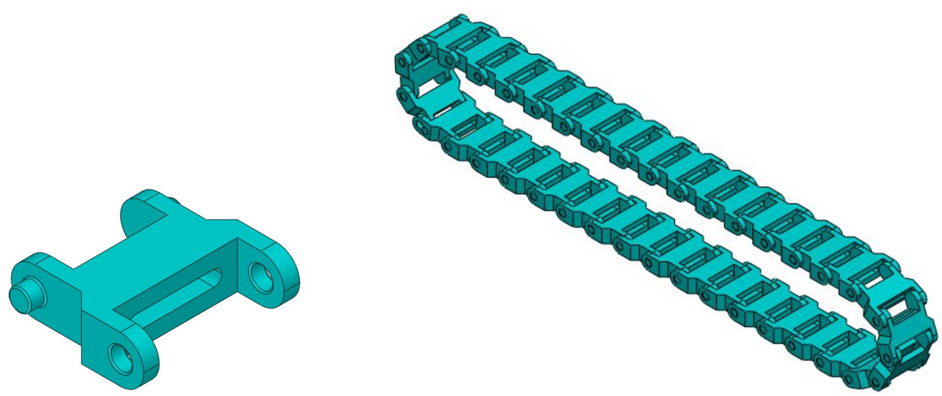


Figure 28: Rover Treads

Since this rover must be able to fit within a circular space with a 6” diameter and the wheel mechanisms would be on the outer sides of the rover, their height would not exceed 2”. The concern became that the rover would be too small to contain the electrical components, collection container, and collection mechanism so the rover length was set to be 12”. After examining models of a 5” by 12” rover with four wheels on the outer edges, the concern was that too much weight would be in the middle of the rover and the structural validity would be compromised. To mitigate this, more wheels would have to be added to the rover to support it, which would require more motors.

By choosing treads, only two motors on each end of the tread would be sufficient to rotate; therefore, more wheels could be added to the center without the need for more motors. To optimize traction, the treads are designed to have a 1” contact with the ground. This will also allow the rover to go over moderate debris on the launch field.

For precision and ease of manufacturing purposes, the treads will be printed out of ABS plastic. To further increase traction with the ground, the team plans to coat the face of the treads that will interface the terrain with a material with a higher coefficient of friction. Currently, some ideas include coating the treads in a thin coat of rubber cement or some sort of adhesive spray. If testing proves that these are not effective enough, the team plans to resort to purchasing rubber treads to cover or completely replace the treads.

The team was unanimous in the aspects of the payload above. Alternate designs were created for the collection mechanism that included a collection arm and receptacle. The major constraints was the amount of space on the rover as well as the team constraint of limiting the motors on the rover to a maximum of six, four along powering the wheels, so only two could be used for the deployment of the collection mechanism and the collection mechanism itself.

4.2.1 Leading Collection Arm

The first idea was to have a sort of shovel attached to the front of the rover that, when rotated to dump the sample into the collection chamber, could also serve as a cover for the container, to ensure no sample loss.

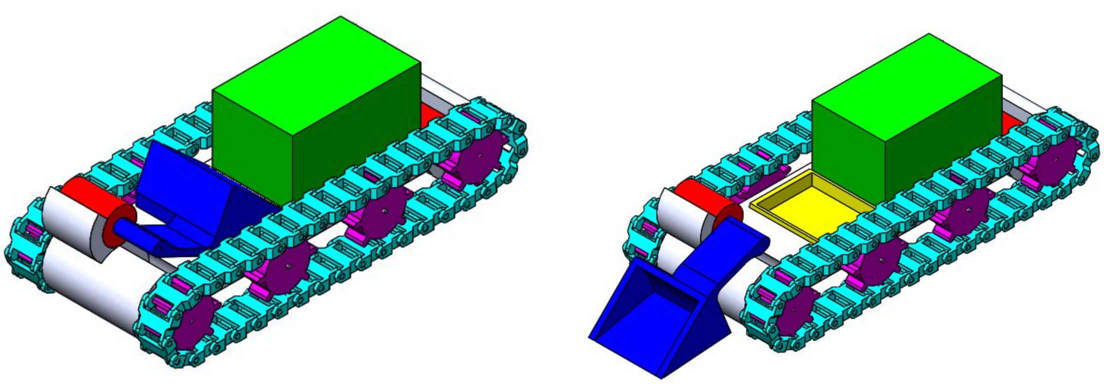


Figure 29: Alternative Rover Design 1

Since the collection mechanism space is used by both components, more space can be allotted to collection. Without focusing on optimizing collection size, the collection chamber in this model alone can hold 20 mL of sample. This is not including any overflow that would still be contained due to the collection arm acting as a roof.

When designing the collection mechanism, any moving part of motor was viewed as a mode of failure that should be minimized. Since this would only have one motor and then only one moving part. Since this completed both the competition volume requirement, team motor requirement, and minimized failure modes, the team continued to examine how the rover would fit within the body tube.

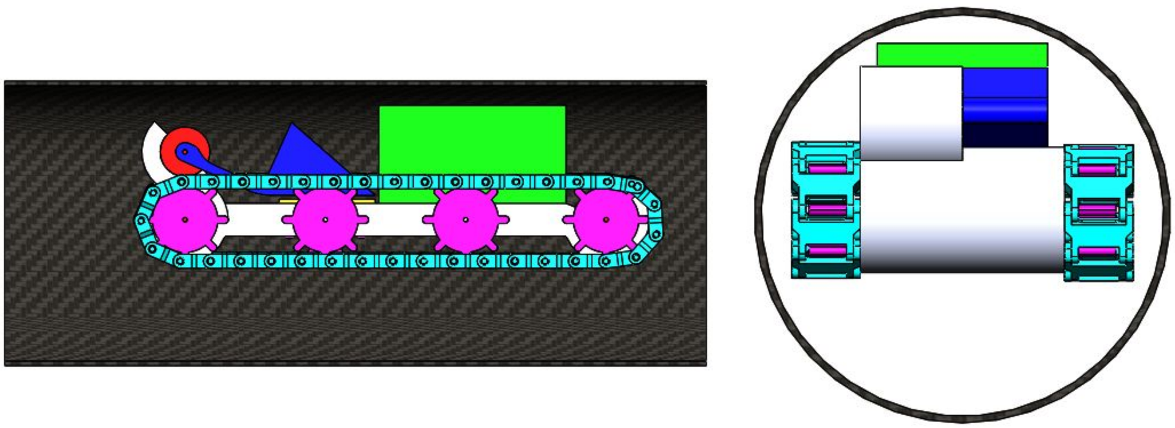


Figure 30: Alternative Rover Design 1, 2

With the collection arm folded without the rover retention mechanism, the rover fits comfortably within the 6” body tube spanning 11” in length. In addition, when fully deployed, the rover arm can reach .55 inches below ground level. This means that collection will be maximized if arm is deployed, the rover drives forward, then the sample is deposited into the container.

The drawbacks of this design are that there is no back up driving system or arm so if either fails or breaks during flight or collection, the rover will not be able to collect the sample. But, since the arm can remain as the container lid for long periods of time, the plan is for this to be the rest position of the arm until it must be deployed.

4.2.2 Under belly Collection Arm

The second design is similar to the first where an arm would collect the sample and deposit it into a collection bin. In this design, the collection arm would be flush with the body in its resting position and could then collect the sample from below the chassis of the rover. A simple design is shown below. To have an arm big enough to collect a sample at ground level, there would be little to no space left for the collection chamber.

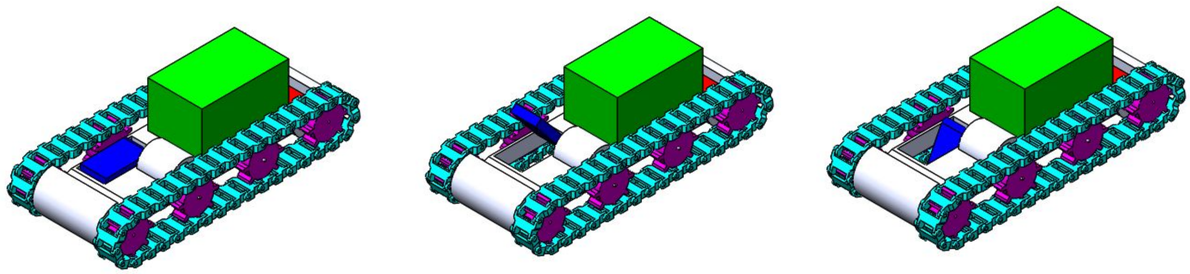


Figure 31: Alternative Rover Design 2

In addition to this set back, when looking at the range of the arm, it was found that the flat arm would be barely able to collect sample below ground level.

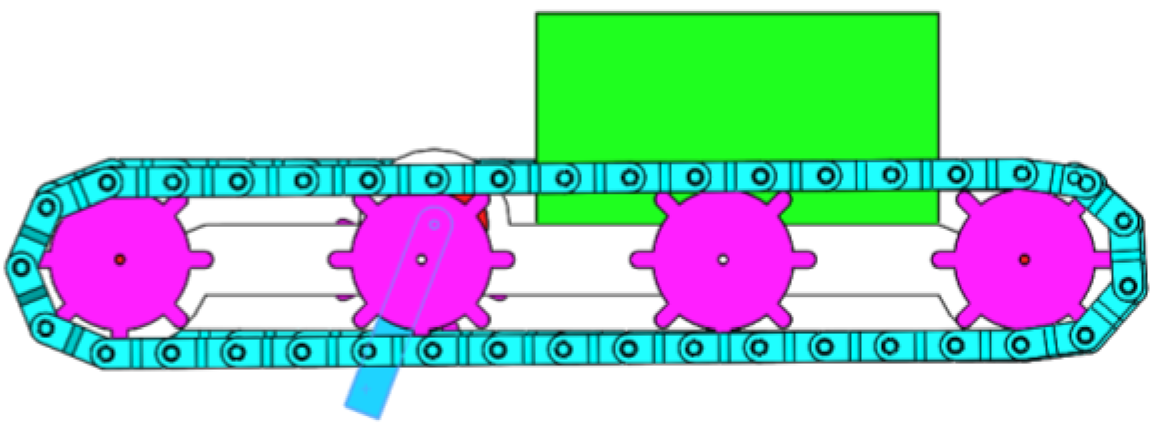


Figure 32: Alternative Rover Design 2, 2

When analyzing this design, it couldn't fulfill the competition requirements of collecting 10mL of sample and would have trouble collecting the sample, especially if it were on an uneven terrain. This design also only had one mode of failure since it only utilized one motor and one moving part.

4.2.3 Conveyor Transport Mechanism

The other design alternative discussed by the team mimicked a conveyor belt designed to transport media (most commonly dirt) up an incline. This design two motors, one to deploy and retract the conveyor belt and one to rotate the belt.

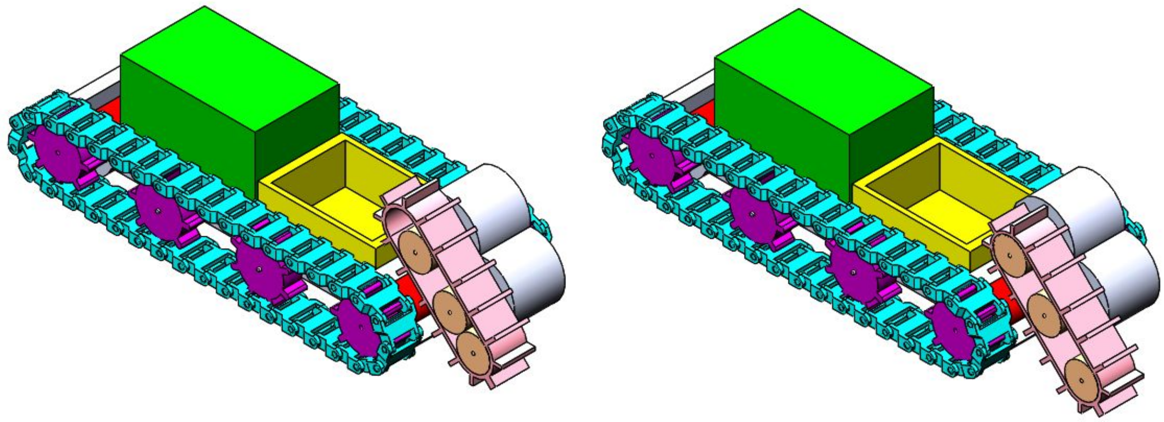


Figure 33: Alternative Rover Design 3

There would be three conveyor belt wheels (seen above in brown) that would define the motion of the belt. The top gear would only have a top attachment to shift the belt along the row of the wheels until the bottom two wheels touched each other (seen right) or the top motor was against the left side of the belt (seen left). Once deployed, the middle gear would rotate, causing the belt to rotate and bring dirt to the container.

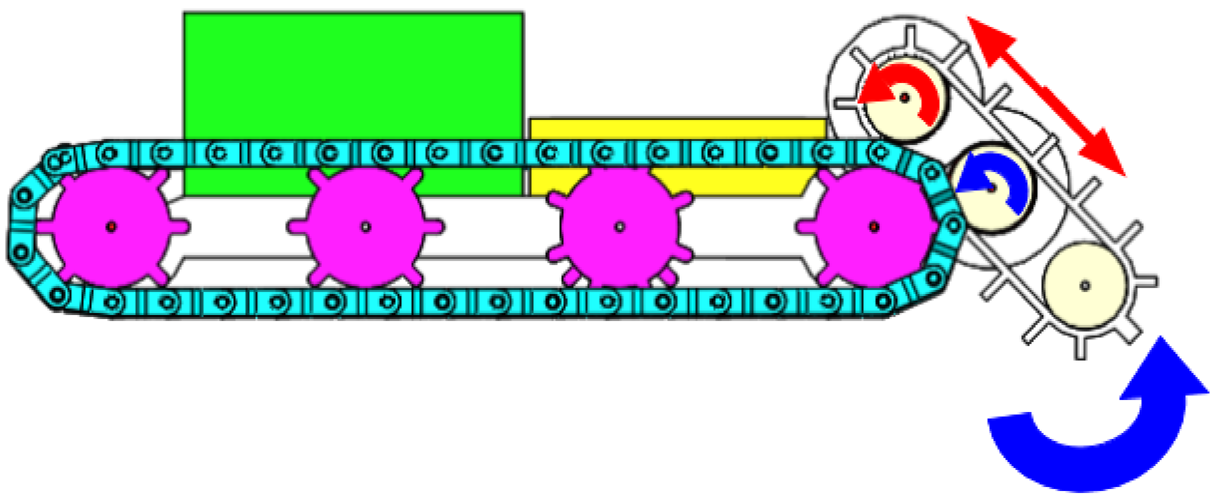


Figure 34: Alternative Rover Design 3, 2

Since the belt is elevated from the body of the rover, the collection chamber could be expanded and the volume it could contain was nearly doubled. But, there would be no retention system or lid on the container so the sample could potentially spill out. Also, this design utilizes two motors and has two degrees of freedom. This means there are potentially four modes of failure at least on this collection method alone.

4.3 Leading Design Choices

When deciding between these three designs, percent chance of completing the objective and minimizing modes of failure were the two main aspects considered. The underbelly collection system would create a sleek and functional system if size constraints weren't an issue. Since space for electronics needs to be maximized and length of the rover is capped at 12", this design isn't practical.

The collection arm only has one degree of freedom, driven by a single motor, minimizing failure modes compared to all other designs. This minimization came with the risk that redundancy does not exist within the system. If either the motor or arm breaks (during launch or collection process) the rover is unable to complete the mission objective. Meanwhile, the conveyor transport mechanism has two degrees of freedom (one rotating the belt and the other deploying and retracting the belt) which increases its possible modes of failure. But if the deployment motor were to malfunction, there is still some possibility that the other motor could allow for some collection of the sample. Furthermore, since the belt can be angled higher than the arm, the container can hold more of the sample.

When choosing between the two, the team decided to disregard the differences in volume each design could hold since both could hold at least double what is required. Since the leading collection arm also serves as a retainment mechanism to the collection container and has the least modes of potential failure, it was decided to be the optimal design. If further testing proves that there is a high chance of failure in the mechanics or structural integrity of the arm then a different design would have to be chosen.

4.4 Rover Ejection Assembly

The rover ejection assembly (REA) is a system designed to safely retain the rover during flight and properly eject the rover from the launch vehicle after landing. The REA must correctly orient the rover before forcibly deploying the rover from the launch vehicle. An automated process is desired to ensure the rover is deployed regardless of the obstacle at the exit of the body tube. Using the automated REA, the amount of electronics on-board the rover is reduced.

4.4.1 Alternate Designs

4.4.1.1 Orientation

Before deploying the rover from the launch vehicle, the rover must be oriented correctly. The UCLA Bearospace team considered various methods to accomplish this goal. One approach is to have a long, unthreaded rod attached to a bulkhead so that the rover could swivel on this rod and orient itself using gravity. A mechanism from behind would then push the rover out in its correct orientation. While this system is mechanically simple, it violates section 4.3.7 in the NASA Student Launch handbook that states that the payload vehicle must be fully retained. This center rod would allow the rover to rotate freely during flight, which may damage the rover. Additionally, the center rod limits the usable space on the rover, which is a critical parameter for its design.

Another concept for correctly orientating the rover before deployment is to use a stepper motor, an accelerometer/gyroscope module, and a barometric pressure (BMP) sensor. This assembly will be mounted onto the avionics bulkhead using the stepper motor. A rotating disk will then be attached to the stepper motor's shaft to allow a linear actuator to be mounted in order to deploy the rover. Since all the weight of the rover and metal rods will rest solely on the small shaft of the stepper motor, a large bearing plate will be layered between the bulkhead separating the avionics bay and the rotating disk. This will transfer all cantilever forces from acting on the stepper motor onto the bearing ring.

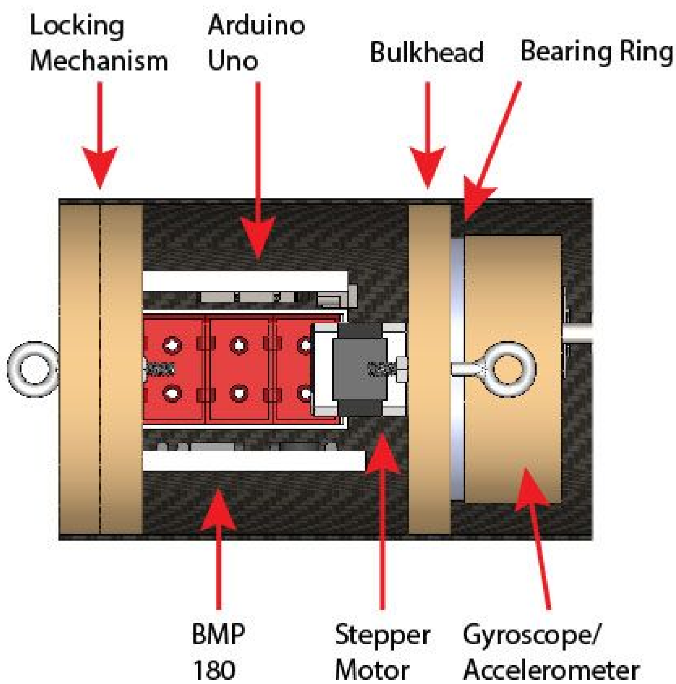


Figure 35: Alternative Deployment Mechanism 1

All operations will be controlled by an Arduino Uno, which is conveniently located in the avionics bay. Having the Arduino Uno microcontroller centralized in the avionics compartment makes it easier to attach and power the REA. Power to the electronics will be provided once safety switches are connected, similar to the avionics recovery system.

4.4.1.2 Scissor Jack

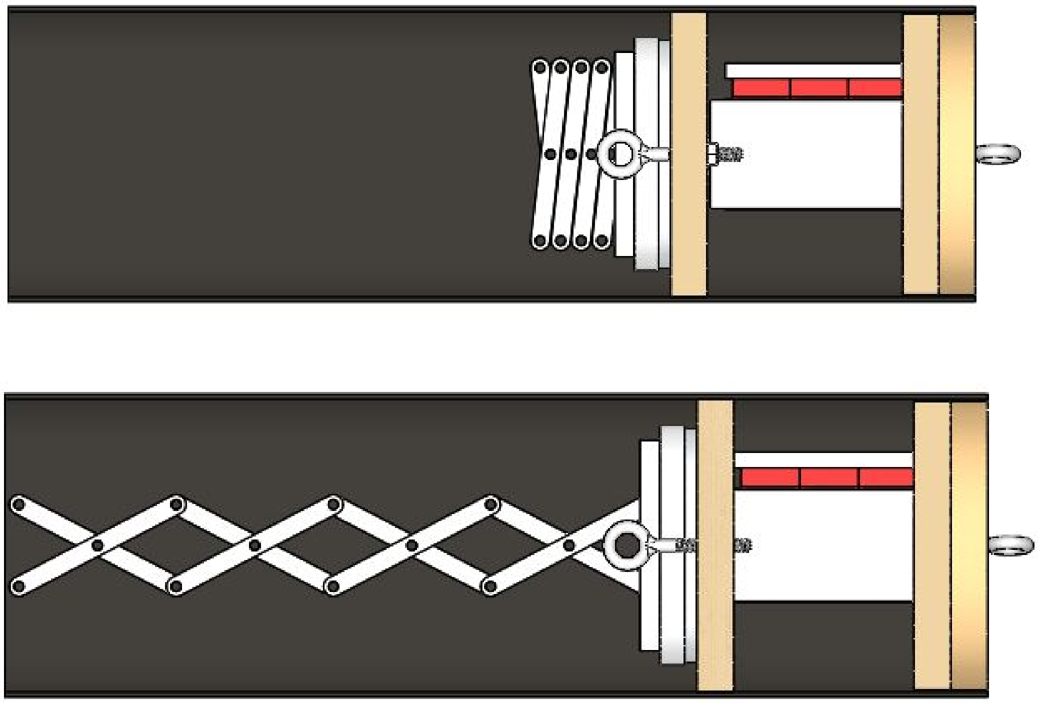


Figure 36: Alternative Deployment Mechanism 2

One design alternative includes a scissor jack for the retention method that collapses when packed and extends when deployed. A stepper motor will drive the sets of scissor jacks using a rack and pinion assembly connected to the base of the scissor jacks to convert the rotational motion of the motor to translational. When the opposing scissor jack bases move towards the center, the scissor jack assembly extends towards the exit of the body tube. To capitalize on the inwards motion of the scissor jacks during extension, the rover will attach to the ends of the scissor jacks using a locking mechanism comparable to a door chain. A screw will slide across a track and releases once the scissor jack is fully extended.

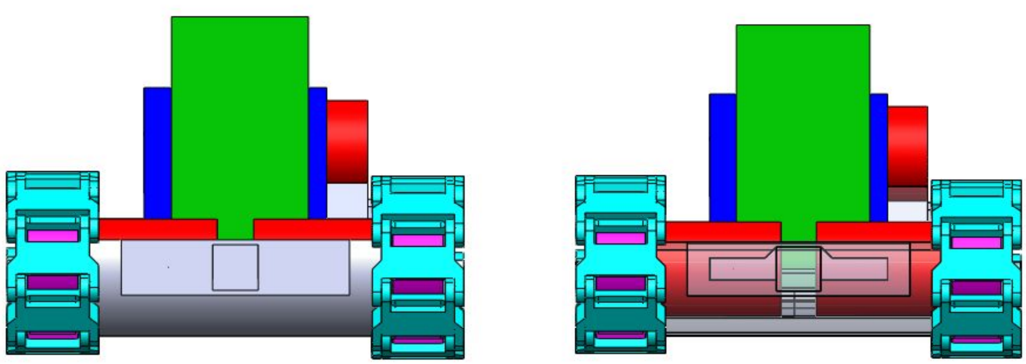


Figure 37: Rover Retention External and Internal View

The largest concern of this design is with respect to the friction between each pivot point. The scissor jack components would be made out of aluminum using a laser cutter. The rack and pinion would be 3D printed using an SLA printer to achieve greater precision and strength. Despite these efforts made to create a more robust mechanism however, some forces experienced during flight remain unpredictable. The robustness of the structure remains questionable as it only supports the payload laterally across. Each junction between the levers undergoes a large amount of stress during launch and is highly vulnerable to breaking. A possible solution for creating additional support for the payload would be to include two scissor jacks, however doing so would require another motor, adding to the total mass and leaving less space for either the payload or the electronics bay. Additionally, the friction between each lever requires a greater force necessary to eject the payload. This requires a greater motor, taking space away from the payload.

4.4.1.3 Electromagnetic

Another design alternative utilizes electromagnets as a retention mechanism for the rover. For the rover to lay flat, 2-4 of the following 9 lb pull DC electromagnets sourced from McMaster-Carr will be positioned in parallel to the bulkhead.

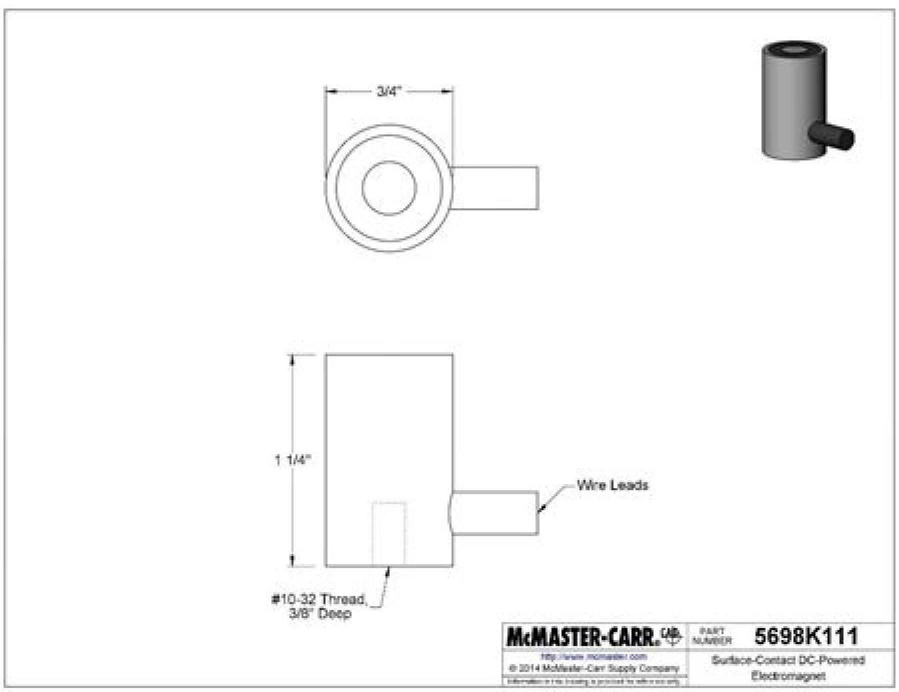


Figure 38: Electromagnetic Design

A threaded rod would then secure the electromagnet, 8LR932 12V battery to power each electromagnet, and a 5V relay since the Arduino cannot innately produce 12V. There are a few critical benefits that distinguish it from the other retention systems. Using electromagnets would naturally secure the rover without risking a permanent break in our retention system. This design easily implements redundancy in the system. The following circuit diagram models the increased redundancy, where the DC electromagnet[M] is connected to the normally open(NO) port of the relay.

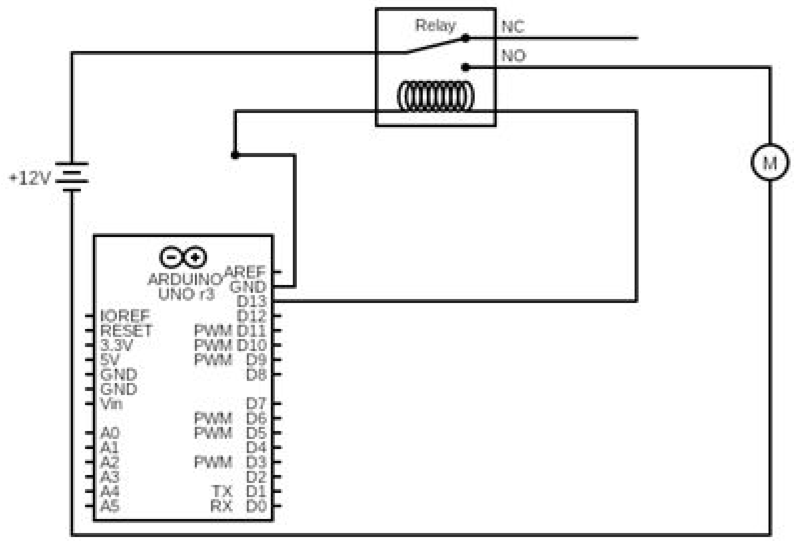


Figure 39: System Redundancy

This connection will create a dead man's switch. Should the avionics fail, the rover will still deploy.

Aside from expanding the avionics system, this design introduces additional complications. By itself it can only retain the rover, using the electromagnets to propel, while possible, would be highly ineffective as the strength of a magnetic field drops by a factor of one over the square of the distance away from the electromagnet. This design would likely have to rely on the strength of an impulse which would require a much stronger and much more expensive electromagnet. Another downside is that it would require much more effort to know the limits of the electromagnets since their strength is also highly dependent on the choice of material. An emphasis must be placed on optimizing weight to magnetic hold strength. Electronics can be corrupted and do not interact well with magnetic fields. Considering the magnets selected wouldn't be remotely powerful enough to damage flash memory, our SD card data will be safe, and the only real design parameter would be the current induced in the Arduino. However, should the rover begin to sway within the rocket, the speed and distance should be insignificant enough that the induced current would also be insignificant. The design of the rover could also take into account that another electromagnet could be used to eliminate side-to-side sway.

4.4.1.4 Rail Gun

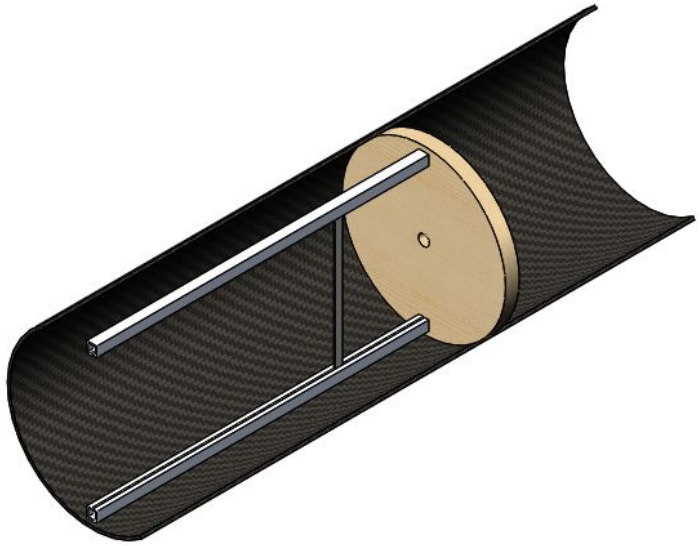


Figure 40: "Rail gun" Alternative Design

Another retention method alternative inspired by a rail gun includes the use of electromagnetics. There would be two parallel beams capable of carrying a current (either carrying it through the rod itself with some insulation or with wires able to extend within the beams). These beams would have areas in the center allowing a third connector beam which can slide within the two beams from the bulkhead to the top of the upper body tube (therefore pushing the payload out of the vehicle.

Upon landing, a current would be driven through the beams, creating an induced magnetic field. Due to the close proximity of the two beams and third moving connector, a force would be created that would cause the connector beam to shoot out of the body tube.

Since current along the beam does not decrease with respect to distance from the source (in this case being the electronics bay below) force on the payload would be constant for the duration of the ejection process (ignoring some small decrease due to resistance in the wire or beam). While this ensures that the payload will make it out of the vehicle, it brings up the additional concern of deployment velocity. Since these rods would be about a foot in length, the payload could reach an unsafe speed that may cause it to break upon impact with the outside terrain.

It is also a major concern that the induced magnetic field will have some negative effects on the various electronics around it. While the electronics bay has already finished its purpose, the electronics on the payload run the possibility of becoming unusable during deployment.

Perfecting of the deployment velocity and electronic safety would have to be tested through numerous (and potentially hazardous) testing.

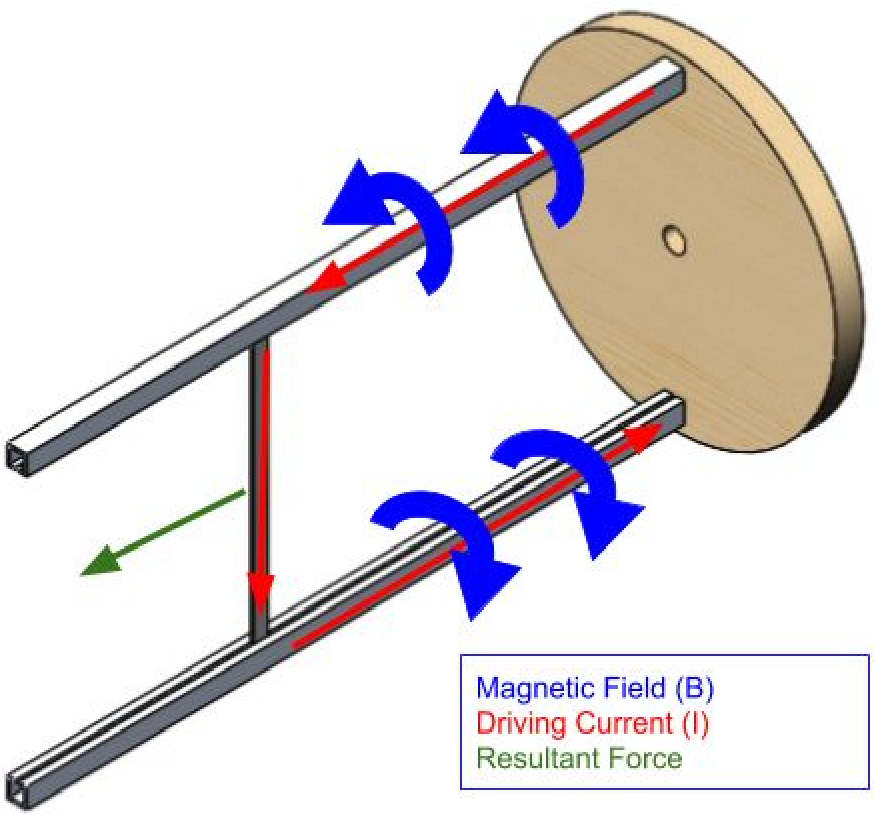


Figure 41: Rail gun Operation

4.4.1.5 Rotating Lead Screw

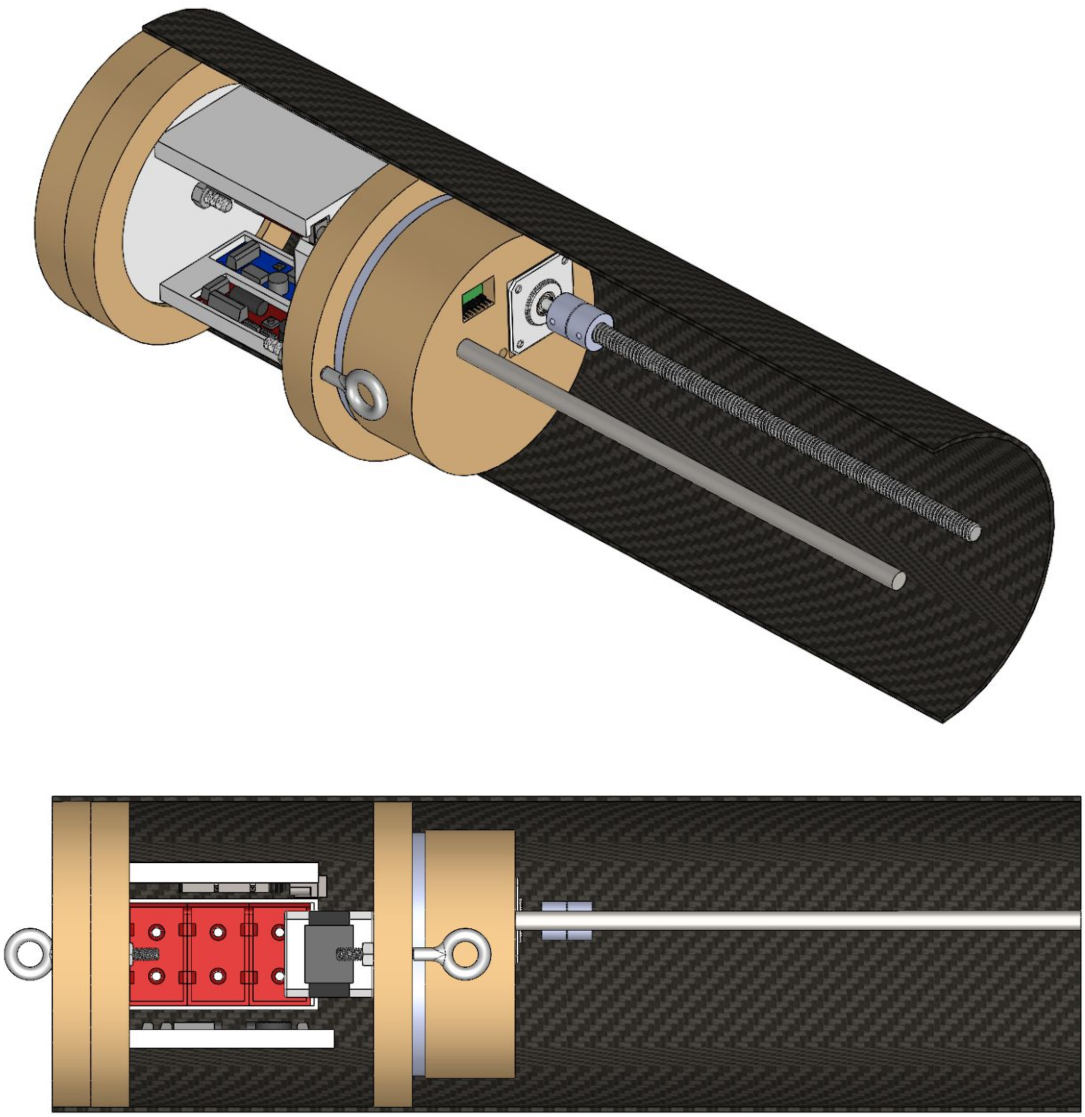


Figure 42: Threaded Rod Mechanism

Another design idea for retaining and deploying the rover involves a rotating lead screw to convert rotational motion into linear motion. The rover will attach to the rods using additional mounting extensions with holes. One of the holes would have a matching nut to attach to the lead screw. When the motor spins, the rover will attempt to rotate with a pivot point on the lead screw, but the unthreaded rod will prevent this. This rotation will cause the rover to deploy.

The design features a simple implementation that requires no additional mechanical assemblies. The lead screw is attached to a stepper motor (discussed in section 4.5.1.1) using a matching coupler. The unthreaded rod is mounted to the rotating bulkhead using an appropriate hole in the rotating bulkhead. The lead screw, coupler, and unthreaded rod are commercially available parts, which further simplifies the manufacturing process. Different sized rods can be chosen after analysis is conducted to reduce the amount of deflection on the rods.

The size of the bulkhead that contains the stepper motor and unthreaded rod is dependent on the size of the motor. A high torque motor is needed to reliably deploy the rover, despite the deflection in the rods. However, a higher torque motor requires more space than a lower rated motor, meaning the amount of usable space for the rover is decreased. A compromise between torque and rover size has to be met.

Another issue with this concept is the deflection from the cantilever weight on the rods. The rods protrude a distance of at least 10” from the base which causes a large moment on the rods. Additionally, the rover will rest on the rods, further increasing the moment experienced by the rods. Rod deflection may prevent the lead screw and threaded nut from aligning properly and consequently causing a jam.

4.4.2 Leading Design Choices

For properly orienting the rover prior to deployment, the electrically controlled method was selected. This design is more controlled than the swivel idea and does not violate any design criterion. Since it is electrically 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 a safe deployment.

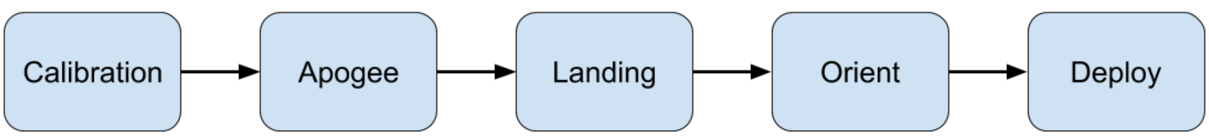


Figure 43: REA Major Events

Calibration: once power is connected, the Arduino will take data measurements from the BMP and average altitude values to determine its current altitude on the launch pad.
Apogee: the Arduino code will define apogee as the highest point after reaching an altitude 1000 ft higher than the calibrated ground level altitude. This is necessary so the Arduino can differentiate between when the launch vehicle is on the pad and when it has landed.
Landing: once values stop fluctuating during descent, a landing will be detected. Current altitude will be compared with calibrated altitude to initiate a five 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.

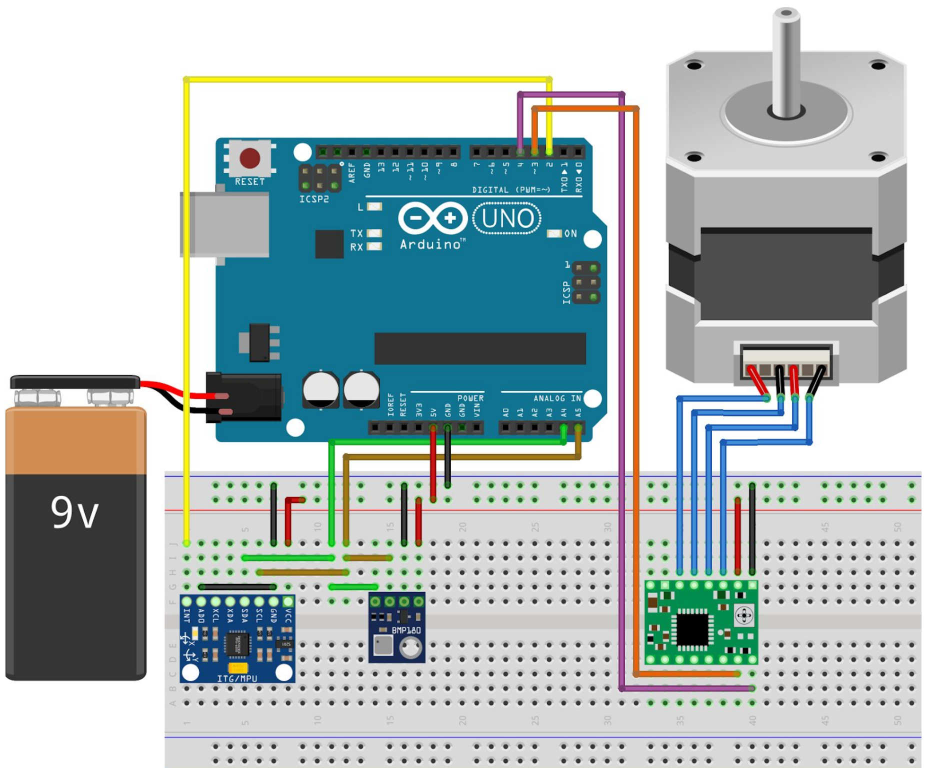


Figure 44: REA Wiring Diagram

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

Since the REA is deployed automatically, the design must be simple and fail-proof. Although many designs were considered, the rotating lead screw method is the most robust. The deployment methods involving magnets are not as predictable as mechanically operated systems and the magnetic field generated during deployment may tamper with onboard electronics, such as the GPS, which is essential for locating the launch vehicle after launch. The scissor jack method, while it operates mechanically, relies on four weak pins to connect and retain the rover to the launch vehicle. The scissor jack method is also affected by the same cantilever moment as the lead screw method. The moment on the scissor jacks increases as the rover deploys further. The lead screw method uses commercially available parts, meaning the diameter and overall strength of each rod can be selected to counteract the cantilever moment.

The rover ejection assembly must also be simple to manufacture. The scissor jack method is complex and more difficult to manufacture than the lead screw design.Original parts would have to be designed, fabricated, and tested to validate the system's functionality. A custom sled, rack and pinion, scissor jacks, pins, and slots would have to be made. The lead screw method capitalizes on commercially available precision lead screws and rods. The lead screw, matching nut, unthreaded rod, and motor shaft coupler will all be bought online from manufacturers with precise machines.

4.5 Electronics

4.5.1 Alternate Designs

4.5.1.1 Motors

The motors implemented serve varied purposes in ensuring the proper deployment of the payload. Specific motors will be implemented based on their implementation of the rover and REA. The motors must move the rover to the collection site, accurately position the collection arm to specified locations to consistently extract samples, and properly orient the rover from within the REA. These requirements mean specialized motors must be implemented. Trade offs between power consumption, size, torque, price, and rpm must be considered to select the best motor for each application.

Motors considered were based on similar implementations of RC vehicles, and were narrowed down between brushed DC Motors, brushless DC Motors, shunt Motors, DC Servo Motors, and Stepper Motors. Below is a break down of relative factors to easily compare trade offs between motors.

Table 10: Motors

	Brushed DC Motors	**Brushless DC Motors**	**Shunt Motor**	**DC Servo Motors**	**Stepper Motors**
Torque	Initially high but loses torque the more weight it carries	Medium, but very consistent	Medium, torque is consistent even with weight	High, and precise for orientation	High, and executed in fixed steps, less maneuverability but highly precise
Price	Relatively inexpensive, but require maintenance/ replacement	Slightly more expensive than Brushed, but longer lasting	Relatively inexpensive but has wind up time	semi-expensive due to built in electronics for orientation sensing	Moderate, but the price can rise with size and speed
Size	Compact and can scale depending on need	Also rather compact but less variants than brushed	Not particularly large or small	Large, but not so much that it impedes payload much	Largest and heavy compared to other motors
Power Consumption	Ratio of torque to rpm ideal for translational movement	Ratio of torque to rpm ideal for translational movement	Good power consumption once motor has winded up	Higher voltage than other DC, but requires continuous power	Consumes high current, but has constant holding without power input
Reliability	Tends to overheat, requires maintenance	Reliable, low maintenance	Reliable, low maintenance	Reliable, low maintenance; but gets more unkempt with larger range of motion	Reliable, low maintenance
RPM	Good speed control	Specializes in speed control	Self regulating but drops sharply when load added	Relatively slow, but quite maneuverable	Very slow, but very consistent

Brushed DC Motors: By far the cheapest motor and has good torque. However, because it is the cheapest it also comes with the need for more general maintenance. After extensive use, the brushes get worn and will need replacement. There is also the issue that the amount of torque given decreases as more weight is added to the rover. Overall, it is a rover that does its job well for the price. However, we might choose a different motor to avoid dealing with the maintenance.

Brushless DC Motors: Slightly more expensive than brushed counterparts. They have the potential to get really expensive but most come at a price for their performance. The main draw of these motors is that their initial torque is high and can run at higher RPMs than their brushed counterparts, while also having more consistent speed controls. Their main downside lies in their price and

Shunt Motor: Shunt motors draw is that they can maneuver higher weight with minimal sacrifice to maximum speed. However this comes at the drawback of having to spin up to reach said speed, providing a boot up time and failure window. Depending on the approximate weight of the rover we will decide whether it is worth it to sacrifice top speed for consistent speed.

DC Servo Motors: Servo motors are a variant of the stepper motor with added electronics for precise orientation, but overall less precise than stepper. Their main appeal is the extremely high torque combined with a good amount of control and being energy efficient when compared to other stepper motors. They have drawbacks in terms of both price and sensitivity to stress caused by the added electronics, and they are also significantly slower than other DC motors.

Stepper Motors: The stepper motor has the best control than any other motors on the list due to their many more poles to lock into to. They can also output high torque for a relatively moderate price, while also having the advantage of being able to dynamically lock itself as it works to prevent backtracking. However, these motors tend to be larger so using them may push the bounds of what can be fit in the tube. Additionally the high torque comes at a much lower RPM which impedes deployment or fast reactions. They also have a hard time dealing with varying loads

4.5.1.2 Communication

The goal of the communication system is to successfully transmit and execute inputs from the operator wirelessly while also providing video feedback to aid the operator in carrying out the mission. To accomplish this, a radio frequency communication system will be established with a minimum transmission range of 2640 feet. A radius of 2640 feet was selected since the launch area has a radius of 2500 feet from the launch pad. However, spectators are a few feet away from the launch pad which is taken into account by choosing a range of 2640 feet.

Antennas communicate with each other by reading frequencies tuned to the antenna's specifications. Common control frequencies used for drone control are 1.2GHz, 2.4 GHz, and

5.8 GHz. A lower rated frequency antenna transmits data at slower speeds, but provides coverage at a longer range, while a higher rated frequency antenna transmits at a faster speed but provides less coverage. Additionally, since lower frequencies have larger wavelengths, a lower frequency antenna is bigger than that of a higher frequency. Because space on the rover is limited, a bigger antenna would not be desired.

To reduce the number of antennas and prevent interference between the onboard antennas, a half duplex radio system could be implemented. A half duplex system allows a pair of antennas to act as both a transmitter and receiver by varying the direction of communication between the antennas. While one transmits, the other receives and vice versa. This would allow one antenna to be shared between the controls receiver and the video transmitter, essentially reducing the amount of space needed for the rover. Since communication between the two antennas is limited to one at a time, the controls and video responsiveness would be delayed by half. In a full-duplex system, both antennas communicate with each other simultaneously. While this would be ideal, commercially available drone parts do not have full-duplex systems.

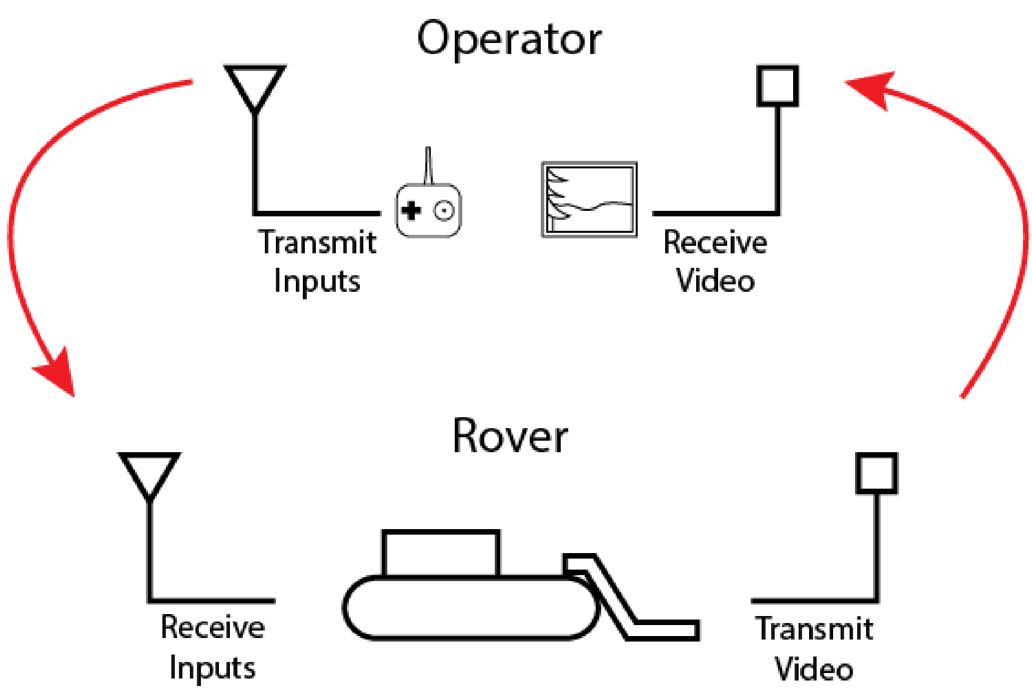


Figure 45: Rover Communications

An alternative to using a half duplex radio system is using two sets of antennas using the correction radiation patterns. A summary of the different types of antenna radiation patterns is provided in the following table.

Table 11: Antenna Radiation Patterns

Type	Polarization		Direction	
	Circular Polarization	**Linear Polarization**	**Directional**	**Omnidirectional**
Pros	-Greater wave overlap, meaning constant transmission during movement. -2 different senses (directions) available to prevent interference.	-Good gain, meaning longer range. -Smaller antennas.	-Increased focused gain.	-Increased radial coverage.
Cons	-Little gain. -Shorter range. -Bigger antennas.	-Less wave overlap. -Antennas must be pointed at each other for constant transmission.	-Reduced narrow coverage.	-Reduced gain.

In addition to selecting the correct antenna radiation pattern, the proper spread spectrum must be selected. Since multiple teams will be operating on similar frequencies, interference may occur. Most commercial remote controlled drones come with receivers/transmitters with 8 channels of the same frequency rating. While selecting 8 channels for 8 teams will work, the competition involves more than 8 teams, so individual assignment of each channel is not possible. Spread spectrum technology mitigates this problem.

One form of spread spectrum is frequency hopping spread spectrum (FHSS). Frequency hopping involves rapidly changing between available frequency channels known to the transmitter and receiver. Each available frequency channel is divided into sub-frequencies. Interference at a specific frequency will only affect the signal during that short interval. This allows multiple users access the same frequency with minimal interference.

Another form of spread spectrum is known as handshake. The handshake method passes a unique synchronizing code back and forth between the transmitter and receiver. When the key is synchronized, only receivers and transmitters with the key can access the information. Other transmitters and receivers perceive the signal as noise.

4.5.1.3 Controls

The purpose of the controls system is to read inputs from the driver and translate those into actions on the rover. A microcontroller should be able to receive inputs from the receiver and have dedicated pins to power and operate the necessary motors. The selected microcontroller should also be simple to code and interface with electrical components. Two main alternatives were considered.

One idea is to use standard microcontrollers such as the Arduino Uno or Arduino Mega. These microcontrollers have dedicated pins that interface well with most electrical components. A common pin type for controlling all onboard motors are pulse width modulation (PWM) pins. An Arduino Uno does not have enough PWM pins to operate all motors, so an Arduino Mega is preferred over the Arduino Uno. Extensive documentation on these components is easily accessible online, so programming the Arduino microcontrollers is possible. The main problem of using an Arduino Mega to control the rover is the large size of the microcontroller. Space onboard the rover is limited, so choosing more compact microcontrollers is crucial.

Another alternative is using a flight controller designed for operating motors on a drone. Flight controllers have dedicated ports for receiving signals from receivers and 6 dedicated ports for all types of motors. Since flight controllers are tailored to be mounted onto drones, flight controllers are a smaller alternative to using microcontrollers. The main flight controllers considered are the CC3D and Naze32. Both flight controllers have the same dimensions, but the Naze32 includes more modules necessary for drone flight and is consequently more expensive than the CC3D. The CC3D has a designated port for receiver signals and 6 ports for motors.

4.5.1.4 Autonomy

As an alternative to controlling the rover with radio signals, making the rover entirely autonomous has become a viable option. This would be beneficial as there would not be any interference that might block any radio signals between the controller and the receivers on the rover, as well as any issues that may arise with the use of live feed cameras on the rover. In making the rover entirely autonomous, the entire operation will go a lot smoother. In order to achieve autonomy, a Raspberry Pi 3 Model B will be used as the computer that will incorporate a machine learning algorithm. In addition, a TCS3200 Color Sensor will be employed, as it can be used to detect specific colors. The TCS3200 essentially converts the color and the intensity of the light that it detects into frequency, which can then be used to determine the color the sensor is detecting. This will be useful, as the target area the rover is trying to locate is bright yellow. The rover can then be programmed to first detect the yellow, by searching for it using the Color Sensor, and then head towards it. Moreover, a HC-SR04 Ultrasonic Sensor can detect objects that may be in the way of the rover, such as the rocket and possible potholes the rover should avoid. For the machine learning algorithms, the team plans to create a three dimensional convolutional neural network and train the network to detect the color and shape of the mining site. Then, the rover would navigate itself based on the values received from the neural network. This can be achieved by using a stereo camera as the eyes for the rover, in order to capture the shapes and colors of the surroundings.

4.5.1.5 Power Supply

The rover requires a power supply on-board in order to power its video systems and controls. For better efficacy, we have decided to have batteries be split into two groups. One set will be powering the video systems, and the other batteries will supply energy to the rover motor controls. We considered using multiple arrays of nickel metal hydride (NiMH) batteries, as they are widely available, relatively inexpensive and even rechargeable. However, there are two major downsides to using these: they have too much weight to them and do not supply a sufficient amount of voltage to power our systems on-board. We need the rover to not exceed a certain calculated threshold for total weight as the center of gravity needs to be balanced with the center of pressure such that the rocket will reach optimal heights and speeds; too much weight on the rover (and, therefore, towards the front of the rocket) will change our center of gravity to an area that is not nominal. Additionally, the batteries need to provide enough power to satiate the needs of each of the motors, the control receiver, the video transmitter and the camera. Of course, we could add more batteries to accomplish this task, but that would take us back to the problem with weight.

Thus, we have turned to another alternative: lithium polymer (LiPo) batteries. LiPo batteries provide enough voltage for the rover's needs while also being lightweight. This comes at a cost, however: while being able to fulfill our needs, it does not last as long as NiMH batteries. In contrast to this speculation, we only need the rover to be powered for a relatively short time. NiMH batteries are usually utilized in powering small commercial items, such as children's toys and device controllers, and are built to last a long time (up to multiple weeks). LiPo batteries only last up to a quarter of this time, if not less. Our rocket will fly for much less than an hour, and our rover will land some time after the launch of the rocket it is housed in. Strong batteries are what we are looking for in this case, not long-lasting ones.

Additional costs to using LiPo batteries as opposed to NiMH alternatives include an increased danger of a combustion if punctured and special care required to recharge them. The batteries contain manganese (Mn), an element known to be flammable with exposure to heat or friction. Thus, extra care is needed to make sure nothing can cause a rupture in these batteries, and this can easily be done by securing them within 3D printed cases. We plan to use these batteries for a couple of times, so the problem with recharging them when they run out of voltage won't be so much of an issue (although it would cut us costs for future projects when battery sources are required).

4.5.2 Leading Design Choices

4.5.2.1 Motors

The brushless DC motors are the best choice for providing traction to propel the payload forward after having ejected. The consistency in both speed and torque, while also requiring relatively low maintenance make it ideal for both troubleshooting and distance performance. Additionally, the relatively low power consumption, cost, and smaller size justify the higher price. A major consideration for selecting these motors is their size since 4 motors will be mounted on the rover for movement. Available space on the rover is limited and reducing the size of the brushless DC motor at the cost of limiting torque is crucial for space management on the rover.

With respect to the collection arm, servo motors were selected for their relative gains in reliability, orientation control, speed, and torque it has over other motors of similar size. Among the different ranges of motion for servo motors, a 180 degree servo will be selected because although the alternative 360 degree and continuous variants provide more maneuverability, the added range comes tacked with more complex pivots which only provide negligible benefit for the collection arm at the cost of more potential points of failure while rotating.

The Stepper motor provides the most powerful, consistent, and failsafe option for the Rover Ejection Assembly. The High torque and many locking poles offset the power costs by being able to withstand whatever stresses incurred during the launch. Additionally the screw ejection assembly couples perfectly with the motors dynamic locking to secure successful ejection. The tube will contain two stepper motors, the first for the purposes of rotation of the entire payload, while the second will eject the payload through rotational motion.

Shunt Motors along with Brushed motors were discarded because of their drawback in consistency. The varying performance and propensity for the Shunt motor to vary speed made it a weak choice for a payload which needs to work consistently after having flown through the air. In a similar vein, the Brushed motors requiring more maintenance and provided less rpm and torque than its brushless counter part makes it more difficult to maintain for the repetitive traction and distanced movement it will require. Additionally neither motors are powerful enough to be utilized in collection or ejection routines.

4.5.2.2 Communication

To reduce the number of antennas and prevent interference between the two antennas onboard the rover, a half duplex radio system was considered. However, since video feed via radio is demanding, this would delay the responsiveness from the controller and provide a more jittery resolution video. A half duplex radio system was not selected to increase control between the driver and the rover.

For communication, an antenna is necessary for transmitting and receiving signals. The correct antenna, frequency, and radiation pattern must be selected to accommodate the objectives of the rover. The antenna must be small, lightweight, cost-effective, and have a minimum range of 2640 feet. A 2.4GHz frequency was selected to achieve a minimum range of 2640 feet at the cost of responsiveness. While a 1.2GHz system provides a stronger and further connection than 2.4GHz, a 1.2GHz system requires a HAM license to operate in the United States. 1.2GHz systems are also bulky and heavy which would weigh down the launch vehicle and take up crucial space on the rover.

Because of the high number of teams at NASA Student Launch, a frequency hopping spread spectrum method was selected to mitigate other teams' radio emitting devices from interfering with communication between the driver and rover. This allows all teams to access a limited number of channels at a cost of responsiveness. Assigning channels to individual teams is not possible since there are not enough channels available for every team.

Since two antennas will be used on the rover (one for communication and one for video), it is necessary to choose circularly polarized (CP) receiver and transmitter antennas. CP antennas have a left hand and right hand sense. A left hand CP antenna can only receive a signal from another left hand CP and vice versa for the right hand CP. Linearly polarized antennas are unable to accomplish this, so two sets of linearly polarized antennas may produce undesirable interference with each other. The only concern with choosing CP antennas is their low gain, which results in a shorter max range.

All antennas on the rover will feature omnidirectional directionality. This will ensure that the rover will emit and receive a signal in the direction of the controller regardless of antenna orientation on-board the rover. The controls transmitter will be directional to achieve greater transmission distances. The only drawback is that the controller must constantly be pointed at the rover. To transmit the video signal from the rover, a 25mW video transmitter will be used to comply with rule 2.22.9 in the Student Handbook, which states that transmitters will not exceed 250mW of power. To receive the video signal, however, a combination of directional and omnidirectional antennas will be integrated using a diversity receiver. A diversity receiver allows multiple types of antennas to be attached at once and provides a constant video feed by (1) using a directional antenna when the rover is long range and in the direction of the antenna and (2) using an omnidirectional antenna when signal is lost from the directional antenna. A diversity receiver allows users to benefit from both types of antennas.

4.5.2.3 Controls

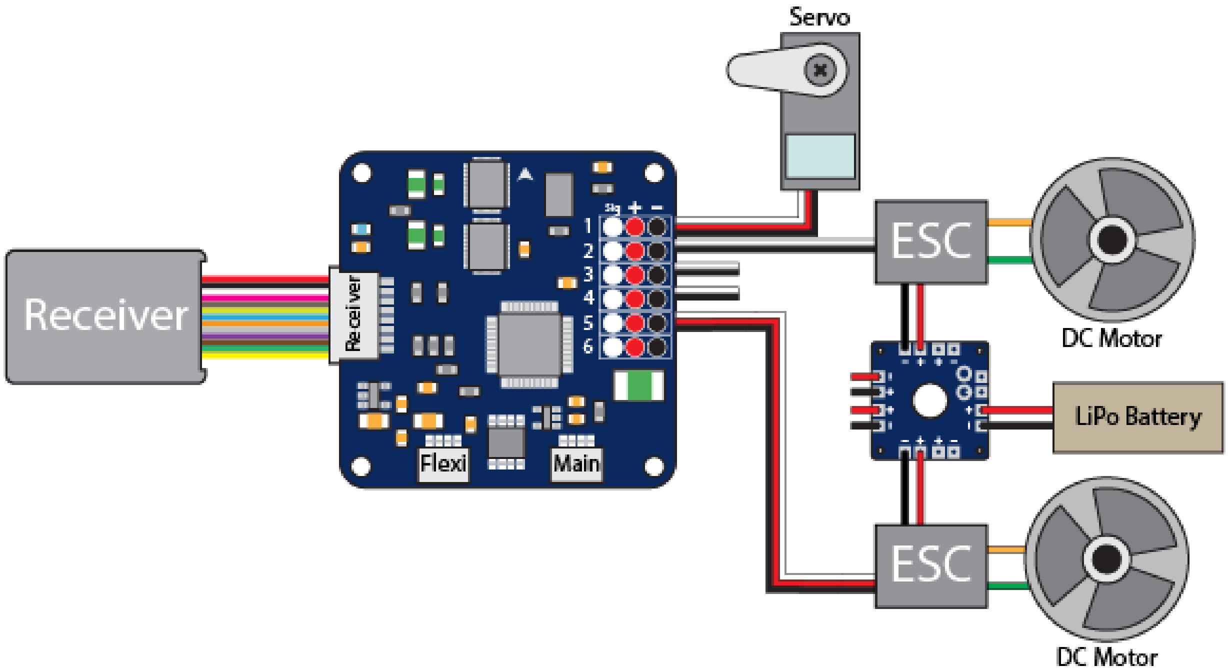


Figure 46: Controls System Schematic

Figure 46 outlines the schematic used for all control based operations (while only two DC motors are shown, 4 DC motors will be used). The receiver, flight controller, DC motors, and servo motor are all powered by one LiPo battery through a power distribution board (PDB).

A flight controller is used to interpret the inputs from the receiver and control the motors. A CC3D flight controller will be used due to its cheap cost, basic operation, and open source compatibility. The Naze32 flight controller was considered but not chosen due to it having more features tailored to drone usage and greater price. Another alternative was to use an Arduino Mega. An Arduino Mega functions the same as an Arduino Uno, but it has more pulse width modulation (PWM) pins than an Arduino Uno. Not only is the Arduino Mega more expensive than the CC3D controller, but it also does not have common connectors used in RC parts, like standard 4mm diameter connectors or receiver cable. The Arduino Mega is also 4 times bigger than the CC3D.

Electronic speed controls (ESC) control and regulate the speed of an electric motor. They are able to reverse the motor and provide dynamic braking without the need of rearranging the wires. An ESC must be used for each DC motor to allow greater rover versatility, easier wiring, and prevent back electromotive force (EMF) from the DC motors from damaging the flight controller. An ESC with at least 10% greater amperage rating than required for each DC motor will be used. This will prevent overheating at the ESC and permits more powerful motors to be used if deemed necessary. The servo motor does not require an ESC because it contains an H-Bridge motor controller.

4.5.2.4 Autonomy

Discuss how success with autonomy will simplify the controls design, reduce weight, and reduce the chance of payload mission failure. If autonomy succeeds, we will not use RF communication

4.5.2.4 Power Supply

Table 12: Power and Controls

Section	Part	Max Voltage (V)	Current Draw (mA)
Controls	380 DC Motor	6.6 - 7.2	80
	380 DC Motor	6.6 - 7.2	80
	380 DC Motor	6.6 - 7.2	80
	380 DC Motor	6.6 - 7.2	80
	Servo Motor	5	80
	CC3D	N/A	60
	Receiver	10	30
	Total	-	490
Video	Transmitter	7.4 - 25.2	90
	Camera	5	90
	Total	-	180

LiPo batteries come in cells with optimal voltage ratings of 3.7V. One LiPo battery set will be assigned to each of the two sections in order to maximize power efficiency. Each battery will be housed in a brightly colored 3D printed case, with a different colored tape to distinguish which battery powers which component. These batteries exceed the maximum voltage of the electrical system components. However, the CC3D will regulate the voltage such that it will only pull what it needs to power each component.

For the control electronics, we will assign one 2 cell battery with a rating of 5200 mAh that can last up to approximately 10.6 hours. The maximum voltage that the control receiver can handle is 10V. The more volts that the receiver receives, the more powerful it becomes. However, the other components handle less voltages; to create a compromise for this, we decided to use the 7.4V battery as a middle-ground voltage for all the components in the control section.

For the video electronics, a 14.8V battery with a rating of 1500 mAh was selected to last 8.4 hours of constant video transmitting time. This far exceeds the team's requirement of at least 4 hours of constant usage for all electronics. Similar to the receiver, more power supplied to the transmitter means greater range. Just like the receiver, the transmitter has a higher voltage capacity than any of the other components in the electronics section, so a compensation between voltage and performance must be considered. A 14.8V battery provides enough power for improved performance while also having a low enough voltage for the camera's maximum threshold.

5. Safety

5.1. Safety Officer

5.1.1. Responsibilities

Leading up to the CDR, UCLA's Student Launch Safety Officer, Andy Muratalla, has adjusted and enhanced his responsibilities for the duration of the project's timeline. He will work in conjunction with subteam leads, group leads, and team mentors to ensure adequate understanding of safety information and quality communication throughout the project's timeline. The Safety Officer 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
- Ensuring all disposable PPE (gloves, respirators, etc.) and First Aid supplies are kept in stock and purchased as necessary
- Obtaining and holding a full list of Material Safety Data Sheets
- Reviewing launch vehicle and recovery system design and assembly
- Subscale launch test analysis and ensuring safe handling
- Ensuring full compliance with NAR safety code and all law compliances
- 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.

5.2. Launch and Safety Checklist

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

If a requirement listed under any of the titled subsections tabled below is not checked, the Safety Officer and/or Project Manager must be notified before proceeding; the SO and/or PM will assess the situation and determine next steps in compliance with written guidelines and laws.

Table 13: Safety Checklist

Pre-Departure	**Completed (✓)**
1. All team members accounted for and roll is taken. Safety agreements on hand.	
2. Tool box and equipment securely fastened. Additional parachutes, shock cords, eye bolts, and epoxy are loaded up.	
3. Additional batteries and contingency electronics bay in case of recovery system failure is packed.	
4. Voltmeter secured and boxed. Gloves, eye protection, and respirators on hand.	
5. Launch vehicle and payload packaged for travel.	
	_______________ 5/5 ✓ - Ready to Depart
Recovery System	**Completed (✓)**
1. Electronics bay properly inspected by Electronic Lead, Project Manager, and Safety Officer to ensure wires are secured and components will be static.	
2. New 9V batteries are installed and tested with voltmeter.	
3. Altimeters are preprogrammed at predetermined chute deployment, fully functional.	
4. Fire clothes are enveloping the chutes and electronics bay.	
5. Chutes are neatly folded and packed with ample room.	
6. Both altimeters are connected to both chutes redundancy.	

7. Bulk heads have been tested against desired force/impulse measurements.	
	______________ 7/7 ✓ - System Ready
Rover Ejection Assembly (Payload)	**Completed (✓)**
1. Arduino Uno working and implemented in position.	
2. BMP 180 (inside) connected, and responses have been confirmed.	
3. Stepper motor and stepper motor driver board properly placed (one inside, one outside) of assembly.	
4. Gyroscope embedded into bulkhead in ejection assembly.	
5. Rover assembly is per design and functional.	
6. 12'' threaded rods is properly attached to 5mm side of coupler, attached to 10mm side of stepper motor using screws.	
7. Components fit perfectly to scale and pose no risk to rover deployment.	
	______________ 7/7 ✓ - Proper Assembly
Rover Assembly and Controls	**Completed (✓)**
1. Antennas are placed in proper radio frequency relative to controls antenna and video antenna.	
2. Receiver properly connected to flight controller.	
3. DC Motors must have singular rotation schematic.	
4. ESC are connected directly to DC Motors (2).	
5. Servo Motor implemented and	

connected directly to flight controller.	
	______________ 5/5 ✓ - Proper Assembly
Launch Vehicle & Flight Inspection	**Completed (✓)**
1. Electronics bay is properly fit and all components snug/static.	
2. Nose cone is packed with main-chute and shock cords properly attached to eybolted bulkheads. Nose cone fits snug and friction test was successful.	
3. Drogue chute fits well within body tubes. Friction test proved successful and shear pin holes have been drilled.	
4. All bulkheads are fully adhered to interior of carbon fiber body tubes.	
5. Fins are completely attached and as defect-free at adhesion point as possible. Visual confirmation necessary.	
6. All exposed wires are tucked away to the interior. Anderson powerpole connectors must be attached and adhered to vehicle at the exterior.	
7. Vehicle is balanced, with center of gravity and center of pressure labeled clearly.	
8. Inspection fulfilled and approval received from Range Safety Officer.	
	______________ 8/8 ✓ - Vehicle Assembly
Launch Procedure	**Completed (✓)**
1. Launch control turns power off and all prior launches have landed.	
2. Vehicle is placed onto launch rail and oriented *x* degrees off of vertical centerline, based on wind speed (within 20 degrees).	

3. All electronics are turned on and connect using Anderson powerpole connectors.	
4. Igniter is inserted at bottom of vehicle, pushed and reaches end of motor, minus 2 inches.	
5. Safety Officer has verified connection to launch control and has given the OK to launch.	
	____________ 5/5 ✓ - Ready for Launch!
Post-Launch Assessment	**Completed (✓)**
1. Range Safety Officer has approved retrieval of launch vehicle.	
2. Rover successfully ejected from body tube in upright orientation. (if applicable)	
3. Electronics are disconnected and altimeter data is accessed.	
4. Vehicle body is recovered.	
	____________ 4/4 ✓ - Success!

In addition, further research has been conducted to strictly comply with all NAR Safety Codes, federal and state laws, and UCLA Machine Shop Safety.

Federal Aviation Regulations 14 CFR

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

Code of Federal Regulation 27 Part 55

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

NFPA 1127

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

5.3. Hazard Analysis

Close inspection of our tentative project timeline, laboratory, member and vehicle construction has been done and many hazards that have been observed and/or can be expected have been identified. This list is made in conjunction with past hazardly experience and will be assessed on a leveled pattern based on likelihood and impact

5.3.1. Defining Risk Levels

5.3.1.1. 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 14: 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%

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5.3.1.2 Impact:

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

Table 15: Risk Impact

Description	Member & Personnel Safety	Equipment & Facility	Project Plan & Timeline	Environment
-A- High or Severe	Fatal injury/death. Permanent disability or impairment.	Elimination and loss of equipment. Irreparable damage and possibly dissipation of location.	Immense effect on project lifetime and results in termination or project.	Irreparable and immense physical damage to the surroundings; violates codes/ laws and regulations.
-B- Medium or Moderate	Fair amount of damage, usually repairable, modest pain, or adequate illnesses.	Significant or notable damage to systems, equipment, or facilities.	May result in temporary pause or significant delay in project timeline and redesign.	Reversible but noteworthy damage to environment and may be subject to review to determine law compliances.
-C- Low or Minor	Minimal or infinitesimal damage that is repairable and yields little to no repercussions.	Small and repairable damage to equipment, materials, systems, or facilities; does not compromise any state.	Minor to extremely minimal delay in project plan or timeline; any delays due to cost or insufficient funds.	Infinitesimal and repairable damage in compliance with regulations.

5.3.1.3 Risk Assessment Levels:

Using the definitions and level placements for the likelihood and impact of predetermined hazards, each risk will be assigned an official risk level (shown in color). Red denotes high, yellow denotes medium, and green denotes low; specific leveling is shown below.

Table 16: Risk Severity

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

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.

Yellow boxes denote medium risk levels: likely and possessing moderate severity, these risks should not be taken unless advised by a team lead or equivalent. Hazards characterized as yellow may be avoidable and mitigated.

Green boxes are deemed low risk with low severity: they are unlikely to occur often or at all, and they may be completely avoidable. They are rare and result in minimal overall effect on the project, personnel, facilities, or environment.

5.3.2. Predetermined Hazard Analysis and Rankings

Table 17: Hazard Analysis and Rankings

Type/ Ranking	Hazard	Cause	Effect	Mitigation	Procedure
Personnel 2C	Cuts/ lacerations	Incorrect use of materials; accident;	Contamination; Immediate first aid; Potential medical attention	Ensure PPE is worn at all times and ensure all safety procedures and guidelines are being met. Always ensure you are working diligently in the lab space and be conscientious of others around you	Immediate attention from team leads and Safety Officer to proceed accordingly. A first aid kit will be readily available to alleviate any immediate injuries
Personnel 2B	Injury from chemical spill	Incorrect handling; incorrect PPE; accident	Epidermal contamination; Cross contamination; Medical attention	Ensure PPE is worn at all times; all chemicals are to be handled carefully; proper lab etiquette enforced	Depending on chemical exposure, a chemical spillage kit will be on hand. Spills are not to be cleaned without the supervision of a team lead or Safety Officer. Certain chemicals react in the presence of water; therefore, hand washing is to be determined as outlined by MSDS present in the workspace at

					all times, which should always be consulted upon any chemical spill
Personnel 3A	Black powder explosion	Static charge or voltage connection; accident	Epidermal injury/burn; Hearing loss; Ataxic gait	Always ensure that one is grounded while handling ejection charges. Ensure proper PPE is worn at all times to mitigate the severity of explosive outcome. To reduce the gravity of the explosion, small amounts of ejection powders are to be handled at any given time. Avoid electrical equipment	MSDS sheets will be readily available and members will be adequately trained and certified to handle. Only small amounts are to be handled
Personnel 3A	Inhalation of chemical fumes	Improper use/lack of PPE	Difficulty breathing; potential organ damage	P100 rated respirator masks and filters and goggles will be worn at all times when working with any chemical substances, required in	Every respirator must be checked for filter cleanliness. Medical attention might be sought and all team members must ensure they perform manufacturing which creates

				well-ventilated areas	particulates in ventilated areas
Personnel 3A	Chemical contact with eyes	Improper use of PPE; accident	Temporary to Moderately sustained blindness; burning sensation;	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	Accompanying team members will navigate student to nearest eye wash station if needed. Depending on chemical exposure, medical attention may be required
Personnel 3A	Exposure to allergen	Handling of known/ unknown allergens without PPE; Improper PPE provided	Epidermal irritation; allergic reaction; burns	Both latex and vinyl gloves will be provided for use when working with known allergens	Ensure that all known allergens are accounted for team safety. Identify the location of reaction if possible and remove all foreign contact immediately. Medical attention may need to be consulted

Personnel 3B	Particulate inhalation	Cutting Carbon Fiber or Fiberglass material with a Dremel in a dry environment	Material is known to cause health problems given long enough exposure	P100 rated respirator masks and filters, a lab coat, gloves, and goggles will be worn when working with these materials along with minimum PPE requirements	Every respirator must be checked for filter cleanliness. Medical attention might be sought and all team members must ensure they perform manufacturing in ventilated areas
Personnel 3B	Inhalation of Lead Fumes	Using lead based solder	Lead has been known to cause physical and mental health problems when ingested or inhaled; difficulty breathing	If lead based solder is used, it will be done in an environment with a fan to diffuse the fumes away from the user, under fume hoods, while user wears a respirator mask	Depending on severity of situation, appropriate attention will be sought by Safety Officer. The team will cease lead work, if being done
Personnel 3B	Spilled or contact with epoxy resin and/or hardener	Epoxing without informing team members; mistakenly tipping bottles; lack of proper PPE	Epidermal injury, medical attention depending on severity and body contact	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	An experienced team member will either be performing the epoxy work or supervising it. Any unused epoxy will be disposed of in the proper waste container. Epoxied materials that are left to dry will have signs

				epoxy work is underway	posted notifying others that they are not to be disturbed
Personnel 2B	Falls/ stumbling	Loose cords; wires running across floor; horseplay through lab area	Moderate to severe injury	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. Team members will be required to follow proper lab etiquette and act professionally at all times while in the lab space	In the case of injury from a fall, appropriate measures are to be taken by the team lead supervising the space. Depending on the severity, medical attention may be sought and the means immediately addressed to all team members for precautions to be taken

Personnel 2C	Open paint fume inhalation	Improper use/lack of PPE	Difficulty breathing; potential organ damage	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 must be checked for filter cleanliness. Medical attention may be sought and all team members must ensure they perform manufacturing in ventilated areas
Equipment 2A	Electric shock	Equipment malfunction; electrical power build-up; damaged wires	Epidermal and organ burns; Temporary numbness; Potential nerve damage; Fatality	Proper PPE must be worn at all times when handling electrical equipment. All wires should be checked for damaged cording before plugging. Refrain from water usage around electronics	In the case of electrical shock, medical attention should be sought. Depending on the location of shock, equipment may cause fire: team lead should immediately obtain fire extinguisher

Equipment/ Facility 2A	Uncontrolled fire	Chemical cross contamination & equipment overheating; incorrect wiring; explosion	Moderate to Fatal injuries or death; irreparable damage to equipment and lab space	All lab coats should be fire resistant. Proper lab etiquette should always be followed to help prevent serious injuries and decrease risk of life-threatening circumstances. Always be aware of one's surroundings and be diligent when working in a lab environment	All team members will be briefed on the location of the laboratory's fire extinguisher and fire blanket. In addition, every member will be briefed on the proper fire escape routes out of the building. Fire protocol is included in all lab safety certified courses
Personnel/ Equipment 3B	Injury from falling tools/equipment or materials	Incorrect storage or placement; Stock not secured or fastened	Moderate to severe injury; depending on height may	All equipment should be stored away appropriately and tucked away from high places. All rolling objects should be securely fastened and heavy equipment should remain away from open shelves. All members will be required to wear proper PPE, including	The state of CA suffers many earthquakes year round; it is important to lower risk of injury from falling items by storing supplies low to the ground. In the event of an injury from falling objects, one is to seek treatment depending on severity of injury

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				closed-toe shoes and long pants	
Equipment/ Payload 2C	Loss of connection from rover antenna.	Incorrect configuration, lack of proper orientation, material	Rover is unable to successfully deploy and mission fails	To combat the instability and possibility that the rover does not receive input from the controller, we will implement a forced ejection method	In the event that the rover is not receiving signal within the body tube, we will have to implement a system with forcing ejection to deploy the payload safely onto solid ground.
Payload 3A	Lithium battery powering the flight control, motors, and receiver, explodes	Malfunction; cross wiring; tampering; EM fields	The rover does not deploy and we cannot fulfill the specifications of the competition. Possible human contact can lead to injury	Project manager and safety officer will inspect all electronic implementations on the launch vehicle prior to launch	We will ensure that only battery between 7.4 and 12 Volts are utilized in all aspects of our launch vehicle
Launch vehicle 3C	LiPO does not have enough power to last at launch pad designated time	Insufficient power	Electronics do not function; mission unsuccessful	Quality check the battery and analyze manufacturer claims, implementing batteries with known W/hr	In the event, we would be automatically disqualified. For future launches, we would need to ensure requirements are met

Launch Vehicle 3B	Component failure	Choosing an ESC with a current rating equal to or less than needed.	Unable to communicate with the rover and thus we would be unable to successfully complete the mission	Choosing an ESC with a current rating 10% or greater than is needed	In the event of component failure, we would need to improvise and transfer out the ESC of the flight controller with new components
Launch vehicle 2C	GPS tracking malfunction	General or unexpected malfunction; battery depletion; erroneous code	Unable to locate the launch vehicle in extreme cases	We will ensure that all batteries are fully charged and checked using the voltmeter. Each GPS used will be tested before flight and approved after showing readings	When we realize that the GPS has malfunctioned, it might be too late for us to begin tracking at whim. Tracking must also be taking place by eye and ensuring that the rocket is recoverable upon landing.
Environment 2A	Contamina-tion of groundwater	Improper handling and/or disposal of chemicals/ materials	Impurities found within soil/ environment causing harm to human health	Proper disposal when handling chemical materials	In the event of a spill, proper actions will be taken to resolve the damage
Environment	Launch vehicle damages land around	The launch vehicle harms the environment around it with	This heat source can damage the surrounding land beneath the launch	This hazard will be diminished by having a launch area that is resistant to damage from	Upon noticing any harm surrounding the vehicle launch area, immediately halt any

2B	launch station	the flame of the motor ignition	area and cause detrimental outcomes to plant and animal life if repeated	this flame. The launch pad area will be on open dirt	proceedings, remain environmentally friendly, and ensure area is free of flammability
Environment 3B	Unsafe landing zone; elevated drift	High wind speeds	High wind speeds can increase the launch vehicle's drift from the launch pad and make it unrecoverable or even land in an area risking safety	If the wind is above 20 mph, it is possible that the launch will be cancelled; monitor wind levels and await approval from the RSO	When high wind speeds are noted, and the vehicle is already on the launch pad, consult with the Range Safety Officer regarding potential hazards and proceed accordingly
Environment 3B	Shorting wires and explosions; apogee not reached	Rainfall	Rain can hinder the arrival at apogee and defer the vehicle course. Soggy land may prove impossible for payload to deploy. Possible shorting of wires and electric shock	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. Team members and leads would consult the RSO and establish ways to proceed	Heavy rainfall may subject the launch to delays. and the vehicle is already on the launch pad, consult with the Range Safety Officer regarding potential hazards and proceed accordingly

Project Timeline 3A	Lack of proper testing due to time constraint	Inadequate time allocated across timeline	Falling far behind with respect to timeline. Inaccuracy when assessing and verifying design/ manufacturing of parts. Can lead to devastating and far more dangerous happenings	Implementing clear checkpoints across both design and manufacturing process	Holding team members accountable through due dates for specific deliverables along with one on one meetings to assess their individual progress on assigned portion
Project Timeline 2C	Setbacks in timeline regarding lack of parts	Defects/ delays in arrival of parts and insufficient funds	Delay on other aspects dependent on prior mentioned parts	Budget time for delay, either due to insufficiency of parts or delay in arrival	Allow for a 1-2 week period for arrival of manufactured parts and budget analysis
Failure Mode/ Launch Site 3A	Instability of launch pad/ rail	Issues concerning the stability of launch pad/ rail	Inaccuracy of launch pad/ rail conditions may lead to unpredictability of the rocket’s trajectory	Inspect launch pad and rail prior to ensure minimum level of stability	Ensure that all personnel are at a minimum distance from the launch site as established by NAR

Failure Mode/ Launch 3C	Malfunction in electronics	Failure in individual systems	May result in failure to deploy/ collect data/ operate as intended	Vigorous testing of separate functions within each part	Implementing redundancy within electronic systems in case of malfunction
Failure Mode 3C	Improper deployment of parachute	Failure in electronics. Failure in black powder to separate sections	Will cause damage to launch vehicle as well as payload	Allow time for ground testing of electronics	Perform ground tests to ensure a sufficient amount of black powder
Failure Mode/ Launch Vehicle 3B	Sections separate prior to indicated altitude of deployment	Structural failure. Failure in electronics, activating black powder prematurely	Rocket does not reach apogee and may follow ballistic path	Increased redundancy incorporated into the system	Increased amount of shear pins or creating a more robust coupler
Failure Mode/ Launch Vehicle 3C	Motor retention failure	A drogue chute applies a force great enough to push out motor	The motor may be lost as it detaches completely from the launch vehicle	Ensure that centering rings have been well epoxied to inner walls of the body tube	Perform ground testing to the motor retention system can resist the forces placed on it

Failure Mode/ Launch Vehicle 3A	Launch vehicle does not reach minimum velocity before leaving the launch rail	Miscalculation of rocket's mass. Motor failure	Decrease in stability of the launch vehicle; rocket plummets down; possible explosion	Verify that simulations run beforehand compare with the actual manufactured product	Issues that arise due to a faulty motor will be further examined for future launches and ensured that we follow proper recovery protocol
Failure Mode/ Launch Vehicle 3A	Bulkheads do not sustain intended force	Incorrect calculation of forces that bulkheads can support.	Intended support provided by bulkheads will no longer effectively secure internal parts. Leads to possible explosion, payload and recovery system damage, and destruction of vehicle	We will ensure the accuracy of calculations using OpenRocket software and test the strength of materials used prior to assembly	Safely wait for all parts to ground and recover. Verify that forces encountered by bulkheads can be supported through future flight tests

UCLA Bearospace places a great emphasis on safety for its members. All Material Safety Data Sheets for chemicals used by UCLA Bearospace will be kept available to membership online and physically in a binder in the workspace along with Standard Operating Procedures for their use. The Safety Officer will ensure that all disposable PPE, such as gloves, napkins, mask filters, and first aid are kept in stock and purchased as necessary. All planning will be overseen and approved by the Safety Officer to abide by all regulations.

All members new to certain equipment or material will be briefed by the safety officer or a team manager on correct handling procedure, required PPE, risk assessment, and what to do in case of an accident. First encounters with materials or equipment will be monitored by a knowledgeable manager or safety officer. When team members are present in the lab, there will always be a minimum of one manager or safety officer present to answer questions or act in case of an incident. In the case of a large event, such as strength testing or launch, all members who will be present will be briefed by a manager or safety officer on safety protocol, risk assessment, and what to do in case of failure prior to the event.

5.4. NAR Safety Code Compliance

Our Pre-Launch Briefings will include a full overview of safety procedures encompassing rules and regulations of the launch site, as well as guidelines set forth by the NRA/TRA. In addition, team managers will ensure all team members are briefed on NASA Student Launch Safety regulations and understand the supreme mandating of the Range Safety Officer. Managers will include an overview of launch procedures, expected outcomes, failsafe options, and roles/responsibilities. The team will abide by all rules set forth by these guidelines, wherein members exhibiting inappropriate behavior will not be permitted to launch and will be asked to leave.

All members will obtain a launch-day checklist, including the Launch and Safety checklist included in 5.1. They will be required to read prior to attending the launch site. If any additional material must be presented concerning pre-launch briefings, the team leads and Safety Officer will present the new material to the team as a group.

Since the proposal, we have made some alterations to better suit the compliance of the NAR Safety Code. Our team, having preliminary designs for our launch vehicle and a better understanding of the competition requirements, has expanded our mission by complying to the NAR Safety codes as expressed in the following:

Table 18: 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	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

flames, nor heat sources within 25 feet of these motors.	mentor, who possesses Level 2 certification.
4. **Ignition System.** I will launch my rockets with an electrical launch system, and with electrical motor igniters that are installed in the motor only after my rocket is at the launch pad or in a designated prepping area. My launch system will have a safety interlock that is in series with the launch switch that is not installed until my rocket is ready for launch, and will use a launch switch that returns to the "off" position when released. The function of onboard energetics and firing circuits will be inhibited except when my rocket is in the launching position.	The safety officer and team leads will be responsible for proper ignition system installation as outlined in the aforementioned code. All launch pad procedures have been briefed to team leads and the standing safety officer.
5. **Misfires.** If my rocket does not launch when I press the button of my electrical launch system, I will remove the launcher's safety interlock or disconnect its battery, and will wait 60 seconds after the last launch attempt before allowing anyone to approach the rocket.	The team will collectively ensure that in the case of a misfire, the battery is disconnected and 60 seconds have elapsed before anyone is to approach the rocket. Note that the Range Safety Officer has encompassing final decisions; therefore, alterations may be addressed by the RSO and additional limitations/regulations may be subject to realize.

6. **Launch Safety.** I will use a 5-second countdown before launch. I will ensure that a means is available to warn participants and spectators in the event of a problem. I will ensure that no person is closer to the launch pad than allowed by the accompanying Minimum Distance Table. When 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

	dependant on the wind speeds on launch day and time.
8. **Size.** My rocket will not contain any combination of motors that total more than 40,960 N-sec (9208 pound-seconds) of total impulse. My rocket will not weigh more at liftoff than one-third of the certified average thrust of the high power rocket motor(s) intended to be ignited at launch.	All leads will collectively ensure the size and design of the rocket satisfies the requirement and will adhere to the constraints set forth. Our predetermined dimensions have all been designed well within the bounds set forth by the code. All possible design options consider the restrictions and allow for marginal freedom to expand pot-design and
9. **Flight Safety.** I will not launch my rocket at targets, into clouds, near airplanes, nor on trajectories that take it directly over the heads of spectators or beyond the boundaries of the launch site, and will not put any flammable or explosive payload in my rocket. I will not launch my rockets if wind speeds exceed 20 miles per hour. I will comply with Federal Aviation Administration airspace regulations when flying, and will ensure that my rocket will not exceed any applicable altitude limit in effect at that launch site.	The guideline set for all flight safety will be followed in conjunction with directions provided from the Range Safety Officer, who has the final say on all launches.
10. **Launch Site.** I will launch my rocket outdoors, in an open area where trees, power lines, occupied buildings, and persons not involved in the launch 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	The team leads and Safety Officer will ensure that the team complies with all regulations regarding the location of the launch site. The launch is to take place in a large, open area with preset parameters that are to be strictly adhered to regarding safe launching. In addition, a hard

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).	copy of 2020 NASA Student Launch Handbook and Request for Proposal has been obtained for our records, allowing us to have resources such as the minimum distance table available. The vehicle and payload will be capable of remaining in launch-ready configuration on the pad for a minimum of 2 hours without losing the functionality of any critical on-board components.
11. **Launcher Location.** My launcher will be 1500 feet from any occupied building or from any public highway on which traffic flow exceeds 10 vehicles per hour, not including traffic flow related to the launch. It will also be no closer than the **appropriate Minimum Personnel Distance from the accompanying table from any boundary of the launch site.**	The Safety Officer and team leads will ensure that the launch is positioned away from all persons and property. The launcher will strictly adhere to the launcher location parameters and remain at a safe distance away from the launch pad. All team members have read through the 2020 Handbook and recognize the importance of adhering to the minimum personnel distance as outlined by the regulations.
12. **Recovery System**. I will use a recovery system such as a parachute in my rocket so that all parts of my rocket return safely and undamaged and can be flown again, and I will use only flame-resistant or fireproof recovery system wadding in my rocket.	All team leads and Safety Officer will ensure the rocket is successfully designed with an excellent recovery system that abides to the guidelines set forth. In addition, our recovery system electronics will not be adversely affected by any other on-board electronic devices during flight. It will be physically

	located in a separate compartment within the vehicle from any other radio frequency transmitting devices.
13. **Recovery Safety.** I will not attempt to recover my rocket from power lines, tall trees, or other dangerous places, fly it under conditions where it is likely to recover in spectator areas or outside the launch site, nor attempt to catch it as it approaches the ground.	The team leads and Safety Officer will collectively will ensure that the team safely recovers the rocket by abiding to the preset guidelines. We will collectively wait for approval from the RSO in case of potential hazardous conditions that may be encountered.

Exclusively TRA/NRA members are allowed to handle rocket motors and any hazardous flammable/pyrotechnic equipment. These members will have read all laws of compliance.

All purchases and handling of rocket motors will be the responsibility of the assigned NAR/TRA personnel. Motor casing and reloads will be obtained and handled by UCLA's Mentor, who is a certified Level 2 TRA member. All motors are to be kept disassembled and packaged until needed for launch. All black powder ejection charges and motors will be stored in a cool container, at roughly 76 degrees Fahrenheit, away from any heat or ignition sources.

Simulations will be retested and rerun with appropriate motors before launching. All team members will be made aware that only NAR/TRA members with proper certification are allowed to handle motors that will be used. Whenever motors are unpacked and assembled for launch, both the Team Mentor, Project Manager, and acting Safety Officer are to be present and following proper procedures.

6. Project Plan

6.1 Requirement Verification

Meeting of all competition and team requirements at the design level have been met, as discussed throughout the entirety of this PDR report. Analysis such as computer simulations and further calculations which require more research will be completed before manufacturing parts related to that aspect of the vehicle. More general restrictions are understood by project leadership and have been divided among leaders appropriately to ensure full completion.

6.1.1 Competition Requirements

Competition requirements have been thoroughly reviewed by project leads. Compliance with each regulation can be found in the respective sections of this report

6.1.2 Team Requirements

Table 19: Team Requirements

Team Requirement	Reason for Requirement	Plan for Fulfillment
Vehicle Requirements		
Upper and lower body tubes will be a cumulative sum of 5’ in length	Minimizes material cost and health risks from additional manufacturing	*Inspection:* When in the early design phase, no rocket exceeding this body tube length will be considered a realistic option
Payload and retention method will recieve 14” within the upper body tube	Avoids crowding in later manufacturing processes as well as resizing if necessary	*Inspection:* When in the early design phase, no rocket without this requirement will be considered as a viable launch vehicle
Recovery System Requirements		
Only one drogue chute and one main parachute will be used in a safe recovery of the launch vehicle	Minimizes material costs	*Analysis, Demonstration:* After designing a launch vehicle and appropriate motor, parachute sizing analysis will be run to ensure a reasonable main parachute diameter that could be purchased from a reliable vendor. At full scale launch parachute sizing will be verified.
Payload Requirements		
Rover will not exceed 12” in the packed position	Size restrictions on the body tubes defines packed dimensions	*Inspection:* Rover body would be designed to be 11”
Rover will not contain	Limiting complexity of	*Inspection:* Four motors

more than 6 on board motors	electronics and minimizing modes of failure	would be used towards the transportation of the rover, then a maximum of two motors could be planned in the designing of the collection system.
Ejection system rod will not experience deflection that compromises its integrity	Failure of the ejection system could cause failure of the objective and safety risks if ejected prematurely	*Analysis, Test:* Material analysis will be performed on the beam to obtain an approximation on deflection and material fatigue. Deflection testing with heavier masses than the rover will support initial numerical calculation

6.2 Budget

Provided below is a budget outlining the various purchases the team anticipates this upcoming school year:

UCLA Bearospace

2019-2020 Budget

	Expense	Company	Projected Units	Projected Unit Price	Projected Total Price
Structures	Totals:				$1,023
	Contingency			10%	$93
	Body Tube	Public Missiles	1	$440	$440
	Coupler	Public Missiles	1	$94	$94
	Fiberglass Sheet	McMaster-Carr	1	$17	$17
	Pine Wood Stock	Anawalt Lumber	4	$12	$48
	Steel Eyebolts	McMaster-Carr	4	$3	$11
	Shear Pins	Apogee Components	1	$4	$4
	Main Parachute	Apogee Components	1	$40	$40
	Drogue Chute	Wildman Rocketry	1	$41	$41
	Shock Chord	Apogee Components	1	$50	$50
	Fire Cloth	Apogee Components	2	$10	$20
	Motor Mount & Ring/Epoxy	Apogee Components	1	$100	$100
	Phenolic Tube	Apogee Components	1	$15	$15
	RocketPoxy	Apogee Components	1	$49	$49
Electrical/Payload	Totals:				$375
	Contingency			10%	$34
	RRC3 Sport Altimeter	Missile Works	1	$70	$70
	Radiolink 2.4GHz Transmitter	Amazon	1	$54	$54

	Furious FPV 2.4GHz TRX	GetFPV.com	1	$55	$55
	BosCam 2.4GHz VRX	DronesVision	1	$18	$18
	OpenPilot CC3D Evo Flight Contr	Amazon	1	$23	$23
	Tamiya 380 Sport Tuned Motor	Amazon	4	$8	$31
	Micro High Torque Servo	Adafruit	1	$12	$12
	PCB	Amazon	1	$3	$3
	10A Brushed ESC w/ Brake	Amazon	4	$9	$36
	120 Degree NTSC Mini Camera	GetFPV.com	1	$8	$8
	2.4GHz SMA Antenna (RHCP)	Amazon	1	$30	$30
Safety	***Totals:***				$34
	Contingency			10%	$3
	Gloves (100 pack)	Fisher Scientific	1	$31	$31
Travel	***Totals:***				$2,130
	Contingency			10%	$194
	Toolbox	Arline	1	$48	$48
	Rocket Shipping Box	Airline	1	$25	$25
	Uber to LAX	Uber	1	$25	$25
	Car Rental	Enterprise	1	$444	$444
	Plane Tickets (Round Trip)	Airline	5	$275	$1,375
	Uber to UCLA	Uber	1	$20	$20
	Grand Total				**$3,561**

6.3 Funding

In the previous academic year, UCLA Bearospace had successfully obtained of $2525 dollars in multiple UCLA grants for use in purchasing materials and travel expenses for First Nations Launch. This upcoming year, funding plan will be twofold: continuing to pursue grants and donations from UCLA organizations and entities, as well as pursuing donations from corporate sponsors.

Firstly, team managers will apply to grants which the team has won in the past. Last year, the UCLA Engineering Alumni Association (EAA) awarded UCLA Bearospace $650 for purchasing rocket materials for First Nations Launch. Considering that UCLA Bearospace won first place overall last year, managers plan on leveraging that fact to justify last year's donation and justify asking for further donations for this upcoming school year. In addition, UCLA Student Organizations, Leadership and Engagement (SOLE) office released the UCLA Leadership Development Fund last year, a grant for covering travel expenses to conferences that promote student leadership development, to which the team successfully applied and won $1875 for travel expenses. Managers plan on applying to this grant again with AISES at UCLA's help. Aside from these two, team managers plan on exploring more opportunities by partnering more closely with UCLA SOLE representatives that have an extensive and positive contributive relationship with AISES at UCLA.

Secondly, the team will pursue corporate donations for UCLA Bearospace. At AISES at UCLA's Industry Advisory Board (IAB) meeting this summer, UCLA Bearospace representatives had the opportunity to meet corporate representatives from Lockheed Martin, Boeing, Northrop Grumman, and others. The Lockheed Martin representatives invited the team to provide them a fundraising-budget plan this upcoming IAB meeting in the winter, at the beginning of their financial cycle, when they can most easily donate money to student organizations. Team managers plan on composing a comprehensive fundraising plan and budget to provide them in hopes of obtaining corporate donations, and in so doing, establish the beginnings of a working relationship between UCLA Bearospace and corporate sponsors that will continue to provide funding for UCLA Bearospace into the future.

6.4 Timeline

6.4.1 Project Timeline

Provided below is an overall schedule for this upcoming school year. By the submission of the PDR (1 Nov, colored magenta), the team will be halfway through the Design Phase, having submitted the selection of different alternative designs listed in the PDR and determining from them the final rocket vehicle and payload designs.

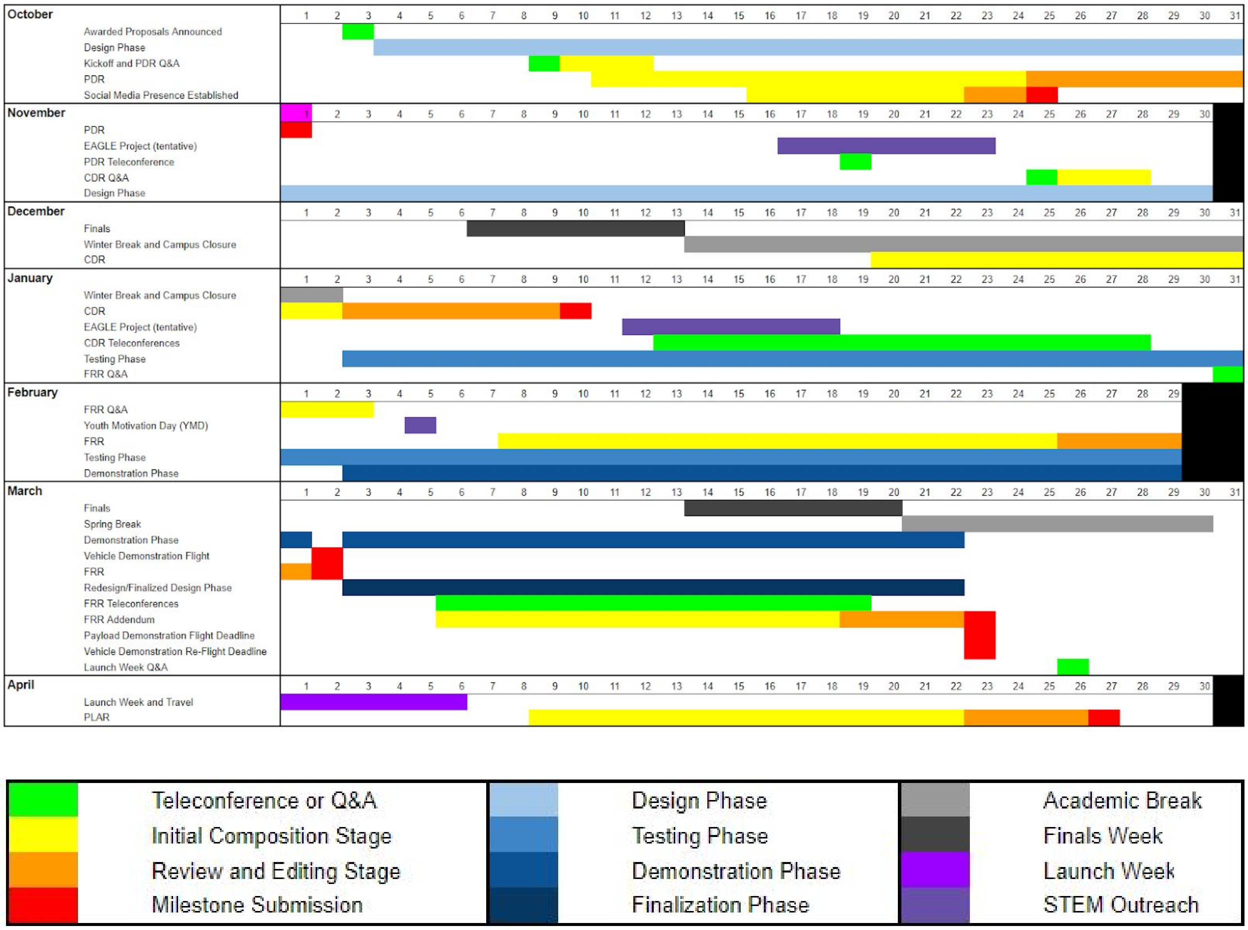

Figure 47: Timeline

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.

The tentative dates of STEM Outreach events have also been included in the project timeline and are as follows

1. EAGLE Project (17-23 Nov or 12-18 Jan): AISES at UCLA and UCLA Bearospace travel to a school on an American Indian (AI) reservation and host STEM workshops for the students to encourage the growth of AI representation in STEM careers. The anticipated turnout is app. 100-200 AI.

2. Youth Motivation Day (YMD): AISES at UCLA and UCLA Bearospace host a day of STEM workshops in the Ackerman Grand Ballroom in UCLA, where app. 200 students from middle schools in minority-majority areas are bused to campus and participate in student-run STEM workshops and activities.

Appendix

Reference List

Pelit, Huseyin, and Abdullah Sonmez. “The Effect of Modification with Epoxy and Polyester Resins on Some Mechanical Properties of Pine and Chestnut Woods.” 26 Sept. 2018, doi:https://www.researchgate.net/publication/328808343.

“What Is Carbon Fiber?” DragonPlate, dragonplate.com/what-is-carbon-fiber.

UCLA Bearospace Team Safety Agreement

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

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

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

Lastly, I agree to adhere to the following regulations:

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

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

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

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

________________________________ ____________________

Member Signature Date

Figure 48: Team Agreement