UC Berkeley Space Technologies and Rocketry
NASA Student Launch Preliminary Design Review
Project Arktos

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Contents

1 Summary of PDR Report

1.1 Team Summary

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1.2 Launch Vehicle Summary

The length of the launch vehicle is 113in. The wet weight of the launch vehicle is 27.13 lbs and the dry weight is 22.19 lbs. The launch vehicle utilizes a Cesaroni L730 motor to achieve a simulated apogee of approximately 5555ft.

The recovery system implements a same-side dual deployment method, with drogue chute deployment at apogee and main chute deployment at 800ft AGL. The 24in elliptical drogue chute and 72in toroidal main chute are systematically integrated with a series of two L2 tender descenders and black powder ejection charges. The ejection is controlled by two altimeters, which sit on an avionics sled design. Furthermore, the avionics bay will be accessible from the airframe exterior via a small door. Further launch vehicle details can be found on our Flysheet at https://stars.berkeley.edu/sl.html.

1.3 Payload Summary

The goal of the payload experiment is to have an autonomous rover deploy from the rocket, drive over five feet away, and deploy solar panels. The payload will be located above the booster and recovery portions of the rocket and directly below the nosecone on the launchpad and during ascent. After recovery and upon landing, a pneumatic cylinder will activate and break two 40lb shear pins, separating the payload section from the lower transition section. After separation, a scissor lift will activate, pushing the rover out of the payload tube. Once the rover has emerged from the rocket, the rover will drive forward approximately 10ft to fulfill the handbook requirements. Upon stopping, it will deploy the solar panels by rotating the hood of the rover up, revealing the two sheets of solar panels.

For ease of organization, payload is split into four subsystems:

- Deployment - Separation of the payload section and the radio link
- Ejection - Ejecting the rover from the payload aiframe section
- Movement - Rover design and its movement away from the rocket
- Solar - Solar subsystem on the rover

2 Changes Made Since Proposal

2.1 Airframe

The internal layout of the airframe has changed significantly since the proposal for NASA SL 2018. Additionally, some external changes have resulted from the internal changes. The major change to the airframe is that the length of the rocket built from 6in tube has been shortened significantly, and the length of the 4in section has been lengthened. This results in a lighter, more aerodynamic, and more stable rocket. In order to compensate for these external changes, the avionics bay has been modified to fit in the section of 4in tubing. Additionally, the parachutes have been moved from the aft end of the avionics bay to the fore end of the avionics bay. As a result, the parachutes are deployed from a more centralized location on the rocket. Additionally, the motor size has been reduced from a 75mm diameter to a 54mm diameter. The current motor in use is a Cesaroni L730, whereas an Aerotech L1150 was used in the proposal. More accurate mass calculations were acquired from the payload, electrical, and recovery subteams, and as a result, the overall weight of the rocket was significantly reduced.

2.2 Payload

The payload Deployment and Ejection plans have undergone major revisions since the last proposal for NASA SL 2018. The original Deployment plan consisted of using a black powder charge on a permanent bulkhead that, when activated, would create a force capable of breaking the shear pins connecting the payload section to the rest of the airframe. A pre-compressed spring behind a protective bulkhead will eject said bulkhead through the opening on the bottom of the payload section, effectively making room for the rover to exit the airframe.

After analyzing the amount of force the black powder charge would produce, it was determined that using black powder in close proximity to the rover payload would be ill-advised. To avoid causing damage to the rover, the Deployment plan was changed to utilize a pneumatic ejection system to clear space for the ejection of the rover. This design should be a safer and more reliable method of deployment.

The original plan for Ejection involved using a large spring to force the rover out of the airframe, but that has since been changed to a scissor lift system. The primary reason behind this change is that a spring system would present undue risk in terms of damaging the rover. In the previous design, because the spring would have been compressed prior to launch with the rover directly next to it, if the clasps securing the spring during flight broke or otherwise failed prior to planned ejection, the rover would not be able to exit the airframe and could likely be damaged during the process. Any spring powerful enough to eject the rover would be difficult to compress safely during packaging of the payload and may be too complicated and potentially unreliable during ejection. As a result, the design was modified to a scissor lift system that is more reliable, more controllable, and less dangerous to the rover and airframe.

For the most part, the design of the rover itself has remained the same except for one key alteration: the body design. The body of the rover was originally going to be cylindrical to maximize space within the payload section of the rocket. The new plan is to have a rectangular body to promote ease of manufacturing and mounting of parts. Most of the electronics housed inside the rover's body are rectangular, so having a rectangular body will allow for more efficient packing. Additionally, the solar panels will now be mounted on the hood of the rover on a shell in the main rover body to fully satisfy the solar panel unfolding requirement.

2.3 Recovery

The parachute deployment system design has remained unchanged from the initial proposal. The avionics bay design has been updated. The decision was made to mount an I-beam-shaped sled vertically inside the avionics bay instead of using a horizontally-mounted sled. The sled will now be oriented along the flight path of the launch vehicle instead of perpendicular to it. The sled will no longer have composite sheets above and below it and will instead fit directly into the bulkheads. The change in sled orientation also leads to a change in bulkhead design. The bulkheads now consist of two one-fourth in pieces of plywood epoxied together, located in between the coupler and the airframe. Blue Tube will continued to be used as the material for the airframe and the coupler. The new design for the sled still includes rails so that it may slide out for easy access, and the avionics bay will still be accessed via a door. It has now been decided that this door will be secured during flight by four screws, one at each corner.

2.4 Project Plan

Due to project delays and a launch day cancellation due to fire concerns, the sub-scale test flight has been moved from November 4th to December 2nd.

3 Vehicle Criteria

3.1 Airframe

3.1.1 Mission Statement

Our mission is to successfully design, manufacture, and fly a fully capable rocket to 5280 feet (1 mile) carrying a deployable rover with solar panel. This will serve as a test or trial run for potential rover missions that NASA will conduct on Mars in the future.

3.1.2 Success Criteria

- Airframe is defined as any of the external tubing, coupler tubing, motor tubing, fins, nose cone, and transition piece. There will be no cracks in the airframe.

- There will be no unwanted separation between the pieces of the rocket.

- The stress in the airframe will not exceed acceptable levels. Acceptable is defined as below the yield strength for the specific member of tubing in question.

- Meets all vehicle requirements set from NASA SL 2018 Handbook.

3.1.3 Objectives

- To educate the public in rocketry
- To advance the technology in aerospace systems and rocketry
- To promote aerospace as a major at UC Berkeley

3.1.4 Transition Piece

A key element in the design of our rocket is the addition of a transition piece, which serves the purpose of reducing the rockets diameter. This causes a shift in the center of gravity, which improves the rockets stability, giving more leeway in other parts of the design to add different kinds of elements that are not necessarily optimal for the stability.

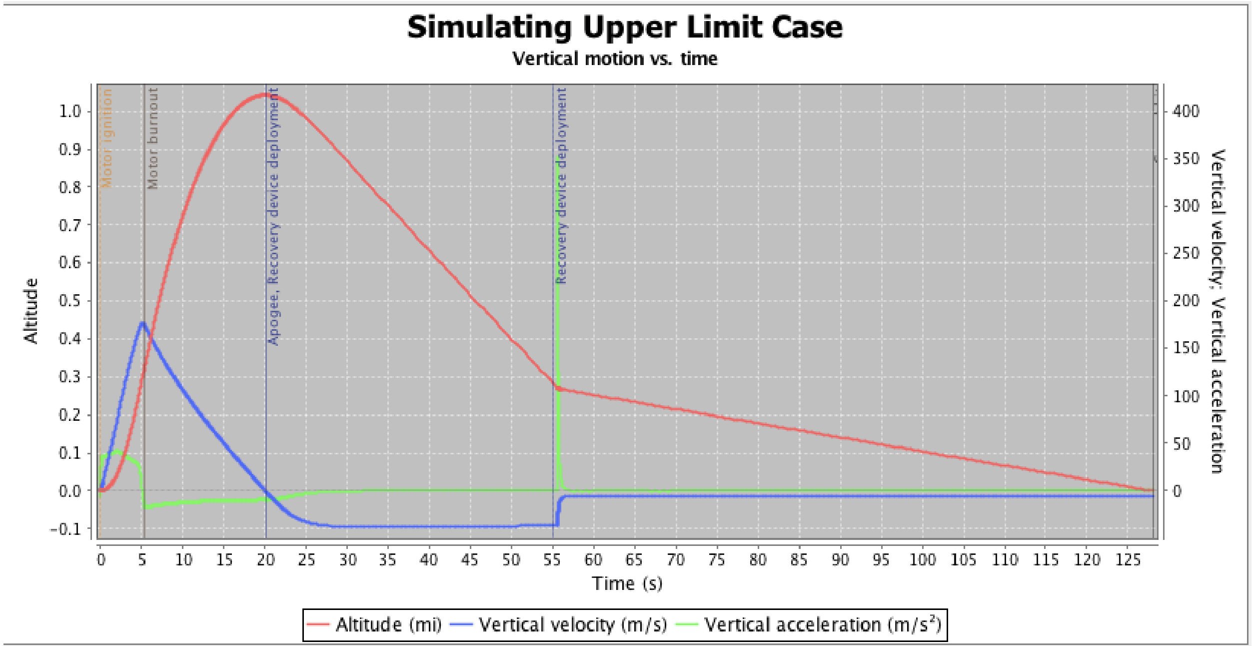
It is clear that a transition piece is essential to change the rockets diameter partway through. In the case of a rocket with no transition where the nose cone is attached straight onto the body tube at the same diameter, the rocket can experience turbulence at the rear end. This turbulence can distort the flight path of the rocket, mitigating the effect of the fins. To counter this problem, the fins have to be larger to make the airflow smoother on the rocket and improve the stability again. This much of a change in the fin size becomes impractical, however, to then physically manage the rocket and minimize the chance of failure during launch. Therefore, the only option left is to create a transition element - a part of the rockets body tube shaped like a frustum, resulting in a smooth change in diameter from that required by the payload and motor elements and the minimum feasible diameter at the nose cone.

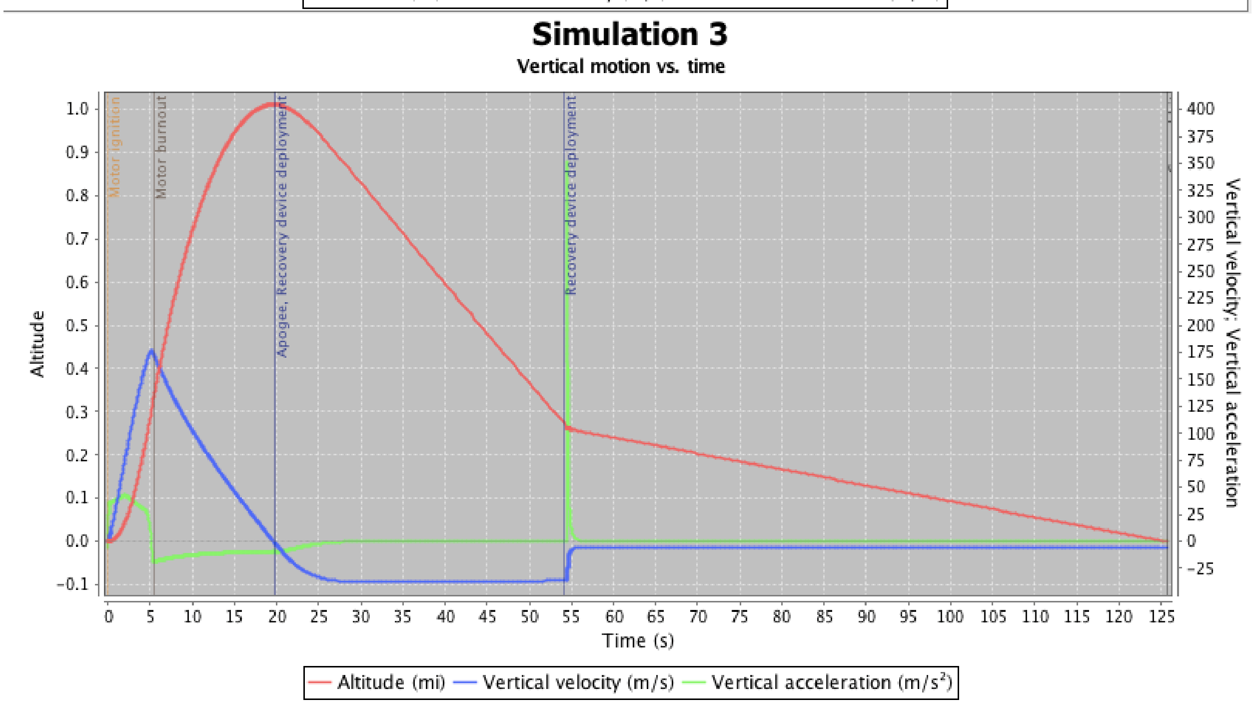
The transition piece can be customized in multiple configurations, which are mainly characterised by the length over which the diameter changes. A tradeoff then arises - a longer transition would improve airflow as it reduces drag, but the cost of an increased surface area and therefore increased materials costs.

However, upon quantifying the increase in the surface area, it turned out to have a relatively insignificant effect on the overall cost. In addition, the cost of having the transition piece at all is offset by current plans of constructing it with facilities that are available to the team (as will be detailed later on). Therefore, as the increase in cost is miniscule, and the expense of having the piece at all is not a factor, there is no significant restriction on the specifications of the transition piece thus far.

Other factors somewhat restrict the dimensions of the transition piece. The pre-made nose cone that is being employed is compatible only with body tubes of specific diameters, of which 6in was the most practical since any less would reduce stability and any more would reduce the positive impact of having a transition piece in the first place. In addition, payload components and the motor tubing require a minimum diameter of 6in. Therefore, the transition pieces fore and aft diameters are 6in and 4in respectively.

Deciding on the length was more complicated, as it depends heavily on the complex subject of airflow over the exterior of the rocket. Any change in the diameter, however gradual, is bound to change these factors, so a decision must be made on how to balance the length with how drastic this change is. This was determined by running simulations in OpenRocket for different values of the transition length, and looking at how it affected the flight path. For some values, no set of small changes in other parameters (e.g. fin size, payload mass, overall body tube length) was able to create a model with the required stability and apogee. Put another way, no possible rocket design could have a transition of that length without redesigning every other aspect. However, the range of feasible lengths was larger than previously anticipated, from 4in to 12in.





When the transition length was longer, the rocket's descent between apogee and recovery device deployment was found to be slightly more gradual, but the margin between the two was small and not something on which a decision could be based off of. Therefore, a length of 8in was selected, in the middle of the previously-determined feasible range, and found that this gave an optimally desired apogee and stability.

Issues associated with the addition of this transition include the possibility of it breaking apart during launch, which can be mitigated by the use of fiberglass in the construction of the transition piece. Additionally, it may make the manufacturing process more difficult, as well as aerodynamic analysis, but its inclusion provides clear benefits that outweigh this. Manufacturing will be carried out via a fiberglass layup on a 3D printed mold.

In conclusion, the addition of a transition section presents clear benefits regarding the rockets mass, stability, apogee, and tolerable error in other factors.

3.1.5 Fins

A trapezoidal shape was chosen for the fins, as it is the optimal shape for reducing drag on the rocket. The size of the fins comes at a compromise between surface area and increased stability. Large fins may provide more stability, but they also contribute to a larger drag force due to their increased surface area. Similarly, smaller fins imply less drag, but a potentially reduced stability as well. Ultimately, the finalized geometry, which is optimal for our rocket, is made of an 8in root chord, and a 6in tip chord, at a height of 5in.

The fin material will be fiberglass, as it is the best combination of strength and weight that fits our budget. The particular type of fiberglass that will be used is G10, also called Garolite, which has a tensile strength of $7.2 \pm 0.3 \cdot 10^7 Pa$, at a density of $2.0 \cdot 10^3 kg/m^3$. Adding an airfoil significantly reduces drag and increases the apogee. However, it makes the manufacturing of the fins more challenging. It is crucial that the height-to-length ratio of the airfoil stay constant, meaning that as the length gets shorter, the fins are at risk of being too thin and breaking off. Additionally, it is important to note that a large apogee can be detrimental, as that could lead to the disqualification of the team. For this reason, it was ultimately decided that the fins will not have an airfoil such that the cross-section of the fins is a rectangle. To compensate for the induced drag force, the edges of the fins will be filleted, such that they are rounded off.

3.1.6 Motor Tube Design and Alternatives

The motor tube design was primarily motivated by the design of the rest of the airframe. A 4in diameter lower end and minimization of overall length led to the general geometry of the motor tube. The geometry was also decided upon in tandem with the motor choice. The specific length (26in) and diameter (Outer: 2.276in, Inner: 2.152in) were chosen to properly fit the chosen motor.

The material used for the motor tube is kraft phenolic. From our research, kraft phenolic offers the best heat resistivity and strength for the price. Other options that were considered were Blue Tube (low heat resistivity), fiberglass (expensive), and carbon fiber (expensive).

3.1.7 Motor Choice and Alternatives

Motor choice was governed by the rest of the airframe design, similarly to the motor tube. The Cesaroni L730 best suits our current design with the goals of minimizing rocket length, providing safe apogee approximation, and capitalizing on use of the boat tail. Other motors such as the Cesaroni L990-BS produced similar results but increased our expected maximum acceleration too much (around 30%). An additional alternative motor is the Animal Works L777 which gives a similar apogee. The local supplier for rocket motors used by CalSTAR currently does not carry motors manufactured by Animal Motor Works, so the Cesaroni L730 was chosen over it.

3.1.8 Boat Tail Design Alternatives

Sub-Scale Boat Tail

There will be no boat tail or tailcone retainer on the subscale rocket. This is due to the very similar outer diameters of the booster tubing and the motor retention cap. Due to the small transition in diameters between the motor tube and the end of the booster tube, manufacturing a boat tail to fit over the motor retention cap would yield a boat tail with an inclination angle around 2 degrees, which is too low to sufficiently reduce drag. Since this would negligibly reduce base drag but still add mass to the vehicle, this design was not selected.

One of the possible ways to compensate for the large diameter of the motor retention system would be to have a tailcone retention cap, where the boat tail also functions as the retention cap. In this way, a smaller base diameter can be achieved for the boat tail, decreasing the amount of base drag. Several of these tailcone retainer caps are available for purchase from multiple vendors, however none of them are the correct diameters to fit both the 2.56in Blue Tube and a 54mm motor. Manufacturing this part in house would be difficult with the machinery accessible to the team. Even if we could manufacture this part, the reduction in drag would not be as significant as on the full scale rocket. The difficulty in manufacturing and the relatively low reduction in drag led to opting out of this design choice.

Full Scale Boat Tail

A conical fiberglass boat tail will be manufactured with a forward diameter of 4.014in, an aft diameter of 2.465in, and a length of 4.7in. The aft end of the boat tail will be rounded out via sanding, and the boat tail should fit snugly around the motor retention system. There will be a section of coupler 0.5in in length on the forward end of the boat tail so that it can be fitted and secured correctly to the end of the rocket.

A conical boat tail was selected over several other shapes, such as ogive and power series. These other shapes may be beneficial for longer boat tails or wider rockets, but for our rocket a conical boat tail was best. This was primarily determined via OpenRocket Data.

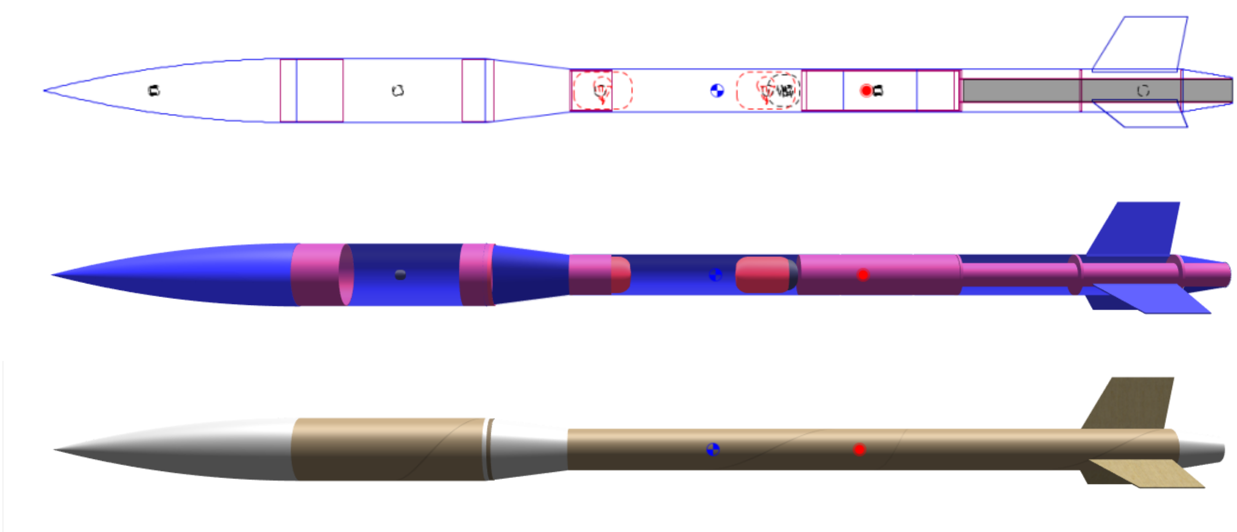
The dimensions of the boat tail could have been different in order to minimize base drag; however, our design had a major constraint in the motor retention system. The inner diameter of the base of the boat tail is designed to fit around the motor retainer, and the length was determined by optimizing the boat tail transition angle to roughly 9 degrees. This serves to maximize the rediction of base drag, as confirmed by OpenRocket apogee simulations.

Fiberglass was chosen as the material for our boat tail over plastic, aluminum, and a few other materials. Aluminum and other metals are difficult and expensive to manufacture, and plastics do not have sufficient heat resistance to survive in such close proximity to the thrust exhaust. Thus, fiberglass cured with high temperature epoxy was selected as our material, as it can be easily manufactued to our specifications and can withstand the stresses of the environment.

3.1.9 Nose Cone Choice and Alternatives

The nose cone choice accompanying the rocket design is intended to minimize inflicted drag and overall rocket mass. As the rocket is designed for subsonic flight, nose cones of ogive geometry are economically and aerodynamically ideal. Additionally, the aforementioned constraints of drag and mass further favor nose cones of minimum size and weight Such constraints indicate that a fiberglass is the ideal material for this rocket due to its high compressive strength and low weight. In accordance with Student Launch guidelines, the nose cone cannot be manufactured in-house, and must be one commercially available by a third-party enterprise. As a result, the optimal nose cone choice for this rocket would be an ogive, fiberglass nose cone of a diameter of 6in and a tip-to-shoulder length of 24in, as this is the smallest and lightest nose cone that is commercially available. Alternatives for nose cone choice are conical, fiberglass nose cones of 6in diameter and 30in length, and ogive, fiberglass nose cones of 6in diameter and 30in length. However, as these nose cones significantly increase overall mass (by roughly 8oz), as well as net drag as modelled by OpenRocket, the preference of nose cone aligns with the design of the aforementioned nose cone.

3.2 Design Metrics



3.2.1 General Overview

- Length: 9.42 ft

- Wet Weight: 27.125 lbs
- Dry Weight: 24.14 lbs
- Apogee: 5555ft
- Maximum Velocity: 0.54 Mach
- Maximum Acceleration: 8.95 g
- Stability: 2.41 cal

3.2.2 Weight Distribution

- Electrical: Electrical will be permitted 2 lbs of mass in the nose cone and an additional 2 lbs for avionics. Avionics will be located in the "Booster+" body tube.
- Payload: Payload will be given 6 lbs to use for the rover and deployment system. This mass will be placed in the payload tube.
- Recovery: For recovery the subteam is allowed a total of 1.568 lbs of equipment plus approximately an additional $\frac{1}{3}$ lbs for miscellaneous parts. Of the 1.568 lbs, the main parachute weighs 0.811 lbs, the drogue parachute weighs 0.134 lbs, and the shock cord weighs 0.623 lbs. This mass will be located in the recovery tube.
- Propulsion: 4.9 lbs (wet mass) will be dedicated to the booster section of the rocket.
- Airframe: The remaining weight (9.849 lbs) is for the airframe of the rocket. This weight will be spread among the body tubes, structural elements, and fins of the rocket.

3.2.3 Length Distribution

- Nose Cone: The rocket will use 24in long fiberglass ogive nose cone made in a 4:1 length to diameter ratio. This space will be made available for payload and electronics equipment.
- Payload Tube: Payload is permitted an 18in by 6in OD body tube for their rover and deployment system.
- Transition Piece: The rocket will utilize an 8in transition piece with a fore OD of 6in and an aft OD of 4in.
  - Payload Coupler: The transition piece will have a coupler on the fore end that extends 3in into the payload tube. Payload will still have access to this space.
  - Recovery Coupler: On the aft end of the transition piece will be a 4in coupler that extends into the recovery tube. This space will still be usable by recovery.

- Recovery Tube: The recovery subteam will have 26in of body tube to store parachutes, shock cord, and any other equipment that will be needed. This section of the rocket has an OD of 4in.
- Avionics Bay Tube: Electrical will have a 7in by 4in OD body tube to store the rocket's flight computers.
  - Avionics Bay Coupler: The coupler between the recovery tube, avionics bay, and booster tube will be one 15in piece that runs through the entire avionics bay.
- Booster: The booster section of the rocket will be 26in long and will house the motor tube and centering rings. At the aft end of the booster tube will be a set of three fiberglass fins to stabilize the rocket in flight.
- Boat Tail: The rocket will have a boat tail that is 4.7in long to reduce drag. The boat tail will bridge the gap between the 4in body tube and the end of the motor retainer.

3.2.4 Mission Performance Predictions

The projected altitude of the rocket is 5555ft. Although this projection is currently above the maximum allowed altitude, we predict that some sections of the rocket may ultimately be heavier than our current prediction. Additionally, ballast can be added to the rocket in order to increase weight and reduce apogee.

The maximum velocity of the rocket during flight is Mach 0.55. The maximum acceleration is 8.83 Gs, and the motor provides a maximum thrust of 273.59 lbf. Flight simulation results are illustrated in Figure 1.

The mass of the payload section is projected to be 6 lbs. The mass of the avionics bay is projected to be approximately 2 lbs. The remainder of the rocket, including the rest of the airframe, the motor, and the parachutes are projected to weigh approximately 21.125 lbs. The total weight of the rocket is 27.125 lbs.

The static stability margin is calculated to be 2.41 calibers. The center of pressure is located 78.2in from the tip of the nose cone, and the center of gravity is located 63.6in from the tip of the nose cone.

Figure 1: Flight Simulations

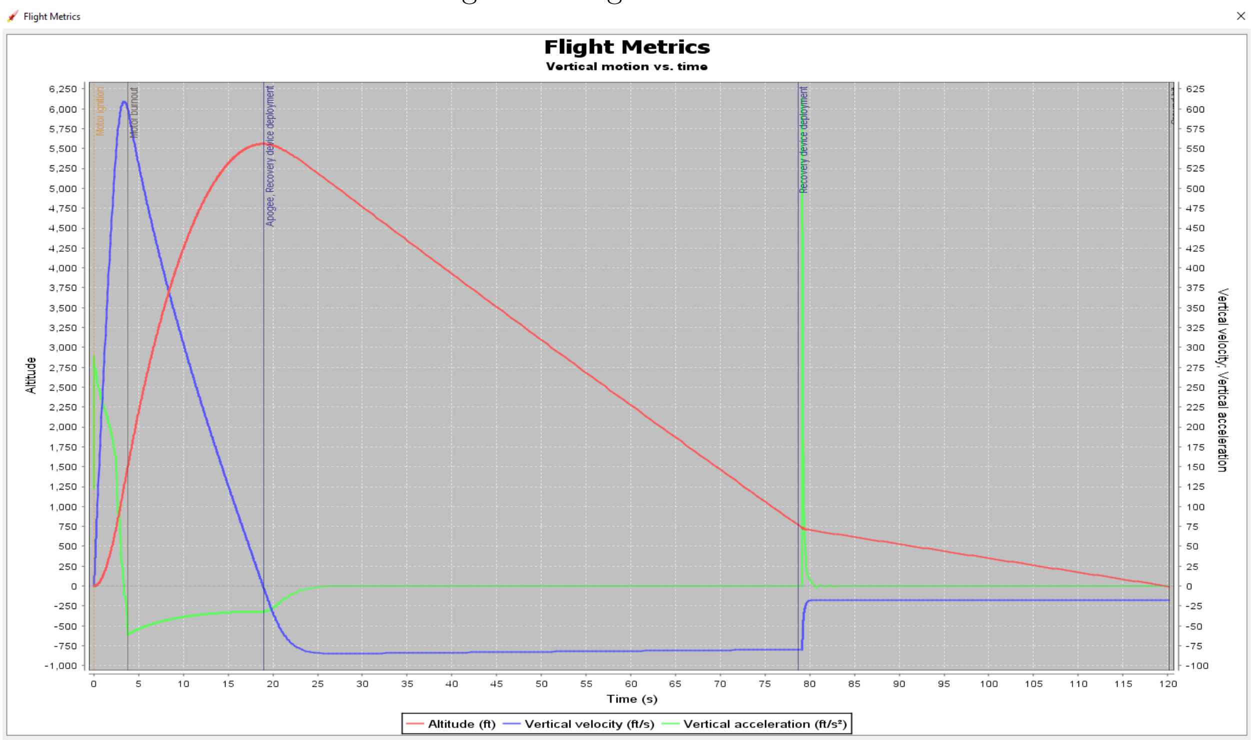


Figure 3: The total drift of the rocket with 5 mph wind is approximately 330ft.

Figure 2: The total drift of the rocket with no wind is approximately 9.5ft.

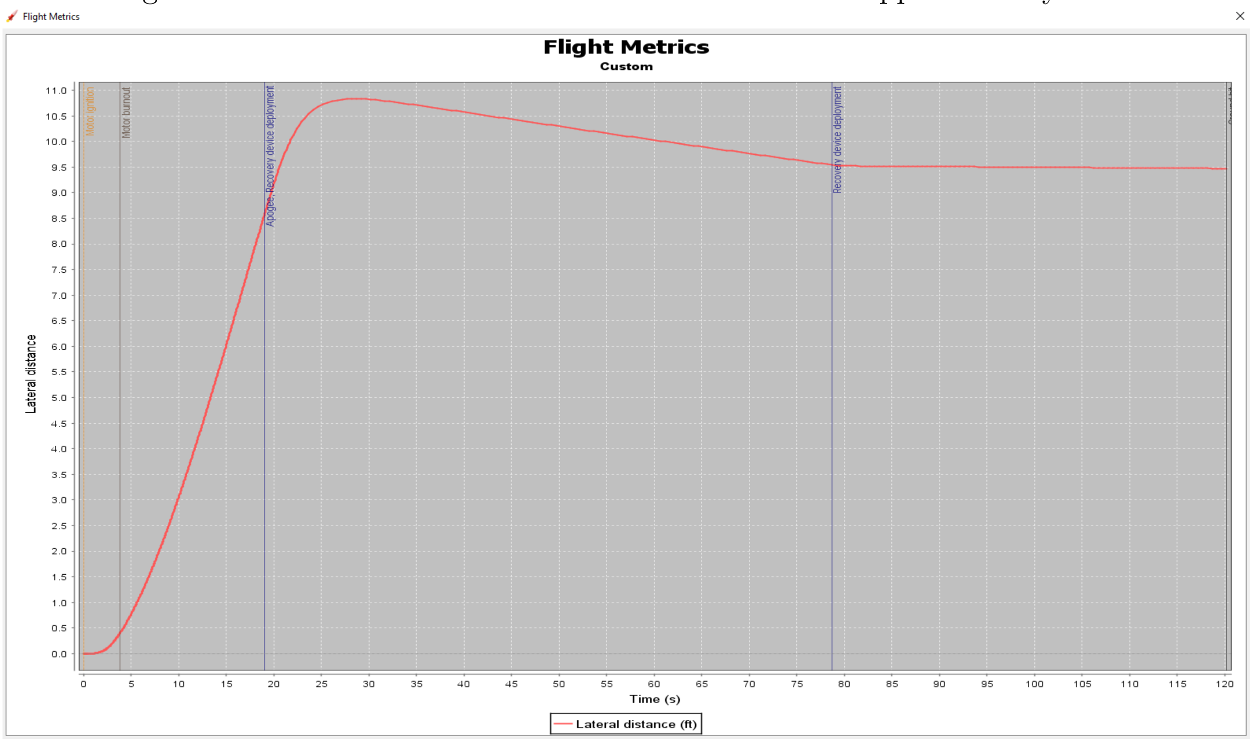


Figure 4: The total drift of the rocket with 10 mph wind is approximately 775ft.

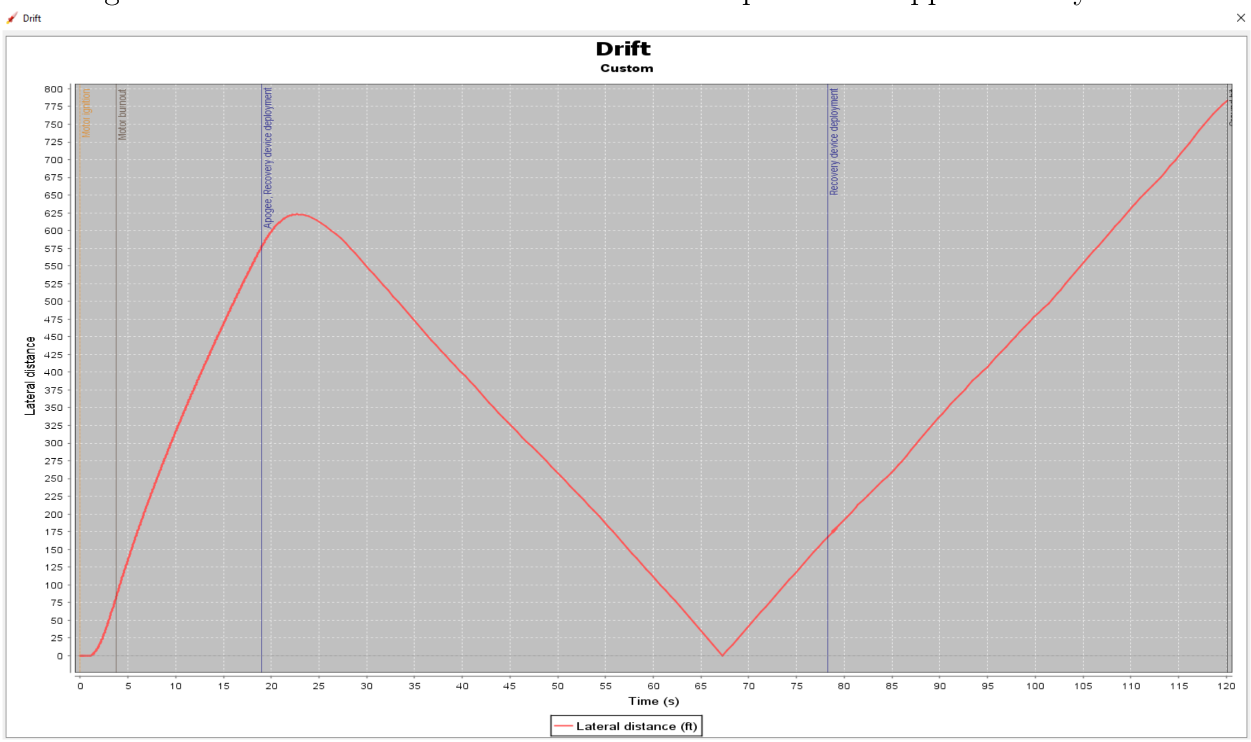


Figure 5: The total drift of the rocket with 15 mph wind is approximately 1300ft.

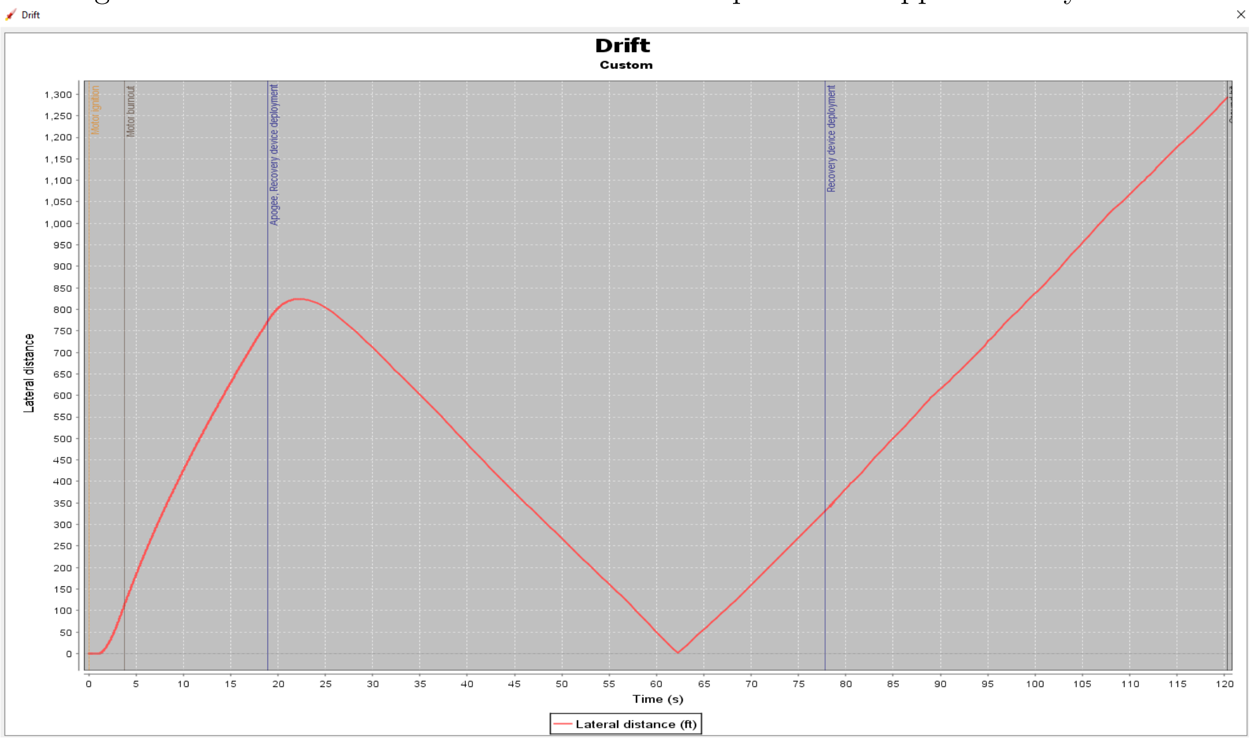
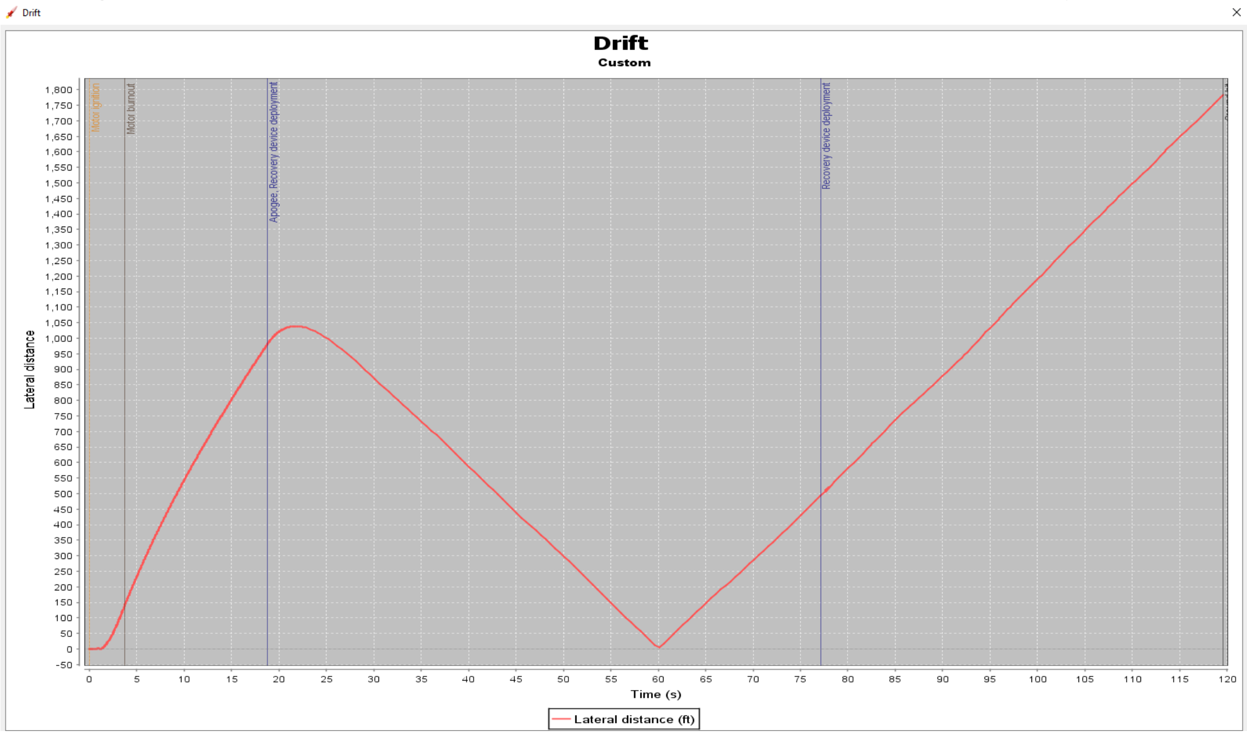


Figure 6: The total drift of the rocket with 20 mph wind is approximately 1750ft.



3.3 Requirements

Requirement	Verification Plan	Status
The vehicle shall deliver the science or engineering payload to an apogee altitude of 5,280ft above ground level.	OpenRocket simulations and the Perfectflite Stratologger CF Altimeter will verify that the design and an Cesaroni Technology L730-P motor meets the altitude requirement.	In Progress. OpenRocket simulations have given an apogee estimate that matches the requirement for the motor selected. Will be verified by further computer analysis and test launch.
The vehicle shall carry one commercially available, barometric altimeter for recording the official altitude used in determining the altitude award winner.	A Perfectflite Stratologger altimeter will be used to record the official attitude.	Completed. Altimeters have been purchased and attachment has been determined.
The launch vehicle shall be designed to be recoverable and reusable. Reusable is defined as being able to launch again on the same day without repairs or modifications.	Structural analysis both in simulation and testing will be performed to make sure the vehicle can withstand recovery at descent velocities.	In Progress. Materials have been selected with this requirement in mind. FEA and physical tests have yet to be conducted.
The launch vehicle shall have a maximum of four (4) independent sections. An independent section is defined as a section that is either tethered to the main vehicle or is recovered separately from the main vehicle using its own parachute.	Verified through inspection of design.	Completed. STAR's vehicle only has 2 independent sections (3 counting the rover).
The launch vehicle shall be limited to a single stage.	Verified through inspection of design.	Completed. STAR's vehicle has one motor and one stage.
The launch vehicle shall be capable of being prepared for flight at the launch site within 4 hours, from the time the Federal Aviation Administration flight waiver opens.	Assembly and pre-launch checklists will be made to make sure preparations takes within 4 hours. Will be verified by test launch(s).	Not started.

Requirement	Verification Plan	Status
The launch vehicle shall be capable of remaining in launch-ready configuration at the pad for a minimum of 1 hour without losing the functionality of any critical on-board component.	Verified through inspection of design.	Completed. No part of the functionality of our design will be affected by the passing of 1 hour.
The launch vehicle shall be capable of being launched by a standard 12 volt direct current firing system. The firing system will be provided by the NASA-designated Range Services Provider.	Verified through inspection of design and test launch.	In Progress. The motor selected is ignitable by standard systems, and no part of the design requires any additional or unique circuitry or equipment.
The launch vehicle shall use a commercially available solid motor propulsion system using ammonium perchlorate composite propellant (APCP) which is approved and certified by the National Association of Rocketry (NAR), Tripoli Rocketry Association (TRA), and/or the Canadian Association of Rocketry (CAR).	Verified by inspection of design and motor selection.	Completed. The Cesaroni Technology L730-P motor satisfies these requirements.
The total impulse provided by a College and/or University launch vehicle shall not exceed 5,120 N-s (L-class).	Verified through inspection of design and motor selection. An Aerotech L1150 motor will be used.	Completed. The Aerotech L1150 motor has an impulse of 2764 N-s.
The launch vehicle shall have a minimum static stability margin of 2.0 at the point of rail exit.	Will be verified using OpenRocket to determine center of pressure and gravity.	Completed. STAR's rocket has a minimum static stability margin during ascent of 2.41, as calculated by OpenRocket.
The launch vehicle shall accelerate to a minimum velocity of 52 fps at rail exit.	Will be verified by testing and OpenRocket simulations of rocket.	Completed. STAR's rocket has a velocity at rail exit of 82.8 fps off an 8ft rail, as calculated by OpenRocket.

Requirement	Verification Plan	Status
All teams shall successfully launch and recover a subscale model of their rocket prior to CDR.	Will be verified by a test launch before the CDR.	In Progress. The team plans to launch the subscale model at LUNAR on December 2nd.
All teams shall successfully launch and recover their full-scale rocket prior to FRR in its final flight configuration.	Will be verified by a test launch.	In Progress. The team plans to launch the full-scale rocket at LUNAR on February 3rd.
Any structural protuberance on the rocket shall be located aft of the burnout center of gravity.	Verified through inspection of design.	Completed. No protuberance on the rocket is located aft of the burnout center of gravity in our design.
Vehicle Prohibitions	Verified through inspection of design.	Completed. STAR's rocket does not utilize any of the materials or features explicitly prohibited in section 1.19 of the NSL Handbook.
The launch vehicle shall not exceed Mach 1 at any point during flight.	Verified through testing and OpenRocket simulations.	Completed. STAR's rocket reaches a maximum velocity of Mach 0.55 during flight, as calculated by OpenRocket.

4 Recovery Subsystem

4.1 Component Analyses

4.1.1 Avionics Bay

Description: The avionics bay is a critical component of the recovery subsystem, containing the altimeters necessary to properly deploy the parachute system. The chart below compares the avionics bay designs up for consideration. All designs relying on two centering rods unless otherwise specified.

Design	Benefits	Costs

Current: I-Beam Sled	1. No wheels or rails, which will simplify the manufacturing process 2. Two rod design preserves structural integrity of the bay along the Z-axis 3. Holes in sled allow for easy wire management 4. Components can be mounted on either side allowing for the sled to be compact	1. Slots may need to be reinforced due to wear over time
Parking Garage Sleds	1. Few movings parts, so the likelihood of a mechanism failure is small 2. Small door compromises less of the the airframe's aerodynamics	1. Horizontal doors take up larger portion of the airframe's diameter 2. Multiple rails creates more sources of failure
Pie Sled	1. All components mounted on horizontally on a single sled 2. Simple construction	1. Due to a decreased airframe diameter, the selected altimeters would not fit properly
Bookshelf Sled	1. Each component has its own specialized section 2. Mounting components own their side would allow them to fit closer together, decreasing door size.	1. Manufacturing process would be difficult due to the small size of the sled 2. Possible complications with load force bearing against the plane of the altimeter

Adjustable Rods	1. Sled is easily removable from the avionics bay	1. Would be difficult to secure sled from moving during flight 2. Three rods would be required for optimal strength, increasing the overall weight of the rocket
Classic Sled	1. Proven to be effective 2. Simple to manufacture 3. good structural integrity	1. Not easy to access and mission could be compromised if quick access is needed 2. Requires a much larger door than other designs 3. No easy way to run wires for the sled components

Final Decision: The I-Beam sled design will be used for the avionics bay. There will be two one-half in. bulkheads on the top and of the bay. Then, there will be an additional two one-fourth in. bulkheads glued together mounted within the existing bulkheads, as shown by Figure 10. These bulkheads will have section removed from them, with their edges cut at a 45° angle in order to create a triangular slot. The I-Beam sled will then slide into these slots and be held in by the door.

There are several reasons why this design was chosen, the main being ease of access combined with door size. This design offered the easiest access to the avionics bay with the smallest door. Cutting into a section of the airframe is not ideal, so the smaller the door, the more aerodynamic the rocket. In addition, the slot-fit design was the simplest mechanism that provided the most structural integrity. Since their are no moving parts other than the sled itself, there are no sources of mechanical failure. The mounting of the components to the sled is also simplified and streamlined. The batteries and altimeters are mounted via two screws each, with the batteries held in a 3D printed case. Rather than a complex bracket system, all components can be removed by just removing two screws. Furthermore, the hole in the center of the sled allows for the wires to be easily routed, connecting all of the necessary components. Overall, this design combines several aspects of simplicity, structural integrity, and accessibility to create the avionics bay most suited for STAR's mission.

4.1.2 Avionics Bay Door

Design	**Benefits**	**Costs**

Current: Four Screws	1. Ensures the door will be securely fastened 2. Ease of manufacturing and repairing	1. Risk of screws protruding from airframe, but can be fixed with some shallow countersinking. 2. Possible leakage of air, but can be fixed with using a decal to cover it
Sliding Magnetic Latch	1. Door locked flush against the airframe causing little to no drag 2. Ease of access and can quickly unlock door	1. Hard to manufacture 2. Difficulty knowing where exactly the slot for the door is along ring 3. The 270 degree ring may have compromised structural integrity 4. The material would most likely be aluminum, which would significantly increase the weight

Final Decision: The four-screw sled design was chosen out of a variety of factors. Primarily, this design was more feasible to manufacture and integrate with the rest of the avionics bay. In particular, this would not require significant increases in mass, which would most likely be necessary for the ferrous material needed for a magnetic latch. Furthermore, this would not risk the possibility of having electrical disruptions resulting from the magnets.

4.1.3 Bulkheads

Description: The bulkhead will isolate the avionics bay from the parachute deployment devices.

Designs	Benefits	Costs
Plywood [Final Design]	1. Lightweight 2. Ease of manufacturing using laser cutters	1. Possibility of ply separation
Fiberglass reinforced plywood	1. Lightweight 2. A hybrid, incorporating the ease of manufacturing plywood and the durability of fiberglass	1. Would need to create the hybrid ourselves

Table 4: Bulkhead Analyses

Final Decision: The bulkheads will consist of six $\frac{1}{4}$in pieces of plywood epoxied together to make a total of two $\frac{3}{4}$in stacks. One piece will be sized to fit tightly in the coupler while the other will be sized to fit the airframe. This staggered area will allow both bulkheads to be comfortably fitted into the ends of the tube of the avionics bay. The efficiency, cost-effectiveness, and convenience of this option outweigh the engineering benefits of the fiberglass/wood hybrid. Plywood is more readily accessible and easier to cut with a laser cutter and miter saw.

4.1.4 Centering Rods

Description: In order to optimize structural integrity, the dual-rod design will be adopted.

Designs	Benefits	Costs
Dual Rod [Final Design]	1. Double the structural integrity (each 1/4 in. diameter) 2. Distribution of stress 3. Better sled support	1. Two times as heavy
Single Rod	1. Allows for rotating altimeter platform 2. Lighter	1. Difficult to manufacture 2. Creates higher stress point in bulkhead

Table 5: Center Rod Analyses

‘

Final Decision: The dual-rod design will be adopted in order ensure the avionics bay portion of the airframe is as structurally stable as possible. Each rod will be made out of aluminum or an aluminum-based alloy, because of the durable properties of aluminum. Each rod will be a quarter inch in diameter and threaded all the way through. Furthermore, the rods will be driven through the platform itself, in order to ensure that it doesn't move during flight.

4.1.5 Bolts

Description: To provide the maximize strength and stress distribution, U-Bolts will be used on each bulkhead.

Designs	**Benefits**	**Costs**
U-Bolts [Final Design]	1. More durable 2. Greater stress distribution as a result of the two connections to the bulkhead	1. Requires two holes, which if not sealed properly, might increase risk of air pressure fluctuations mid-flight
Eye-Bolts	1. Lighter 2. Only need one hole per bulkhead	1. Not as strong as the U-Bolt 2. Most likely thinner than U-bolt

Table 6: Bolts Analyses

Final Decision: In order to distribute the stress and force of thrust during launch, U-Bolts will be used instead of Eye-Bolts. Attaching a U-Bolt to each bulkhead, positioned between the two protrusions from the two center rods, would provide for a much more sturdy avionics bay.

4.1.6 Shock Cords

Description: This is an analysis on the type of shock cord to be used to tether the rocket and parachutes together.

Designs	Benefits	Costs
Tubular Kevlar [Final Design]	1. Very durable 2. Can hold high amounts of strain 3. Lighter than strap nylon	1. More expensive per length ($4.34 /yard)
Strap Nylon	1. Cheaper per length ($1.87 /yard)	1. Not as durable and more massive

Table 7: Shock Cord Analyses

Final Decision: Tubular kevlar will be used for the shock cord, because it has more durability and can handle higher amounts of strain relative to the strap nylon. Despite the higher price, it is worth the increased precaution.

4.2 Deployment System

Summary: The deployment system used for this launch vehicle utilizes a systematic design of black powder ejection charges, altimeters, and Tender Descenders and focuses on two critical facets: 1) redundancy and 2) consistency.

To ensure that the launch vehicle will safely land for every launch, the deployment system must have redundancy. This is to create the highest probability of success. First and foremost, we will be using two vials of black powder, rather than one, for the separation of the rocket during drogue chute deployment. Each would have enough to separate the rocket on its own, and the rocket is designed to withstand such structural loads. Furthermore, there are two altimeters to ensure the firing of the e-matches at the detection of the correct barometric reading. The two altimeters will simultaneously and independently read the barometric data and deploy the black powder ejection charges. These, in turn, are each powered by their own 9V-Duracell battery. Finally, in order to ensure the success of the same-side dual deployment procedure, a system of two Tender Descenders in series was developed. More details are found in Figure 7.

Along with redundancy, consistency is also crucial. This is one of the primary purposes for flying the following recovery deployment system; because it is a heritage design and has proved to be 100 percent successful at all of the previous years' launches.

1. The following orientation will be described in order beginning from the avionics bay to the transition tube.
2. Altimeters: PerfectFlite StratoLoggerCF
    - Dual deployment
    - Data storage after power shut-off

- Audible continuity checks
- Relays flight data via a series of beeps
- Tolerant to 2 seconds of power loss during flight
- Resistant to false readings due to wind gusts up to 100mph

3. Two L2 Tender Descenders (TD) linked together in series
   (a) Will be designated as TD1 for the TD located closest to the Av-Bay and TD2 for the TD located after the TD2
   (b) Contains two small quick links on each side of the quick link
   (c) Will eventually contain an E-Match in each
   (d) Contains 0.5 g of Black Powder in each
4. Shock Cords
   (a) Use one very long length of $\frac{1}{4}$in tubular kevlar shock cord, knotted at various distances and attached with quicklinks.
   (b) BAY-to-MAIN (B2M): This is the shock cord length between QL1, which is attached to the Av-Bay, and the main chute. This is stored as a closed loop and will not be extended until after the Tender Descender Charges are released. Its length is 48.75ft
   (c) MAIN-to-DROGUE (M2D): This refers to the length of shock cord between the Main Chute and the Drogue Chute. It is pulled out during the first Av-Bay and Transition section separation stage when the drogue chute catches air. Its length is 24.58ft
   (d) DROGUE-to-TRANSITION (D2T): This refers to the length of shock cord between the Drogue Chute and QL3, which is directly attached to the Transition section of the rocket. Like the M2B, it is also pulled out during the first two stage separation. Its length is 12.00ft
5. Quicklinks
   (a) QL1 - the one closest to the avionics bay; is connected to the following: 1) U-Bolt connected to Av-Bay, 2) Stingray Main Chute Bag, 3) B2M, 4) TD1
   (b) QL2 - the one connected to the main chute; connected to the following: 1) TD2, 2) Shock Cord to QL1, 3) Main Chute, 4) M2D
   (c) QL3 - the one connected to the drogue chute; connected to the following: 1) M2D, 2) Drogue chute, 3), D2T
   (d) QL4 - the one connected to the Transition; connected to the following: 1) D2T, 2) U-Bolt on the Transition Section Bulkhead
6. Parachutes

(a) Drogue Chute: 24in Elliptical parachute from Fruity Chutes; the red and white one, Coefficient of Drag - 1.5

(b) Main Chute: 72in Toroidal parachute from Fruity Chutes; the orange and black one, Coefficient of Drag - 2.2

7. Parachute Bag

   (a) Stingray: beige/off-white Kevlar bag with a custom fit pocket to protect the main chute during the black powder ejection charges. This is connected to QL1. The main chute is going to be pulled out of the Stingray when the Tender Descenders release the charges.

8. Parachute Blankets

   (a) Drogue Chute Blanket: Orange blanket that will cover the wrapped drogue chute

   (b) Complete Chute Blanket: Olive-green/gray blanket that will cover the stingray, drogue chute blanket, both tender descenders, and all shock cords excluding the D2T

4.3 Drawings and Schematics

Drawings and schematics of the electrical and structural assemblies can be found below:

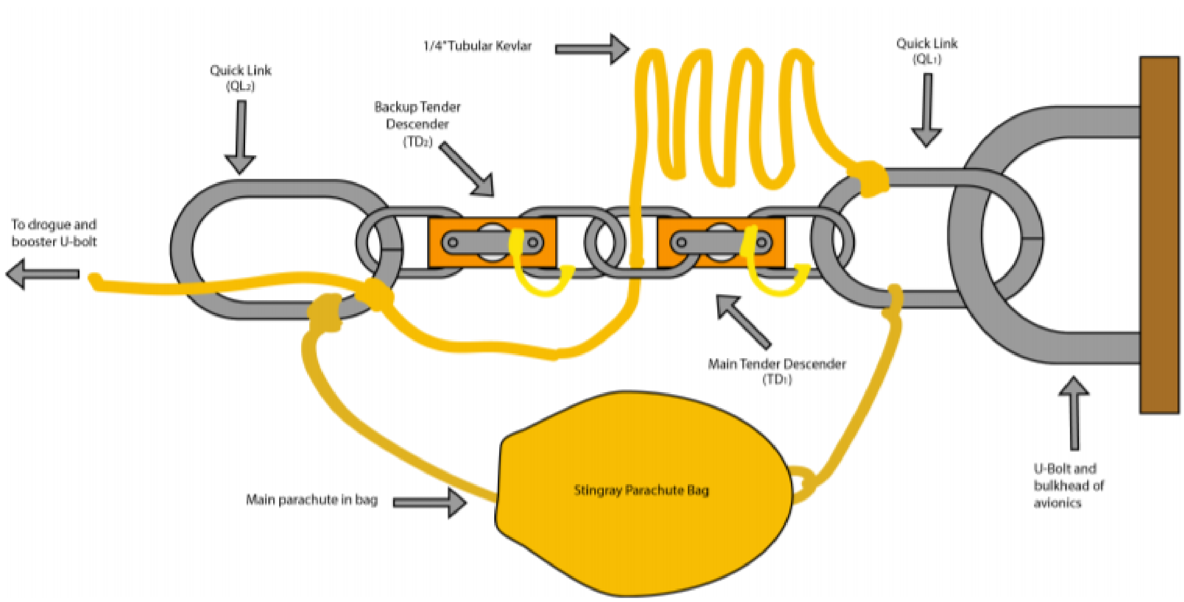


Figure 7: *Dual Deployment Orientation*

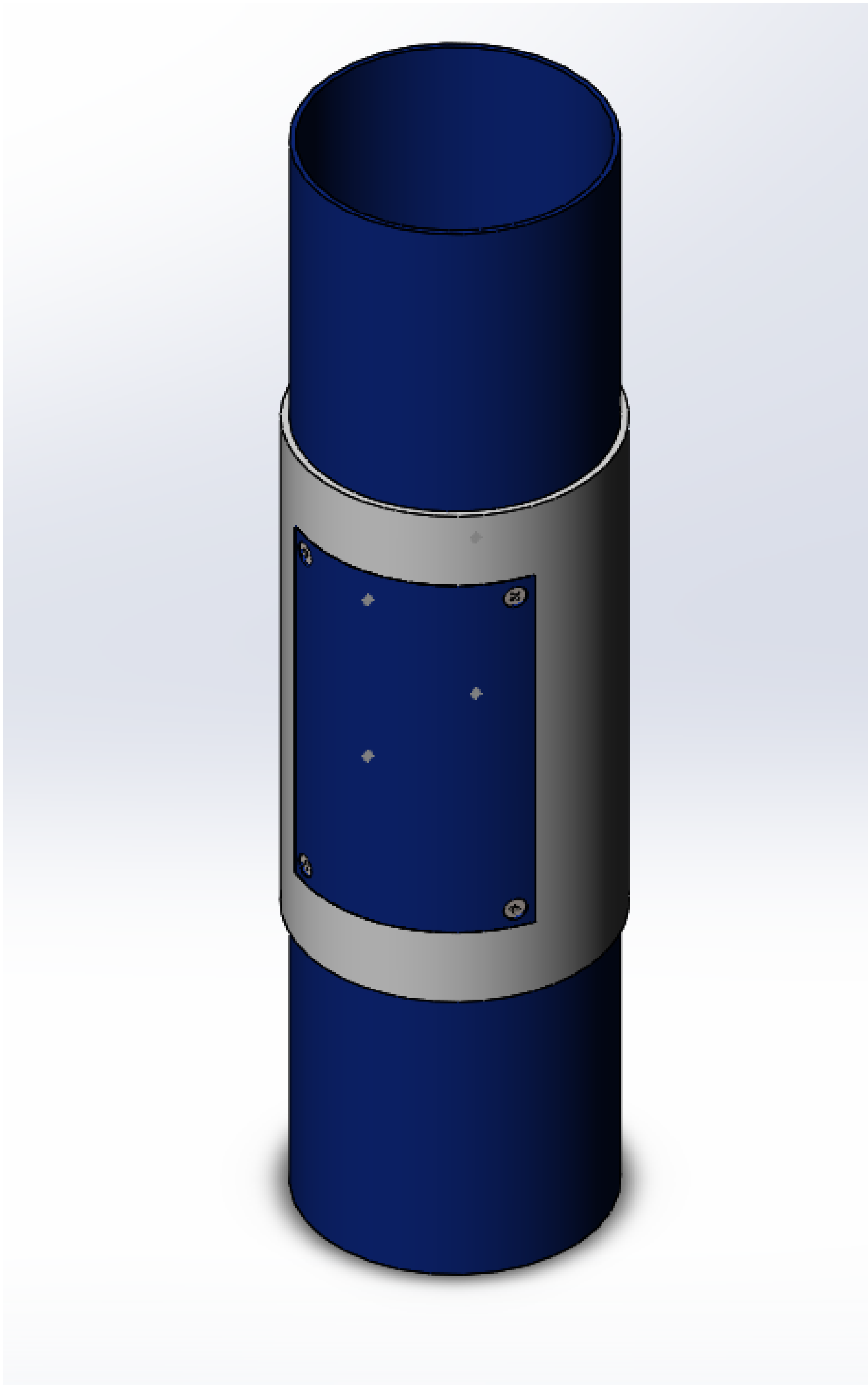


Figure 8: *Avionics Bay External Isometric View*

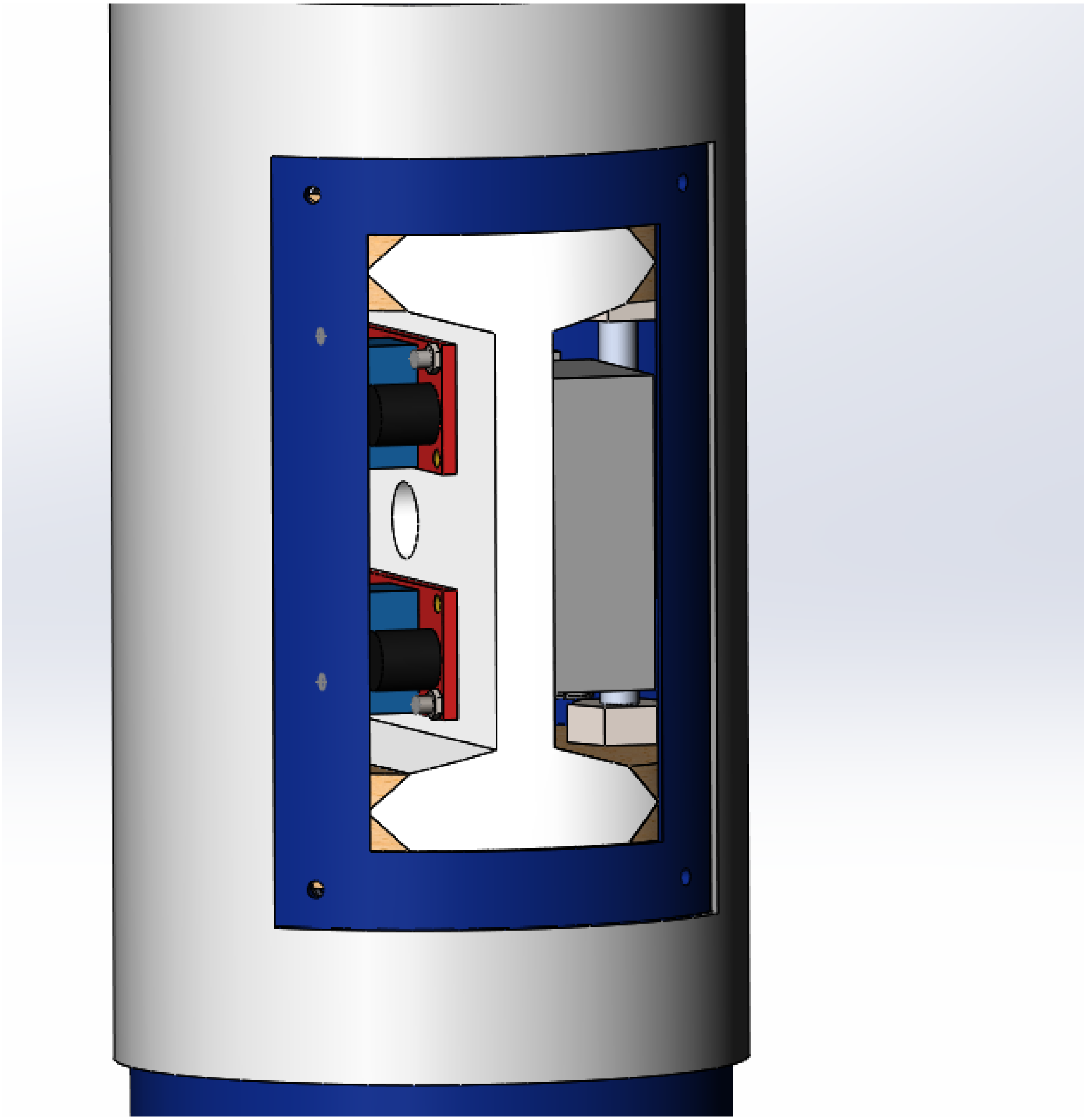


Figure 9: *Avionics Bay External View with Open Door*

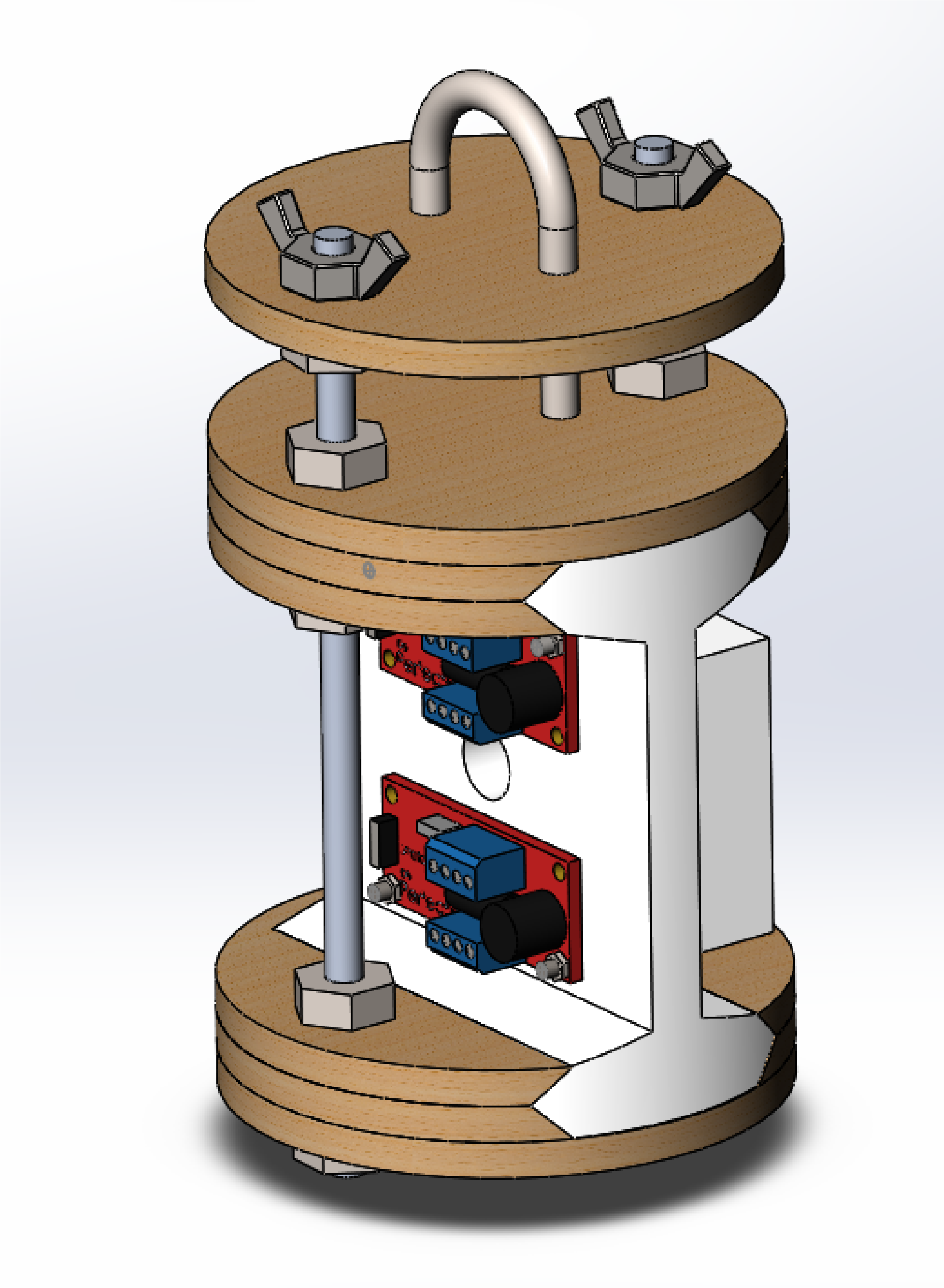


Figure 10: *Avionics Bay Internal Altimeters*

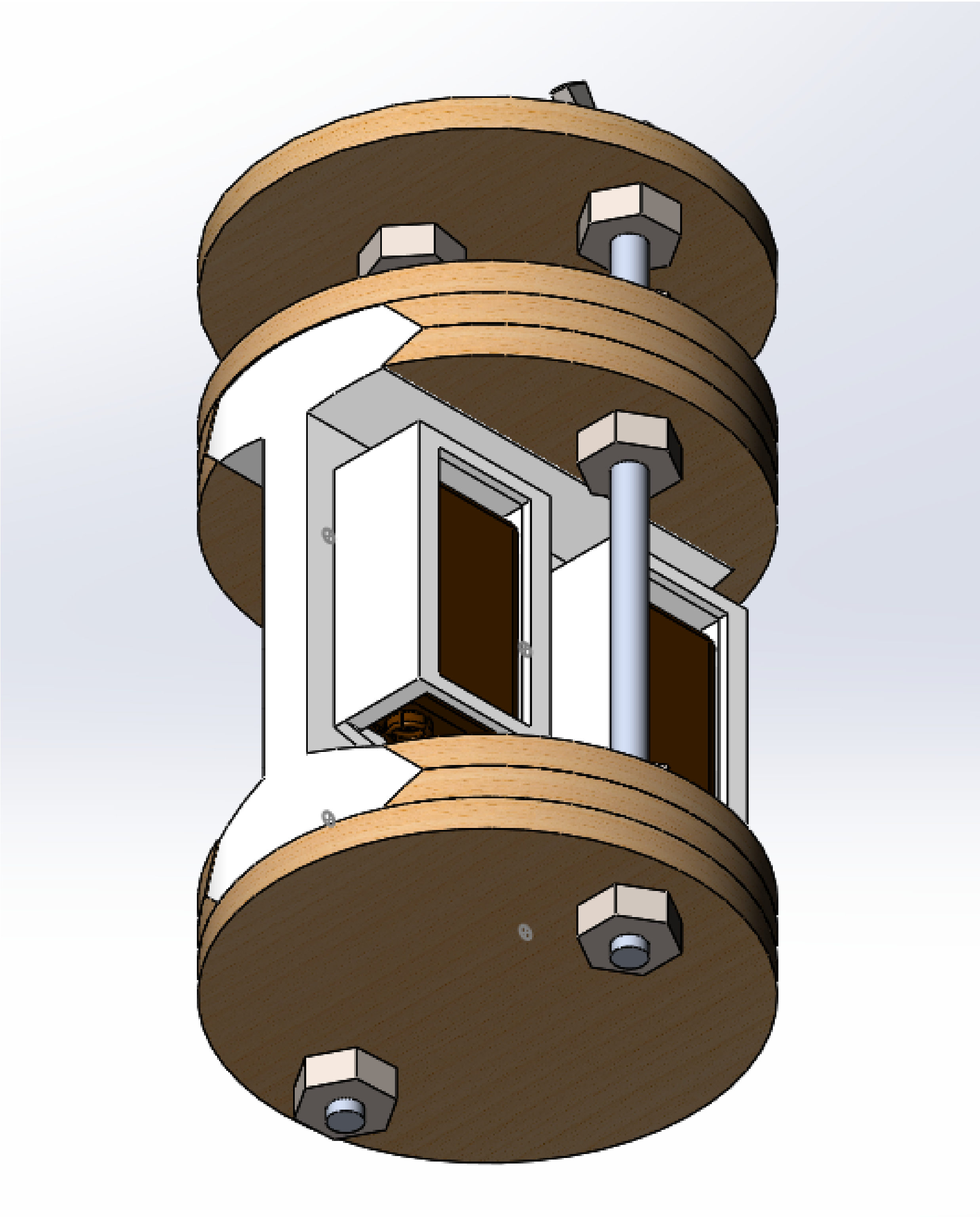


Figure 11: *Avionics Bay Internal Batteries*

4.4 Black Powder Calculations

To deploy the parachutes two altimeters will be used. The main altimeter is the Perfectflite Stratologger CF Altimeter, which is capable of deploying both the drogue and main chute. It will ignite an electronic match, which will then ignite black powder. The black powder will break the shear pins that hold the sections together and release the drogue parachute. The code written to calculate this number can be found in the Appendix. Two 4-40 shear pins will be used. The inputs into the program are 2 shear pins, a shear force of 40 lbs, an internal length of 14.75in, and a multiplication factor of 2. This yields a black powder quantity of 1.2180 grams to deploy the drogue chute. The Tender Descenders used to deploy the main chute will each contain 0.5 grams of black powder.

4.5 Kinetic Energy Calculations

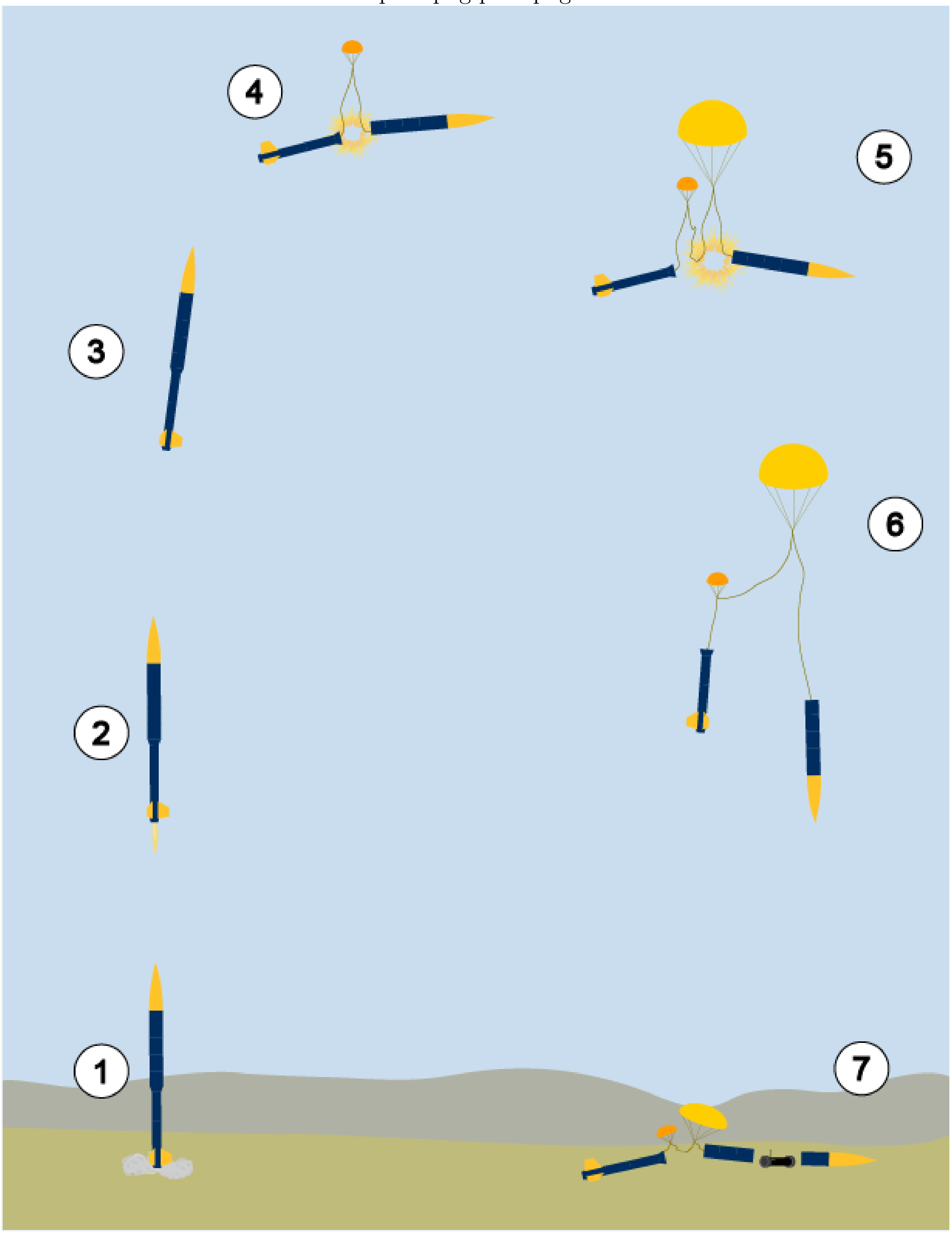
A Matlab program was written and used to perform drag force, terminal velocity, and kinetic energy calculations for the descent of the rocket. During parachute deployment, the rocket splits into two parts. The upper part has a weight of 11.12 lbs, the lower part has a weight of 10.61 lbs, and the parachutes have a weight of 2.04 lbs. The drogue parachute has a diameter of 24 in and a drag coefficient of 1.5, and the main parachute has a diameter or 72 in and a drag coefficient of 2.2. Using these numbers, it was calculated the rocket would descend with a terminal velocity of 17.29 ft/s. The final energy for the upper part of the rocket would be 51.63 ft-lbf, and the final energy for the lower part of the rocket would be 49.27 ft-lbf. This is significantly lower than the maximum allowed energy of 75 ft-lbf, so descent using these parachutes should be safe. The code used can be found in the appendix.

4.5.1 Flight Plan

The flight plan for the rocket can be seen in Figure 12.

Phase	Event
1	Ignition.
2	Powered flight.
3	Coasting.
4	Drogue parachute deployed at an apogee of 5567ft. AGL.
5	Main parachute deployed at an altitude of 1000ft. AGL.
6	Launch vehicle descends under main and drogue chute.
7	All sections of the rocket land with a KE under 75 ft-lbf. The rover is deployed.

Figure 12: Phases of Flight
path.png path.png



4.6 Rocket Locating Transmitters

The GPS system used to the track the avionics bay and booster is the TeleGPS Module, which operates at a unique frequency. This GPS has a clear-air operating range of 8,000ft, which is well over the maximum drift limit. The GPS has 10mW RF power. This GPS has been found to be fairly reliable during testing. The GPS will be housed in the nosecone portion of the rocket to ensure no potential interference of electronics within the avionics bay.

5 Safety

5.1 Responsibilities

The Safety Officer for CalSTAR is Grant Posner. The Safety Officer's responsibilities include:

- Ensuring that construction is carried out safely. In particular, the Safety Officer will maintain MSDS documentation for various chemicals and materials that team members may be working with, will ensure that the relevant team members understand the risks and procedures involved in these materials, will identify construction risks, and will design and implement procedures for minimizing these risks.
- Ensuring that all tests and launches abide by relevant codes and regulations. In particular, the Safety Officer will design and implement procedures to abide by the NAR High Power Rocket Safety Code; NFPA 1127; FAR 14 CFR, Subchapter F, Part 101, Subpart C; and CFR 27 Part 55; and verify team compliance through observation, instruction, and team agreement to the Appendix B. Furthermore, the Safety Officer will ensure compliance with all relevant local codes and regulations, and compliance of every team member with the commands of the Range Safety Officer at any launch site.
- Maintaining hazard analyses, team procedures, and safety protocols.
- Conducting pre-launch briefings and hazard recognition and accident avoidance briefings.

The utmost concern of the entire team during all team operations is safety. The primary duties and responsibilities of the Safety Officer and the members of the Safety Team are therefore intended to maximize team safety and minimize hazards and risks.

5.2 Personnel Hazards Analysis

The CalSTAR safety subteam does not envision any major safety issues with any of the team personnel. Certainly the risks below may occur, but we expect that proper training and safety reviews will mitigate all of the risks and allow for safe construction, assembly, and launch of the sub-scale and full-scale rockets. All construction will be carried out only by experienced and university-trained team members, and our mentor or other certified adults will handle hazardous materials whenever possible. Thus we expect team members to be exposed to a minimal number of possible hazards.

Furthermore, the team has MSDS documents available online at the team website for team members to read and use, and will have these MSDS documents in hard copy at our Richmond Field Station space, along with summarized team procedures. We have MSDS for the more hazardous materials we will be working with, and encourage all team members to understand the documents fully. We do not have operating manuals for machinery on our team website, but all team members who construct using university machinery (such as in the Etcheverry machine shop or in the Jacobs Hall MakerSpaces) must complete stringent university training, which cover topics such as proper operating and handling of machinery and all safety protocols. Jacobs Hall does have operating manuals online, and all team members who use the equipment in Jacobs Hall should be familiar with these manuals.

Finally, the Safety subteam has purchased PPE for team members' use, and requires the use of such PPE at all build events: any team members who do not use proper PPE will not be allowed to help with rocket construction, to maintain proper safety protocols.

The table below depicts the categorization method that is used throughout all the failure modes and analysis sections.

	Consequence					
Likelihood		Trivial	Minor	Moderate	High	Critical
	Rare	A1	B1	C1	D1	E1
	Unlikely	A2	B2	C2	D2	E2
	Moderate	A3	B3	C3	D3	E3
	Probable	A4	B4	C4	D4	E4
	Very Likely	A5	B5	C5	D5	E5

Figure 13: *Risk Assessment Matrix*

Risk	Effects	Severity & Likelihood	Mitigations
Inadvertent launch before rocket is at launch pad and site is clear	Possibility of major injury to team members or bystanders from physical contact with the rocket or its exhaust	E2	The motor will be installed only when required, and the launch system will be armed only when the rocket is at the launch pad. There will be minimal time between the rocket being ready to launch and the launch itself.

Risk	Effects	Severity & Likelihood	Mitigations
Unstable rocket path off the launch rail	Possibility of major injury to team members or bystanders from physical contact with the rocket or its exhaust	E2	The launch vehicle will have an acceptable stability and all appropriate safety checklists will be followed while loading the vehicle onto the launch rail to allow for most stable flight outcome. All nearby personnel will be attentive of occurring launches.
Rocket components falling without a parachute	Possibility of major injury to team members or bystanders from being hit with the free falling object.	E3	All components of the rocket will be secured properly and parachute connections will be secure. This will be verified before launch during a pre-launch checklist. All nearby personnel will be attentive of occurring launches and descents.
Injury during ground testing	Personnel experiences injury such as burns or trauma after being hit with part of the launch vehicle	D2	Make nearby personnel aware of dangers prior to ground testing. Personnel cannot stand in line with the rocket but instead must stand at least 10ft perpendicularly away from the long axis of the rocket body. The team member conducting the ground test will clearly and loudly announce the countdown.
Improper use of machining tools	Damage or wear to equipment, minor personal injury; possibly major damage to construction components.	D2	Workshop training is always required before personnel are allowed to use machines and equipment for construction. UC Berkeley machine shops only admit personnel once training and a test are completed.

Risk	Effects	Severity & Likelihood	Mitigations
Touching a hot soldering iron	Minor personal injury to due localized burns	C3	Electronics team members should be particularly careful around any soldering iron, and all soldering irons should always be assumed to be on and hot unless directly verified otherwise. Team members should never touch any part other than the handle of a soldering iron.
Improper handling of hazardous materials or chemicals	Explosion or fire, personal injury (burns, loss of eyesight, cuts, etc.); possible damage to rocket components.	C2	Experienced team members/team mentor should supervise all handling of hazardous materials, or the team mentor should handle materials himself. Also, use of Personal Protective Equipment and applying lab safety standards can help: wearing safety goggles, lab coats, closed-toed shoes, having minimal exposed skin, wearing gloves, etc.
Exposure to hazardous materials or chemicals (in particular fiberglass, epoxy, spray paints)	Skin, eye, and/or respiratory irritation; coughing or, in severe cases, lung damage and reduced respiratory capability	C2	Clothing that covers the arms, along with safety goggles and either a respirator or a dusk mask, should be worn when machining materials that may release dust or fibers into the air, and if possible work should be done outside or in an otherwise ventilated area (especially when spray-painting components). MSDS for particular materials have more information, which team members should be aware of before construction.

Risk	Effects	Severity & Likelihood	Mitigations
Electric shock while working with electronic components	Tingling, minor muscle contractions	B2	Batteries will not be installed except when testing or launch requires their installation. Rubber-encased wires primarily should be used in construction. Before touching bare wires, team members should ensure that batteries or power sources are disconnected.
LiPo battery explosion	The explosion of the battery could cause damage to personnel working nearby the electronics and could cause damage to nearby hardware.	C3	Personnel working with the LiPo batteries will use appropriate chargers that do not continue applying voltage once the battery is fully charged.
Finger pinched by the Ejection scissor lift	Hand injury to personnel due to the mechanism.	C1	Before operating the scissor lift, a safety check must be performed to ensure all personnel are clear of the mechanism.
Compressed air	Unexpected actuation of solenoid may cause damage to internal equipment and nearby personnel.	B1	Wear required PPEs. Nearby personnel will be made aware of the hazard and told to keep their hand away from the stroke of the piston.

5.3 Failure Modes and Effects Analysis

This is not a comprehensive list of failure modes, but the safety team expects that these failure modes are the most likely and problematic and have therefore considered how to address these issues in particular.

We have separated the failure modes analyses into multiple sections, each particular to one subteam.

Airframe Failures Modes

Risk	Causes	Effects	Severity & Likelihood	Mitigations

Rocket altitude does not reach desired range of 5280ft	Inaccuracy of OpenRocket model; weather conditions at launch	Significant loss of points	E3	Use OpenRocket to ensure vehicle will reach range at a variety of given wind conditions; verify accuracy of calculations with hand calculations and results of sub-scale and full scale launch
Recovery System does not deploy	Inadequate setup during launch	Extreme hazard to bystanders; extreme risk of damage to rocket	D2	Have thorough pre-launch and launch checklists; practice during sub-scale and full scale launches
Motor failure	Motor fails to ignite; faulty motor; improper storage/installation of motor	Rocket will not take off	D3	Double check out igniter; research company and motor for any faulty motors; use manufacturer's instruction to properly store motor
Rocket becomes unstable	Thrust to weight ratio does not meet minimum requirements to stabilize against wind speed	Loss of height	C2	Perform a series of test that determine the conditions the rocket might be exposed to during flight to ensure stability
Frame becomes compromised	Severe impact or other external forces	Instability during flight; failure to meet ready-to-fly condition after landing	D2	Perform structural analysis on material to ensure that structural integrity is not severely affected during flight; ensure all parts of rockets are intact and free of any imperfections that might occur during shipment

Motor tube failure during flight	Weak adhesive bonds between motor tube, centering rings, and body tube	Complete loss of flight vehicle; likely payload damage	E1	Take extra care to ensure epoxy is affixed to centering rings, as well as checking that centering rings are properly attached to the body tube; double check that motor tube is not damaged before constructing; use styrofoam to fill space between motor mount and body tube to absorb torsional forces
Launch rail fails to maintain vertical	Improper setup	Launch vehicle launches at an angle, potential danger posed to life and property	D1	Use structural analysis and ensure launch rail is constructed properly; check security of fasteners and components
Coupler failure	Weak fit between coupler and body section; weak adhesive bond with frame	Loss of stability and structural integrity; hazard to people on the ground; compromise internal systems	E2	Inspect rocket components thoroughly before launch; ensure sections are properly fitted together
Minor nose cone fracture	Improper handling or landing	Poor aerodynamic flow and possible trajectory deviation	C2	The rocket will be handled with care in transit, construction, and minor defects will be patched with epoxy filler.
Major nose cone fracture	Severe mishandling or failed parachute deployment	Mission failure	D1	Small-scale static testing will help mitigate accidents resulting in such a failure. In the case of major damage, a replacement can be salvaged or purchased.
Minor fin damage	Improper handling or landing; fin flutter during flight	Poor aerodynamic flow and guaranteed trajectory deviation	D3	The fin roots will be reinforced with fiber composite fillets and the fin section will be stored in an upright position as often as possible to keep stress on the fins to a minimum.

Major fin damage	Severe mishandling or failed landing	Compromised aerodynamics and rocket tumbling	D2	In the case of major fin damage, it may be possible for the fin to be replaced. In severe situations, the booster section of the rocket may need to be rebuilt.
Failed parachute deployment	Failure to break the shear pins or the tolerances between the body tube and coupler are excessively tight	Mission failure	D1	Extensive testing will be done to simulate separation during flight and couplers will be sanded for smooth and easy deployment.

Recovery Failures Modes

Risk	Causes	Effects	Severity & Likelihood	Mitigations
Drogue parachute fails to deploy	Rocket travels at too high of speed when main parachute is deployed, potentially severely damaging the rocket	Altimeters fail to recognize air pressure change, causing the black powder charges to not fire	E3	Use of two, redundant altimeters; perform several ground tests to be sure that charges will deploy parachutes.
Main parachute fails to deploy	Rocket lands at kinetic energy higher than 75 ft-lbf, damaging the rocket and potentially injuring bystanders	Altimeters fail to recognize air pressure change, causing the black powder charges to not fire; Tender L2 Descender fails	E3	Use of two, redundant altimeters; perform several ground tests to be sure that charges will deploy parachutes.

Risk	Causes	Effects	Severity & Likelihood	Mitigations
Altimeters shut off during flight, causing deployment system to malfunction	Parachutes either deploy too early or not at all, damaging the rocket and potentially injuring bystanders	Forgetting to turn on altimeters before flight; batteries run out	E3	Use new 9V Duracell batteries, check batteries before flight, and tightly secure all power supplies before flight.
Parachutes melt	Rocket is not ready for launch after landing; rocket potentially lands at kinetic energy higher than 75 ft-lbf, damaging the rocket and potentially injuring bystanders	Black powder deployment charges explode, creating too much heat inside parachute chamber	E2	Properly wrap parachutes in heat blankets.
Deployment charges are not sized properly	Rocket is either damaged from too large of ejection charge or parachutes are not deployed from too small of ejection charge	Black powder was not accurately allocated for each charge region	E2	Perform several ground tests to be sure that charges will deploy parachutes.
Shock cords snap at deployment	Sections of the rocket descend without parachute, damaging the rocket and potentially injuring bystanders	Minor cut to begin with; force of rocket is too much to hold for kevlar shock cords	E1	Perform force analysis and tensile test on shock cords.
Black powder residue enters avionics bay	Potential damage to electronic devices; heavy cleaning needed after flight	Bulkhead of avionics bay not secure/airtight enough	C2	Make sure avionics bay is completely sealed off from ejection charges using rubber gaskets.

Risk	Causes	Effects	Severity & Likelihood	Mitigations
Recycled component fails	Wear from use in previous launches	Rocket may impact ground with higher than allowed kinetic energy due to parachute failure.	D1	Carefully verify the launch integrity of all recycled components, particularly parachutes: check for any tears or holes, verify that parachute lines are still properly wound and have maintained tensile strength, and ensure (through testing) that any recycled parachute maintains its airtight qualities.

Avionics Bay Door Locking System Failures Modes

Risk	Causes	Effects	Severity & Likelihood	Mitigations
Magnetic disruption of electronics (detected pre-launch)	Using magnets while electronic systems are active.	Electronics malfunction causing a delay in launch.	3D	Put warning signs on magnets. Isolate magnets from electronics until it is confirmed that electronics are off.
Magnetic disruption of electronics (detected during launch)	Using magnets while electronic systems are active and not testing the systems pre-launch	Electronics malfunction which could deploy parachutes too early or not at all. The rocket could sustain damage and injure bystanders.	2D	Same mitigations as above with the addition of doing electronic tests pre-launch.

Risk	Causes	Effects	Severity & Likelihood	Mitigations
Rails holding locking metal bars fall off.	Rails are not adequately attached to the interior wall of the avionics bay	Door will be compromised. Electronic systems malfunction, and parachutes will either open too early or not at all. The rocket could sustain damage and injure bystanders.	2D	If screws are used, make sure the rail is securely bolted onto the wall. If adhesives are used, make sure the adhesives are applied thoroughly on the surface of the rails and placed firmly on the wall.
Battery or altimeters fall out of slides	Battery/altimeter is not securely bolted into slide.	Wires may sever and electronic systems may malfunction. The rocket could sustain damage and injure bystanders	2D	Secure the electronics as tightly as possible with bolts and screws.

Electronics Failures Modes

Risk	Causes	Effects	Severity & Likelihood	Mitigations
Connection failures between electronic components	Launch trauma, failure to properly test electronics	Payload will fail to eject and deploy.	E4	Minimize push-pull connections. Use PCB in place of breadboard. Ensure soldered joints are solid. Ensure wire lengths are appropriate (not taut).
Batteries are too low	Not double-checking batteries before launch, and not putting enough battery power in the rocket	Payload will never eject and deploy	E3	Pre-flight testing before setup and on launchpad. Include enough battery power to last two hours. Have full replacement batteries available.

Risk	Causes	Effects	Severity & Likelihood	Mitigations
Altimeter failure or miscalibration	Launch trauma, failure to properly test electronics on launchpad	If payload does not detect targets, the payload will not eject or deploy.	E3	Include comprehensive testing process in launch procedure. Secure altimeter to payload, and ensure connections are solid.
Accelerometer failure or miscalibration	Launch trauma, failure to properly test electronics	Payload data will be incorrect.	A3	Include comprehensive testing process in launch procedure. Secure accelerometer to payload, and ensure connections are solid.
Gyroscope failure or miscalibration	Launch trauma, failure to properly test electronics	Payload data will be incorrect.	A3	Include comprehensive testing in launch procedure. Solidly secure gyroscope to payload body.

Due to the complexity of the rover payload, the Failure Modes and Effects Analysis of the payload system is separated into multiple phases of the system: *deployment* of the payload portion from the primary body of the rocket, *ejection* of the rover from the payload section of the air frame, *movement* of the rover, and deployment of the *solar* panels.

- Overall Payload Failure Modes
  - Battery Power Management
    - Causes: A lack of proper battery sizing may cause batteries to run out of power before launch. Some batteries are not built to be able to withstand high acceleration.
    - Effects: All electronic components, including avionics, radio trigger, deployment solenoids, and ejection servos, are not powered on launch.
    - Mitigation: Make sure battery has enough amperage/capacity for tests and for one-h standby, and additionally use known battery types and brands, namely Duracell, that are known to withstand launch forces. Use external switches so that electronic systems can be turned on when on the pad.
    - Likelihood/Severity Rating: E1
- Deployment of the Payload
  - Deployment Timing
    - Causes: Programming errors, sensor failure, or radio failure.

    * Effects: The payload may deploy too early or too late. This type of deployment can affect the trajectory of the rocket, influence future rover actions, result in the rover failing to eject, or possible damage to equipment and bystanders.
    * Mitigation: Design of deployment systems will be mitigated through redundant systems for verification of deployment conditions. Namely, the combination of a accelerometer and an altimeter will verify that the payload has landed before deployment is initiated.
    * Likelihood/Severity Rating: E1
  - Break-Wire Disconnecting Early
    * Causes: Insufficient friction in the connector at the break point.
    * Effects: The payload will not deploy.
    * Mitigation: Use a connector that has sufficient friction to not disconnect from normal vibration and shock. Design the rocket assembly in such a way that assembly will force the connector together.
    * Likelihood/Severity Rating: C2
  - Failure of CO_2 Pressure Vessel
    * Causes: The difference between high pressures in the air canisters and the atmospheric pressure increases due to ascent of the rocket, acceleration, or other effects.
    * Effects: The carbon dioxide pressure vessel could undergo unplanned depressurization. Deployment would fail to occur, leading to a payload experiment failure.
    * Mitigation: The CO_2 pressure vessels will be chosen for similarity to flight heritage pressure vessels with similar purposes, and will be tested on subscale launch.
    * Likelihood/Severity Rating: E1
  - Displaced Tubing
    * Causes: Due to the turbulence of launch, tubes leading into the air tank may be disconnected, jammed, or torn.
    * Effects: Any sort of disturbance to the tubing of the deployment system may lead to the loss of air pressure. Deployment would fail to occur, leading to a payload experiment failure.
    * Mitigation: Tubing will be securely fastened and routed, and all connections will be thoroughly sealed and tested multiple times prior to launch.
    * Likelihood/Severity Rating: C2
  - Insufficient Clearance for Rover Ejection
    * Causes: The separation of the transition section and the payload portion of the rocket is insufficient due to insufficient forces acting on the airframe.
    * Effects: The main airframe of the rocket could interfere with the ejection of the rover from the rocket.

    - Mitigation: The deployment system will be sized and tested to reduce the likelihood of insufficient clearance.
    - Likelihood/Severity Rating: D1
  - Pneumatics-Induced Rover Failure
    - Causes: 120lb+ force may be experienced by the rover during deployment by the pneumatic deployment system.
    - Effects: Such force may destroy the finer mechanisms of the rover and render it inoperable.
    - Mitigation: Rover system design will include a factor of safety and be reviewed prior to manufacturing through finite element analysis. Additionally, analysis and proof testing will be conducted to reduce the chance of failure.
    - Likelihood/Severity Rating: D3

- Ejection of the Rover
  - Ejection binding
    - Causes: Part of rover binds on the inside of the payload section and does not fully exit the airframe.
    - Effects: The rover may not be able to move, or it may sense that it has been deployed and start its movement prematurely.
    - Mitigation: The ejection mechanism will reduce the risk of binding by design and will be tested multiple times to ensure the rover is fully ejected from the payload section.
    - Likelihood/Severity Rating: B3
  - Scissor lift shearing
    - Causes: Turbulent forces during launch may exert too much pressure on the scissor lift mechanism.
    - Effects: The rover fails to eject.
    - Mitigation: The scissor lift will be properly reinforced and structured to endure the stress of launch.
    - Likelihood/Severity Rating: D2
  - Scissor lift unable to eject rover
    - Causes: The scissor lift does not generate enough force to eject the rover.
    - Effects: The rover is not ejected.
    - Mitigation: The scissor lift will undergo FEA and significant lab testing prior to flight.
    - Likelihood/Severity Rating: C3
  - Friction-derived rover ejection failure
    - Causes: The friction between the wheel and the interior airframe is too strong for the ejection mechanism.

    * Effects: The rover fails to eject fully from the payload.
    * Mitigation: The scissor lift will be designed to produce more force than is necessary to eject the rover. Additionally, a friction-reducing thin sheet will be placed between the wheels and the airframe to reduce friction between the wheel-airframe interface.
    * Likelihood/Severity Rating: C2
  - Scissor lift failure
    * Causes: Too much force on the bottom links of the scissor lift.
    * Results: The bottom links can snap or break off and prevent the ejection mechanism from working at all.
    * Mitigation: The scissor lift will be designed with an additional margin of safety to account for unexpected forces encountered by the lift.
    * Likelihood/Severity Rating: D3

- Movement of the Rover
  - Failed collision detection
    * Causes: Sensors do not recognize a divot, hill, or anything abnormal not planned for in code. Rover does not move perfectly smoothly
    * Results: Rover is unable to detect obstacles in front of it, may cause rover to be impeded
    * Mitigation: Sensors will be repeatedly tested and are programmed around possible issues in order to reduce their impact during the competition. Additionally, wheels will be designed to move over rugged terrain.
    * Likelihood/Severity Rating: B3
  - Wheel tears/deformations during movement
    * Causes: A sharp object or edge comes into contact with moving wheels.
    * Results: Wheels are uneven and movement is affected.
    * Mitigation: The wheels will be made out of a material that is not easily torn and will be relatively wide in order to mitigate any damage during movement.
    * Likelihood/Severity Rating: C3
  - Wheels do not have sufficient torque for terrain
    * Causes: The site may have varied terrain, fine loose dirt, or mud due to rain. Other slippage can arise from disjointed contact between the axles and the wheels or motors not geared for appropriate torque.
    * Results: Rover has a difficult time moving and may especially struggle with obstacles. Minimum distance of 5ft possibly not achieved.
    * Mitigation: Tests will be conducted on a wide variety of terrains, including mud, and motors will be oversized to provide a buffer.
    * Likelihood/Severity Rating: D2

- Axle failure
    - Causes: Repeated use, weak axles, axles moving on one side and not the other
    - Results: Wheels do not move effectively, unlikely to move in the expected way.
    - Mitigation: Axles will be designed with a margin of safety and an FEA will be conducted.
    - Likelihood/Severity Rating: D3
- Skid preventing movement
    - Causes: Skid gets caught on unusually steep and abnormal terrain.
    - Results: Rover is unable to move well or at all.
    - Mitigation: The type of terrain that would cause this issue is unlikely to be present at site.
    - Likelihood/Severity Rating: D2
- Skid fails to deploy
    - Causes: Servos fails to work or the skid gets caught on an obstacle during its deployment.
    - Results: The rover may have difficulty climbing hills or approaching uneven ground not perpendicular to rover movement. Additionally, rover orientation might be affected.
    - Mitigation: Test skid deployment multiple times and have two separate servos so there is a backup if one fails.
    - Likelihood/Severity Rating: D3
- Rover begins movement early
    - Causes: Sliding of the rover within the airframe may cause the rover to mistakenly think that it has been ejected and begin to move.
    - Results: Rover could be misaligned during ejection or affect trajectory of rocket.
    - Mitigation: Deployment mechanism makes sure the rover is secured prior to deployment. Additionally, redundant sensors (physical, light) ensure that movement happens at the proper time.
    - Likelihood/Severity Rating: D1
- Battery disconnects
    - Causes: The battery or other electronics are jostled during previous phases.
    - Results: The rover is unable to move or complete the objective.
    - Mitigation: Ensure that all connections are secure and can sustain movement during tests and practice launches. Design will reduce risk of disconnection by reinforcing connection points and using latching connectors.
    - Likelihood/Severity Rating: E2

- Deployment of the Solar Panels

- Panels are damaged
    - Causes: Panels are damaged and/or detached during previous phases.
    - Results: The objective is not completed.
    - The current design protects the solar panels from the environment when not deployed.
    - Likelihood/Severity Rating: D2
- Panel deployment fails
    - Causes: The servos lock up, the movement is obstructed somehow, or the servos are not applying enough power can all cause mechanical failures. Additionally, the panels may not recognize the correct time to unfold due to issues with the sensors.
    - Results: The panels are not deployed at the right time.
    - Mitigation: Mitigated by design.
    - Likelihood/Severity Rating: D2
- Solar Panels open before the 5ft minimum distance
    - Causes: Vibration during rocket flight and rover travel lead to the solar panels opening prematurely.
    - Results: Following the scoring guidelines, the 5ft minimum distance will not have been achieved.
    - Mitigation: Magnets will be used as a redundant latch to keep the panels closed. Only once 5ft has been achieved will the magnets be released and the solar panels allowed to unfold.
    - Likelihood/Severity Rating: B3

Launch Operations Risks

Risk	Causes	Effects	Severity & Likelihood	Mitigations
Altimeters are not set up correctly	Incorrect wiring, incorrect mode set on altimeter, incorrect calibration	Black powder detonation before launch, or failure of payload ejection and parachute deployment	E2	Test altimeter setup before launch and verify correct wiring and altimeter mode.
Motor does not ignite	Improper installation of igniter, slow burn, electrical delay	Failure to launch the rocket, injury to nearby personnel if motor ignites after a delay	B3	Per the NAR High Power Rocket Safety Code, remove the launcher's safety interlock and then wait 60 seconds after a motor misfire before approaching the rocket.

Risk	Causes	Effects	Severity & Likelihood	Mitigations
Improper installation of rocket on launch rail	Misalignment of launch rail buttons, launch rail is bent or not smooth	Launch rail negatively affects flight path of rocket	C2	Visually inspect the launch rail and rocket rail buttons and verify that there are no burrs, bumps, bends, etc.
Premature black powder detonation	Altimeter gives false reading due to improper setup	Possible injury to nearby personnel, possible damage to rocket components	D2	Verify several times that all altimeters have correct settings and are correctly wired.
Couplers are loose	Couplers were not machined correctly to specifications	Rocket may come apart on the launch rail or in flight	C3	Verify that couplers are tight enough by lifting the rocket and ensuring that no part falls off the bottom. If couplers are loose, then add tape around the coupler.
Payload Airframe Separation Event	Personnel standing too close to the airframe during the separation event.	Personnel may be hit with either end of the launch vehicle and experience personal injury.	B1	Prior to separation event, make all nearby personnel aware of upcoming event and maintain a radius of 20ft.

5.4 Environmental Risks Analysis

Overview:

STAR's safety team will prepare and observe all environmental and safety issues. These guidelines will be followed completely throughout all tests and deployments, including any competitions. All team members will be instructed on these procedures and be required to sign off that they understand and will comply with these safety procedures. Monitoring of compliance will be performed and documented by the safety team.

Safety Issues:

Any procedures that involve chemicals, explosive devices, electricity, waste or runoff, shall be contained to all local, university, state, federal and national rocketry and contest regulations. This includes the expectation of failure of any rocket component relating to liquids, solids, devices, or any exhaust or by-products of any part of the experiments. As such, this contemplates containing any negative impacts with barriers, shields, liquid containment, and exhaust containment. In addition, site preparation and post-experiment cleanup and waste issues will be contained.

Environmental Issues:

The following are the contemplated areas of environmental concern:

- Shore/water hazard
- Soil impact (chemical changes)
- Air impact (unwanted gas emission)
- Waste disposal
- Drainage/runoff
- Fire/explosion

Monitoring:

The safety team will monitor these concerns at all tests and deployments. This includes monitoring and gathering all sensor, blast, and payload data for the launch and comparing it to expected values.

Documentation:

The safety team shall document these procedures are followed at all tests and deployments. In addition, we will record the complete deployment of any launch in order to document the success or failure of any and all procedures and activities connected to the launch and to enable a post-mortem after the launch if necessary.

Specific Concerns:

- **Rocket motors:** While we do not know the exact contents of the rocket motor that we plan to use, solid rocket motors are likely to give off harmful gases, such as: hydrogen chloride (HCl), alumina particle (Al2O3), Chloro-fluoro-carbons (CFCs) and chlorine gas (Cl(g)). Although Level 2 rockets aren't comparable in emissions to (sub-orbital) rockets, they still have an impact on the local environment and the deployment envelope.
- **Launch area:** Before doing any rocket launch, it is critical to inspect the site of launch for potential fire risks, ecological environments and nearby water sources. Rocket launches can damage local ecological environments by affecting soil quality, and local ecosystems.

  A site survey should be performed to note any nearby areas that may be impacted by the launch, such as any water, streams, or lakes, as well as flammable structures or objects, such as buildings, bushes, or trees. It is devastating to the ecosystem of a water environment to expose it to such inorganic chemicals. It may destroy chemical properties of the water as well as affecting the rest of the water surroundings. Such ecosystems including any organisms and microorganisms will be affected by the contaminants.

There also should be an animal impact assessment to consider any negative impacts to animals in the blast or deployment area. (The launch site shall not be near any animal habitats.)

- **Electrical systems and batteries:** The performance characteristics of any electrical systems, including batteries shall be documented, per their manufacturers, in order to contain any malfunction. In addition, any electrical systems should be protected against human contact, even in a malfunction. Any chemical runoff from a malfunction of an electric system will have serious negative impacts to the local environment. The chemical runoff shall be immediately picked up and contained, and disposed of in an appropriate waste bin.

- **Hazardous disposal:** Any identified hazardous parts, needs to be picked up, contained, and disposed of in accordance with applicable laws and safety considerations. This includes any chemicals typically used to construct the rocket, such as glues or resins. This also includes any malfunctioning parts, or parts that may have exploded. This also includes any used or malfunctioning rocket engines, chemicals and batteries. Rocket engines shall be neutralized chemically, per manufacturers instructions, before being bagged.

- **Waste disposal:** All other non-hazardous waste from the launch area shall be accumulated and disposed of appropriately so that the launch area is completely clean after the launch.

5.5 Project Risks and Consequences Analysis

This section contains logistical risks (typically money and time, rather than mechanical failure of devices).

Payload Risks

Risk	Causes	Effects	Severity & Likelihood	Mitigations

Risk	Causes	Effects	Severity & Likelihood	Mitigations
Construction of payload falls behind schedule	3D printing failure, purchasing parts from slow/unreliable vendor, building backup payload, reprinting parts, lack of materials, lack of clear schematics, lack of effort.	Does not affect subscale launch, will use weight substitute in place of unobtained parts.	C4	Ensure strict schedule is laid out for payload construction, designs are completed and checked, and vendors are chosen carefully.
Payload goes over budget	Reprinting parts, purchasing special parts/backup parts, building backup payload, lack of budget planning.	Does not affect subscale launch, will use weight substitute in place of unobtained parts.	C4	Make sure costs are considered while designing the payload, and keep a large discretionary fund in case of emergency.

Recovery Risks

Risk	Causes	Effects	Severity & Likelihood	Mitigations
Recovery construction falls behind schedule	Lack of materials; Lack of effort; Lack of clear schematics	Will prevent successful subscale launch as recovery is responsible for separation and landing	C1	Make sure a strict schedule is laid out and that design is complete. Also make sure to buy materials early so that shipping is not an issue.
Recovery goes over budget	Parts too expensive or too many mistakes and redos required	Critical, as recovery has one of the highest costs for parachutes and charges. May prevent teams from buying other necessary components	D1	Make sure costs are considered while designing. Reuse as many components as possible from previous team rockets. Use substitutes as necessary, and exercise extreme caution or extreme caution while testing, and keep a large discretionary fund in case of emergency.

Risk	Causes	Effects	Severity & Likelihood	Mitigations

Airframe Risks

Risk	Causes	Effects	Severity & Likelihood	Mitigations
Airframe construction falls behind schedule	Lack of materials; Lack of effort; Lack of clear schematics	Will prevent successful subscale launch as airframe makes up the rocket.	C1	Make sure a strict schedule is laid out and that design is complete. Also make sure to buy materials early so that shipping is not an issue.
Airframe goes over budget	Parts too expensive or too many mistakes and redos required	Blue tube is decently expensive, and carbon fiber components are difficult to manufacture. May prevent teams from buying other necessary components	C2	Make sure costs are considered while designing and either use substitutes or extreme caution while testing, and keep a large discretionary fund in case of emergency.

6 Payload Criteria

6.1 Payload Description/Objective

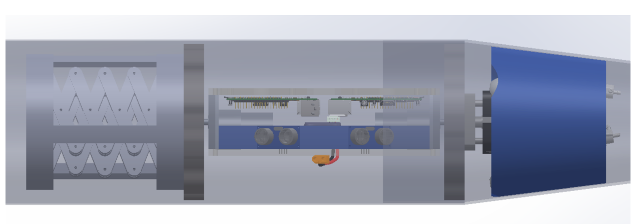


Figure 14: *Transparent overview of the payload section and all component subsystems*

STAR's payload, TARS (Terrestrial Autonomous Rover System), will satisfy handbook requirement 4.5: deployable rover (Figure 14). During flight, the rover rests inside the frame of the rocket until landing, upon which a radio signal will initiate deployment (separation of the airframe sections). A pneumatic cylinder system housed in the transition airframe section, below the payload, will push up on the rover wheels with enough force to break two shear pins which secure the airframe sections during flight. After complete separation, a scissor lift mechanism mounted within the nosecone will push the rover out of the airframe body towards the bottom of the section. After ejecting from the rocket, the rover will travel autonomously a minimum of five feet away from the rocket and stop. A panel located at the top of the rover will unfold, exposing a set of functional solar cells. All parts of the rover will be five or more feet away from the rocket before and after solar panel deployment.

6.2 Payload Electrical Systems

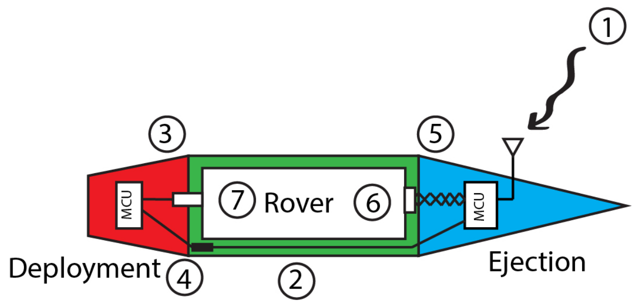


Figure 15: *Graphic overview of full payload system. The relevant subsytems are labeled and color-coded. The overall shape corresponds to the shape of the payload airframe section. Labelled numbers correspond to the numbers provided in the following text.*

The full payload system (Figure 15) consists of a pneumatic deployment mechanism, a scissor lift mounted in the nose cone used for ejection, and the rover itself. Each subsection has its own microcontroller unit (MCU). The Ejection and Deployment computers are connected by two breakaway wire connections, which allow the ejection computer to communicate with the deployment computer.

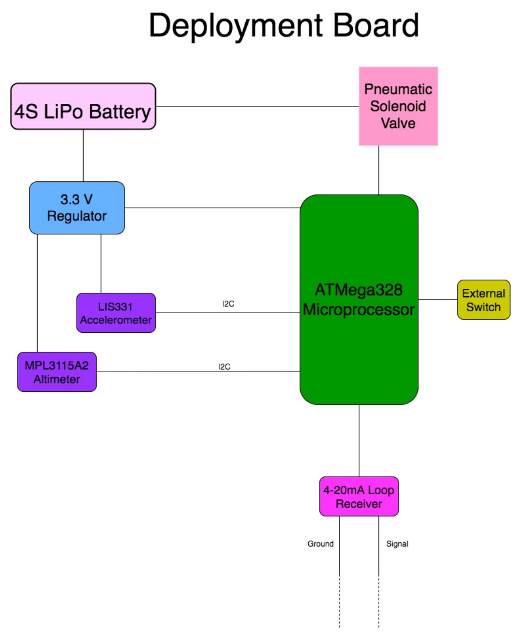


Figure 16: *Electrical component overview of Deployment subsystem.*

Upon receiving the radio signal to begin deployment (1), the Ejection computer (Figure 17) transmits the start signal (2) to the Deployment computer (Figure 16). This transmission uses a 4-20mA current driver, which is less prone to noise than a voltage-based signal. This initiates payload deployment (3), separating the airframe and causing the transmission wire to break at point (4).

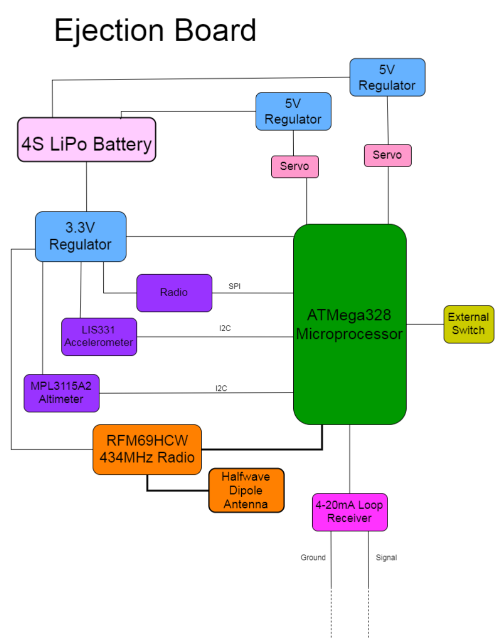


Figure 17: *Electrical component overview of Ejection subsystem.*

When the wires break, the 4-20mA current driver detects the disconnection, signaling to the Ejection computer that deployment is complete, initiating ejection (5). When the rover senses ejection is complete, using a combination of a touch sensor on the wheel and an accelerometer and gyroscope on the rover body (Figure 18) (6), it begins driving away from the rocket (7).

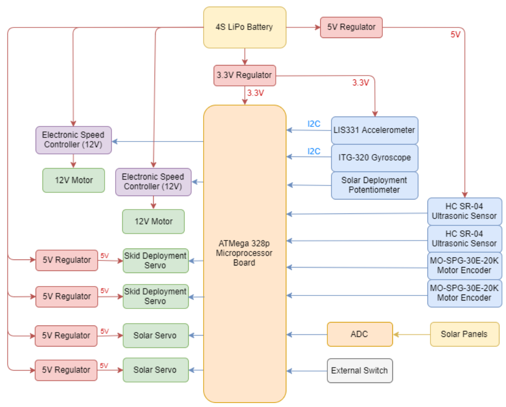


Figure 18: *Electrical component overview of rover subsystem.*

6.3 Design Alternatives

6.3.1 Deployment

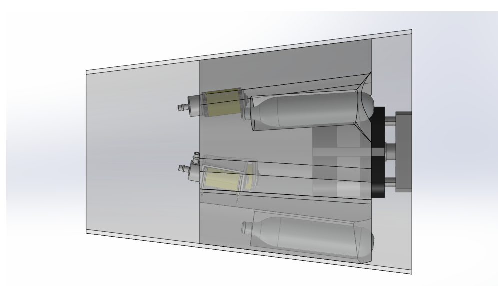


Figure 19: *Translucent view of deployment subsystem*

1. **Remote Trigger Reception**
   Several design alternatives were considered for the reception and sensing of the remote trigger in the Deployment computer. A breakaway wire connection between the Deployment and Ejection computers was chosen as the final design.

   (a) **3-Radio Configuration**
   This design would include separate radio receivers in the computers for the rover, the pneumatic Deployment mechanism, and the Ejection scissor lift. This would give us the greatest degree of remote control over the entire payload separation sequence, but would put a much greater burden on our wireless devices, which are not as reliable as physically-wired systems. We ultimately discarded this idea to minimize the number of radio receivers on the vehicle.

(b) **2-Radio Configuration**
This design would include one radio in the Ejection computer and one in the rover computer. The Ejection computer would receive the remote trigger signal and send a signal via a breakaway wire connection to the Deployment computer, which would initiate Deployment. Then the Ejection computer would detect the disconnection of the breakaway wire connection and would begin ejection. When finished, it would signal to the rover via the radio link that the rover can begin to move.

(c) **1-Radio Configuration**
This design, which is selected configuration, will include only a single radio in the Ejection computer. The Ejection computer will receive the remote trigger signal and will send a signal via a breakaway wire connection to the Deployment computer, which will initiate deployment. Then the Ejection computer will detect the disconnection of the breakaway wire connection and begin ejection. The rover will have no wired or wireless link to the Deployment or Ejection computers, and will instead use an on-board physical switch to detect when ejection has completed successfully.

2. **Physical Separation Methods**
There were two alternatives which were given serious consideration: Black Powder charges and an actuatable locking-pin mechanism. Both of these concepts were discarded in favor of a pneumatic system.

(a) **Black Powder Charges**
In a black powder based system, small packets of black powder are situated above the payload, and each packet is attached to a forty pound shear pin. Each packet is attached to an electric match, which triggers once the rocket has confirmation of touchdown, detonating the black powder charges. This breaks the shear pins and ejects the transitional section from the rest of the airframe. The black powder system was discarded in favor of the pneumatic system due to concerns about the inherent inconsistency of a black powder charge and the proximity of detonation to the payload, which may result in damage to the rover.

(b) **Locking-Pin Mechanism**
The locking-pin mechanism operates via a single servo which can retract or extend a number of radial pins which interlock between the sections of the airframe in much the same way that shear pins do. While in flight, these pins constrain the airframe and prevent separation. The force of flight increases the resistance that the pins have and prevents accidental separation. Once the rocket has confirmed touchdown, the stress associated with flight is eased, and the centrally-situated servo is able to retract these radial pins, effectively separating the transitional section of the airframe from the remainder of the upper section of the rocket. The complexity of the locking-pin mechanism led to concerns about manufacturability and reliability.

(c) **Pneumatic Piston**

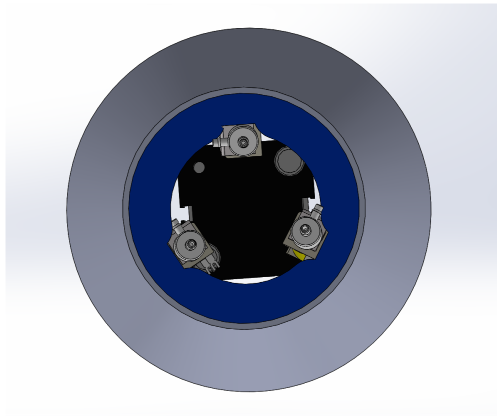


Figure 20: *View of transition section housing the deploying subsystem from the 4in dia. section*

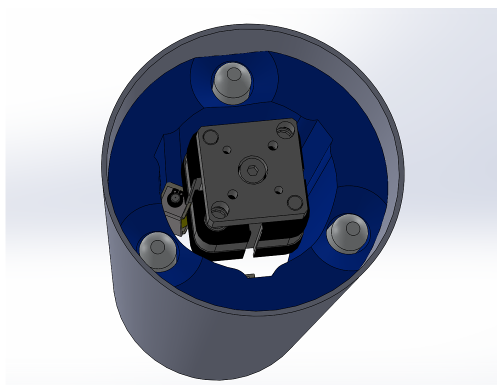


Figure 21: *View of transition section housing the deploying subsystem from the 6in dia. section*

This design uses pressurized air with 1-2in of stroke to provide approximately 80lbs of force (Figure 19). The pressure will be provided by a number of 16g CO_2 threaded cartridges. These cartridges offer a low cost solution due to their availability in bulk, the threaded nature of the cartridges allow scalability, advantage of higher capacity than 12g, as well as overall low weight. In reference to the scalability, more cartridges can be added to increase the pressure potential of the system. The piston itself has a short stroke to ensure a delivery of high force (Figures 20 and 21). One issue with the pistons would be their weight, but due to other sections of the airframe weighing less than what was planned, the issue can be mitigated within reason. A breakaway wire connection is also being used to confirm deployment due to ease of design and implementation, as it just requires a connection from the Ejection computer that can easily be broken when the two sections of the airframe separate. This will also include a custom bracket that allows the force from the Deployment to be parallel to the connector so as to facilitate the break. The design also includes a solenoid valve rated for approximately 100psi that will be used to open the airway tubing that fills the piston, which was chosen due to its small, lightweight, and inexpensive manner and because its voltage matches our ideal range. Finally, it was determined that the deployment system would be powered by 4S LiPo over AAAA series adapters due to the uncertainty of the stage performance under rocket acceleration. The main drawback to 4S LiPo batteries is their weight, which is mitigated by the electrical team lending Deployment the necessary weight.

6.3.2 Ejection

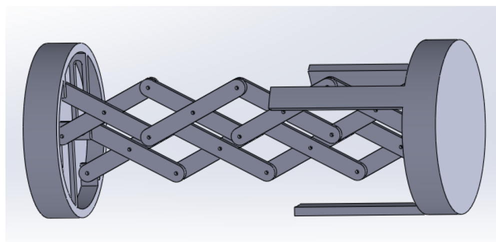


Figure 22: *View of scissor lift extension*

1. **"Explosive" Designs**
   The Ejection team considered several different design alternatives before finally selecting the servo-powered scissor lift.

   (a) **Preloaded Spring**
   The original design that was chosen and originally outlined in the NASA SL proposal involved a preloaded spring on the rocket, located in the nosecone, that would shove the rover out after the Deployment stage had completed. However, this design was ultimately changed for several reasons. Primarily, there were concerns with the potential risks/hazards associated with having a large, high-preload spring on the flight vehicle during launch, parachute deployment, and landing. Not only are there risks of the spring accidentally deploying at any time during the rocket flight, it will also transfer additional shear stress to the airframe on the nosecone, an extremely flight-critical region of the rocket.

   (b) **Preloaded Slingshot**
   Another similar design, using a railed system and preloaded elastic band was eventually rejected for the same reasons mentioned in the above section. Concerns about the mechanism triggering early, high ejection loads on the rover, and reliability eventually ruled out this design. Furthermore, the triggering of such a large spring with high reliability and consistent force would be an extremely complex technical challenge that seemed unnecessary. Finally, the large amount of force imparted over such a small amount of time on the rover led to concerns about high accelerations and damaging sensitive electronics and/or the actual frame of the rover.

(c) **Other Designs** The final proposed designs in the "explosive" category were an attempt to avoid the earlier concerns about stress in the airframe and potential early activation. These designs involved springs or other mechanisms that would be loaded after landing via a motor or electronically powered mechanism. However, if the design will ultimately require a motor or electrical power, then it was decided that the advantages of controllability and low acceleration would outweigh the advantages provided by any of the explosive designs

2. **"Controlled" Designs**
The electrically-integrated designs proposed ended up falling in to two categories: telescoping mechanisms and scissoring mechanisms. This is because the primary design constraint on the Ejection mechanism is the limited vertical (Z-axis) space. Since a non-explosive (i.e. low force for extended time rather than high force at a single instance) mechanism must remain in contact with the rover face throughout the entire ejection procedure, it is necessary for the mechanism's plate to move along with the rover as it exits the airframe.

(a) **Telescoping Arm**
The first proposed "controlled" design was a telescoping plate that would expand to force the rover out of the payload airframe section via servo power. While this design is relatively simple to implement and extremely space-efficient (a primary concern), one significant issue was electrical wiring and actuation. Because of the way the telescoping mechanism works, wiring would need to move along with the design, and the servo powering the system would either need to move along with the front plate, or mechanically intertwine the levels of the telescope. Since this challenge seemed overly complicated compared to the scissor lift, the design was ultimately dismissed.

(b) **Scissor Lift**

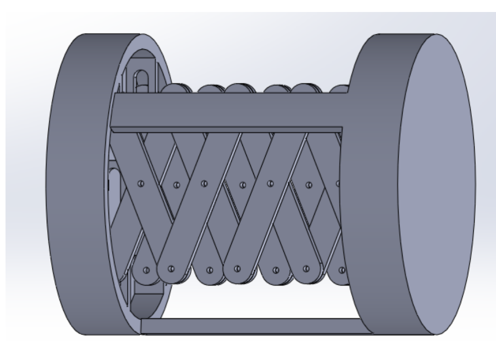


Figure 23: *View of scissor lift in compression*

The other design, and the one that was ultimately selected, was a scissor lift. Since the servo won't need to move, and the force/torque required to actuate the lift is minimal, this design is among the easiest to implement and most customizable. Furthermore, the design is primarily 3D printed, and thus can be exchanged and replaced easily, making testing and prototyping quick and easy. Finally, the design is easily scalable - if larger links or a smaller base plate are required, the rest of the design can be easily adjusted to meet the parameters (Figures 22 and 23).

6.3.3 Movement

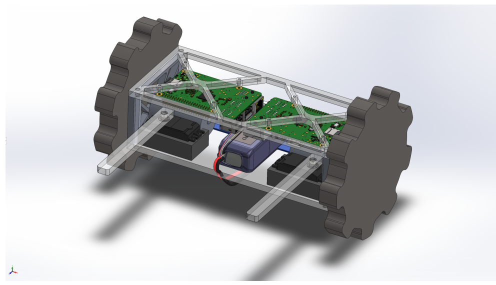


Figure 24: *Isometric view of Rover. Note: Solar panels are not depicted.*

1. **Rover Chassis**

   The chassis of the rover is the frame to which all other components will be mounted. It will provide the structure of the rover's body and should shield sensitive components from environmental conditions.

   (a) **Chassis Design**

   Several layouts for the body were considered, including a cylindrical shell design, an enclosed box design, and a partially-enclosed frame design.

   The cylindrical shell body was the original design considered. The benefits of this design include the greatest storage volume for a given radius, as well as inherent axisymmetry. Drawbacks include the increased difficulty of mounting internal components and decreased packing efficiency of rectangular components compared to a rectangular design. Layouts with this design suffered from considerable amounts of wasted space.

   The fully-enclosed box design offers the best environmental protection, as well as being easy to manufacture. Furthermore, a rectangular design allows for high component packing efficiency and ease of mounting components. Drawbacks include higher weight than necessary and low structural strength for a given weight. Another possible drawback would be heat dissipation, and the design may require some form of ventilation in hot conditions.

   Considering the drawbacks of the other designs, a partially enclosed frame design was selected (Figure 24). This design provides high structural integrity as well as ample mounting surfaces, while minimizing weight and being well ventilated. The drawback of this design compared to the enclosed box is the lack of environmental protection.

   (b) **Chassis Materials**

Rover chassis materials were selected based upon strength, weight, and ease of manufacturing. Some chassis materials did not have sufficient strength on their own and would require additional supports to be used as the main structural component.

The first proposed material was PLA as the original plan was to 3D print the payload. The advantages were ease of manufacturing and low weight, but strength was a concern.This became increasingly unfeasible as the Rover Chassis Design changed towards the rectangular shape as 3D printing a rectangular prism was not highly practical nor structural powerful.

Wood was considered for the payload material after the chassis transitioned to a rectangular prism due to ease of manufacturing and acceptably low weight. The structural strength of the wood was a concern, along with the fact that the direction of the grain in the wood is significant for determination of strength. Additionally wood would need further supports to be structurally sound which would require additional weight. These structural and weight issues led to us discarding it in favor of a mixed polycarbonate and aluminum design.

The materials being used are polycarbonate and aluminum. Polycarbonate has the advantage of high strength with relatively low weight and the ability to be safely milled out for weight reduction without significant decreases in strength. Aluminum has similar properties and provides additionally rigidity for motor mounting. With polycarbonate and aluminum combined a relatively lightweight and highly structurally sound rover is created which is fairly easy to manufacture.

2. **Skids**

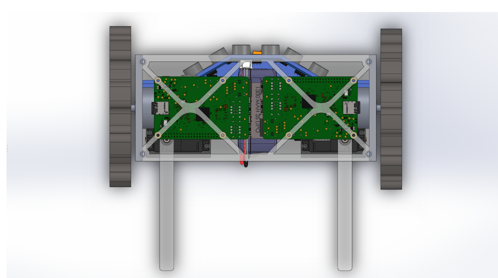


Figure 25: *Top view of rover depicting skids*

The cylindrical design of the rover necessitates some form of support to counter the torque of the motors moving the wheels. This support will take the form of trailing arms that drag along the ground to provide a moment arm for the motors to push against.

(a) **Skid Design**

Options for this skid include single or double-skid designs and wheeled or non-wheeled designs. A single skid design is lighter and simpler than a double skid, but would need to be center mounted to preserve symmetry. This limits the length of the skid. A double skid design was selected to allow for longer, offset symmetrical skids.

A wheeled skid design would reduce friction of the skid dragging along the ground, improving efficiency of movement. However, it would also add additional weight, complexity, and would introduce possible failure modes such as the wheel jamming. A non-wheeled design was selected for use.

(b) **Skid Deployment**

The skid must extend past the radius of the wheels in order to be effective. This means they must be stored inside the rover before Ejection in order to fit. Therefore, there must be some mechanism to deploy the skids. Options considered include telescoping, vertically unfolding, and horizontally unfolding skids.

Telescoping skids were ruled out because of the added complexity of an automatically telescoping skid. Vertically deploying skids, while they could allow for a large skid surface, would require either a strong holding servo and significant power usage to remain deployed, or a mechanical locking system that would add complexity and be relatively difficult to implement. Both of these systems also have the potential to move the rover by pushing against the ground, providing a potential tool for clearing obstacles or getting unstuck. However, it was decided that these benefits did not justify the drawbacks of these designs.

Horizontally deploying skids are functional, lightweight, cost effective, and easy to implement. Thus, a design of dual, horizontally unfolding skids has been selected (Figure 25). The skids are initially stored breadthwise underneath the rover. Upon deployment, servos will rotate the skids into their rear-facing position. Once deployed, the skids will fit into physical slots on the bottom of the rover, which will help support the mechanical load placed on them during movement.

(c) **Skid Material**

The material used in the skids should be lightweight and durable enough to withstand the torque of the motors. Options considered include PLA, Aluminum, Wood, and Polycarbonate. Aluminum is the strongest of these materials, however it is also the heaviest and most difficult to machine. Polycarbonate is stronger than wood and PLA and still lightweight, and the team also has a surplus of polycarbonate is supply. Thus, polycarbonate was chosen as the material for the skids.

3. **Rover Wheels**

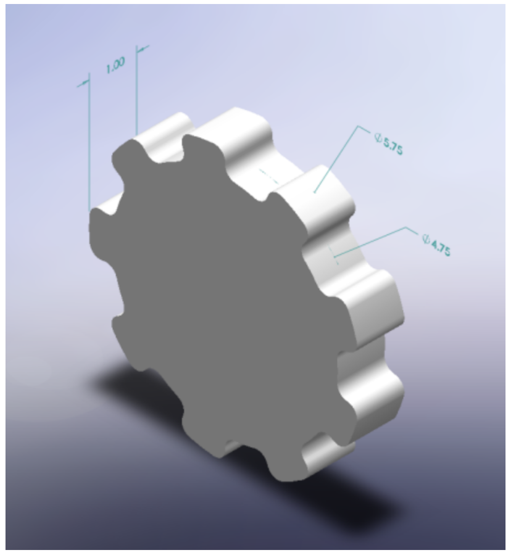


Figure 26: *Isolated wheel design*

The wheels of the rover must provide enough traction and terrain navigation capability, while being as lightweight and cost-effective as possible. They also must fit within the payload section of the rocket (of diameter 6in).

(a) **Wheel Shape**

The two options considered for wheel shape were solid wheels and whegs. Solid wheels have the advantage of being durable, while having the disadvantages of being heavier than necessary and unable to get over large obstacles. Whegs have the advantages of being lighter and an improved ability to cross large obstacles, but have the disadvantages of decreased efficiency of travel, possibility of leg failure, and added stresses on rover components while driving.

(b) **Wheel Material**

The options for wheel material were aluminum, PLA, ABS, plywood, and foam. The advantage of aluminum is high durability with the disadvantage of a high density relative to the other options. The advantages of PLA are durability and ease of manufacture, but has the disadvantage of lack of heat resistance. The advantage of ABS is that it is less brittle than other plastics and is easy to manufacture, but has the disadvantage of having low tensile strength and is not heat resistant. The advantage of plywood is ease of manufacturing, but has the disadvantage of low tensile strength.

There are many varieties of foam, most of which are lighter weight and more deformable than plastics, metal, or wood. However, foam is also more vulnerable to tearing and shearing and offers less structural rigidity.

Types of foam considered include polystyrene and cross-linked polyethylene. Polystyrene is very light and relatively rigid, but is more brittle and has less tensile strength than other types of foam. Cross-linked polyethylene is more dense, but is more durable and deformable, while being still relatively lightweight compared to other alternatives.

4lb density cross-linked polyethylene was selected for wheel construction, as it is lightweight, sufficiently durable, and deformable enough to facilitate obstacle clearance while absorbing shock and vibrations. This density was selected as a compromise between 2 lb and 6 lb foam, which will also be tested.

(c) **Wheel Tread Design**

The options considered for the wheel tread design are smooth round wheels, studded round wheels, polygonal wheels, and toothed wheels. The advantage of smooth wheels is low friction and a smooth ride but has the disadvantage of low traction. The advantage of studded wheels is increased traction, but has the disadvantages of increased weight, and higher friction. The advantage of polygonal wheels is better traction, but the disadvantages are a bumpier ride and a higher torque requirement. The advantages of a toothed wheel are better traction and reduced weight, but the disadvantages are that the teeth are vulnerable to wear and tear.

The toothed wheel design was selected over other alternatives, as it offers both weight reduction and increased traction over a standard full-wheel design while avoiding unacceptable compromises in travel efficiency or ride smoothness (Figure 26).

The current design is a 5.5in cross-linked polyethylene wheel with gear-like toothed treads. This size was selected to maximize clearance while leaving space in the payload compartment for electronics and a sleeve to facilitate deployment. Possible improvements include adding studs to the wheel treads or treating them with a high-traction coating.

4. **Electronics Housing**

The electronics housing must be able to protect the electrical components from the stresses of launch and landing. The housing must also protect the electronics from environmental conditions. The size of the housing should be minimized to reduce weight by precisely encasing the electronics with little free space remaining.

Options for the electronics housing include the enclosed body design, attached plates, and flexible wrapping such as cling wrap. The enclosed body design was ruled out due to the added weight and possible heat concerns.

The option of attaching plates to the rover as necessary allow for the installation of modular shielding to protect sensitive components, while avoiding the added weight of a fully enclosed design. The drawbacks of this design include the need to fabricate shielding separately, the additional weight of mounting fasteners such as screws, and the usage of valuable mounting space on the rover frame.

Using a flexible coating would provide water and environemtal protection with minimal weight additiom, as well as being easy to apply. However, it may cause heating issues and could interfere with electronics if it contacts exposed components.

Of the options considered, the current selection for electronics housing is to use attachable modular plates, with the possibility of adding flexible coating upon further testing.

5. **Battery Selection**
   The battery selected for the rover must provide a high enough voltage and discharge rate to power the rover's electronics and enough capacity to supply power for the duration of the autonomous movement and solar panel deployment. The battery will be one of the heaviest and largest components in the rover, so choosing one with minimal physical dimensions is very important.

   (a) **Battery Type**
   The first consideration in battery selection is the type of battery, and the three primary types considered were NiMH, LiPo, and LiFe. NiMH batteries were ruled out as lithium based batteries provide better performance for comparable physical dimensions and are still affordable. LiFe batteries are safer to recharge than batteries with LiPo chemistries, at the cost of higher prices. LiPo batteries were selected for use as there are no plans to recharge the rover's main battery during its operation.

   (b) **Battery Size**
   4 cell (4S) batteries were chosen to be optimal as 14.8V 4S LiPo batteries provide sufficient voltage to run 12V motors, servos and other components, while a higher cell count unnecessarily increases weight and cost.

   Finally, with respect to capacity, a 1300mAh battery was chosen as it offers a much smaller form factor than comparable higher capacity batteries, while still having sufficient charge capacity to last for the duration of the rover's mission. The specific battery chosen is a Turnigy Graphene 1300mAh 4S 45C LiPo battery.

6. **Motor Selection**

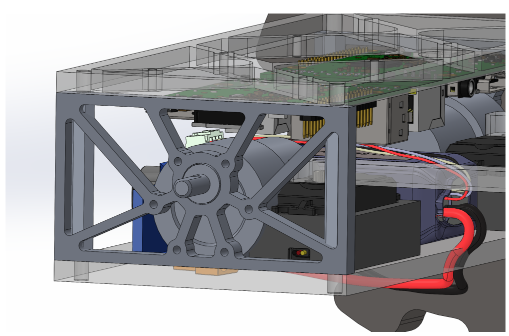


Figure 27: *Side view of rover motor*

The motors must propel the rover outside of a 5ft radius from the rocket. It must be as efficient, lightweight, and cost effective as possible while providing maximum terrain navigation ability. The motors should also be fast enough to fulfill the 5ft travel requirement in a timely manner. Furthermore, the motor must be compatible with the onboard voltage regulation and wheel encoders for navigation.

(a) **Motor Type**

The first consideration for motor selection is the type of motor. Only electric motors were seriously considered, due to the weight and complexity requirements of using other types of motors such as combustion engines.

Options for electric motors include the selection between DC and AC motors, between brushed and unbrushed motors, selection of motor voltage, and selection of gearbox (considering type of gearbox and gear ratio). In order to meet the criteria set for the motor, it must be geared to achieve high torque, driven by approximately 12V or less, and compatible with encoders.

12 volt motors were selected for use as these are common and inexpensive that offer improved performance and a greater selection compared to lower voltage (6V, 7.2V) motors, while not being much larger or more expensive (Figure 27).

Furthermore, there are a large selection of brushed DC gearmotors. Brushless motors are more expensive than comparable brushed motors and generally required separate gearboxes. Additionally, AC motors require an alternating current power source which introduces unnecessary complexity. Spur gear motors were found to be more compact and cost effective than comparable planetary gear motors, many of which would not fit in the planned chassis layout.

(b) **Gear Ratio**

The gear ratio of a motor is a tradeoff between RPM and torque. For this application, higher torque would be optimal as the rover must clear terrain, but does not need to move very fast. A 120:1 gear ratio was chosen to be a good compromise between reasonable speed and high torque for terrain navigation.

The current choice of motor is a 12V Cytron SPG30 series motor with 120:1 gearbox.

7. **Collision Detection**

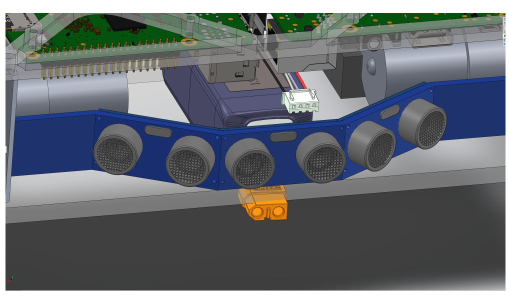


Figure 28: *Close-up view of collision detection sensors*

The collision detection system must detect the presence and location of obstacles that could impede the rover's movement so that these obstacles can be avoided. Design criteria include the system being as lightweight as possible, drawing minimal power, and being durable enough to survive the stresses of landing, recovery, and travel over terrain. The system will consist of an array of sensors that pass data to the rover's central MCU, which would use the measurements in closed-loop feedback to avoid obstacles.

(a) **Sensor Type**

Three types of sensors were considered for usage in this system: mechanical, infrared, and ultrasonic sensors. Mechanical sensors would function as "whiskers" and would detect objects around the rover by contacting them. This system was ruled out as it increases the weight and physical size of the rover more than other alternatives, as well as introducing the risk of sensors getting caught or impeding the movement of the rover.

Infrared sensors offer remote contact-free measurement and are affordable. However, they can be inconsistent over different measurement surfaces and different lighting conditions[1]. Furthermore, IR sensors of the scale and budget appropriate for the rover suffer from narrow detection zones.

Ultrasonic sensors are inexpensive, reliable, and offer wider coverage than comparably-priced IR sensors. The ultrasonic sensors tested were fragile to impacts and would have to be shielded in order to ensure proper operation. More durable ultrasonic sensors are also available.

Ultrasonic sensors were determined to be most suitable for the requirements of the collision detection system, as they can detect objects over a larger area and in a wide range of conditions compared to the alternatives (Figure 28). If standard unshielded sensors such as the SparkFun HC-SR04 prove to be too fragile, more rugged environment-shielded ultrasonic sensors could be used instead.

8. **Distance Measurement**

The distance measurement system must determine the rover's position relative to the rocket frame, in order to plan navigation and verify the minimum 5ft clearance radius before deployment of solar panels.

(a) **Sensor Type**

Options for distance measurement include dead reckoning using encoders, inertial navigation using accelerometers and gyroscopes, or sonic/light based triangulation using transmitters on the payload frame.

Encoders provide a fairly reliable method of navigation and distance measurement using minimal hardware, as the selected motors feature integration for encoders. Encoders are also very useful in closed-loop motor control, which will be important for navigation. Drawbacks of this system include vulnerability to wheel slippage and a lack of an absolute distance measurement from the rocket frame.

Accelerometers offer another way to calculate the rover's position by integrating acceleration over time. However, accelerometers suitable for our application and

[1] http://iopscience.iop.org/article/10.1088/1757-899X/149/1/012141.pdf

budget are typically not accurate enough to implement accurate inertial navigation. Thus, this system will be used as a very rough check of the accuracy of other measurement systems such as the encoders.

Another option for distance measurement would be to use a visual or audio signal transmitted from the rocket frame to determine distance from the rocket using triangulation or computer vision. This would require transmitters to be installed in the payload frame and receivers on the rover. While this system would ideally provide an accurate, absolute distance measurement from the rocket, it is the most hardware and software intensive and difficult to implement of the options.

A combination of encoder dead-reckoning and accelerometer integration has been selected as the primary navigation and distance measurement system for the rover, using accelerometer and gyroscope data to compensate for wheel slippage. This system is more practical and reliable than any one of the three options alone, and should be adequately reliable to navigate outside of the 5ft clearance radius.

6.3.4 Solar

1. **Panel Choice and Layout**
   The primary consideration for panel choice was size of the individual panels. Panels were needed that were thin and could fit inside the rover. The available options were a single fabric mounted panel set, long individual panels, and small individual panels. The first two options don't provide the flexibility required for the limited space available in the rover. It was decided that the best option is to use small 1in x 1in panels and chain them together.

   The panel layout was chosen based on the simplicity of the design. Several options considered were origami-based panels, double/triple folded panels, and a two effective panel layout. To meet the size and weight constraints, two effective panel layouts were settled upon. This consists of laying the small panels next to each other on two larger panels of plastic (or similar material). The voltage outputs of all panels would be chained together, forming effectively two panels. The bottom panel would be mounted inside the main body of the rover. The top panel would be mounted upside down on the inside of the hood of the rover. Initially, the top panel will lay flat upon the bottom panel before the rover has cleared the rocket. Upon deployment, the hood will open, flipping the top panel up and exposing both panels.

2. **Panel Deployment**
   The panel deployment options were also limited by the available space. Based on the choice of layout, the top panel should simply flip open. To do so, it is attached to a hood which helps keep the internal components of the rover safe prior to panel deployment. Several options for how to actuate the hood of the rover to deploy the panels were: pneumatic, motorized, and gravity/inertia dependent. Pneumatic would require several other components in the rover, including a pressure storage unit, that would take up a lot of space. Inertia-driven deployment would be unreliable, as it would require a specific set of motions to accommodate. Motorized deployment was

decided upon since it would only require the addition of servos and motor controllers. In addition, it is very reliable. Two servos will be mounted in the center of the rover near the hinge of the hood. This will ensure that there is enough force to open the hood and that there is no uneven torque about the hinge that would wear it out.

3. **Other Minor Modifications**
   Three minor modifications to this deployment scheme were made to increase robustness. The first is that the voltage output of the solar panels would be passed into the microcontroller onboard the rover. Thus, there is no need to carry a second battery that needs to be charged and have a voltage regulator. This makes the design safer. Second, a potentiometer was added to hood, such that it would notify us of the hood position independent of the servo input. This adds a backup verification for deployment orientation. Lastly, magnets will be added to where the hood connects with the main body of the rover. These are to prevent the hood from opening besides when it is programmed to do so. This makes the system more robust and reliable.

6.4 Vehicle Interfaces

There are several interfaces on which the payload interacts with the launch vehicle during Deployment and Ejection, both mechanically and electronically. During Deployment, the payload interacts with the airframe through the piston that is located in the transition section of the vehicle.

The Deployment sequence is initiated by a radio link from the ground station to the Ejection computer located in the nosecone. If the Ejection computer determines that the rocket is at rest via altimeter and accelerometer readings, it sends a signal to the Deployment computer, which verifies those readings with its own independent altimeter and accelerometer. Following both confirmations, the pneumatic deployment sequence is started, which severs the breakaway wire connection between the Deployment computer and the Ejection computer.

The piston's purpose is to break the three 40lb shear pins that keep the top and bottom portions of the rocket interlocked. In addition, through the pneumatic ejection process, the payload interacts with the launch vehicle through a scissor lift mechanism to push the payload out of the airframe after landing. The Ejection sequence is activated by the Ejection computer after the breakaway wire connection is severed. The rover will determine that it has safely ejected from the vehicle via a physical switch which will no longer be compressed when the payload exits the airframe. Following detection of rover separation from the airframe, the rover autonomous movement sequence will activate.

Through these interfaces, the payload will be able to effectively deploy and separate from the launch vehicle to complete the required tasks.

7 Project Plan

7.1 NSL Handbook Requirements

7.1.1 General Requirements

1.1. Students on the team will do 100% of the project, including design, construction, written reports, presentations, and flight preparation with the exception of assembling the motors and handling black powder or any variant of ejection charges, or preparing and installing electric matches (to be done by the teams mentor).
Non-students (mentor, faculty, other advisers) will only perform the duties allowed above in addition to advising designs during internal design reviews and the like.
Status: Requirement has been thus far meant.

1.2. The team will provide and maintain a project plan to include, but not limited to the following items: project milestones, budget and community support, checklists, personnel assigned, educational engagement events, and risks and mitigations.
Extensive project plan has been included in this report and in even more extensive consideration on the team Google Drive. Proper sub-tam leads will verify that all aspects of project plan are kept up-to-date.

1.3. Foreign National (FN) team members must be identified by the Preliminary Design Review (PDR) and may or may not have access to certain activities during launch week due to security restrictions. In addition, FNs may be separated from their team during these activities.
An complete team roster including citizenship information of all members is being maintained. All 9 FN team members have been identified in an email (not including in appendix because sheet has prsonal contact information).
Status: Complete

1.4. The team must identify all team members attending launch week activities by the Critical Design Review (CDR). Team members will include: 1.4.1. Students actively engaged in the project throughout the entire year. 1.4.2. One mentor (see requirement 1.14). 1.4.3. No more than two adult educators.
All members and our mentor have been made aware of launch week dates and logistics. Members will be asked to give their best guess of interest/availability by end of the semester (a month prior to CDR).
Status: Incomplete

1.5. The team will engage a minimum of 200 participants in educational, hands-on science, technology, engineering, and mathematics (STEM) activities, as defined in the Educational Engagement Activity Report, by FRR. An educational engagement activity report will be completed and submitted within two weeks after completion of an event. A sample of the educational engagement activity report can be found on page 31 of the handbook. To satisfy this requirement, all events must occur between project acceptance and the FRR due date.
At all outreach events, a clicker is used to record the number of participants reached. The Outreach Team lead is responsible for activity report submission.

Status: Requirement exceeded. Over 932 participants reached at point of submission (11/03/17).

1.6. The team will develop and host a Web site for project documentation.
The team website has been active for over a year and is being managed by our Web Team.
Status: Complete

1.7. Teams will post, and make available for download, the required deliverables to the team Web site by the due dates specified in the project timeline.
The Web Team lead will add all report deliverables to the team website by the due dates. The Reports Team lead will confirm that this has been done.
Status: Complete for PDR.

1.8. All deliverables must be in PDF format.
Will be verified by Reports Team lead. Status: Complete for PDR.

1.9. In every report, teams will provide a table of contents including major sections and their respective sub-sections.
As reports are being compiled using LaTeX the "tableofcontents" command as well as necessary packages allow for the team to easily have accurate table of contents providing both sections and all sub-sections. The Reports Team lead is responsible for verifying this has indeed been done.
Status: Completed for PDR.

1.10. In every report, the team will include the page number at the bottom of the page.
Similarly to the previous requirement, LaTeX packages will automatically and accurately perform this task. The Reports Team lead is responsible for verifying this has indeed been done.
Status: Completed for PDR.

1.11. The team will provide any computer equipment necessary to perform a video teleconference with the review panel. This includes, but is not limited to, a computer system, video camera, speaker telephone, and a broadband Internet connection. Cellular phones can be used for speakerphone capability only as a last resort.
Campus meeting rooms and equipment will be reserved for each review teleconference. Acceptable internet connection will be verified approximately 15 minutes prior to the scheduled start time. The Team President will be responsible for verifying all aspects are satisfied.
Status: A campus meeting room has been reserved for the PDR teleconference.

1.12. All teams will be required to use the launch pads provided by Student Launchs launch service provider. No custom pads will be permitted on the launch field. Launch services will have 8ft. 1010 rails, and 8 and 12 ft. 1515 rails available for use.
The vehicle has been designed to be used with a 1515 rail of either design. Internal Design Reviews (IDR's) will ensure that there are no design features preventing this. A piece of 1515 will be used to ensure proper rail button alignment.
Status: Incomplete

1.13. Teams must implement the Architectural and Transportation Barriers Compliance Board Electronic and Information Technology (EIT) Accessibility Standards (36 CFR Part 1194).

All web based information created by the club is made available to people with disabilities.
Status: Complete

1.14. Each team must identify a mentor. A mentor is defined as an adult who is included as a team member, who will be supporting the team (or multiple teams) throughout the project year, and may or may not be affiliated with the school, institution, or organization. The mentor must maintain a current certification, and be in good standing, through the National Association of Rocketry (NAR) or Tripoli Rocketry Association (TRA) for the motor impulse of the launch vehicle and must have flown and successfully recovered (using electronic, staged recovery) a minimum of 2 flights in this or a higher impulse class, prior to PDR. The mentor is designated as the individual owner of the rocket for liability purposes and must travel with the team to launch week. One travel stipend will be provided per mentor regardless of the number of teams he or she supports. The stipend will only be provided if the team passes FRR and the team and mentor attends launch week in April.
Our mentor (see Team Summary) has all necessary qualifications, will be taking legal responsibility of the rocket, and will be traveling to launch week.
Status: Complete

7.1.2 Airframe Requirements

See subsection 3.3.

7.1.3 Payload Requirements

1. *4.5.1 Teams will design a custom rover that will deploy from the internal structure of the launch vehicle*
   STAR plans to field a custom two-wheeled rover design. Ejection of the rover from the internal structure will be verified through a touch sensor, an accelerometer, and a gyroscope integrated into the rover.

2. *4.5.2 At landing, the team will remotely activate a trigger to deploy the rover from the rocket.*
   An onboard altimeter and accelerometer are used to verify that the vehicle has landed and settled. In the absence of this condition, the radio trigger for Deployment will be disabled.

3. *4.5.3 After Deployment, the rover will autonomously move at least 5ft (in any direction) from the launch vehicle.*
   To address this requirement, the rover will have sensors to detect obstacles that may prevent the achievement of a 5ft distance. Wheel encoders will measure the distance traveled from the rocket to the rover, while the accelerometers and gyroscopes will help compensate for possible wheel slippage error.

4. *4.5.4. Once the rover has reached its final destination, it will deploy a set of foldable solar cell panels.*
   To address this requirement, wheel encoders will be used to detect the number of revolutions of the wheels, translating revolutions to distance traveled with added safety

factors to account for slippage and navigation. Once the rover reaches the final destination, servo arms will open the hood of the rover, in turn deploying the panels. To prevent accidental early solar panel unfolding, magnets will provide additional force to keep the rover hood closed. The servos that open the hood will be able to overcome this extra force.

7.2 Team Derived Requirements

7.2.1 General TDRs

There will be a sub-report document for all sections within a report.
A workshop was held to teach LaTeX to club members. In addition a club specific .Tex sourcecode tutorial is available for all members of the club. This ensures that there will be ample members of each sub-team with the necessary skills to create LaTeX reports. Master document access will be severely restricted until final editing to ensure all sub-documents are as complete and up-to-date as possible. Verified by inspection of Reports lead.
Status: Verified for PDR.
All reports have consistent style, formatting, and elements.
There is a document containing the numerous conventions members will follow when writing reports (e.g. how to format a certain table, when to use ft vs. in, etc.). In addition, deadlines will be enforced to allow sufficient time for editing. Verified by inspection of team leads and Reports lead.
Status: Verified for PDR. Conventions document will continue to be updated as needed for future reports.

7.2.2 Payload TDRs

1. Deployment

   (a) *The Deployment system should not initiate until on the ground after being given the command by the main flight computer.*
   To address this requirement, we will use accelerometer and altimeter data to verify a successful flight, touchdown, and settling of the airframe, with the Deployment unable to initiate until these conditions have been met.

   (b) *The system should receive a signal when separation is complete.*
   To address this requirement, a breakaway wire connection between the Ejection computer and the Deployment computer will be separated, which will signal that separation is complete.

   (c) *The breakaway wire connection should not be broken before the separation event due to flight and touchdown stresses.*
   To address this requirement, failure modes and effects analysis will be done to investigate the likelihood of rocket acceleration causing the connector to detach. Additionally, within subscale launches, the connector will be tested to see if it will separate in an experimental setting.

(d) *The batteries used to power the pneumatic pistons must be able to withstand rocket acceleration.*
To address this requirement, a 4S LiPo battery will be used, since lithium polymer batteries are not likely to shear internally and malfunction.

(e) *The Deployment system must not damage the rover.*
To address this requirement, the method of Deployment was changed to a pneumatic piston system over the previously approved black powder charges to minimize any unintended explosive force damaging the rover. FEA will be done to investigate any potentially harmful forces that may damage the rover, as well as extensive prototyping of the rover and the pneumatic piston system to the same end.

(f) *The lower part of the airframe must be fully separated to allow successful rover ejection.*
To address this requirement, the pneumatic pistons will generate 120lbs of force to push the payload away from the rest of the launch vehicle.

2. Ejection

(a) *The payload Ejection system shall be able to successfully eject rover on a slope of up to at least 20 degrees.*
To address this requirement, a servo powered scissor lift will be used to push the rover out of the payload section. To verify the requirement, the payload Ejection subsytem will be tested under these conditions.

(b) *The payload Ejection system must be reusable and easily resettable.*
To address this requirement, the scissor lift will be able to retract after ejecting the rover. To verify this requirement, reusability will be demonstrated through multiple and consecutive tests of the Ejection system.

(c) *Critical components of the Ejection system must have redundancy.*
To address this requirement, the scissor lift will be powered by two servos, but will only necessitate one servo to successfully eject the rover. To verify this requirement, the Ejection system will be tested for successful rover ejection with only one of two servos powering the Ejection scissor lift.

(d) *Payload Ejection must occur only after a complete and successfully separation of airframe.*
To address this requirement, the separation of the airframe will disconnect the breakaway wire connection to signal to the Ejection computer to begin the Ejection process.

(e) *The payload Ejection system shall not damage the rover.*
To address this requirement, the servo-controlled scissor lift will provide a slow and controlled method of ejecting the rover. FEA will be performed before manufacturing.

(f) *The Ejection scissor lift must sustain the compressive force from the pneumatic piston.*

To address this requirement, the compressive forces of the piston will be redirected away from the linkages of the scissor lift by means of a brace supporting the upper platform of the lift. FEA will be performed on the models before manufacturing. Additionally, stress tests will be conducted on the scissor lift components.

3. Movement

   (a) *Wheel design must allow the rover to traverse rough terrain.*
   To address this requirement, a solid toothed wheel made out of crosslinked polyethylene will optimize weight, cost, durablilty, and practicality. FEA will be conducted on the model before manufacturing.

   (b) *Electronics housing must shield components from environmental conditions and flight stresses.*
   Electronics housing will be designed to minimize vibration and fully enclose components from outside elements such as dust. Vibrational testing will be performed on all components to verify requirement is met.

   (c) *Detect obstacles near the rover in order to avoid collisions.*
   To address this requirement, adequate sensors will be chosen to ensure accurate measurements and detection of obstacles in the direct path of the rover. To verify this requirement, the hardware and software will be tested prior to launch.

   (d) *Design must actively prevent movement while rover is within airframe.*
   A physical switch will send a signal to the rover computer as it is depressed while the rover rests within the airframe. Until that signal is no longer present for an extended period of time, the rover will not activate the autonomous movement portion of its program.

   (e) *Rover must be reusable after launch.*
   Rover materials were chosen for resilience to launch and terrain conditions, as well as strength and reliability, and the rover electronics housing is designed to minimize any possible damage to the electronics during flight and movement.

4. Solar

   (a) *Upon deployment of the solar panels, no part of the rover or panels should be within 5ft, as measured in a straight line, from any part of the launch vehicle.*
   To address this requirement, wheel encoders will be used to measure the number of rotations of the wheels, translating that value to distance traveled. A safety factor to account for slippage and navigation will be included, to ensure that the rover will have traveled at least 5ft from the airframe before deployment occurs.

   (b) *The design and operation of the solar panel system is not regulated other than that it must utilize real solar cells, the solar panel(s) must be foldable, and the solar panel(s) must be deployed by the rover at least 5ft away from the launch vehicle.*
   To address this requirement, the voltage output of the solar panels will be monitored. This output will be passed into an analog-to-digital converter which will then be passed into an input on the rover computer. Thus, this ensures that the

functionality of the solar panels is always monitored. The solar system will be folded via servos which will open the rover housing. The servos will be controlled by the rover computer, allowing for autonomous deployment once the rover is at least 5ft away from the airframe of the rocket.

(c) *The system should measure the extent of panel deployment with minimal additional hardware and power.*
To address this requirement, a potentiometer will be used as a secondary means of verification. The device will be mounted in the main body of the rover with the rod attached to the hood. Any changes in hood position will correspond to a change in rod rotation angle.

(d) *The system should work under a realistic range of weather and lighting conditions, such as nighttime, sunny, overcast.*
To address this requirement, solar panels with a sealed exterior will be used, allowing for use in a wide variety of weather conditions. Deployment of the panels will be determined by the distance that the rover has traveled relative to the airframe, so no environmental stimuli are required for deployment.

(e) *The system should communicate with the rover's main computer.*
To address this requirement, the computer will communicate with the servos to deploy the hood when it has verified that the rover has traveled at least 5ft from the airframe.

(f) *The system will require multiple measurements in order to confirm deployment status.*
To address this requirement, a potentiometer will be used on top of monitoring the servo rod angles. These give us two independent verifications of panel deployment.

(g) *The system should fully fit inside the rover before deployment.*
To address this requirement, the components of the solar array will be recessed within the housing of the rover.

(h) *The system should be robust such that it survives launch, flight, touchdown, rover deployment, and rover movement.*
To address this requirement, the recessed solar panels will be permanently attached to the housing of the rover with no clearances, as to avoid movement within the space allotted for the panels.

(i) *The system should be reusable and able to be folded back into place, preferably electromechanically. No parts should need to be replaced.*
To address this requirement, servo arms operating on an independent electrical system will open and close the housing of the rover to deploy the panels. This system should be fully reusable.

(j) *The system should not deploy nor should the panels unfold unless intentional.*
To address this requirement, servos and magnets will hold the housing of the rover closed until the desired time (after driving at least 5ft from the rover).

7.3 Budget

7.3.1 Airframe Budget

Sub-scale				
Component	Vendor	Unit Cost	Quantity	Total Cost
Nosecone	Apogee Components	\$37.95	1	\$37.95
Payload Tubing	Apogee Components	\$38.95	1	\$38.95
Aft Tubing	Apogee Components	\$26.95	1	\$26.95
Transition	Fibre Glast	\$36.25	$\frac{1}{3}$	\$12.08
Boat tail	Fibre Glast	\$36.25	$\frac{1}{3}$	\$12.08
Fin can	Fibre Glast	\$36.25	$\frac{1}{3}$	\$12.08
Forward Couplers	Apogee Rockets	\$10.95	1	\$10.95
Aft Couplers	Apogee Rockets	\$9.25	2	\$18.50
Motor Tubing	Public Missiles	\$14.99	1	\$14.99
Motor Retainer	Apogee Components	\$31.03	1	\$31.03
Glue/Expoxy	Fibre Glast	\$44.95	1	\$44.95
			Subtotal	\$260.51
Full-scale				
Nosecone	Public Missiles	\$104.99	1	\$104.99
Payload Tubing	Apogee Components	\$66.95	1	\$66.95
Aft Tubing	Apogee Components	\$38.95	1	\$77.90
Transition	Fibre Glast	\$36.25	$\frac{1}{3}$	\$12.08
Boat tail	Fibre Glast	\$36.25	$\frac{1}{3}$	\$12.08
Fin can	Fibre Glast	\$36.25	$\frac{1}{3}$	\$12.08
Forward Couplers	Apogee Components	\$19.95	1	\$19.95
Aft Couplers	Apogee Components	\$39.95	1	\$39.95
Motor Tubing	Public Missiles	\$18.99	1	\$18.99
Motor Retainer	Apogee Components	\$58.85	1	\$58.85
Glue/Expoxy	Fibre Glast	\$44.95	1	\$44.95
			Subtotal	\$468.77
			Total	\$729.28

7.3.2 Recovery Budget

N.B.: Please note that because the launch vehicle was designed so that many recovery components used on last year's rocket (including parachutes) could be re-used this year, many components have a price of \$0.

Component	Vendor	Unit Cost	Quantity	Total Cost
Main Altimeter	N/A	\$0	2	\$0
Back-up Altimeter	N/A	\$0	2	\$0
Duracell 9V Battery	N/A	\$3	5	\$15
TeleGPS	N/A	\$0	1	\$0

L2 Tender Descender	N/A	$0	2	$0
Large Heat Blanket	Apogee Rockets	$70	1	$70
24in Torodial Drougue	N/A	$0	1	$0
72in Torodial Main	N/A	$0	1	$0
Sub-scale drougue	N/A	$0	1	$0
Sub-scale main	N/A	$0	1	$0
$\frac{1}{4}$in tubular kevlar	N/A	$0	150ft	$0
Small heat blanket	Apogee Rockets	$50	1	$50
Black powder		$.13	40g	$5
$\frac{1}{4}$in Threaded Aluminum Rods	N/A	$0	2	$0
U-bolt	N/A	$0	1	$0
Plywood 18inx24in	Jacob's Hall (campus)	$3	1	$3
High Fidelity 3D Prints	Jacob's Hall (campus)	$50	2	$100
Wire	Ace Hardware	$2	5ft	$10
$\frac{1}{4}$-20 Screws	N/A	$0	4	$0
$\frac{1}{4}$-20 Nuts	N/A	$0	4	$0
2-56 Screws	N/A	$0	16	$0
2-56 Nuts	N/A	$0	16	$0
Misc		N/A	N/A	$30
			Total	$283

7.3.3 Payload Budget

The structures for the scissor lift will be 3D printed, and thus incur no or almost no cost to manufacture each.

Deployment					
Part Type	Part Name	Dimensions (in)	Unit Price	#	Total Price
Pneumatic Piston	Parker Hanifin Series LP Non-Lubricated Compact Air Cylinder	To be Confirmed	$23.97	1	$23.97
Pneumatic Tank	Genuine Innovations G21513 Threaded CO2 Cartridge	To be Confirmed	$14.75	6	$14.75
Polyethylene Tubing	PureSec White PE Tubing 1/4" OD x 0.142 in. OD. 5ft. length	To be Confirmed	$6.99	1	$6.99

Accelerometer	LIS331	0.60x0.70x0.062	$9.95	1	$9.95
Altimeter	MPL3115A2	0.80x0.50x0.062	$14.95	1	$14.95
Solenoid	V2 Valve - Miniature Pneumatic Solenoid Valve	0.63x0.67x2.02	$80	1	$80
Structure	Piston Pressure Plate	4.00 dia. x 0.500 thick	$0 (3D printed)	1	$0
Breakaway Wire Connector	Molex, LLC 0510470200 M/F Pair	To be Confirmed	$30	1	$30
Misc Hardware	N/A	N/A	$20	1	$20
				Sub-total	$200.61
		Ejection			
Part Type	Part Name	Dimensions (in)	Unit Price	#	Total Price
Structure	Base Plate	5.00x5.00x1.00	$0.00	1	$0.00
Structure	Linkage	3.15x0.50x0.175	$0.00	20	$0.00
Structure	Top Plate	5.00x5.00x4.50	$0.00	1	$0.00
Motor	Servo, Hitec HS-75BB Retract	1.73x0.90x0.98	$25.00	2	$50.00
Fastener	Push-In Rivets (McMaster Part #: 98295A100)	0.354x0.354x0.5	$5.31 (pack of 25)	2	$12.00
Accelerometer	LIS331	0.60x0.70	$9.95	1	$9.95
Altimeter	MPL3115A2	0.80x0.50	$14.95	1	$14.95
Radio	RFM69HCW, 434MHz	.63x.63x0.062	$4.95	1	$4.95
Misc Hardware	N/A	N/A	$15	1	$15
				Sub-total	$106.85
		Movement			
Part Type	Part Name	Dimensions (in)	Unit Price	#	Total Price
Motor	Cytron MO-SPG30-20K	1.50x15.00x2.24	$21.32	2	$42.64
Motor Controller	Cytron 13A, 5-30V Single DC Motor Controller	To be Confirmed	$13.82	2	$27.64
Wheel Material	4lb density cross-linked polyethylene	24.00x24.00x1.0 (sheet)	$12.50	1	$12.50
Wheel Hubs	Pololu 6mm Universal Aluminum Mounting Hub	1.00x1.00x0.36	$3.95	2	$7.90

Battery	Turnigy Graphene 1300mAh 4S 45C Lipo Pack w/ XT60	2.87x1.34x1.38	$19.94	1	$19.94
Ultrasonic Sensor	SparkFun HC SR-04	1.77x0.79x0.59	$3.95	2	$7.90
Microprocessor	ATMega 328p	1.50x0.27x0.13	$1.90	1	$1.90
Body Material	1/4" thickness Lexan	24.00x24.00x0.25	$20.00	1	$20.00
Skid Deployment Servos	HiTec HS-77B	1.73x0.90x0.98	$24.49	2	$48.98
Gyroscope	SparkFun ITG 3200	0.70x0.85x0.062	$24.95	1	$24.95
Accelerometer	SparkFun LIS331	0.60x0.70x0.062	$9.95	1	$9.95
Misc Hardware	N/A	N/A	$25	1	$25
				Sub-total	$249.30
Solar					
Part Type	Part Name	Dimensions (in)	Unit Price	#	Total Price
Solar Panels	Micro Mini Power Solar Cells	2.08x1.54x0.12	$16.49	2	$32.98
Servo	TowerPro SG-5010-5010	1.59x0.79x1.50	$12.00	2	$24
Potentiometer	Bns Inc. 3590S-2-103L	1.58x0.87x0.75	$14.35	1	$14.35
Misc Hardware	N/A	N/A	$15	1	$15
				Sub-total	$86.33
				Total	$643.09

7.3.4 Outreach Budget

Ohlone College Night of Science			
Component	Unit Cost	Quantity	Total Cost
Film Canisters (Pack of 60)	$26.06	1	$26.06
Wooden Coffee Stirrer, 5.5" (Pack of 2000)	$8.91	1	$8.91
Construction Paper Ream, 9 x 12, (500 Sheets)	$10.41	1	$10.41
Bayer Alka-Seltzer, Original (116ct)	$10.69	4	$42.76
Craft Smart Mini Glue Gun	$2.99	10	$29.90
Surebonder Mini Glue Sticks (Pack of 100)	$9.99	2	$19.98
1/2 in. 2 ft. x 2 ft. Medium Density Fiber Board	$5.95	1	$5.95
1in. x 3in. x 6ft. Select Pine Board	$6.72	1	$6.72
1/4 in. x 36 in. Plain Steel Round Rod	$3.42	1	$3.42

1/8 in. x 1-1/2 in. Lead-Free Brass Pipe Nipple	$3.54	2	$7.08
SAKRETE 60 lb. Multi-Purpose Sand	$3.35	1	$3.35
14in. x 25in. Polypropylene Sand Bag	$0.32	4	$1.28
Painters Touch 2x White Primer Spray Paint	$3.87	1	$3.87
Specialty Metallic Silver Spray Paint	$2.98	1	$2.98
Scissors (Pack of 12)	$12.60	2	$25.20
		Subtotal	$197.87
High School Engineering Program			
Wooden Coffee Stirrer, 5.5" (Pack of 2000)	$8.91	1	$8.91
		Subtotal	$8.91
Discovery Days CSU East Bay			
Film Canisters (Pack of 60)	$26.06	2	$52.12
Bayer Alka-Seltzer, Original (32ct)	$6.50	2	$13.00
3D printed parts	$0.10	25	$2.50
Lunch for volunteers	$5.00	6	$30.00
		Subtotal	$97.62
Discovery Days AT&T Park			
Film Canisters (Pack of 60)	$26.06	4	$104.24
Bayer Alka-Seltzer, Original (116ct)	$10.69	6	$64.14
3D printed parts	$0.10	260	$26.00
Lunch for volunteers	$5.00	16	$80.00
		Subtotal	$274.38
First Friday at Chabot Space & Science Center			
Unkown Materials	$150.00	1	$150.00
		Subtotal	$150.00
Space Day			
Unkown Materials	$400.00	1	$400.00
		Subtotal	$400.00
		Total	1,128.78

7.4 Funding

7.4.1 Summary

This year, we project a total budget of approximately $24,000. This is a marked increase from 2016-17's budget, $5,000. Of the $24,000, we have obtained approximately $20,000 and spent about $2,000.

7.4.2 Description of Accounts

As a Registered Student Organization (RSO) at UC Berkeley, we are required to hold all funds within school accounts. Due to the structure of the Associated Students of the

University of California (ASUC), we have two main accounts, one managed by the umbrella ASUC, and one managed by an engineering RSO specific organization called the Engineering Student Council (ESC). Each of these two funds are further subdivided into a Miscellaneous and Programs account. Miscellaneous funds have little to no restriction on their use. The team plans on using these funds for travel and most material purchases. Program funds come from the school and are heavily restricted. They can only be used on materials that directly benefit Berkeley students.

All private and most corporate donations go directly into our ASUC-Misc Account. Due to the structure of the ASUC and ESC, all program (school) funds go into our ESC-Programs Account. Bulk donations from GM, Boeing, and other large corporations typically go to our ESC-Misc Account as ESC handles the subdivision of large engineering donations. Below is a diagram illustrating how our funds are stored.

```
Account Organization
├── ASUC
│   ├── Programs ($0 since Program funds go through ESC)
│   └── Misc (Most Small Donations)
└── ESC
    ├── Programs (Usually $2,500 from school)
    └── Misc (Bulk Corporate Donations)
```

7.4.3 Funding

As of now, the bulk of our funds are from crowdfunding campaigns. Of our projected $24,000 , we have already secured approximately $20,000 (approximate as a few transfers are still pending and fees may reduce actual amount). Of this, $9,500 was generated through three crowdfunding campaigns (two through the school as part of the Big Give and Berkeley Crowdfunding, and one from our own GoFundMe page).

We also recieved a $2,500 initial allocation from the school (pulled from campus wide student activity fees). The remaining $8,000 comes from a few corporate sponsors including Boeing, Aragon Research, Google, and Northrop Grumman.

We currently have a few fundraising projects underway. First, with the increasing success and turnout of our outreach events, we are beginning to sell team made science kits on a recommended donation basis (e.g. we recommend a donation of $5 dollars for the kit, but feel free to give us less or more for the kit.). Second, we have a pending application for $2,000 from SpaceX. Third, we have pending applications for other school funds ($5,000 from the Student Technology Fund, $750 from the Academic Oppurtunity Fund, and $750 from the Intellectual Community Fund).

7.4.4 Distribution of Funds

To more efficiently handle funds, we have allocated our projected $24,000 budget into 9 subteams and 1 discretionary fund. The discretionary fund is very large, at approximately 2.5 times the size of any other subteam. This fund is used to handle emergencies like CATOs or ballistic recoveries. This fund contains $8,000.

The next largest allocated amount goes to Propulsion, which has $3,000. This is 18.8%

of non-discretionary funds. Propulsion will also be working on an Intercollegiate Rocket Engineering Competition rocket and liquid motor, on top of choosing and purchasing a COTS motor for NASA SL, hence the large budget.

After Propulsion is Airframe, with $2,800 at 17.5%. We expect to spend money on prototyping various modifications to the airframe, such as custom composites rolling (a table roller, heat shrink tape wrapper, oven, and mandrel extractor have already been acquired), boat tails, and control surfaces.

Next is Payload with $2,200 at 13.8%. Payload will be responsible for designing, prototyping, testing, and building the scientific challenge. Payload will also be working with local organizations like the Space Sciences Laboratory to send up other scientific experiments.

Recovery will have $1,900 at 11.9%. Recovery plans on reusing chutes and prototyping two-stage single-chute recovery.

Electronics has $1,800 at 11.3%. Electronics purchases ALL electronics and controls equipment for this project.

Safety has $1,700 at 10.6%. As we are still forming as a team, safety will have many large one-time purchases this year, including flammables cabinets, infrastructure for inventory, and PPE. We also expect recurring costs like hazardous waste disposal and materials handling training.

Outreach has $1,150 at 7.2%. Outreach plans on expanding drastically. In fact we have already interacted with over 1,000 local students in just two months. We plan on hosting larger events as the year progresses.

Logistics also has $1,150 at 7.2%. Logistics funds will be used for travel, shipping, facilities, and human resources. Funds from logistics will be used to buy tools, pay for non-safety related training, convention fees, and maintainence fees.

Lastly, our Reports team will also have $300 at 1.9% of our non-discretionary budget. This will be used to pay for food at report writing parties and any fees that may come up.

7.4.5 Material Acquisition

Not mentioned in Section 7.4.3, we also have several in-kind sponsorships. As of now, we are partnering with Bay Area Circuits to have our custom internally designed flight computers manufactured for free. Additionally, we have approximately 100 software licenses from Solidworks and training for 2 members from Ansys. We plan on asking TAP Plastics (a local plastics distributor) if they are interested in working with us to supply epoxies, plastics, and composite materials.

We typically source our raw materials from McMaster-Carr, our electronics components from Adafruit and DigiKey, and our motors from HobbyKing. We source our rocket materials from Always Ready Rocketry (Blue Tube), Fruity Chutes (parachutes), Apogee Rockets (assorted rocket parts), and Public Missles (fiberglass fins and assorted rocket parts).

7.5 Timeline

7.5.1 Design Team Tasks

Task	Start Date	End Date
Team-Wide		
PDR due		Nov 3rd 2017
PDR Video-conference		Nov 13th 2017
Sub-scale Launch		Dec 2nd 2017
Sub-scale Back-up Launch		Jan 6th 2018
CDR Due		Jan 12th 2018
Full-scale Launch		Feb 3rd 2018
Full-scale Back-up Launch		March 3rd 2018
FRR Due		March 5th 2018
Launch Week	April 4th 2018	April 8th 2018
Airframe		
Manufacture sub-scale launch vehicle	Nov 4th 2017	Nov 27th 2017
Get Ansys simulations functional	Nov 4th 2017	Dec 2nd 2017
FEA on all possibly failing components	Nov 4th 2017	Dec 2nd 2017
Necessary changes to full-scale design	Dec 3rd 2017	Dec 24th 2017
Manufacture full-scale launch vehicle	Jan 14th 2017	Jan 30th 2017
Payload		
Rover Prototype Full Scale	Nov 6th 2017	Dec 24th 2017
Ejection and Deployment Prototype Subscale	Nov 6th 2017	Dec 2nd 2017
Deployment shear pin forces testing	Nov 13th 2017	Dec 24th 2017
Scissor-lift force testing	Nov 13th 2017	Dec 24th 2017
Rover Distance verification testing	Nov 24th 2017	Dec 2nd 2017
Rover movement testing	Nov 24th 2017	Dec 2nd 2017
Remote trigger radio tests	Nov 20th 2017	Dec 2nd 2017
Solar Assembly testing	Nov 24th 2017	Dec 2nd 2017
Payload Complete Assembly Full scale testing	Jan 22th 2018	Jan 26th 2018
Full scale payload	Jan 15th 2018	Feb 3rd 2018
Recovery		
Sub-scale Sled Design	Nov 1st 2017	Nov 13th 2017
Figure out wiring systems	Nov 1st 2017	Nov 6th 2017
Figure out switch placement	Nov 1st 2017	Nov 6th 2017
BOM Table	Nov 1st 2017	Nov 13th 2017
Discuss lock mechanism	Nov 6th 2017	Nov 6th 2017
Determine manufacturing or bulkheads	Nov 4th 2017	Nov 6th 2017
Verify Parahute Usability	Nov 4th 2017	Nov 6th 2017
Sub-scale Parachute calculations	Nov 6th 2017	Nov 13th 2017
Sub-scale prototype printed	Nov 13th 2017	Nov 20th 2017
Ventilation hole calculations	Nov 13th 2017	Nov 20th 2017
Full-scale recovery system mock-up	Nov 13th 2017	Nov 27th 2017
Static Load Test		Dec 1st 2017

7.5.2 Outreach Events

Event	Date
Ohlone College Night of Science	October 7th, 2017
Parent Education Program	October 14th, 2017
High School Engineering Program	October 21st, 2017
Discovery Days, CSU East Bay	October 28th, 2017
Discovery Days, AT&T Park	November 11th, 2017
First Friday at Chabot Space & Science Center	January 5th, 2018
Space Day	TBD

Ohlone College Night of Science

The Ohlone College Night of Science (October 7, 2017) is an annual event at Ohlone College where various groups provide science demonstrations and activities to the general public. STAR held three classrooms at the event; one classroom as a general display where the public can learn more about NASA SL and the team, one classroom with an alka-seltzer rocket lesson, and one classroom with a spacecraft structures activity. In total, 407 students were directly interacted with and 469 adults were indirectly interacted with.

Parent Education Program

The Parent Education Program hosted by the Society of Women Engineers (October 14, 2017) is an event where lower-income parents were invited to talk to STAR, alongside other clubs, to learn about engineering and how to get their daughters involved in engineering. STAR brought the NASA 2016-2017 rocket to the event, and talked to both parents and their children about aerospace engineering, mechanical engineering, computer science, and rocketry in general. In total, STAR indirectly interacted with 6 parents and 14 students.

High School Engineering Program

The High Engineering Engineering Program hosted by the Society of Women Engineers (October 21, 2017) is a 10 week long program for high school girls to get introduced to engineering. STAR gave a presentation on aerospace engineering, then did a hands-on activity where the students were able to build their own engine structures. The engine structures had to be as light as possible, yet survive the forces of launch. In total, STAR directly interacted with 14 students and 7 educators.

Discovery Days, CSU East Bay

Discovery Days, CSU East Bay (October 28, 2017) is a free day of science where community members are able to participate in hands on science activities. Approximately 8,000 people attended the event. At the event, STAR brought the NASA 2016-2017 rocket and several components as a display. STAR volunteers also built alka-seltzer rockets with the participants, where they were able to choose a nosecone, fins, and the amount of "fuel" they wanted to use. At the event, STAR directly interacted with 511 students and indirectly interacted with approximately 300 adults.

Discovery Days, AT&T Park

Discovery Days, CSU East Bay (November 11, 2017) is a free day of science where bay area residents are able to participate in hands on science activities. It it estimated that approximately 30,000 people will attend the event. STAR will bring display pieces for this event, as well as host the alka-seltzer rocket activity again, as it has been a huge success. Plans for improvement include better 3D printed parts and more stable launch pads.

First Friday at Chabot Space & Science Center

First Friday at Chabot Space & Science Center (January 5, 2018) is a night of science open to the community. This year's theme is "Rockets and Robotics." STAR will host a display booth and a hands-on activity related to rocketry or space.

Space Day

Space Day (TBD) is an event that STAR is currently planning. The event would be a day of space related activities that students from around the bay area would be able to attend for free. Other student groups on campus would be able to sign up and host their own activities during the event. STAR would provide lunches for all students and volunteers.

Summary

In summary, STAR has directly interacted with 932 students as of PDR. STAR is aiming to directly interact with at least 1500 students by CDR, which is a reasonably attainable goal given the current events that are planned.

Appendix A List of Project Leaders

Name	Primary Duties
Aaron Togelang	Logistics Officer
Adam Huth	Outreach Officer
Allen Ruan	Recovery Officer
Brunston Poon	Vice President, Payload Officer
Carly Pritchett	President, Payload Officer
Dinesh Parimi	Electronics
Evan Borzilleri	Recovery
Grant Posner	Safety Officer
Jacob Posner	Electronics Officer
Jacob Barkley	Safety
Jun Park	Budget Officer
Ryan O'Gorman	Reports
Sean Pak	Outreach, Website Management
Surya Duggirala	Outreach
Tushar Singla	Airframe Officer

Appendix B Safety Agreement

It is a particular interest and duty of the safety team to ensure that requirements of safety codes and regulations are met when constructing, assembling, and launching a rocket. To abide by these regulations, and in order to maintain overall safety, each team member must follow these rules:

1. Before any launch, pay attention to the pre-launch and safety briefings.
2. At any launch of our main rocket (not sub-scale), stay at least 200 feet away from the launch site when the rocket is ready to launch, and focus on safety.
3. When constructing the rocket, always wear appropriate clothing (no loose clothing near machinery and power tools) and proper personal protective equipment (PPE), and make sure to read relevant MSDS data sheets.
4. If there is any confusion over how to use a tool or machine, ask a more experienced person for help.
5. Always follow instructions of launch officers at a launch site, including the Range Safety Officer.
6. If our rocket does not pass a safety inspection or does not meet all relevant safety requirements, then we must comply with the determination of the inspection and not launch the rocket.
7. Before a launch the team's Safety Officer and team mentor, along with the Range Safety Officer, have the right to deny the launch of our rocket for safety reasons.

Furthermore, each member must agree to abide by all of the following codes and regulations, at the direction of the safety team:

1. NAR High Power Safety Code
2. FAA regulations, including 14 CFR Subchapter F Part 101 Subpart C
3. NFPA 1127

The team as a whole agrees to abide by the following regulations from the Student Launch Handbook:

1. Range safety inspections of each rocket before it is flown. Each team shall 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. Any team that does not comply with the safety requirements will not be allowed to launch their rocket.

Any team member who does not agree to any of the rules above may be refused access to rocket construction or assembly, may not be allowed to attend launches, or may even be removed from the team if necessary.

Appendix C NAR High Power Rocket Safety Code

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.

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.

3. Motors. I will use only certified, commercially made rocket motors, and will not tamper with these motors or use them for any purposes except those recommended by the manufacturer. I will not allow smoking, open flames, nor heat sources within 25 feet of these motors.

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 on-board energetics and firing circuits will be inhibited except when my rocket is in the launching position.

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.

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 on-board 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.

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.

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.

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.

10. Launch Site. I will launch my rocket outdoors, in an open area where trees, power lines, occupied buildings, and persons not involved in the launch do not present a hazard, and that is at least as large on its smallest dimension as one-half of the maximum altitude to which rockets are allowed to be flown at that site or 1500 feet, whichever is greater, or 1000 feet for rockets with a combined total impulse of less than 160 N-sec, a total liftoff weight of less than 1500 grams, and a maximum expected altitude of less than 610 meters (2000 feet).

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.

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.

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.

Installed Total Impulse (Newton-Seconds)	Equivalent High Power Motor Type	Minimum Diameter of Cleared Area (ft.)	Minimum Personnel Distance (ft.)	Minimum Personnel Distance (Complex Rocket[2]) (ft.)
0 — 320.00	H or smaller	50	100	200
320.01 — 640.00	I	50	100	200
640.01 — 1,280.00	J	50	100	200
1,280.01 — 2,560.00	K	75	200	300
2,560.01 — 5,120.00	L	100	300	500
5,120.01 — 10,240.00	M	125	500	1000
10,240.01 — 20,480.00	N	125	1000	1500
20,480.01 — 40,960.00	O	125	1500	2000

Appendix D Matlab Code for Recovery

To calculate the sizes of black powder charges the following MATLAB code was used.

```
function [Powder_quantity] = Black_Powder(N,F,L,K)
% This function calculates the amount of black powder necessary to deploy
% our parachutes. N is the number of shear pins, F is the force required to
% break one shear pin, L is the internal length between bulkheads, and K is
% the factor the amount of blackpowder will be scaled by to be sure all
% parachutes will deploy. Powder_quantity is the amount of black powder
% necessary in grams.
Powder_quantity = (5.161*10^(-4))*N*F*L*K; % where 5.161*10^(-4) is a
% constant derived from the ideal gas law.
```