



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

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# 1 Summary of CDR Report

## 1.1 Team Summary

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### Team Mentor

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## 1.2 Launch Vehicle Summary

Many changes since CDR have been minor, so this section is largely similar to the matching CDR section. Many of the measurables of our launch vehicle can be found on our Flysheet at <https://stars.berkeley.edu/sl.html>. The launch vehicle is constructed of bluetube tubing and couplers and has a fiberglass nosecone, a 3D printed boattail, and a transition piece from 6-4in which is also 3D printed, but is also reinforced with fiberglass. The length of the launch vehicle is 111in. The wet weight of the launch vehicle is 27.9 lbs and the dry weight is 22.9 lbs. The launch vehicle utilizes a Cesaroni L730 motor to achieve a simulated apogee of 5323ft. The recovery system implements a same-side dual deployment method, with drogue chute deployment at apogee and main chute deployment at 550ft 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.

## 1.3 Payload Summary

Payload Title: TARS (Terrestrial Autonomous Rover System)

The goal of the payload experiment is to: a) deploy an autonomous rover from the launch vehicle; b) drive five or more feet away, and c) deploy solar panels. In the launch configuration, the payload section is located above the booster and recovery sections of the launch vehicle and directly below the nose cone. After recovery and upon landing, a black powder charge will be activated, breaking three 40lb shear pins and 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 launch vehicle, the rover will drive forward approximately 10ft to fulfill or exceed 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, the payload is split into four subsystems:

- Deployment – subsystem for separating the payload section from the lower airframe
- Ejection – radio link and subsystem for ejecting the rover from the payload airframe section
- Movement – rover subsystem
- Solar – solar panel subsystem on the rover

## 2 Changes made since CDR

### 2.1 Launch Vehicle

The main difference from the manufacturing of the subscale rocket to fullscale was how the 3D printed parts were dealt with. There are two major 3D printed parts in the fullscale rocket. This is the transition piece and the boattail. In the CDR it was listed that the only manufacturing process on the transition tube would be 3D printed out of PETG. However, upon some stress and flex testing, it was determined that the transition was not strong enough for separation procedures. This is especially true with the updated rover deployment system that now uses black powder to separate the tubes. In light of this design change, the transition tube is now being reinforced with fiberglass. There are 8 strips of 1.5-in width and 15-in length. The boattail is also printed out of PETG and added. There was no boattail on the subscale flight due to high complexity of manufacturing as well as diminished returns. Additionally, due to the change in the recovery section since the CDR, airframe had to come up with a tentative plan for the manufacturing process of the recovery tubes. The exterior of the fore recovery section will be made from 4-in diameter bluetube ordered from Apogee Rockets. The tube will be cut to a length of 9.5-in. A 4 inch coupler will be added on the side connected to the transition piece. The exterior of the aft recovery section will also be made from 4-in diameter bluetube. The tube will be cut to a length of 16.5-in. A 6 inch coupler will be added on the side connected to the booster section. The coupler will be extended until it ultimately touches the bulkhead of the booster.

### 2.2 Deployment

The design of the Deployment subsystem has remained largely unchanged from the design as detailed in the CDR report, with some minor changes to improve ease of use and compatibility with other subsystems. The following changes have been made since the CDR Report:

- The centering ring assembly inner diameter has increased by .125 inches radially
- The centering ring assembly now features a small radial cutout to allow for more comfortable wire pass through.
- The insert which houses the electronics sled has been shifted from being situated in the center of the airframe to being situated offset to one edge. This was done to more evenly distribute weight and to accommodate taller standoffs for the electrical board

- A hard mount for the vial of black powder for the deployment charge has been implemented to ensure that the pressure from charge detonation is more evenly distributed. This was done to more confidently insure consistent forces from flight to flight.

On the electrical side, the design of the board remains the same, but its firmware now includes a fully featured testing mode. The deployment board can enter test mode via a UART serial command from a computer. In test mode, the deployment board listens for further commands via UART serial, which allow the checking of the values of sensors and pins and the setting of outputs and LEDs. This streamlines the debugging process, and removes the need to upload separate firmware to the board for testing and launch, saving time on launch day when testing and preparing the launch vehicle.

## 2.3 Ejection

The completion of the payload ejection subsystem requirements verification tests prompted several minor changes that must be made in order to ensure successful ejection. However, these changes do not affect the fundamental design detailed in the CDR report and major design, structural, and material elements remain unchanged. These changes include the need to add a lubricating interface between the inner walls of the vehicle airframe tube and the scissor-lift.

As with the deployment board, the ejection board now features a testing mode. The ejection board can enter test mode over either UART serial or radio. Once in test mode, the ejection board listens for commands and can check values of sensors and pins, set outputs and LEDs, and send signals over radio. The rationale for this testing mode is the same as that of the deployment board; the debugging process is made easier and time is saved on launch day.

## 2.4 Movement

Since CDR, a new version of the rover board has been designed and ordered. The new board features an ATmega644P processor, which has more program memory and also more GPIO pins. Ultrasonic sensor connectors have been switched to 4-pin blocks with resistive dividers to shift 5V ultrasonic output to 3.3V for compatibility with the microprocessor. Additionally, minor inconsistencies in layout such as the arrangement of UART pins and capacitors have been corrected to match other boards. Motors have been changed to 88 RPM as the torque of the previous motors was deemed unnecessary, as well as suffering from limited supply.

Additionally, the chassis has been revised to point sensors downward, allowing better detection of low obstacles while driving. The aluminum side plates are being replaced with polycarbonate to facilitate machining, and T-nuts are now being utilized to mount the side plates.

## 2.5 Solar

The overall design of the solar subsystem remains unchanged from the CDR. However, minor modifications were made to the opening mechanism, hood, and potentiometer bracket.

The opening mechanism is now secured with one neodymium magnet instead of two; the neodymium magnet removed was replaced with tin plates. The shape of the hood is filleted instead of having rectangular edges. The potentiometer bracket was changed from a rectangular shape to that of a semicircle.

## 2.6 Project Plan

Due to an unsuccessful full-scale flights, and the back-up launch day being rained out, the final full-scale test flight will now take place on March 10th or 11th.

# 3 Vehicle Criteria

## 3.1 Design and Construction of Vehicle

### 3.1.1 Changes in Launch Vehicle Design

The recovery section of the airframe has been altered from the previous single chamber construction using tender descenders to a dual chamber design which removes the need to use tender descenders. This dual chamber design features two parachute sections separated by the avionics bay. One section will house the drogue chute, and the other will house the main chute. This change was made in order to avoid an issue discovered at the first full-scale test launch that resulted in unexpected failure. During the recovery sequence, deployment of the drogue parachute was unsuccessful due to increased friction resulting from over-dense packing of the recovery material. This and the shock cord becoming taut resulted in forces that caused premature separation of the payload tube and nose cone assembly at apogee. As a result no parachutes were deployed and the launch vehicle lower assembly (transition to booster) crashed at critical speeds. Our rebuild of the full-scale will reuse the booster section, which survived the launch except for a 2 inch length at the fore end that was cut off. In addition, a bulkhead will be epoxied to the inside of the booster tube to accommodate the new recovery tube. As a result of these changes the launch vehicle is now 111in long as opposed to its original 113in length.

### 3.1.2 Safe Launch and Recovery Features - Structural Elements

### 3.1.3 Flight Reliability Confidence

The full-scale launch vehicle accomplished its apogee goal by reaching 5360ft, 80ft higher than the goal set by NASA and 100ft higher than the OpenRocket simulation's prediction. These changes can be contributed to changes in weight that resulted from simulation inaccuracies as well as paint. To minimize these differences as well as improve our flight reliability confidence, we are in the process of:

1. Measuring and weighing every component of the finished launch vehicle and updating our simulations with more accurate weight estimates.

- Carrying out further simulations of airflow and drag in ANSYS CFD to improve the accuracy of our apogee estimate.

For the following reasons, we have confidence in our ability to complete the mission 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.* Any tubing with visible cracks that were spotted after the February 3rd test flight were removed or repaired. Out of the entire airframe salvaged from the crash, only the nose cone and booster tube are being reused. The nose cone has a minor crack in the paint finish that can be repaired with filler. The first 2in at the fore end of the booster were irreparable and were completely removed.
- There will be no unwanted separation between the pieces of the rocket.* To prevent premature separation of the payload tube during flight a third shear pin will be added to the transition-payload tube interface. In addition, both recovery tubes will be secured with enough shear pins to only allow for separation with black powder charges.
- 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. ANSYS simulations verify that no component of the airframe undergoes stress exceeding its material yield strength. Furthermore, the structural integrity of the airframe was checked for extensive damage following the February 3rd crash.
- Meets all vehicle requirements set from NASA SL 2018 Handbook.* The design of the launch vehicle meets all requirements set by NASA SL.

### 3.1.4 Construction Process Documentation

4" and 6" blue tube and couplers were bought from Apogee Rockets. For the 6" tubes, one piece was cut to a length of 18" to hold the payload. The 4" tube was cut into three pieces of lengths 7"(avionics bay), 26"(recovery section), and 25.3"(booster section). The nose cone and the motor tube, made out of phenolic, were bought from Public Missiles, and the tube was cut to a length of 26". Additionally, the motor retainer was bought from Apogee Rockets and three G10 fiberglass fins were custom made and brought from Fibre Glast. The boat tail and the transition piece were 3D printed out of PETG filament. Finally, plywood was laser cut to make the couplers, bulkheads, and standoffs.

For the standoffs, it was divided into two components, airfoils and a block. For the airfoils, three holes were added to the CAD so that they could be laser cut to avoid drilling them later. Each standoff is made up of 6 airfoil pieces, each laser cut from 1/4" birch plywood. The outer holes are for a 10-24 bolt, while the middle hole is for a 1/4"-20 bolt. For assembly, the top layer of the standoff had the outer holes countersunk with a countersink bit on a drill. Each layer was then JB welded and had its alignment checked by placing the bolts in their respective holes.

The standoff block was cut from a piece of a standard 2x4" board and the holes were drilled based on their placement on the airfoil pieces. The block was sanded so it would sit

flush with the inside of the 4" tubing and then the rest of the edges were sanded to minimize the chances of the parachutes in the recovery tube getting caught on them. On the inside side of the block, a dremel was used to sand pits in the wood so that the nuts for the bolts would sit flush with the wooden block. The nuts were 5-minute epoxied to the inside of the pits. Then the bolts were cut to length and holes were drilled through the airframe. The block is JB welded to the inside of the tube and the standoff is bolted to the block. For the payload and the recovery sections, minimal changes were made. On the recovery tube, a standoff was added 5" away from the aft end of the tube. For the avionics bay, a door was created by laser cutting a rectangular shape onto the tube and a smaller shape on the coupler. 4 holes on the coupler door were also cut to hold screws. The coupler was then epoxied with JB weld onto the tube lining up the two cut sections. The avionics sled was then inserted into the airframe and was epoxied with JB weld.

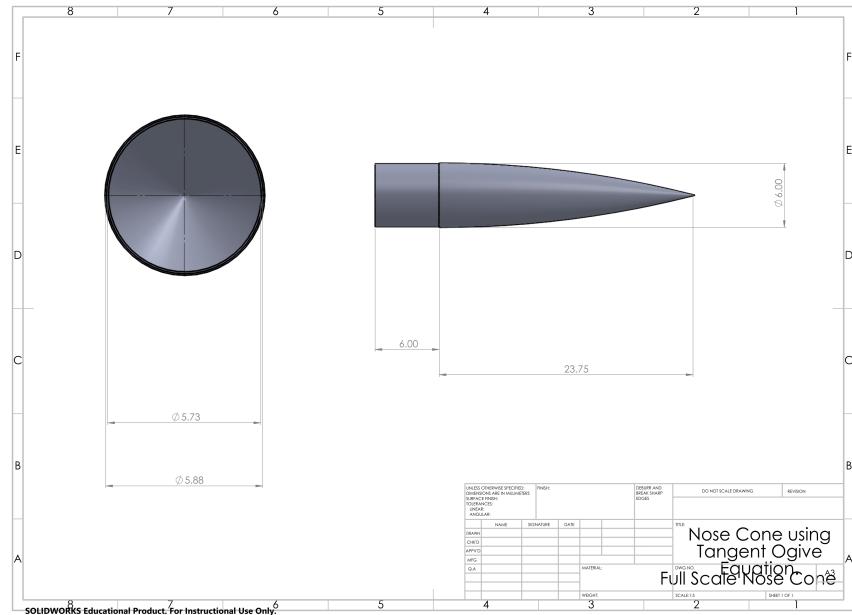
In order to reinforce the transition piece, 8 strips of 1.5 width and 15 long fiberglass were cut and epoxied axially with West System epoxy onto the interior of the transition piece, and then the transition piece was left to cure. A bulkhead attached with a U bolt is epoxied onto to the start of the 4" side of the transition piece.

For the booster section, three fin slots were symmetrically cut on a mill. The motor retainer was then JB welded into the motor tube. In order to stabilize the motor tube and center it with the booster tube, three centering rings were used, made out of laser cut plywood. One centering ring was placed at the end of the motor tube. The second was placed slightly offset from the other end so that it touches the boat tail, which will be flush with the body tube. The third centering ring was placed a distance away from the second centering ring such that the fins fit snugly with no gaps between the two centering rings. The three centering rings were attached by JB welding the inner circle of the rings and inserted into their correct locations. After being put into the right positions, they were filleted, and the centering rings were kept aligned with the body tube by using a leveling tool. After letting the centering rings cure, the outer circles of the rings were layered with JB weld and inserted into the body tube. After the first and second centering rings are fully in, the standoff was put in as far down as possible, positioned in the gap of the second and third centering ring. Once the standoffs were in, the motor tube was fully inserted, leaving enough room for the lip of the boat tail to be connected to the body tube while minimizing how much the motor retainer sticks out. The fins were layered with JB weld epoxy and slid through the fin slots and onto the motor tube. The boat tail was then JB welded onto the body tube. Finally, the fins were filleted with JB weld. While the epoxy was being cured, a fin jig was secured on the fins, ensuring that the fins were aligned such that they straight and parallel to the blue tube. The fin jig is a large circular piece of plywood that was laser cut to have three slots to fit the fins, and a hole in the center to fit the motor tube. Additionally, an extra rectangular cut was made near the center to accommodate the standoff.

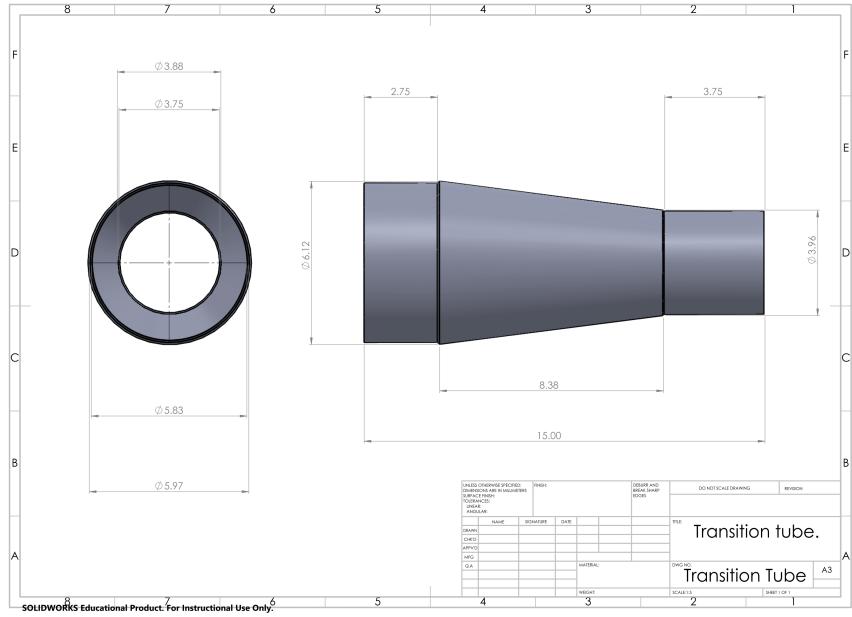
After all these sections were built, the vehicle is assembled in the order from top to bottom: nose cone, payload, transition, recovery, avionics bay, and booster. For each of the connections, two holes opposite from each other were drilled into. Two shear pins were inserted in the holes with the connections between the payload and transition, the transition and recovery, and the recovery and avionics bay. On the connections between the nose cone and payload and between the avionics bay and the booster, wood screws were inserted.

### 3.1.5 Vehicle Schematics and Dimensioning

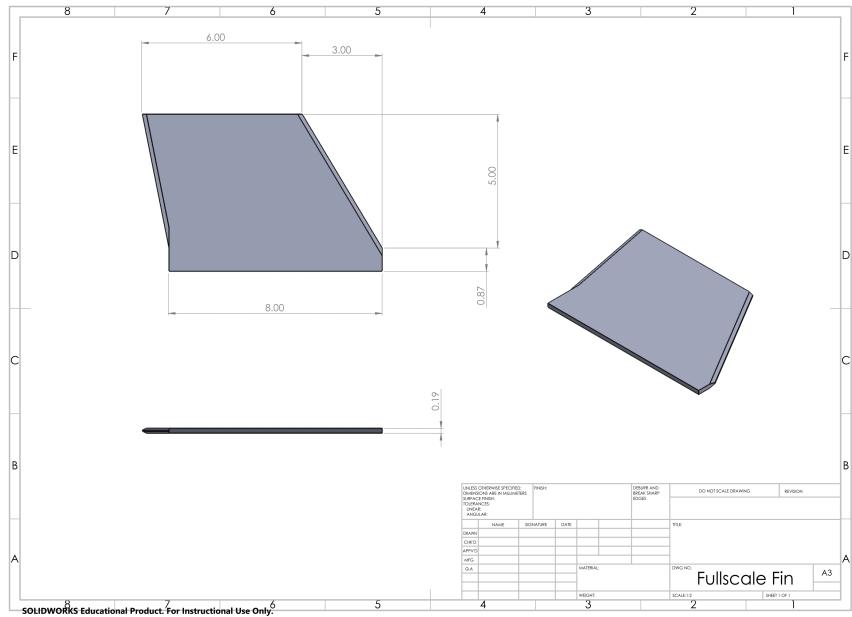
- *Nose Cone* The nose cone that was selected is a fiberglass wound tangent ogive nose cone made in a 4:1 height-to-diameter ratio with a 6in base diameter. Fiberglass was chosen for its high strength and lightweight properties. The nose cone will be purchased from Apogee Components, so no manufacturing is required and there are no concerns about integrity of design. Since the aim is for a higher apogee, its more ideal to have a nose cone that is optimized for high speeds, so the Ogive Nose Cone is the best fit.



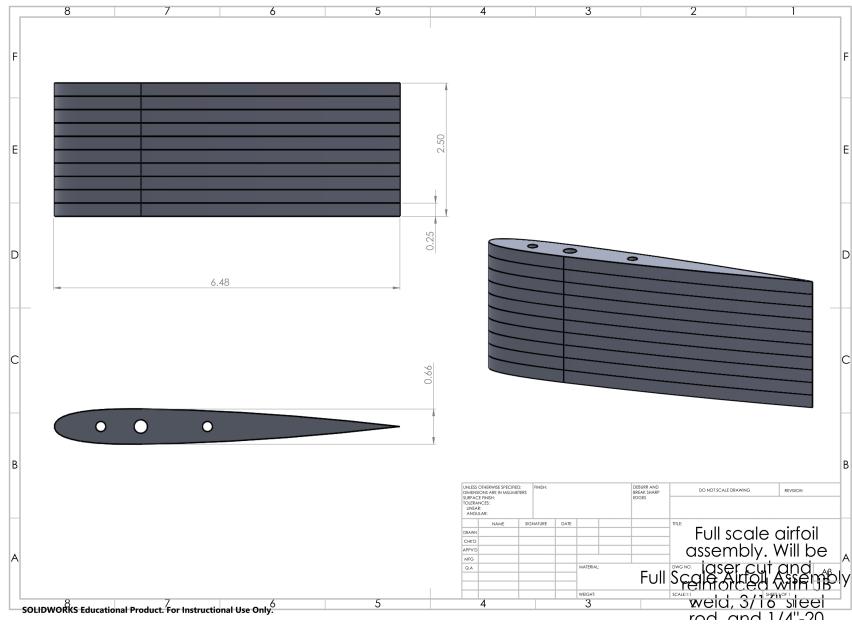
- *Transition Piece* The final launch vehicle design utilizes a transition piece that goes between the payload tube and the recovery, avionics, and booster section of the launch vehicle. The sub-scale transition was 5.3in long and connected airframe tubes of diameter 2.56in and 4in. The full-scale transition is 8in long and connects tubes of diameter 4in and 6in. It will be manufactured with 3D printed PET-G and strengthened on the inside walls with fiberglass strips and West System epoxy.



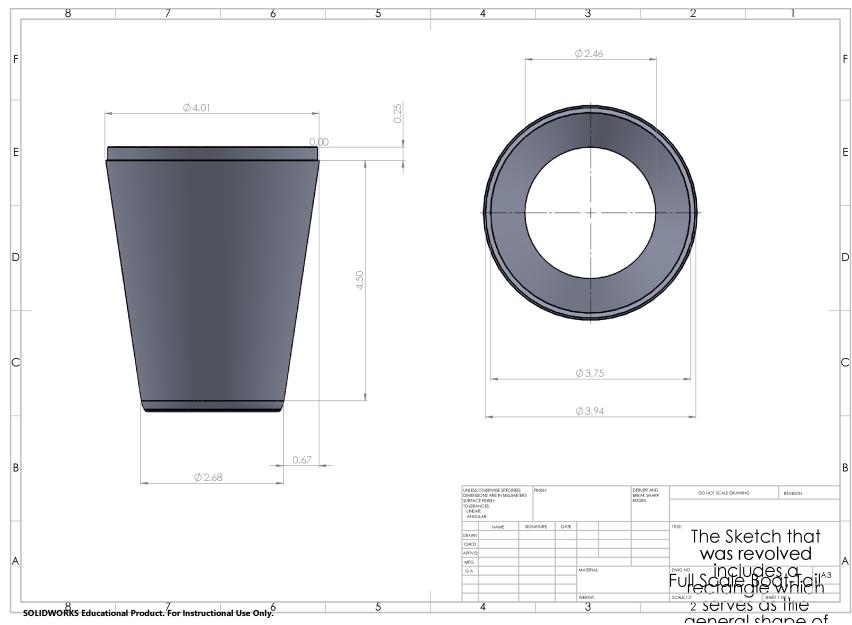
- *Fins* The launch vehicles fins will be 0.1875in thick G10 fiberglass ordered from Public Missiles Ltd. and will have its leading edge rounded to improve aerodynamic flow. For the same reasons that were given for the nose cone, we chose to have the fins made from fiberglass for its high impact tolerance and low weight. The fins will be aligned with a precision cut fin jig and the root will be reinforced with carbon fiber fillets.



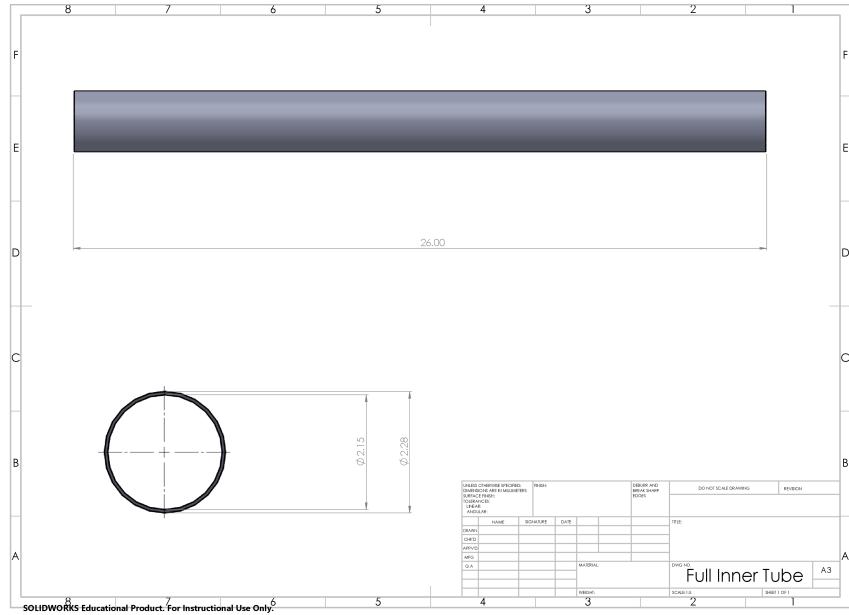
- *Rail Button Standoffs* In order to compensate for the larger fore diameter while on the pad along the rail, wooden standoffs were added.



- *Boat Tail* To improve aerodynamic flow, a boat tail measuring 4.7in long with a fore diameter of 4in and aft diameter of 2.5in inches was added to the end of the launch vehicle. It will be manufactured in a similar method to the transition piece where the inside of a 3D printed part will be reinforced with fiberglass strips and West System reinforced epoxy. There is fiberglass reinforcement on the



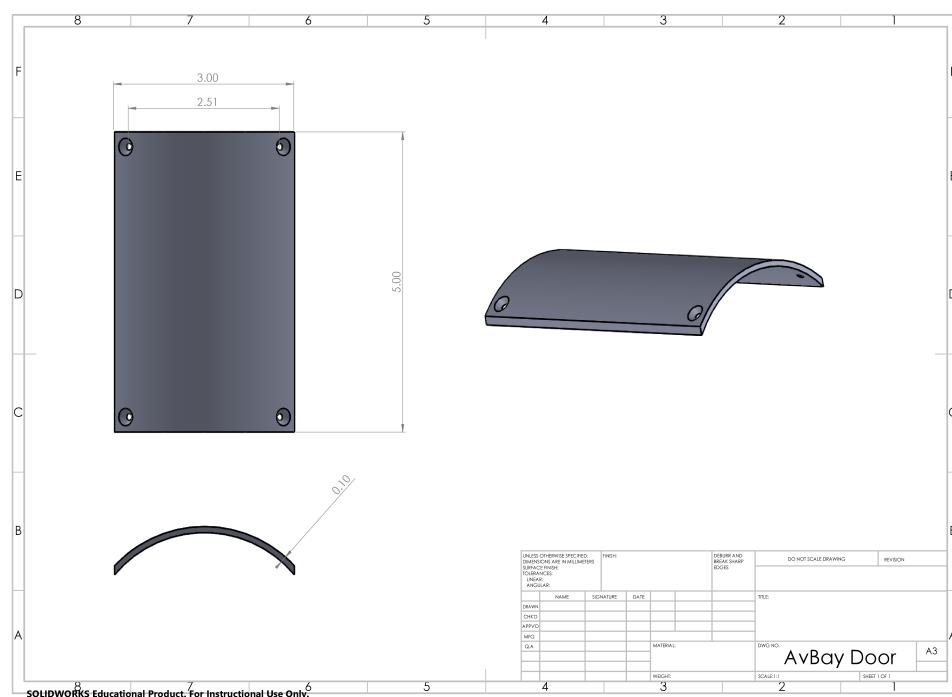
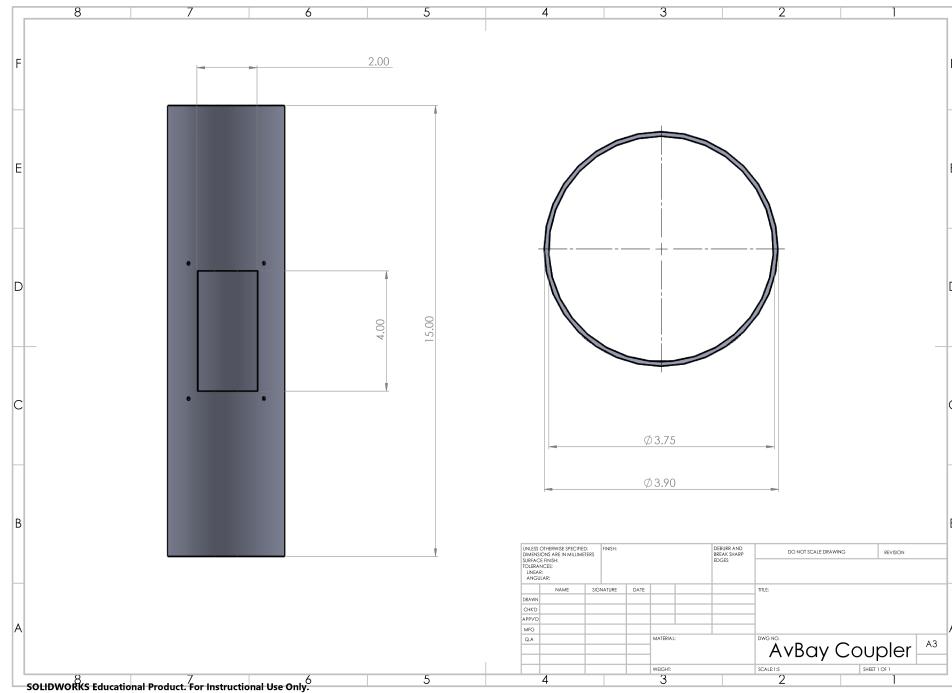
- *Motor Tube* The motor tube will be 26in long with an approximately 2.3in diameter. It will be manufactured from kraft phenolic for its high temperature tolerance, which will protect the main airframe from thermal damage during flight.

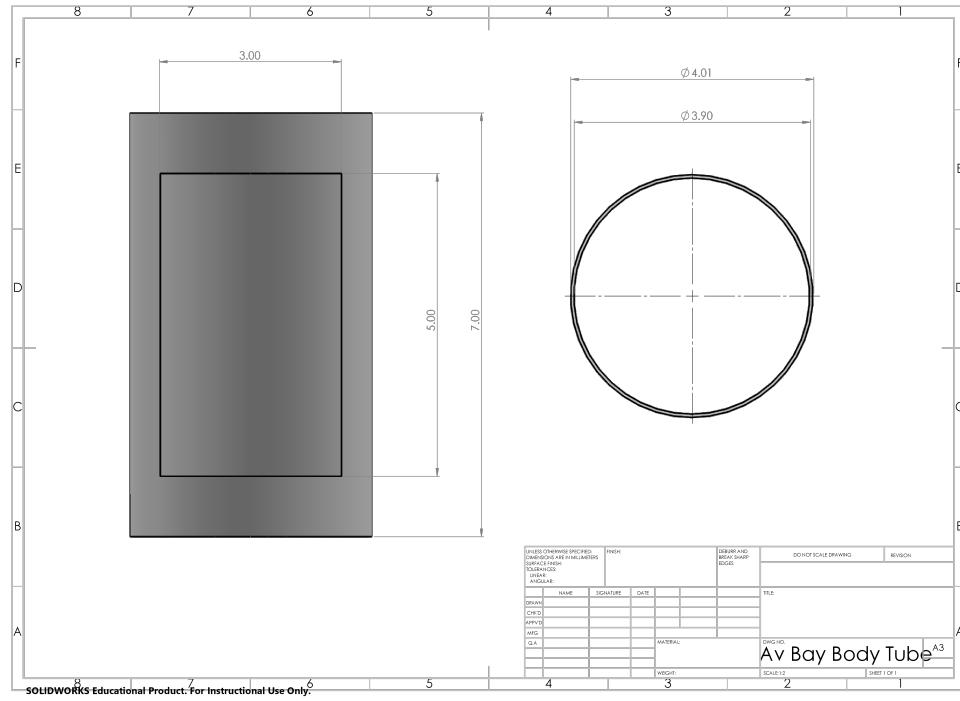


- *Motor Retainer* The motor retainer will be manufactured and purchased from Aero Pack Incorporated and is made from precision machined aluminum. The part ensures that the motor remains inside its inner tube during the entire flight. The mounting point for the retainer will be secured to the end of the motor tube with JB Weld steel reinforced epoxy.
- *Airframe Tubing* The airframe tubing will be cut from 4in and 6in diameter blue tube purchased from Apogee Components; the lengths will be 18in for the 6in diameter and 58.3in for the 4in diameter. Blue tube was selected for its high impact and fracture tolerance, which increases the likelihood of the airframe surviving each flight.
- *Payload Tube* The outer diameter: 6.080 inches, the inner diameter is 5.973 inches, the length is 18 inches. The payload tube has enough length to house the entire payload and ejection mechanism.

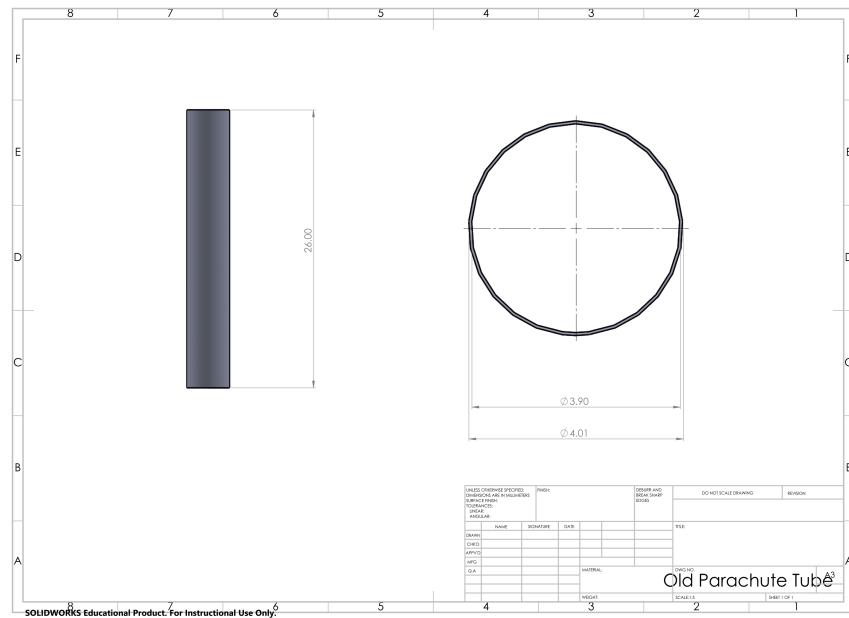
 [Payload\\_Tube.png](#)

- *Avionics Bay* The Avionics Bay body tube is 7 inches in length, with an outer diameter of 4.014 inches, and 3.9 inches in inner diameter. The Avionics Bay is between recovery and the motor tubes.

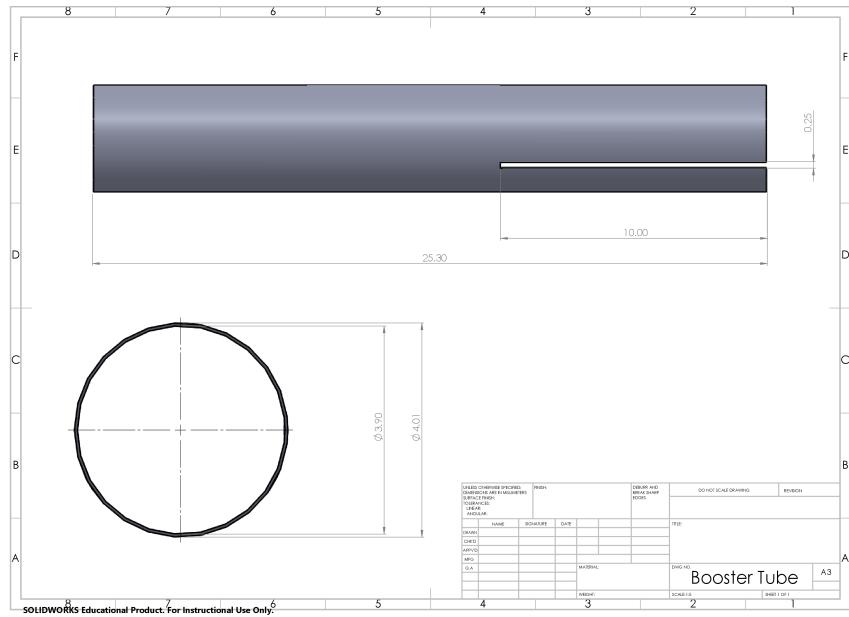




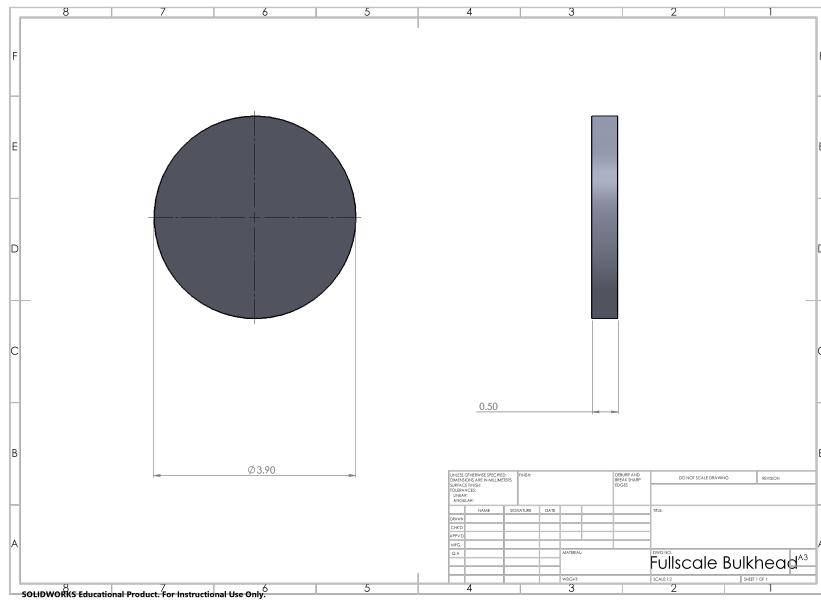
- *Parachute Tube* The drogue and the main parachutes are in the same tube, which is 26 inches, with an outer diameter of 4.014 and an inner diameter of 3.9 inches. This tube is made out of blue tube for optimization of high altitude flight.



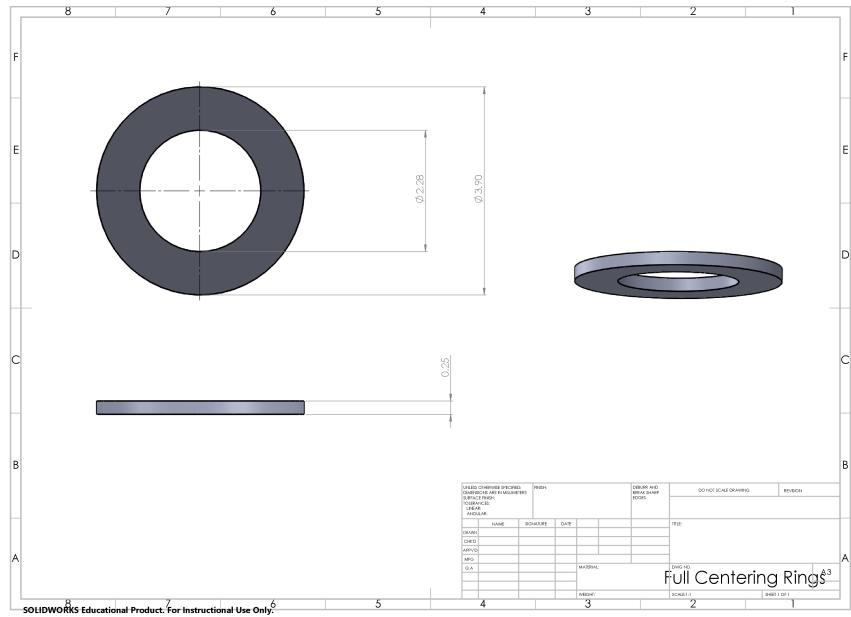
- *Booster Tube*



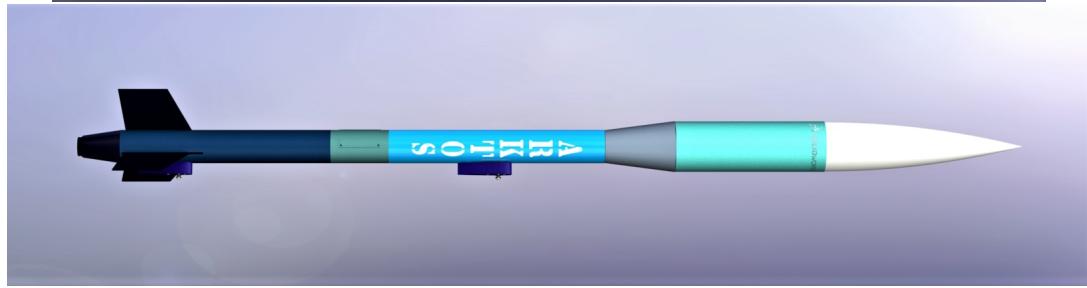
- *Bulkheads* All bulkheads on-board the launch vehicle will be constructed from laser cut plywood. Plywood was chosen because it is lightweight and sufficiently strong enough to withstand flight loads and black powder charge separation. They will be laser cut at Jacobs Hall at UC Berkeley and secured to the inside of the airframe with JB Weld steel reinforced epoxy.

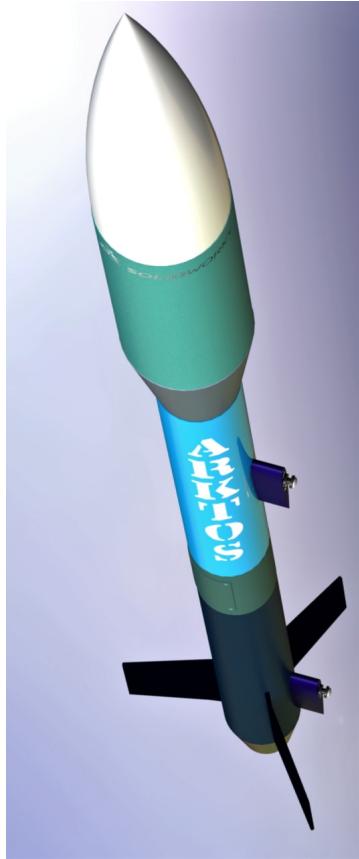


- *Centering Rings* Similar to the bulkheads, the centering rings will be made from laser cut plywood for the same reasons. It is important that the rings are made to precision in order to ensure that all parts are centered and aligned with the launch vehicles vertical axis. They will be secured to the airframe and inner tubing with JB Weld steel reinforced epoxy.



- Fully Assembled CAD Renders





## 3.2 Recovery Subsystem

### 3.2.1 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.

*Final Decision:* The I-Beam sled design is used for the avionics bay. There are two one-half in. bulkheads on the top and of the bay. Then, there are an additional two one-fourth in. bulkheads glued together mounted within the existing bulkheads, as shown by Figure ???. These bulkheads have a section removed from them, with their edges cut at a 45° angle in order to create a triangular slot. The I-Beam sled then slides 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 launch vehicle. In addition, the slot-fit design was the simplest mechanism that provided the most structural integrity. Since there 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 the mission.

*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.

### 3.2.2 Bulkheads

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

*Final Decision:* The bulkheads consist of eight one-fourth in. pieces of plywood epoxied together to make a total of two three-quarters stacks. One piece is sized to fit tightly in the coupler while the other is sized to fit the airframe. This staggered area allows 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.

### 3.2.3 Centering Rods

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

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

### 3.2.4 Bolts

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

*Final Decision:* In order to distribute the stress and force of thrust during launch, U-Bolts are used instead of Eye-Bolts. Attaching a U-Bolt to each bulkhead, positioned between the two protrusions from the two center rods, provide for a much more sturdy avionics bay. The U-Bolts are steel rather than stainless steel, as to increase the toughness of the bolt while

decreasing the hardness; using a more ductile material would absorb more energy.

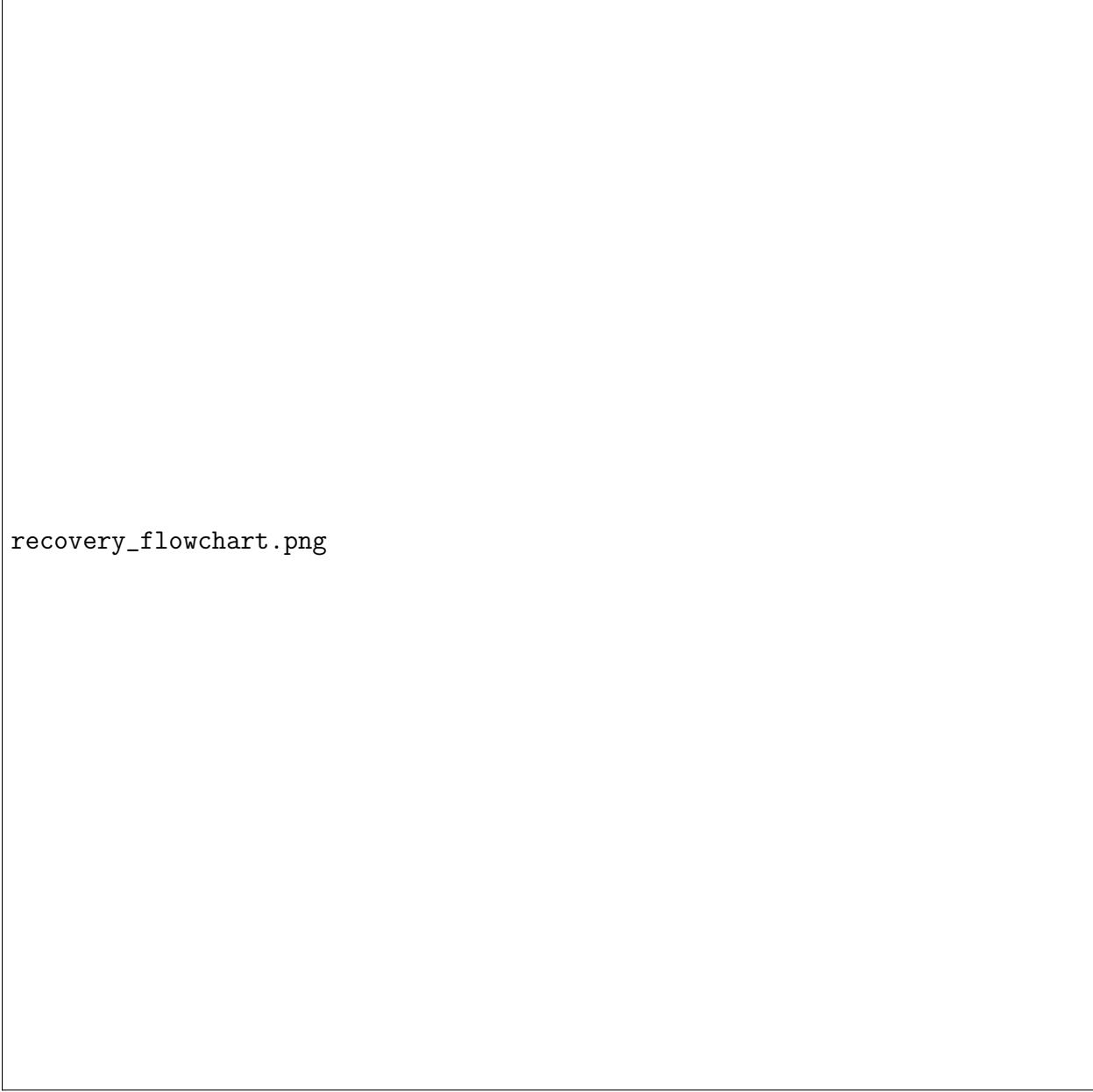
### 3.2.5 Shock Cords

*Description:* Shock cord is used to attach the parachutes to the launch vehicle.

*Final Decision:* The launch vehicle uses 1in tubular nylon for its shock cords. This decision was made as a result of considering the high energy experienced by the initial pyroshock. While flight-proven, tubular kevlar tended to be too inelastic, which could potentially create zippering during deployment. Thus, adopting 1in nylon would allow for the pyroshock energy to be absorbed more gradually, diminishing chances for fracture during high shock deployments. However, nylon is also not flame-retardant. As a result, the nylon shock cords are covered with kevlar shock cord sleeve, at least for the 3ft closest to the black powder, to ensure that the shock cord is not damaged.

## 3.3 Deployment System

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



recovery\_flowchart.png

Figure 1: A flowchart of the deployment process

To ensure that the launch vehicle will safely land for every launch, the deployment system must have redundancy. This is in the case that one of the components unpredictably fails, then its redundant counterpart will be utilized and recovery will proceed smoothly. First and foremost, two vials of black powder will be used, instead of just one, for the separation of the launch vehicle during drogue chute deployment. Each would have enough power to separate the launch vehicle on its own, and the launch vehicle is designed to withstand such structural loads. This design will decrease the chance that our black powder explosion will fail to separate the vehicle. 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. These batteries will be brand new in order to diminish the chance of failure due to previous use. This redundant system ensures that a mechanical or software issue in one of the altimeters will not hinder the entire recovery system as a whole.

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 reliable and successful at 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. Shock Cords

- (a) Use one length of 1in tubular kevlar shock cord, coated with shock cord sleeves, knotted at various distances and attached with quicklinks.
- (b) MAIN TO TRANSITION/AV-BAY - A 27' length of shock cord used to attach the main chute to the transition section of the payload tube and the avionics bay.
- (c) DROGUE TO BOOSTER/AV-BAY - A 33' length of shock cord used to attach the drogue chute to the booster section of the launch vehicle and the avionics bay.

4. Parachutes

- (a) Drogue Chute: 12 in Elliptical parachute from Fruity Chutes. Will be positioned in the 9.5 inch booster tube above the avionics bay. Color - orange and black. Coefficient of Drag - 1.5
- (b) 72in Toroidal parachute from Fruity Chutes. Will be positioned in the 16.5 inch booster tube below the avionics bay. Color - orange and black. Coefficient of Drag - 2.2

5. 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.

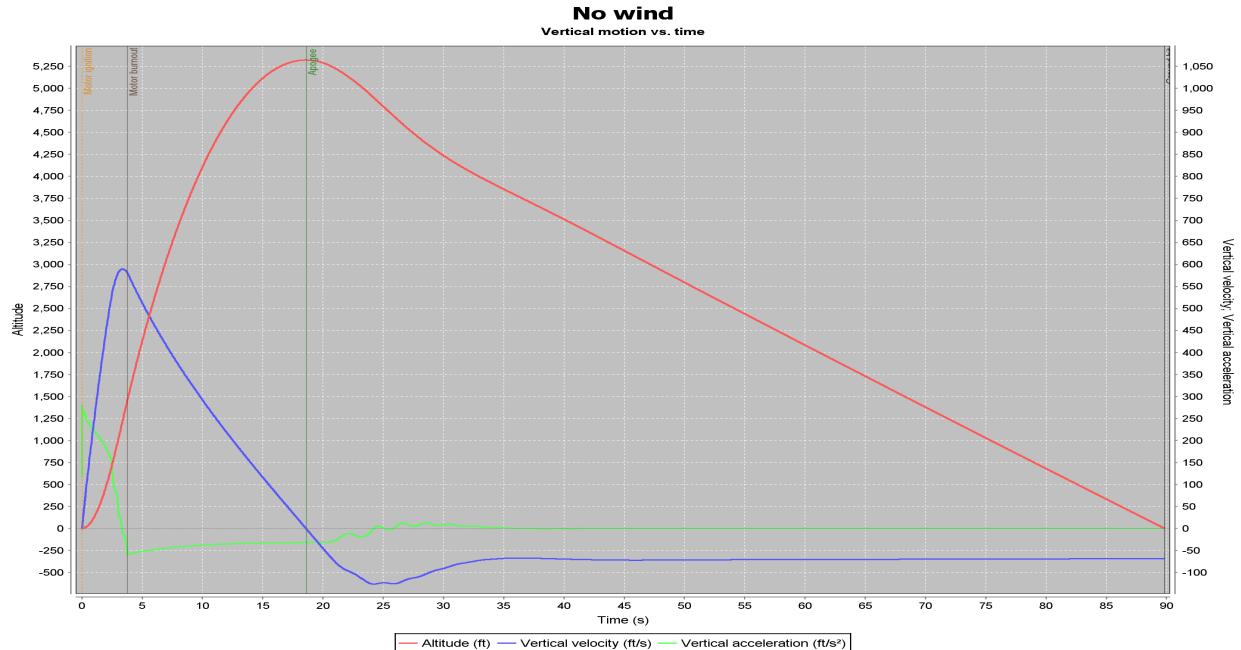
## 6. Parachute Blankets

- (a) Drogue Chute Blanket: Orange blanket that will cover the wrapped drogue chute. This will be positioned in the 9.5 inch booster tube above the avionics bay
- (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. Despite our previous statement in part 1, this will be positioned beneath the avionics bay in the 16.5 inch booster tube

### 3.3.1 Recovery Part Drawings

## 3.4 Mission Performance Predictions

The thrust curve for the Cesaroni L730 motor.



OpenRocket simulation flight profile for zero wind. Resulting simulated apogee is 5323ft.

Since the CDR, the team has developed ANSYS Computational Fluid Dynamics simulations to compare with OpenRocket results. The developed method is to perform multiple simulations at various air velocities and determining the total drag forces (pressure and frictional) on the launch velocity at each velocity. From this we determined an equation that describes the drag force on the launch vehicle as a function of velocity and heading of the launch vehicle. This, combined with the thrust curve data, allows us to predict the acceleration the vehicle will undergo at any point in ascent. Using a timestep of 0.01 seconds, the following equations were used.

$$a(t) = \frac{Thrust(t) - Force_{Drag}(v)}{mass(t)} - g$$

$$v(t + dt) = v(t) + a(t)dt$$

$$x(t + dt) = x(t) + v(t)dt$$

The simulated apogee using this method is 3838ft. This is SIGNIFICANTLY lower than both our OpenRocket simulated value, and our full-scale launch recorded value (5360ft, to be discussed in depth in [subsection 3.5](#)). The most likely explanation for this is that there were major inaccuracies and improper assumptions in our ANSYS model. For the time being, these results will not be considered, but we will continue to work toward improving and developing our simulation methods.

### 3.4.1 Stability

The positions for the center of pressure and gravity were calculated using OpenRocket software. The CG is located 61.537in aft the tip of the nosecone and the CP is located 77.158in aft the tip of the nosecone. The "on-pad" stability is 2.57 calibers.

### 3.4.2 Kinetic Energy of Landing

A Matlab program was written and used to perform drag force, terminal velocity, and kinetic energy calculations for the descent of the launch vehicle. During parachute deployment, the launch vehicle 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 12 in and a drag coefficient of 1.5, and the main parachute has a diameter of 72 in and a drag coefficient of 2.2. Using these numbers, it was calculated the launch vehicle would descend with a terminal velocity of 130.27 ft/s after drogue deployment and 17.76 ft/s after main deployment. The final energy for the upper part of the launch vehicle would be 54.51 ft-lbf, and the final energy for the lower part of the launch vehicle would be 52.01 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.

### 3.4.3 Drift

Drift calculations have been revised since CDR to account for the decision to decrease the size of the drogue parachute. The drogue parachute diameter was reduced from 20 inches to 12 inches in order to reduce drift. Drift distance was calculated as the product of the descent time and the wind speed. The following shows various drift distances at their respective wind speeds based off of the descent time of 83 seconds determined from simulations.

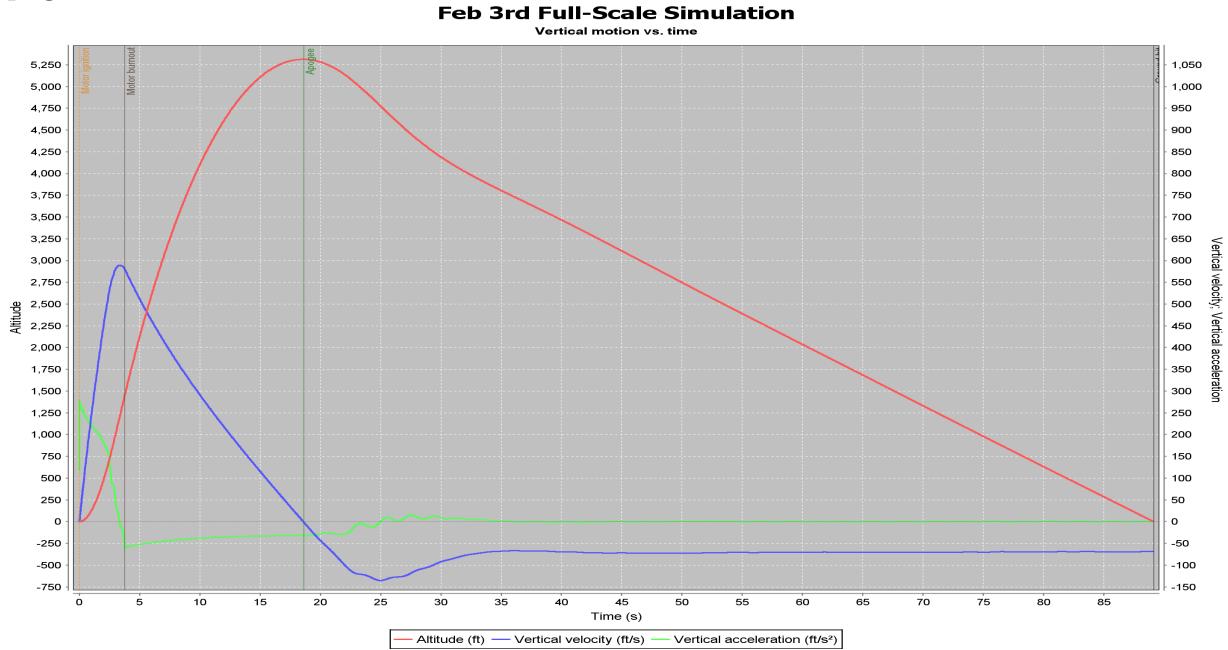
Wind Speed (mph)	Drift (ft)
5	609
10	1217

15	1826
20	2435

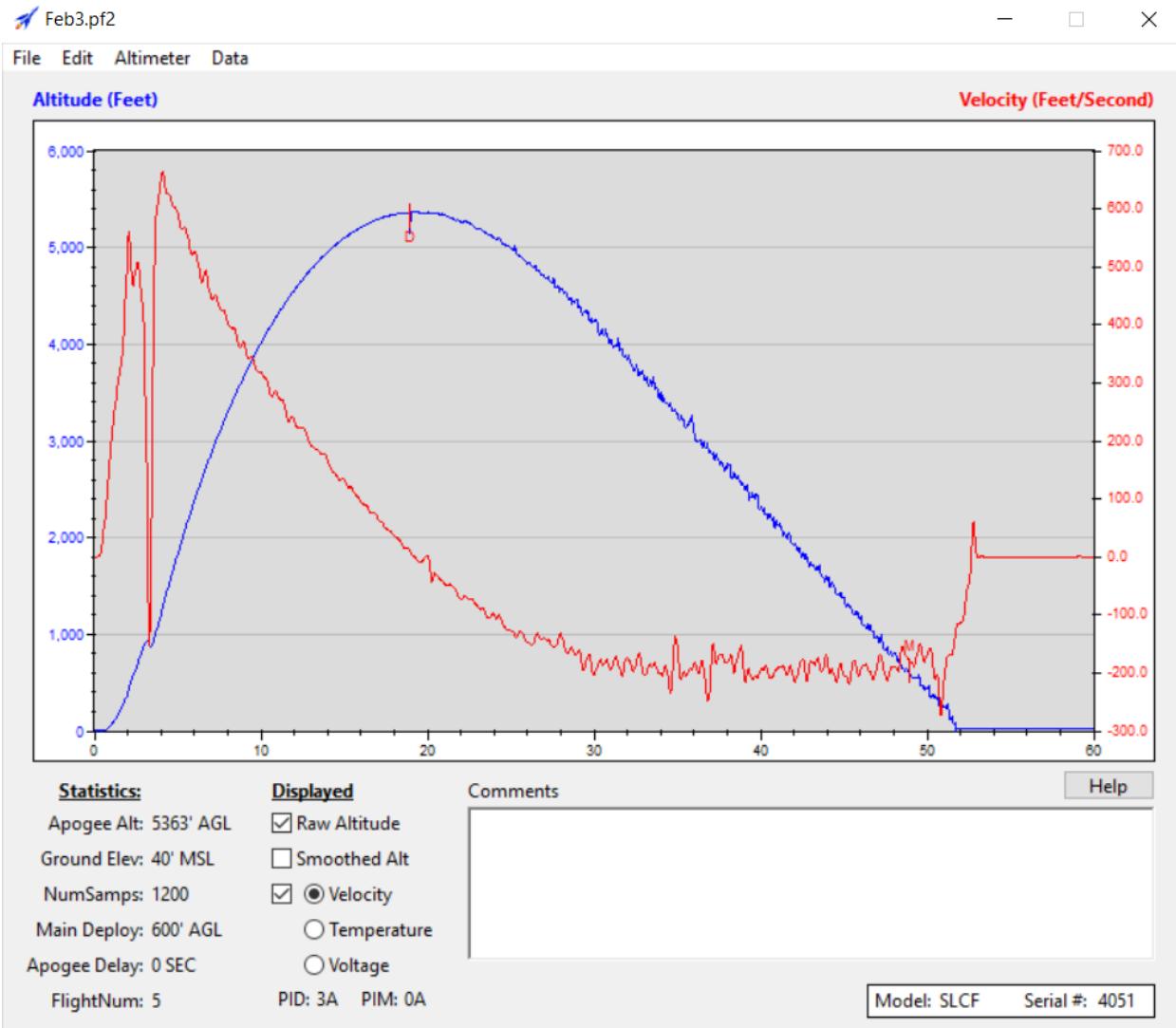
### 3.5 Full Scale Flight

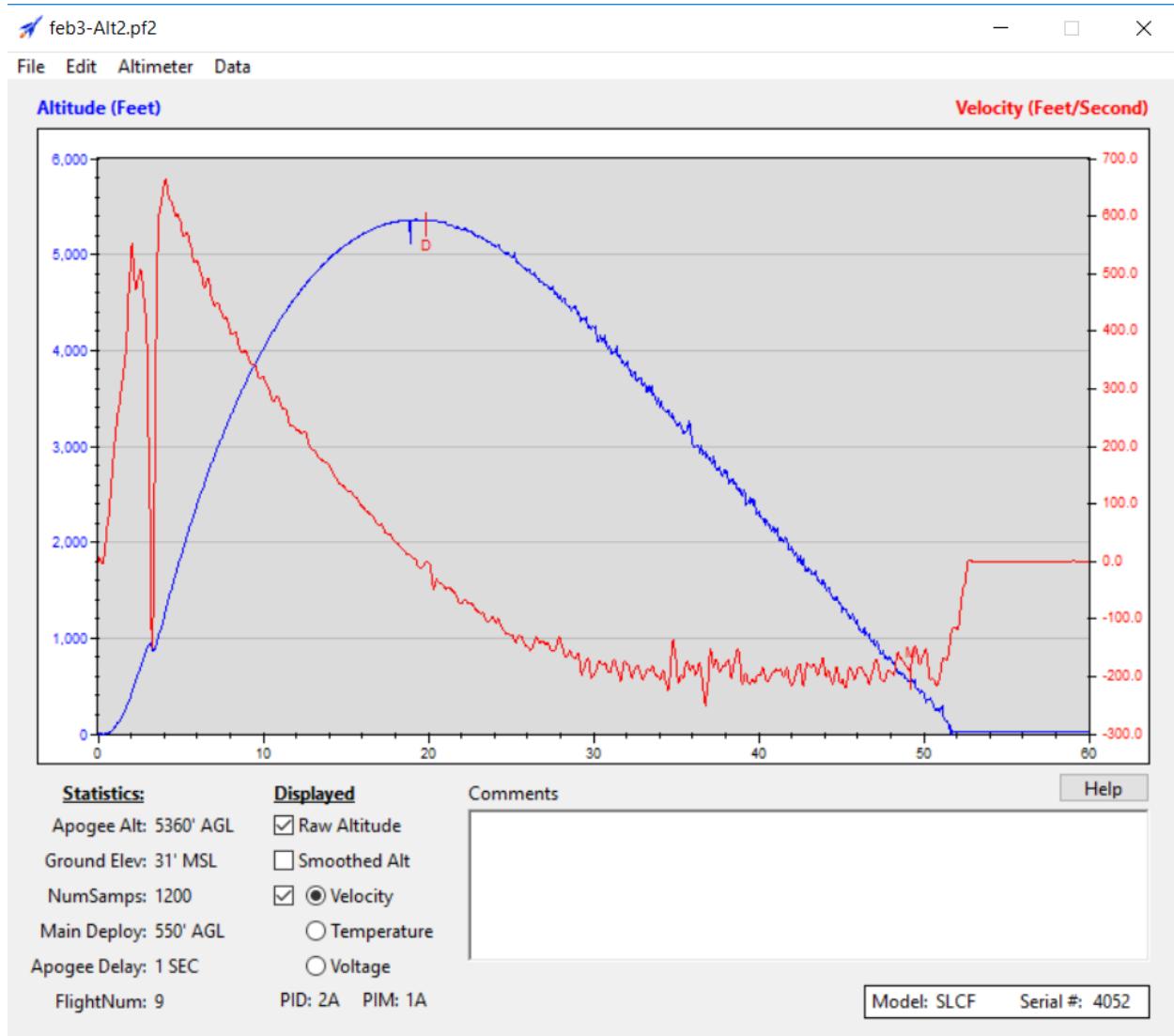
As noted in this report, during the February 3rd full-scale flight the recovery parachutes never fully deployed and the launch vehicle crash landed. However, because the ascent of the launch vehicle was not at all affected by the recovery failure, and because full flight data was still able to be acquired from both altimeters, an analysis of this flight was analyzed. The temperature for the February 3rd launch was recorded as 72°F, and the wind-speed as 4.6 mph.

An OpenRocket simulation was run with the given weather conditions and the resulting apogee was 5314ft AGL. The plot for vertical motion of this simulation can be seen in subsection 3.5. Note that because the actually flight resulted in a crash landing, the there were no parachute deployments included in the simulation, though this has no affect on apogee.



The simulated apogee of 5314ft is compared to the recorded apogees for the February 3rd full-scale flight by the two altimeters of 5360ft and 5363ft. The simulated and recorded values are very close with a difference of less than 1%. This difference is less than the range of error we expect from inaccuracies in our rocket model and the nature of the OpenRocket simulations.





A simple MATLAB script was created to estimate the drag coefficient of the full scale rocket. The script, uses an iterative process with a time-step of 0.01 seconds. The thrust and mass data for the motor are taken from an online source and are interpolated as needed. The equations for the acceleration, velocity, and position are shown below.

$$a(t) = \frac{Thrust(t) - \frac{1}{2}C_D v(t)^2}{mass(t)} - g$$

$$v(t + dt) = v(t) + a(t)dt$$

$$x(t + dt) = x(t) + v(t)dt$$

Using a drag coefficient of 0.3347 results in an apogee of 5361.6ft, which is in between the two values provided by the altimeters. Therefore, we will estimate our drag coefficient to be 0.3347 from the full-scale test flight results.

## 4 Payload Criteria

### 4.1 Changes made since CDR and reasons (expanded on)

#### 4.1.1 Deployment

The payload deployment subsystem passed all three of the verification tests. P.D.1 Remote Trigger Radio, P.D.2 Separation Distance, and P.D.3 Rover Shielding were all successfully completed with all success criteria met when ground tests were completed. However, due to the damage/loss of components during our flight testing, insufficient data was collected to determine whether or not the flight testing was successful. Changes to the design were made in response to changes from other aspects of the vehicle design. The charge being used was upped from 4g of black powder to 6g in the interest of increasing separation force after landing. This change was made in response to the failure mode of the interface between the deployment section of the airframe and the tube housing the rover as observed during the flight test. The airframe design was changed to incorporate an additional shear pin constraining this interface, as such, the force required to separate the tubing was increased. The increase from 4g to 6g of black powder allows the separation force provided by the deployment subsystem to increase substantially. The remainder of the design remained unchanged as the increased stressed remained within a factor of safety of 2 for the stress placed on the airframe.

#### 4.1.2 Ejection

The payload ejection subsystem requirements verification tests, more specifically P.E.1 Frame Load Bearing Capacity and P.E.2 Lift Actuation Force, showed that the scissor-lift is able to successfully eject a rover mass weight when the scissor lift is outside of the vehicle tube. However, when mounted inside the nosecone and payload tube sections, the scissor lift was only able to successfully eject the weight from a partially extended position and was unable to extend from the fully compressed position. This issue was subsequently determined to be caused by the frictional forces between the scissor-lift top plate and inner wall of the nosecone shoulder. To mitigate friction the two surfaces be abrasively treated and lubricating materials, specifically a PTFE spray coating and PTFE/UHMW adhesives, will be added between the two sliding surfaces. In the unlikely event that the lubricating interfaces are not sufficient, minor changes will be made to the servo drive system of the scissor lift such as the replacement of the current servo motor with a servo motor that has a higher torque rating. However, this would be a minor change as any replacement servo motor would have the same physical dimensions and control specifications.

#### 4.1.3 Movement

Since CDR, a number of mechanical and electrical changes have been made to the rover. On the mechanical side, the PLA chassis has been redesigned to orient the ultrasonic sensors for better detection of low obstacles, and the internal structure has been revised to improve the fit of electronic components. The aluminum side plates containing the motor mounts have been replaced with polycarbonate plates to save weight and facilitate machining, and they

will be secured to the chassis using T-nuts as the previous mounting solution using screws through the top and bottom plates proved cumbersome to work with during assembly and disassembly.

On the electrical side, an entirely new board has been designed to control the rover, featuring a more powerful ATmega644P processor to accommodate more complex firmware. An additional pin for each ultrasonic sensor has been added, to allow the echo signal to be adjusted from 5V to 3.3V for compatibility with the processor. New 88 RPM motors have been selected to replace the previous ones, as the previous motors were unavailable and were deemed to have excess torque that could not be fully utilized by the rover.

#### 4.1.4 Solar

The design of the opening mechanism for the solar system was altered to allow for better ease of opening of the system. The neodymium magnet in the top plate was removed and replaced with stacked tin plates. After testing the system, it was determined that the servo that we used to open the hood did not have sufficient torque to open the system with two neodymium magnets. By replacing the neodymium magnet in the top plate with plates of tin, less torque is required to open the hood. Other minor modifications made to the hood and potentiometer bracket to reduce mass and volume, as well as to improve efficiency of design. The edges of the hood were filleted to mitigate the risk of harm when handling the solar system. The potentiometer bracket was changed from a square design to a semicircular design to better fit the shape of the potentiometer that we decided to use for the final design.

## 4.2 Unique structural elements, electrical elements

### Deployment

The deployment subsystem has undergone significant design changes throughout development in the interest of safety to both the components of the launch vehicle, those operating on the launch vehicle, and those in the immediate vicinity of the launch vehicle during preparation and operation. The shift from a pressurized air to black powder system was premeditated by the relative ease of control of a black powder system and simplicity of the mechanism. Changes to the design of both the airframe design and design of the movement subsystem allowed for a smooth integration of a black powder based mechanism through the integration of the same Nomex shielding used by the recovery team to protect their parachutes during black powder ignition and the integration of large wooden supports into the airframe section containing the rover allows the use of a bulkhead which is left unconstrained within the airframe to act as a piston to force the separation of the airframe.

#### 4.2.1 Ejection

As discussed in both the CDR and PDR, the decision to use a scissor lift was made over other, potentially more dangerous and highly variable systems such as explosive ejection or a system with springs. This was made both for safety/integration reasons as well as practical reasons such as controllability. Since it was feasible and just as effective to adopt a more controlled system, that was selected. The choice of a scissoring/folding design was made for

space efficiency reasons. Since the design needed to actuate over the entire length of the rover, but also compress to a size that fit in the payload tube with the rover, designs were narrowed to telescoping or scissoring mechanisms.

#### 4.2.2 Movement

As noted in previous design reviews, the design of the rover was devised to best suit the goals of the competition. A two-wheeled cylindrical design using stabilizer skids was selected for efficient packing into a cylindrical airframe. The use of toothed cross-linked polyethylene wheels allows for good traction and terrain clearance ability while further facilitating packing into the airframe due to the compressibility of the foam. Finally, the enclosed chassis provides environmental protection for electronics while utilizing lightweight supports for structural integrity. Most chassis components are 3D printed, laser cut, or waterjet cut allowing for easy manufacturing of spares.

In terms of electronic components, a custom PCB using an ATmega644P processor was developed, as off-the-shelf solutions such as the Raspberry Pi have proven unreliable in past competitions. The high-torque motor used in the CDR design has been replaced with a higher RPM model, as it was determined that the design was not able to make full use of the torque, as well as due to better part availability.

#### 4.2.3 Solar

The panel layout was chosen based on the tight space constraints. The top and bottom panels are composed of individual 2in x 1in cells that lay flush on top of each other when the panels are not deployed (folded). Integration of smaller cells gives us much more flexibility when compared to using larger panels, the limited size selection of which would force too many additional constraints to the rover design. A potentiometer is attached to the rod which rotates the solar hood open. This potentiometer allows for monitoring of solar panel deployment independent of the servo rotation angle, which is set by the software. The magnet in the hood and magnetic metal in the top plate of the rover prevent unintended deployment of the solar panels.

## Drawings and Schematics

### Deployment

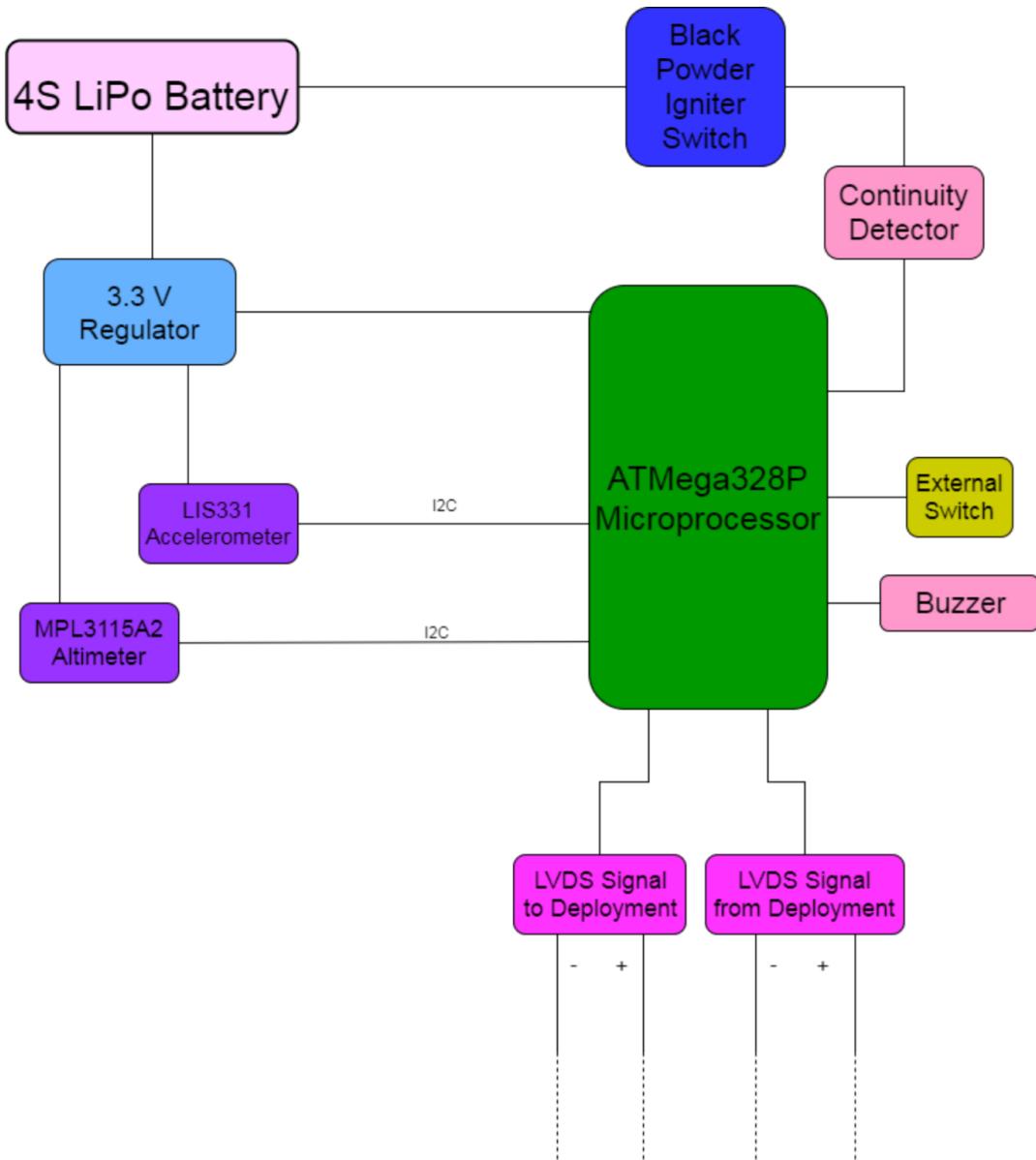


Figure 2: *Deployment Block Diagram*

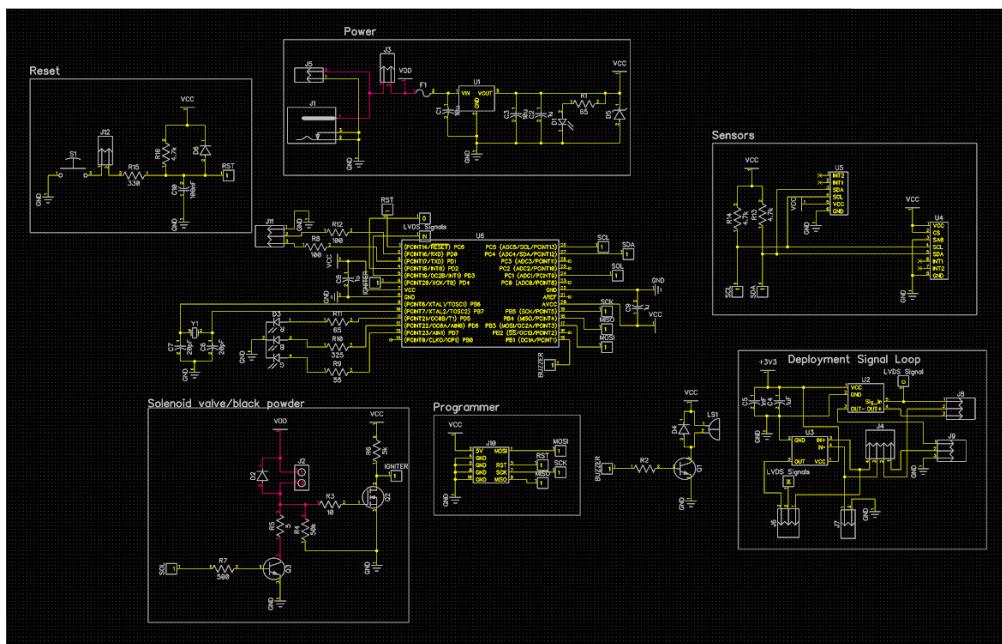


Figure 3: Deployment Schematic

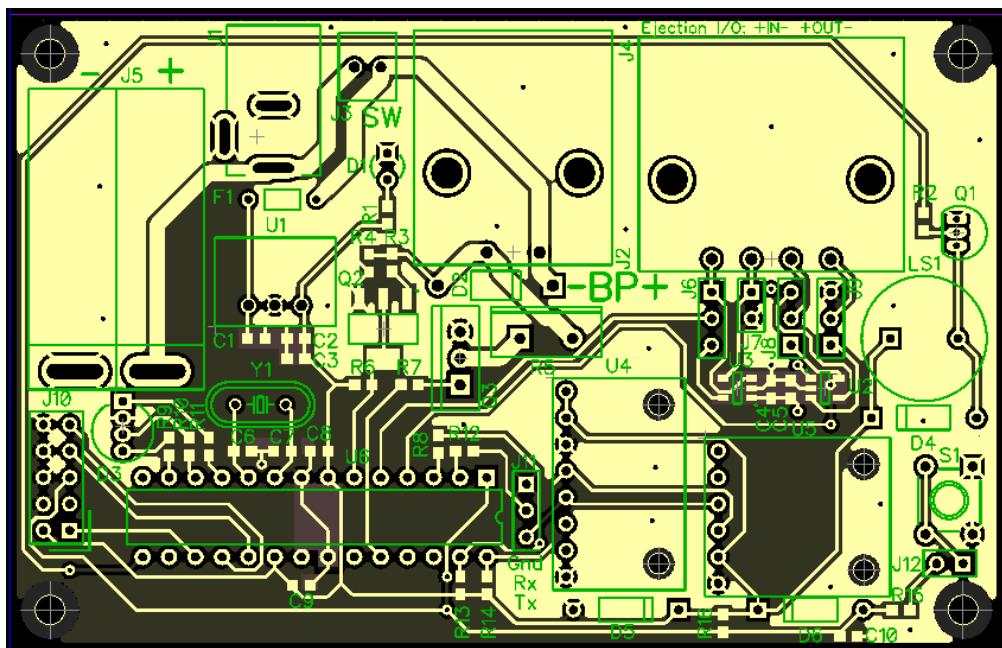


Figure 4: Deployment Layout

## Ejection

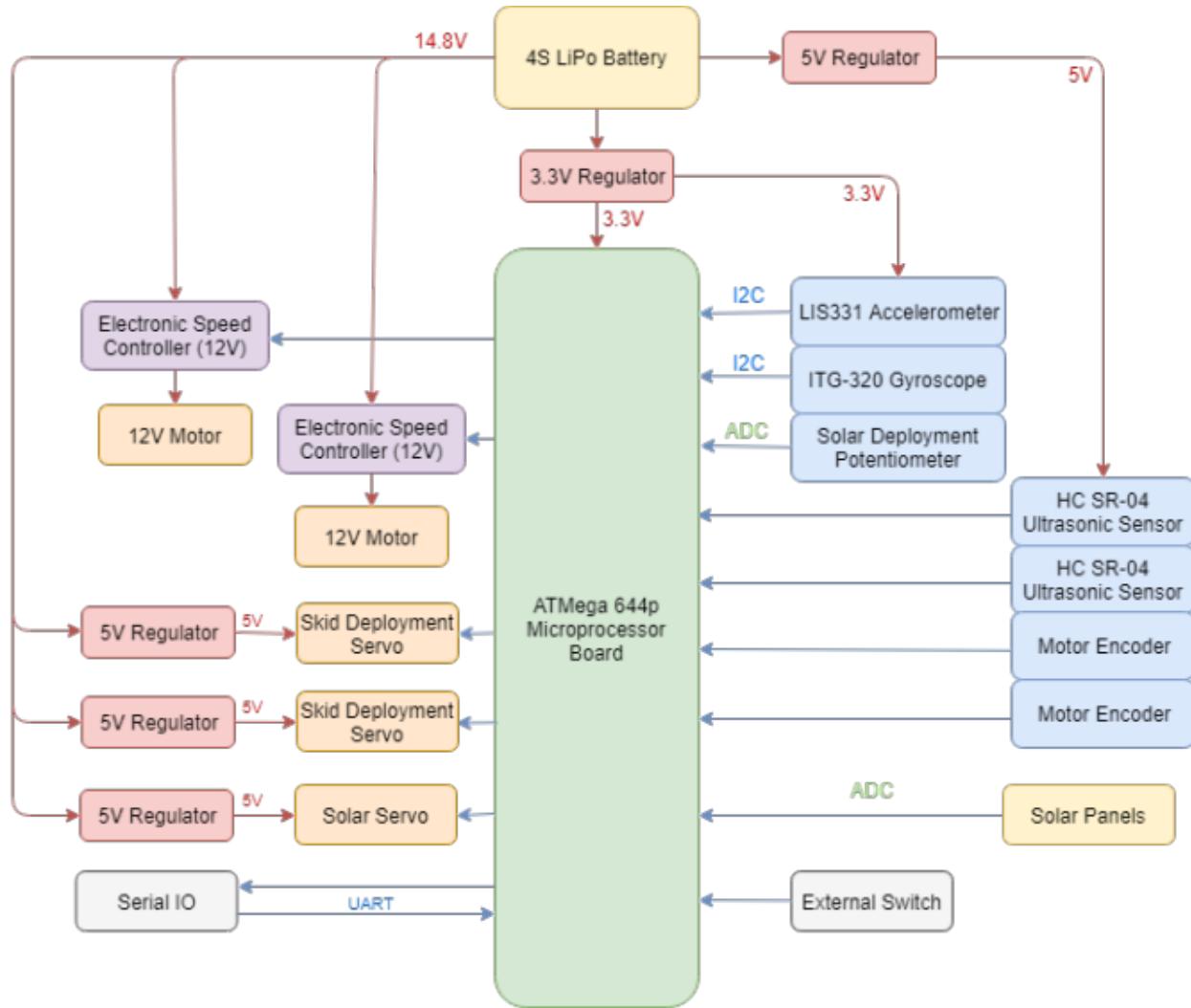


Figure 5: *Rover Block Diagram*

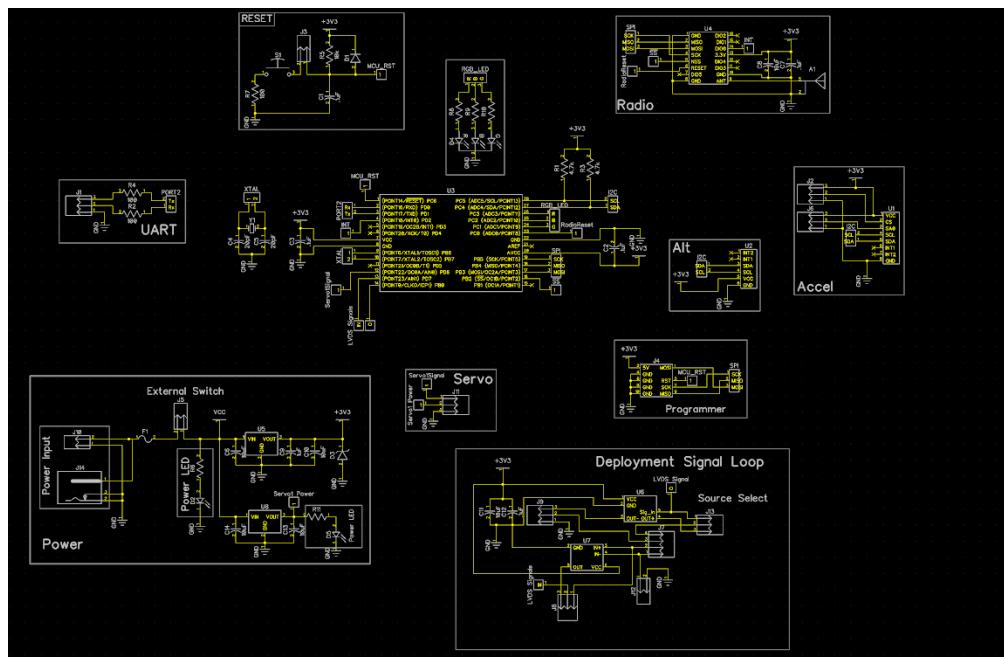


Figure 6: *Ejection Schematic*

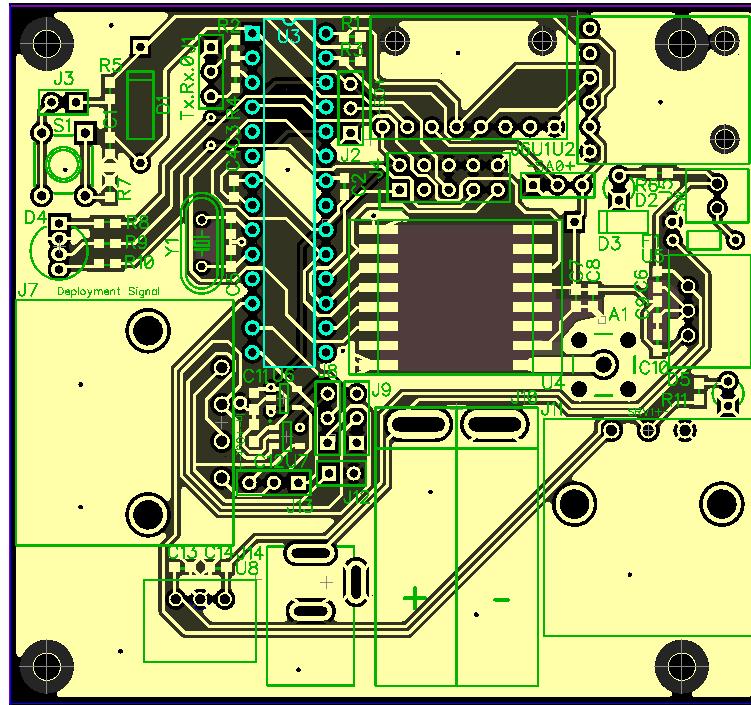


Figure 7: *Ejection Layout*

## Rover

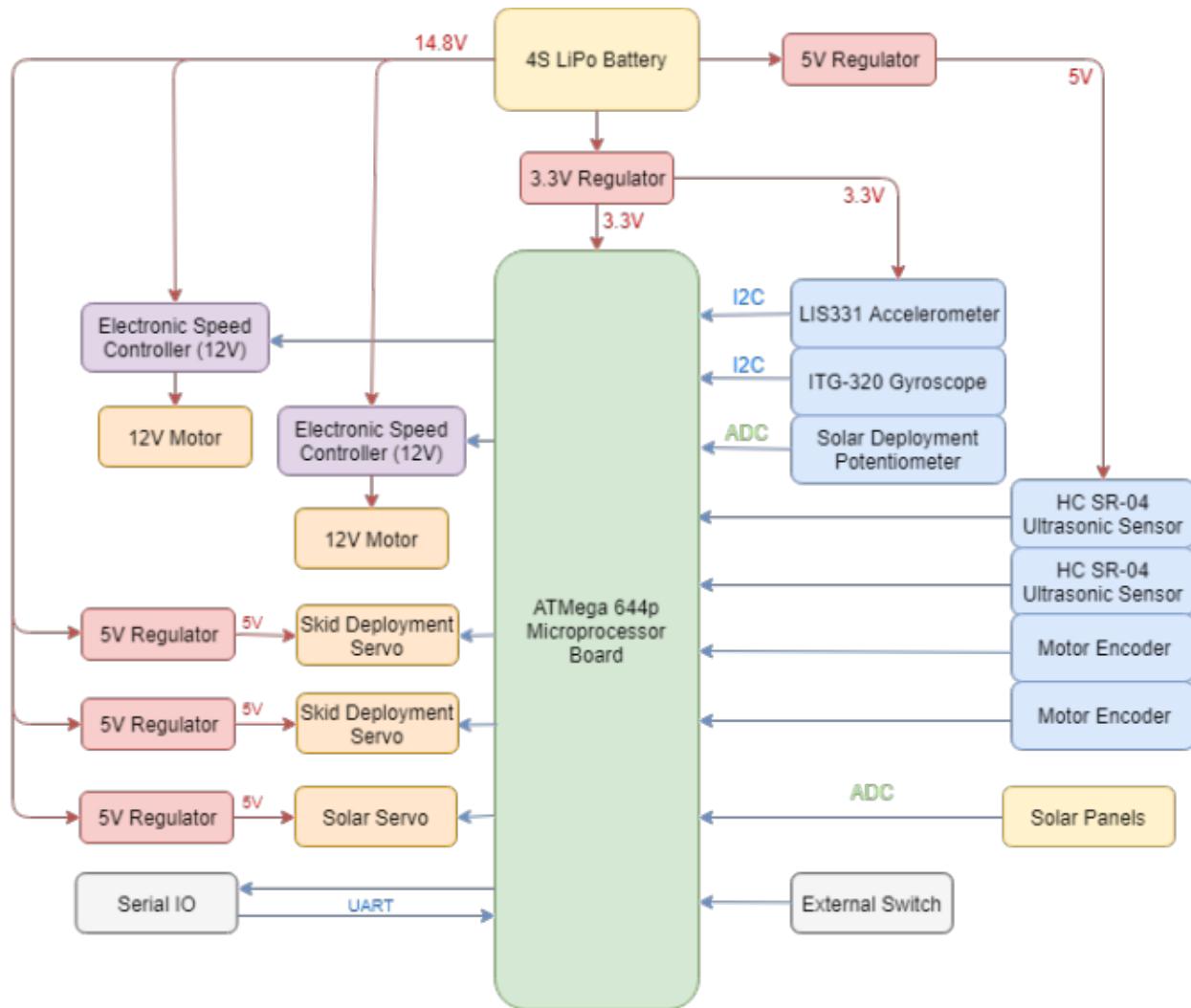


Figure 8: *Rover Block Diagram*

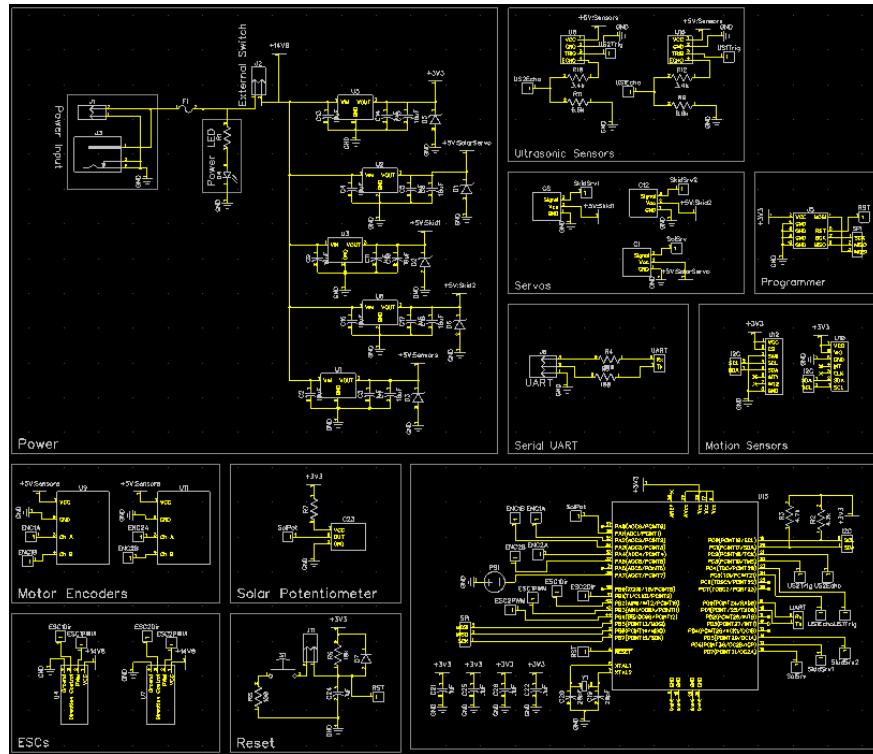
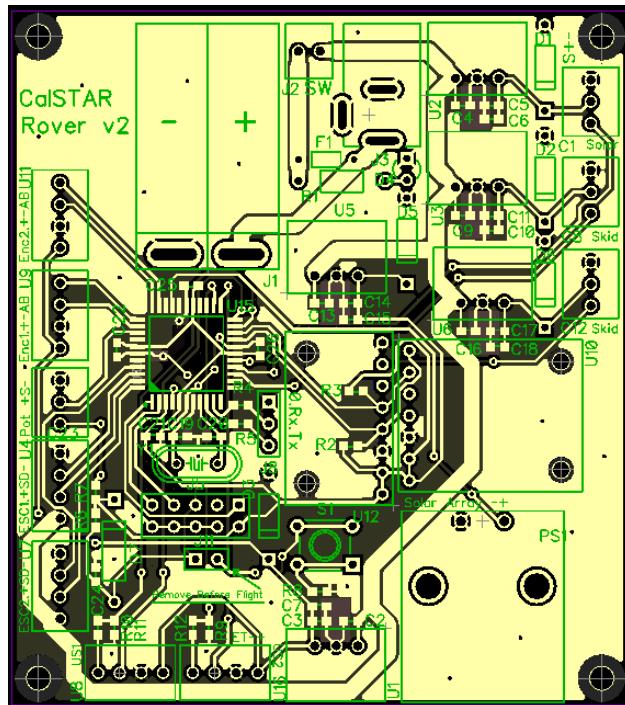


Figure 9: *Rover Schematic*



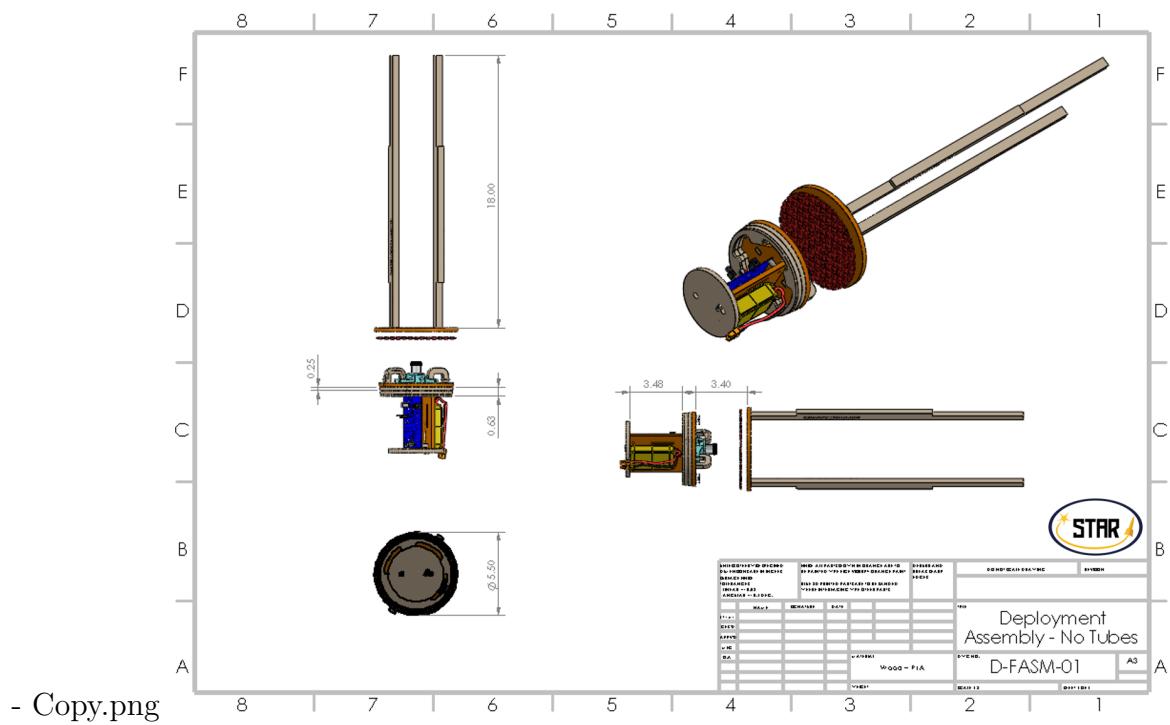


Figure 11: Deployment Without Airframe Showing

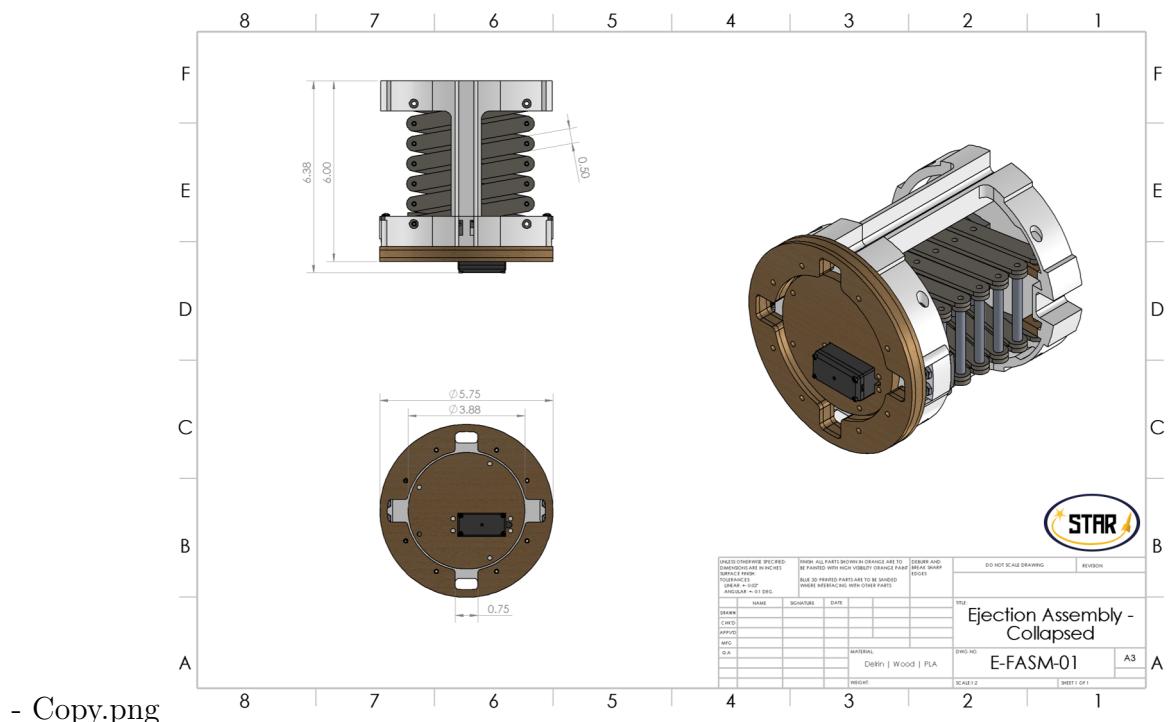


Figure 12: Ejection Subsystem Collapsed

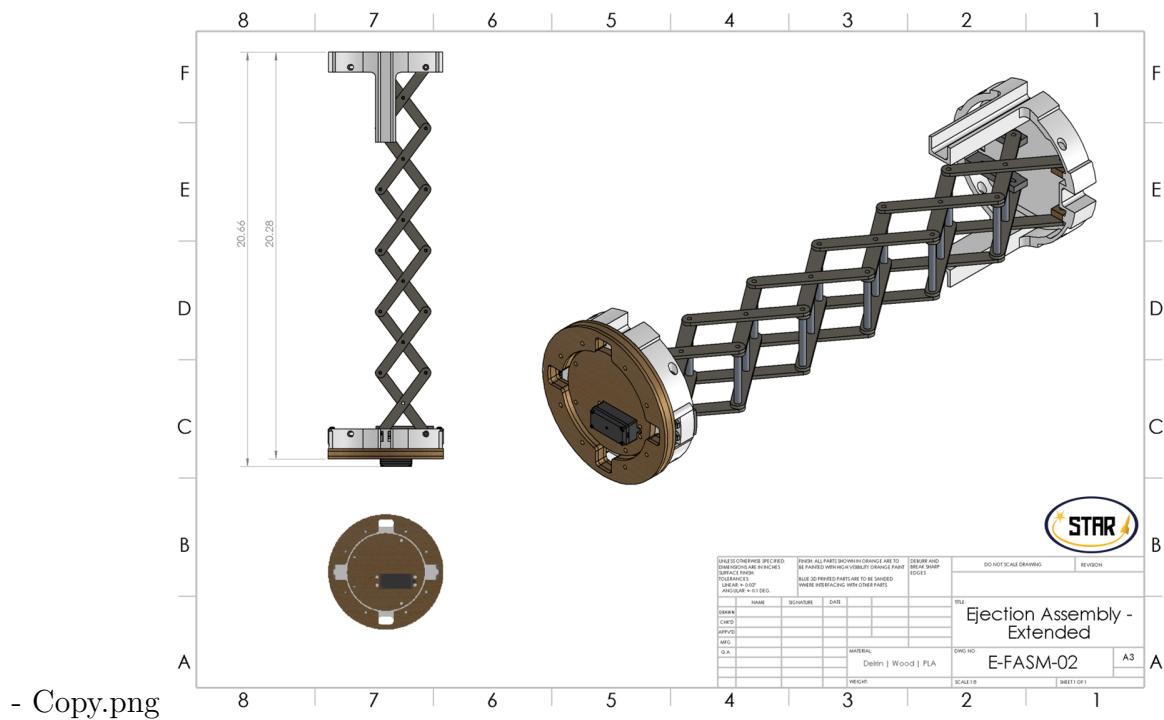


Figure 13: *Ejection Subsystem Extended*

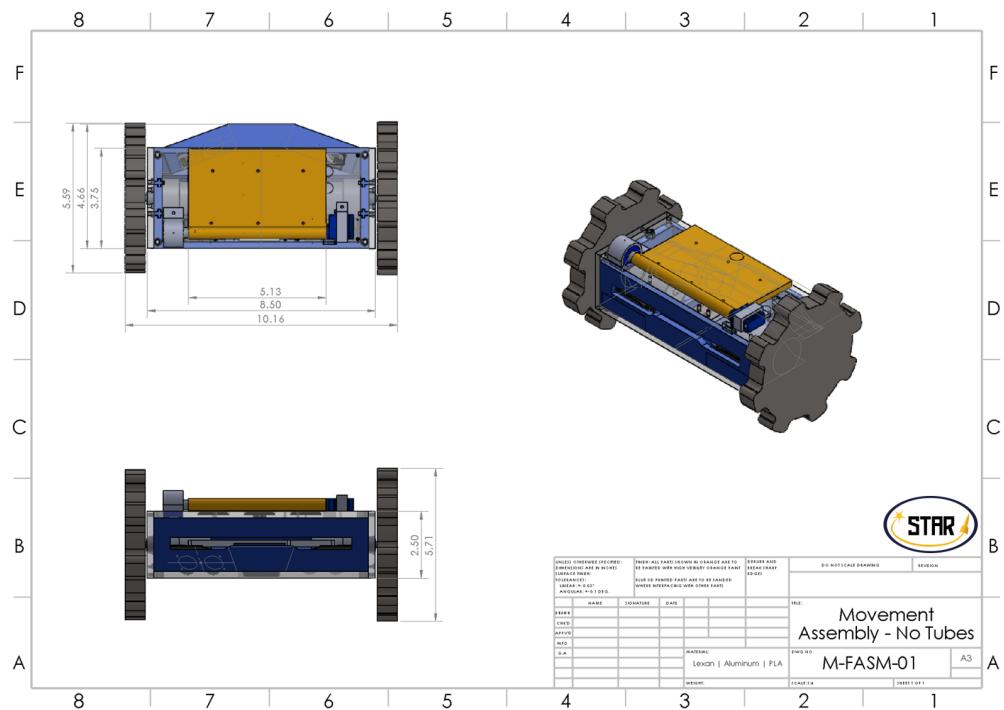


Figure 14: *Rover in flight configuration*

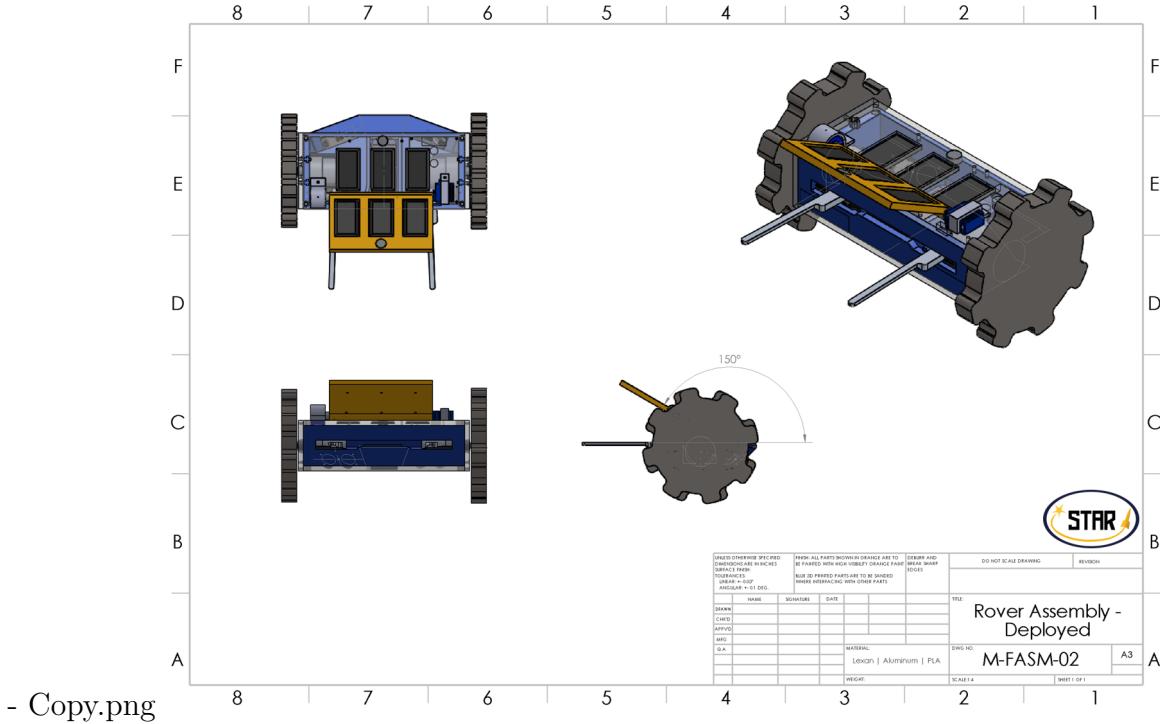


Figure 15: *Rover in final configuration*

### 4.3 Discuss flight reliability confidence

The electronics are designed to function and survive under the conditions of launch and landing to be able to successfully deploy and eject the rover and maneuver the rover at least 5 feet away from the closest part of the air frame and deploy solar panels.

The deployment and ejection of the rover is controlled by a radio signal, but is verified by data received from the altimeter and accelerometer to prevent a premature deployment and ejection sequence. During a test launch, the deployment failed primarily due to a recovery failure. To prevent another failure, the number of shear pins used to secure the payload section is increased and the amount of black powder is proportionally increased. Ground tests and design reviews have increased flight reliability confidence.

The movement of the rover is controlled by microprocessor that is activated by a tactile switch that decompresses when the rover is ejected from the payload tube. The rover board controls two electronic speed controllers(ESCs), which control the motors for the wheels, and three servos, two to deploy skids and one to deploy the solar panels. During a test launch, the rover was prematurely ejected from the payload tube as a result of the deployment failure. The current configuration of the trigger of the movement system is slightly unreliable and the tactile switch may be replaced by a radio board for an external signal to prompt the movement program.

## **4.4 Construction process.**

### **Rover Assembly Instructions**

- Simultaneous assemblies

## **4.5 Discuss how and why the constructed payload differs from earlier models**

The payload as constructed for launch saw some small scale differences from models initially prototyped the designs as detailed in the CAD and technical drawings. These differences, in almost all cases, stemmed from difficulties during the manufacturing process.

### **I. Deployment Subsystem**

I.1 Nomex Shielding used was 202 in. sq. smaller than originally intended.

This change was made due to availability of Nomex shielding on launch day. There were no adverse effects to the functionality of the subsystem as a result of this change

I.2 Centering rings as inserted within Airframe were between 0.75" and 1.0" out of tolerance

This change was made due to discrepancies with the thickness of the airframe as described in the CAD model of the launch vehicle and the thickness of the section as built for the flight configuration. There were no adverse effects to the functionality of the deployment subsystem as a result of this change

### **II. Ejection Subsystem**

II.1 Standoffs used to support the electrical board within the subsystem differed from intended design

This change was made out of the unavailability of the correct components during the assembly of the subsystem onsite. Post flight analysis has led the Electrical subteam to believe that it was this difference which resulted in critical components failing on the electric board responsible for the control of the ejection subsystem.

### **III. Movement Subsystem**

III.1 Drive motors were not mounted with all six mounting screws

This change was made due to tolerancing issues which presented themselves during the manufacturing period. Due to the intricate nature of the part the manual milling machines on which they were produced were unable to center the holes within 0.075in of their intended location, preventing all holes available from being

usable on the flight configuration. There were no adverse effects to the functionality of the movement subsystem as a result of this change

- (a) The bottom Lexan plate was left unconstrained relative to the side motor plates.

This change was made due to tolerancing issues which presented themselves during the manufacturing period. Due to the thin nature of the plates which act as motor mounts in the design, the precision required to drill mounting holes in the intended locations was greater than the hand drilling method of manufacture was able to provide. There were no adverse effects to the functionality of the movement subsystem. Design changes were made to the design of the top and bottom Lexan plates to accommodate a less precise manufacturing method in the future.

#### **IV. Solar Subsystem**

- IV.1 The assembly of the solar subsystem on launch day omitted the magnet which constrains the solar cell array and prevents premature activation.

This change was made due to unavailability of the part in question come launch day. There were no adverse effects to the functionality of the solar subsystem as a result of this change.

All other aspects of the payload were as specified in CAD and technical drawings within tolerance and performed as expected during ground and flight testing.

### **4.6 Electronics**

The electrical systems for the payload consist of three different custom printed circuit boards (PCBs): one for deployment, one for ejection, and one for the rover. The deployment PCB is located in the transition section below the rover; the ejection PCB is located in the nose cone, above the rover; and the rover PCB is located inside the rover.

The deployment and ejection PCBs are connected by a set of four wires that are used to communicate digital logic signals. These four wires run the length of the payload tube, from the nose cone to the transition section, and each of them has a friction-fit connector that allows it to disconnect during the separation event of deployment. These four breakaway wires are grouped into two sets of two: one set to send signals from the ejection PCB to the deployment PCB and one set to send signals in the opposite direction.

Each set of wires transmits a Low-Voltage Differential Signal (LVDS), which is a voltage-based transmission scheme that reduces interference from electromagnetic noise when compared to a normal single-ended ground/signal scheme.

#### **4.6.1 Ejection**

The ejection board is powered by a 4-cell Lithium Polymer (LiPo) battery, which has a nominal voltage of 14.8V. The ejection board contains an ATmega328P microprocessor that interface with an SPI-controlled 434 MHz radio, an I2C-controlled barometric altimeter

sensor, an I2C-controlled 3-axis accelerometer sensor, one servo for the scissor lift, and the breakaway wires carrying LVDS signals to and from the deployment board.

The altimeter and accelerometer are used for verification purposes to ensure that the entire payload process does not spuriously begin; the ejection board will only send the signal to the deployment board to start the process once it confirms with the altimeter and accelerometer that it is on the ground and not moving.

The radio is used both to send a live stream of telemetry data from the ejection board to the ground station and to receive the initial remote signal to the payload to start the entire deployment and ejection process. When the ejection board receives the signal from the deployment board to begin ejecting the rover, it first verifies that is on the ground and not moving using the altimeter and accelerometer, and then activates the scissor lift via the attached servo to push the rover out of the airframe.

The ejection board implements an external switch so that the board can be turned on when the launch vehicle is on the pad.

#### 4.6.2 Deployment

The deployment board is similarly powered by a 4-cell LiPo battery. It also contains an ATmega328P microprocessor and the same model of barometric altimeter sensor and 3-axis accelerometer sensor used in the ejection board.

The altimeter and accelerometer are used for the same purpose as in the ejection board; the deployment board will only commence firing the black powder charge for separation once it independently verifies with its own sensors that it is on the ground and not moving. The deployment board also implements an external switch for the same reason as the one in the ejection board.

The deployment board incorporates a continuity detector circuit for the black powder igniter port and has a buzzer to allow for verification of continuity.

When the deployment board receives the signal from the ejection board to begin deployment, it verifies that it is on the ground and not moving using the altimeter and accelerometer, and then passes current through the attached black powder igniter. This then separates the airframe at the transition section, opening the rover to the air and disconnecting the four breakaway wire connectors. This signals the ejection board to begin pushing the rover out of the airframe via the scissor lift.

#### 4.6.3 Rover

The rover board is also powered by a 4-cell LiPo battery. The voltage provided by a 4-cell battery is high enough to power the several motors needed for rover movement. The rover board will be controlled by an ATmega644P microprocessor. This microprocessor has twice as much program memory as the ATmega328P, and so will be able to store the larger rover control program. This microprocessor also has more pins, which are needed for the more sensors and actuators used by the rover.

The rover board has connection points for two electronic speed controllers (ESCs), which control the two motors needed to move the rover. Each of the motors has an encoder attached, which sends feedback to the microprocessor. The rover board incorporates an

I<sub>2</sub>C-controlled gyroscope and accelerometer, and has connections for two ultrasonic distance sensors. These sensors, along with the encoders, allow the rover control program to detect and avoid obstacles in the rovers path and to accurately estimate its distance travelled from the airframe.

The rover board is able to control three servos: two to control the rovers skids, and one to control the solar panel hood. The hinge of the solar panel system is attached to a rotary potentiometer that allows the rover board to measure the progress of the solar panel extension. The voltage output of the solar cells is also passed as an input to the rover board to verify that the cells are working as expected.

The rover board has a connection point for an external physical switch that will not be activated until the rover is fully ejected from the airframe. By detecting the state of this switch, the rover board can ensure that the rover does not begin to attempt travel until the rover is on the ground, next to the launch vehicle.

All electronic components of the rover are visible in the ??.

## 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 materials safety data sheet (MSDS) documentation for various chemicals and materials that team members may be working with, ensure that the relevant team members understand the risks and procedures involved in these materials, identify construction risks, and 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 Safety Agreement. 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 as necessary.

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 Checklists

The checklists are drafts of final assembly and launch procedures. The Safety Officer will bring these checklists to any launch of the launch vehicle, and will verify that the procedures are followed by team personnel.

See [section 6](#) for the complete listing of launch-day procedures.

## 5.3 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 team has purchased personal protective equipment (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, in order to maintain proper safety protocols.

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

		Consequence				
		Trivial	Minor	Moderate	High	Critical
Likelihood	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 16: *Risk Assessment Matrix*

## Personnel Hazards Analysis

- **Risk:** Scissor lift mechanism injures personnel.

**Causes:** Hand injury to personnel due to the mechanism actuating with the hand/fingers in close vicinity. Software issues.

**Effects:** Minor injury to personnel, particularly to fingers.

**Severity/Likelihood:** A2

**Mitigations:** Before operating the scissor lift, a quick safety check should be performed to ensure all personnel are clear of the mechanism. Tests should be done on the scissor lift in isolation to mitigate the possibility of software issues.

**Verifications:** Launch day procedures have a caution message regarding scissor lift operation. Test that scissor lift is operating correctly in isolation.

- **Risk:** Unexpected or premature black powder charge explosion.

**Causes:** Unexpected explosion of black powder may be caused by electrical systems not properly being verified as being in the OFF state before black powder charges are introduced/installed to the system.

**Effects:** Injury to nearby personnel: burns, cuts.

**Severity/Likelihood:** E2

**Mitigations:** Before any launch vehicle component has black powder installed, a team lead is required to verify that relevant electrical systems are off. Even with this consideration, any personnel working with vehicle components that have black powder charges installed are required to wear PPE, including at least safety goggles and a face shield. While charges are armed, all non-essential members will remain at least 10ft perpendicular to the main axis of the rocket. No members will stand in line with the main axis of the rocket. Redundant systems will ensure the rover deployment charge is not activated prematurely; an accelerometer and altimeter ensure the system is activated only at rest on the ground.

**Verifications:** Launch day procedures have specific caution messages regarding black powder charge installation and verification steps for team leads to ensure that electrical systems are off. The Safety Officer will monitor launch site operations to verify that personnel use proper PPE. Unit testing deployment software may verify that rover deployment will only activate upon receipt of the deployment signal, and when the system is at rest.

- **Risk:** Unexpected deployment of one or both skids.

**Causes:** Software issues or failure to follow safety protocol.

**Effects:** Hand or eye injury to personnel due to the mechanism.

**Severity/Likelihood:** B1

**Mitigations:** Before initiating skid deployment, a safety check must be performed to ensure all personnel are clear of the mechanism. Mechanism should not be powered except in the case of testing or use.

**Verifications:** Launch day procedures have a warning message regarding skid operation, and personnel working with the rover will be required to wear safety glasses. Test that skid deployment operates correctly in isolation.

- **Risk:** Unexpected activation of wheels.

**Causes:** Software issues or failure to follow safety protocol.

**Effects:** Hand injury to personnel due to the mechanism. Fingers or hand may become trapped and/or pinched between rotating axle and frame.

**Severity/Likelihood:** A2

**Mitigations:** Before operating the wheels, a safety check must be performed to ensure all personnel are clear of the rover. Rover should not have battery connected except in case of testing or use.

**Verifications:** Launch day procedures have a warning message regarding wheel activation. Test that each motor and wheel assembly operates correctly; perform unit testing on movement software.

- **Risk:** Electric shock while working with electronic components.

**Causes:** An electrical system is unexpectedly on.

**Effects:** Tingling, minor muscle contractions.

**Severity/Likelihood:** B3

**Mitigations:** 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.

**Verifications:** Usage of rubber-encased wires is by design.

- **Risk:** Electrical components on the ejection sled are hot enough to cause a burn.

**Causes:** A shorted decoupling capacitor.

**Effects:** Injury to personnel may suffer various degrees of burns depending on how hot the component is.

**Severity/Likelihood:** B2

**Mitigations:** Take care around components that may be abnormally hot. Make sure all components of the board are functioning properly. Use robust standoffs to mount the board so no components suffer mechanical stress.

**Verifications:** While testing the ejection mechanism, the electronic components will be evaluated as well.

- **Risk:** Injury during ground testing.

**Causes:** Personnel are too close to the launch vehicle, or are located along the vertical axis of the vehicle.

**Effects:** Personnel experiences injury such as burns or trauma after being hit with part of the launch vehicle.

**Severity/Likelihood:** D2

**Mitigations:** 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 mentor, who shall conduct the ground test, will clearly and loudly announce a countdown.

**Verifications:** The Safety Officer and team mentor will ensure that personnel are a proper distance away before any ground test. This step is integrated in the launch day procedures.

- **Risk:** Improper use of machining tools.

**Causes:** Inexperience with machining tools.

**Effects:** Damage or wear to equipment, personal injury; possibly major damage to construction components.

**Severity/Likelihood:** D2

**Mitigations:** 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.

**Verifications:** University machining facilities verify that personnel have proper certification and training.

- **Risk:** Improper handling of hazardous materials or chemicals.

**Causes:** Inexperience handling hazardous materials. Unfamiliarity with proper procedures.

**Effects:** Explosion or fire, personal injury (burns, loss of eyesight, cuts, lung damage); possible damage to rocket components.

**Severity/Likelihood:** D2

**Mitigations:** 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. MSDS is available to all team members, and understanding MSDS is required. Only minimal interaction with hazardous materials is expected.

**Verifications:** Launch day procedures have, where applicable specific cautions and indications regarding handling of hazardous materials, and the Safety Officer will monitor proper use of PPE.

- **Risk:** Inadvertent launch before rocket is at launch pad and site is clear.

**Causes:** Ignition system is armed inadvertently or unexpectedly.

**Effects:** Possibility of major injury to team members or bystanders from physical contact with the rocket or its exhaust

**Severity/Likelihood:** E1

**Mitigations:** The motor will be installed only when required, and the launch system will be armed only when the launch vehicle is at the launch pad and all personnel are a safe distance away. There will be minimal time between the rocket being ready to launch and the launch itself.

**Verifications:** Launch day procedures have very clearly indicated steps regarding ignition system safing.

- **Risk:** Unstable rocket path off the launch rail.

**Causes:** Poor stability margin. Low speed off the rail.

**Effects:** Possibility of major injury to team members or bystanders from physical contact with the rocket or its exhaust

**Severity/Likelihood:** D1

**Mitigations:** 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.

**Verifications:** The Safety Officer will verify before launch that the launch vehicle stability is in the proper range. The vehicle is designed to have appropriate speed off the launch rail.

- **Risk:** Touching a hot soldering iron.

**Causes:** Team member does not know soldering iron is hot.

**Effects:** Minor personal injury due to localized burns.

**Severity/Likelihood:** C2

**Mitigations:** 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.

**Verifications:** The Safety Officer and/or electrical team lead will monitor personnel using soldering irons.

- **Risk:** LiPo battery explosion.

**Causes:** Improper charging or storage. Impact during flight or during landing.

**Effects:** The explosion of the battery could cause damage to personnel working nearby the electronics and could cause damage to nearby hardware.

**Severity/Likelihood:** E2

**Mitigations:** Personnel working with the LiPo batteries will use appropriate chargers that do not continue applying voltage once the battery is fully charged. Personnel approaching the rover after landing must wear proper PPE, and be cautious of the possibility of a damaged LiPo battery.

**Verifications:** Finalized checklist will have a warning regarding proper PPE usage for team members safing the rover after flight. The electrical team will only buy appropriate LiPo chargers.

- **Risk:** Launch vehicle components falling without a parachute.

**Causes:** Tether ripping through. Shock cord breaking. Tether mount breaking off of a vehicle component.

**Effects:** Possibility of major injury to team members or bystanders from being hit with the free falling object.

**Severity/Likelihood:** D1

**Mitigations:** 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.

**Verifications:** Launch day procedures include several steps for verifying that all attachments are properly mounted and secured.

- **Risk:** Launch vehicle deteriorates upon ascent

**Causes:** Improper application of binding agents or other improper manufacturing issue. Vehicle components are damaged from previous launch.

**Effects:** Possibility of injury to team members or bystanders from impact with falling debris.

**Severity/Likelihood:** C2

**Mitigations:** All components of the vehicle will be thoroughly inspected prior to launch. This will be verified before launch during a pre-launch checklist. All nearby personnel will be attentive of occurring launches and descents.

**Verifications:** Launch day procedures include several steps for verifying that all attachments are properly mounted and secured. Should any defects be found during the pre-launch check, launch will be delayed until the found issue is resolved.

- **Risk:** Shear pin failure upon deployment of recovery system

**Causes:** Inadequate binding force between the payload bay and the transition piece as a result of design flaw or tampering to the pins prior to launch.

**Effects:** Fore segment of vehicle descends separate from the recovery system integrated aft of the transition piece. Uncontrolled descent of nose cone and payload section, resulting in major injury to team members or bystanders from impact.

**Severity/Likelihood:** D1

**Mitigations:** Shear pins will always be inspected and properly assembled prior to launch, and checked during the pre-launch inspection. All nearby personnel will be attentive of occurring launches and descents.

**Verifications:** Launch day procedures include several steps for verifying that all attachments are properly mounted and secured. Should any defects be found during the pre-launch check, launch will be delayed until the found issue is resolved.

## 5.4 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.

### 5.4.1 Airframe Failures Modes

- **Risk:** Launch vehicle does not reach the desired altitude of 5280ft.

**Causes:** Inaccuracy of OpenRocket model; unsatisfactory weather conditions at launch.

**Effects:** Significant loss of points.

**Severity/Likelihood:** E3

**Mitigations:** 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 subscale and full-scale launch.

**Verifications:** Confirm the trajectory and apogee by running simulations on different programs using the same data.

- **Risk:** Coupler failure.

**Causes:** Weak fit between coupler and body section; weak adhesive bond with frame.

**Effects:** Loss of stability and structural integrity; hazard to people on the ground; compromised internal systems.

**Severity/Likelihood:** E2

**Mitigations:** Inspect launch vehicle components thoroughly before launch; ensure sections are properly fitted together.

**Verifications:** Run FEA analysis on a model of the launch vehicle to verify that the coupler and body tubes will be able to withstand launch and recovery.

- **Risk:** Motor failure.

**Causes:** Motor fails to ignite; faulty motor; improper storage/installation of motor.

**Effects:** Launch vehicle will not take off.

**Severity/Likelihood:** D3

**Mitigations:** Double check the igniter; research the company and motor for faulty systems; use the manufacturer's instructions to properly store the motor.

**Verifications:** Double check the igniter wiring during setup and pre-launch; Make sure the launch pad is armed and ready during launch.

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- **Risk:** Minor fin damage.

**Causes:** Improper handling or landing; fin flutter during flight.

**Effects:** Poor aerodynamic flow and guaranteed trajectory deviation.

**Severity/Likelihood:** D3

**Mitigations:** 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.

**Verifications:** The fin section of the launch vehicle will be stored carefully to avoid damage; prior to launches, the fins will be inspected and will have forces applied on them in multiple directions to verify that they are securely mounted.

- **Risk:** Motor tube failure during flight.

**Causes:** Weak adhesive bonds between motor tube, centering rings, and body tube.

**Effects:** Complete loss of flight vehicle; likely payload damage.

**Severity/Likelihood:** E1

**Mitigations:** Taking extra care to ensure that the epoxy is affixed to the centering rings, as well as checking that the centering rings are properly attached to the body tube; double checking that the motor tube is not damaged before construction; using styrofoam to fill spaces between the motor mount and body tube to absorb torsional forces.

**Verifications:** Prior to launch, apply torque to the motor tube to verify structural integrity.

- **Risk:** Major fin damage.

**Causes:** Severe mishandling or failed landing.

**Effects:** Compromised aerodynamics and rocket tumbling.

**Severity/Likelihood:** D2

**Mitigations:** 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 launch vehicle may need to be rebuilt.

**Verifications:** If major fin damage is noticed with at least a week left until a launch, the booster section of the launch vehicle will be rebuilt with new parts; otherwise, the damaged fin will be cut off, replaced, and reinforced with fiber composites.

- **Risk:** Failed parachute deployment.

**Causes:** Improper setup during launch; parachute becomes stuck inside the airframe.

**Effects:** Extreme hazard to bystanders; extreme risk of damage to the launch vehicle.

**Severity/Likelihood:** D2

**Mitigations:** Parachute packing and deployment will be rehearsed and inspected prior to launch. This will be verified before launch during a pre-launch checklist.

**Verifications:** Run a manual test and check tolerances prior to launch; conduct ground tests with black powder charges. Launch day procedures include several steps for verifying proper parachute setup.

- **Risk:** Recovery system does not deploy.

**Causes:** Failure to break the shear pins or the tolerances between the body tube and coupler are excessively tight.

**Effects:** Mission failure; severe danger to bystanders.

**Severity/Likelihood:** D2

**Mitigations:** Extensive testing will be done to simulate separation during flight and couplers will be sanded for smooth and easy deployment.

**Verifications:** Prior to launches tubes will be manually separated to check their separation tolerances; Ground tests using live black powder will be conducted to verify body tube separation.

- **Risk:** Frame becomes compromised.

**Causes:** Severe impact or other external forces.

**Effects:** Instability during flight; failure to meet ready-to-fly condition after landing.

**Severity/Likelihood:** D2

**Mitigations:** Perform structural analysis on material to ensure that structural integrity is not severely affected during flight; ensure all parts of launch vehicles are intact and free of any imperfections that might occur during shipment.

**Verifications:** Conduct thorough checks after every major movement of launch vehicle components; keep records of damages and changes made to the airframe.

- **Risk:** Failure of launch button standoffs.

**Causes:** Inadequate reinforcement and excessive launch forces.

**Effects:** Loss of control; danger posed to life and property; failure of launch vehicle reusability condition.

**Severity/Likelihood:** D2

**Mitigations:** Manufacture the standoff in one piece from a stronger material and reinforce the base with fiber composite fillets.

**Verifications:** Perform FEA to verify structural integrity during launch.

- **Risk:** Launch rail fails to stay vertical.

**Causes:** Improper setup.

**Effects:** Launch vehicle launches at an angle, potential danger posed to life and property.

**Severity/Likelihood:** D1

**Mitigations:** Use structural analysis to ensure the launch rail is constructed properly; check security of fasteners and components.

**Verifications:** During setup, check that the launch pad is level with the ground; any off-balance force might push the pad onto its side during launch.

- **Risk:** Major nose cone fracture.

**Causes:** Severe mishandling or failed parachute deployment.

**Effects:** Mission Failure.

**Severity/Likelihood:** D1

**Mitigations:** 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.

**Verifications:** The nose cone will be packed with foam prior to every major transport to ensure that damage is mitigated; if a major fracture occurs, the damage must be spotted at least a week prior to any major launches for a new part to be purchased; Otherwise, a new nose cone will be fabricated out of other materials or salvaged from another launch vehicle.

- **Risk:** Launch vehicle becomes unstable.

**Causes:** Thrust to weight ratio does not meet minimum requirements to stabilize against wind speed.

**Effects:** Loss of altitude, danger to bystanders, damage to launch vehicle.

**Severity/Likelihood:** C2

**Mitigations:** Perform a series of tests that will determine the conditions the launch vehicle might be exposed to during flight to ensure stability.

**Verifications:** Verify the stability with OpenRocket and hand calculations at multiple points leading up to the official launch; Keep all simulations updated with accurate center of lift and center of mass data.

- **Risk:** Minor nose cone fracture.

**Causes:** Improper handling or landing.

**Effects:** Poor aerodynamic flow and possible trajectory deviation.

**Severity/Likelihood:** C2

**Mitigations:** The launch vehicle will be handled with care in transit, construction, and minor defects will be patched with epoxy filler.

**Verifications:** The nose cone will be packed with foam prior to every major transport to ensure that damage is mitigated; During pre-launch, the nose cone will be inspected for any defects.

#### 5.4.2 Recovery Failures Modes

- **Risk:** Drogue parachute fails to deploy.

**Causes:** Altimeters fail to recognize air pressure change, causing the black powder charges to not fire.

**Effects:** Launch vehicle descends at excessive speed when main parachute is deployed, potentially severely damaging the launch vehicle.

**Severity/Likelihood:** E3

**Mitigations:** Use of two, redundant altimeters; perform several ground tests to be sure that charges will deploy parachutes.

**Verification:** Ground test will verify proper deployment.

- **Risk:** Main parachute fails to deploy.

**Causes:** Altimeters fail to recognize air pressure change, causing the black powder charges to not fire.

**Effects:** Launch vehicle lands at kinetic energy higher than 75 ft-lbf, damaging the launch vehicle and potentially injuring bystanders.

**Severity/Likelihood:** E3

**Mitigations:** Use of two, redundant altimeters; perform several ground tests to be sure that charges will deploy parachutes.

**Verification:** Ground test will verify proper deployment.

- **Risk:** Altimeters shut off during flight, causing deployment system to malfunction.

**Causes:** Forgetting to turn on altimeters before flight; batteries run out.

**Effects:** Parachutes either deploy too early or not at all, damaging the launch vehicle and potentially injuring bystanders.

**Severity/Likelihood:** E3

**Mitigations:** Use new 9V Duracell batteries, check batteries before flight, and tightly secure all power supplies before flight.

**Verification:** Launch day procedures explicitly specify use of new, fresh batteries in the avionics bay.

- **Risk:** Parachutes melt.

**Causes:** Black powder deployment charges explode, creating too much heat inside parachute chamber.

**Effects:** Launch vehicle is not ready for a subsequent launch after landing; launch vehicle potentially lands at kinetic energy higher than 75 ft-lbf, damaging the launch vehicle and potentially injuring bystanders.

**Severity/Likelihood:** E2

**Mitigations:** Properly wrap parachutes in heat blankets.

**Verification:** Ground test will verify that the parachutes are well-protected.

- **Risk:** Deployment charges are not sized properly.

**Causes:** Black powder was not accurately allocated for each charge region.

**Effects:** Launch vehicle is either damaged from too large of ejection charge or parachutes are not deployed from too small of ejection charge, damaging vehicle upon touchdown.

**Severity/Likelihood:** E2

**Mitigations:** Perform several ground tests to be sure that charges will deploy parachutes.

**Verification:** Ground testing will refine and optimize charge sizing prior to launch.

- **Risk:** Shock cords snap at deployment.

**Causes:** Minor cut to begin with; force of launch vehicle is too much to hold for kevlar shock cords.

**Effects:** Sections of the launch vehicle descend without parachute, damaging the launch vehicle and potentially injuring bystanders.

**Severity/Likelihood:** E1

**Mitigations:** Visually inspect the entire length of shock cord before use. Use shock cord rated to a high enough tensile strength.

**Verification:** Perform force analysis and tensile test on shock cords.

- **Risk:** Magnetic disruption of electronics (detected prior to launch).

**Causes:** Using magnets while electronic systems are active.

**Effects:** Electronics malfunction causing a delay in launch.

**Severity/Likelihood:** D3

**Mitigations:** Put warning signs on magnets. Isolate magnets from electronics until it is confirmed that electronics are off.

**Verification:** Launch day procedures specify isolation of magnets from electronics.

- **Risk:** Magnetic disruption of electronics (detected during launch).

**Causes:** Using magnets while electronic systems are active and not testing the systems pre-launch.

**Effects:** Electronics malfunction which could deploy parachutes too early or not at all. The launch vehicle could sustain damage and injure bystanders.

**Severity/Likelihood:** D2

**Mitigations:** Same mitigations as above with the addition of doing electronic tests pre-launch.

**Verification:** Launch day procedures specify isolation of magnets from electronics. Electronic tests will verify that magnetic disruption is negligible.

- **Risk:** Rails holding locking metal bars fall off.

**Causes:** Rails are not adequately attached to the interior wall of the avionics bay.

**Effects:** Door will be compromised. Electronic systems malfunction, and parachutes will either open too early or not at all. The launch vehicle could sustain damage and injure bystanders.

**Severity/Likelihood:** D2

**Mitigations:** 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.

**Verification:** Physical testing (such as grabbing and pulling) may be used to verify proper mounting.

- **Risk:** Batteries or altimeters fall out of sled.

**Causes:** Battery/altimeter is not securely bolted into slide.

**Effects:** Wires may sever and electronic systems may malfunction. The launch vehicle could sustain damage and injure bystanders.

**Severity/Likelihood:** D2

**Mitigations:** Secure the electronics as tightly as possible with bolts and screws.

**Verification:** Ground test should indicate mitigation. Physical pull test on the batteries/altimeters can verify proper mounting.

- **Risk:** Recycled component fails.

**Causes:** Wear from use in previous launches.

**Effects:** Launch vehicle may impact ground with higher than allowed kinetic energy due to parachute failure.

**Severity/Likelihood:** D1

**Mitigations:** Recycled components should be used only if they are undamaged, and verifiably so.

**Verification:** 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.

- **Risk:** Black powder residue enters avionics bay.

**Causes:** Bulkhead of avionics bay not secure/airtight enough.

**Effects:** Potential damage to electronic devices; heavy cleaning needed after flight.

**Severity/Likelihood:** C2

**Mitigations:** Make sure avionics bay is completely sealed off from ejection charges using rubber gaskets.

**Verification:** Ground test can verify proper sealing.

### 5.4.3 Electronics Failures Modes

- **Risk:** Black powder charges trigger prematurely.

**Causes:** Launch trauma, software issues, sensor miscalibration.

**Effects:** Premature deployment of rover, separation of payload from the launch vehicle.

**Severity/Likelihood:** E2

**Mitigations:** Ensure proper telemetry calibration. Deployment board will trigger black powder only if both a signal from ejection board is received and deployment sensors detect craft is landed.

**Verifications:** Launch day procedures contain tests to verify that the deployment boards react properly to appropriate commands, and that sensors are properly calibrated.

- **Risk:** Black powder charges fail to trigger.

**Causes:** Launch trauma, software issues, sensor miscalibration, failure in circuit boards.

**Effects:** Rover unable to deploy.

**Severity/Likelihood:** E2

**Mitigations:** Make sure the igniter is connected appropriately.

**Verifications:** Buzzer on deployment board will buzz to indicate presence of charge both in flight and when landed.

- **Risk:** Loss of radio connection.

**Causes:** Launch trauma, trauma in mounting of circuit boards.

**Effects:** Inability to receive telemetry data and deploy rover.

**Severity/Likelihood:** E2

**Mitigations:** Include comprehensive testing procedure between mounting of PCBs and launch. Ensure soldered joints are solid. Ensure wire lengths are appropriate (not taut).

**Verifications:** Launch day procedures contain testing for radio connection after PCBs are mounted, and will provide adequate time to mount backup boards in event of failure.

- **Risk:** Connection failures between electronic components.

**Causes:** Launch trauma, failure to properly test electronics.

**Effects:** Payload will fail to eject and deploy.

**Severity/Likelihood:** E2

**Mitigations:** Minimize push-pull connections. Use PCB in place of breadboard. Ensure soldered joints are solid. Ensure wire lengths are appropriate (not taut).

**Verifications:** Launch day procedures contain steps for testing solder joints, connection points, and wire connections before launch.

- **Risk:** Batteries are too low.

**Causes:** Not double-checking batteries before launch, and not putting enough battery power in the rocket.

**Effects:** Payload will fail to eject and deploy.

**Severity/Likelihood:** E3

**Mitigations:** Pre-flight testing before setup and on launchpad. Include enough battery power to last two hours. Have full replacement batteries available. Do not launch the vehicle if it has been on the launch rail for over two hours.

**Verifications:** Electronics team will only purchase batteries with long enough life, and design the launch vehicle to require an acceptably high number of batteries to be used. Launch day procedures explicitly allow launch to proceed only if the launch vehicle has not been on the rail for an extended period of time.

- **Risk:** Altimeter failure or miscalibration.

**Causes:** Launch trauma, failure to properly test electronics on launchpad.

**Effects:** Parachutes deploy at incorrect altitude, or not at all.

**Severity/Likelihood:** E2

**Mitigations:** Include comprehensive testing process in launch procedure. Secure altimeter to payload, and ensure connections are solid.

**Verifications:** Launch day procedures specify testing program for verification of altimeter data.

- **Risk:** Accelerometer failure or miscalibration.

**Causes:** Launch trauma, failure to properly test electronics.

**Effects:** Payload data will be incorrect.

**Severity/Likelihood:** A3

**Mitigations:** Include comprehensive testing process in launch procedure. Secure accelerometer to payload, and ensure connections are solid.

**Verifications:** Launch day procedures specify testing program for verification of accelerometer data.

- **Risk:** Gyroscope failure or miscalibration.

**Causes:** Launch trauma, failure to properly test electronics.

**Effects:** Payload data will be incorrect.

**Severity/Likelihood:** A3

**Mitigations:** Include comprehensive testing in launch procedure. Solidly secure gyroscope to payload body.

**Verifications:** Launch day procedures specify testing program for verification of gyroscope data.

#### 5.4.4 Payload Failure Modes

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 launch vehicle, *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

- **Risk:** Battery power management.

**Causes:** Incorrect battery capacity selection 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.

**Severity/Likelihood:** E1

**Mitigations:** Make sure battery has enough amperage/capacity for tests and one-hour 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.

**Verifications:** Step 1 of phase 1 of the ejection checklist ensures that the battery is sufficiently charged at launches.

#### 5.4.5 Deployment of the Payload

- **Risk:** Black powder destroys tube of the launch vehicle.

**Causes:** Too much black powder is activated.

**Effects:** Damage resulting from an excessive use of black powder can range from cosmetic to structurally compromising dependent on the amount used.

**Severity/Likelihood:** D3

**Mitigations:** An acceptable amount of black powder to be used will be calculated from known quantities of black powder, such as the black powder used in the recovery system of the vehicle. Multiple tests will then be conducted to ensure that the calculated

amount of black powder will cause no damage to the structure of the launch vehicle. Further incremental adjustments to the amount of black powder used will enable the correct force to be achieved without exceeding safe limits.

**Verifications:** Due to LEUP (Low Explosives Users Permit) restrictions, it is unlikely that testing will be possible before to the first test launch date; development of a backup payload system and availability of black powder at the launch site will allow for testing procedures as described above.

- **Risk:** Rover is not protected by shielding from black powder.

**Causes:** Shielding is insufficient, or unrealistically able to be sufficient. Shielding can be worn down after repeated testing.

**Effects:** Rover may be damaged and possibly unable to function properly.

**Severity/Likelihood:** B3

**Mitigations:** The Nomex shield will be tested multiple times with the black powder and examined for anomalies. If the shield is determined to be insufficient and no thicker shielding can be implemented, an alternative pneumatic separation design that is being simultaneously designed will be implemented.

**Verifications:** Due to LEUP restrictions, it is unlikely that testing will be possible before the first test launch date; development of a backup payload system and availability of black powder at the launch site will allow for testing procedures as described above.

- **Risk:** Breakaway wire disconnects early.

**Causes:** Insufficient friction in the connector at the break point.

**Effects:** The payload will not deploy.

**Severity/Likelihood:** D2

**Mitigations:** Use a connector that has sufficient friction to not disconnect from normal vibration and shock. Design the launch vehicle assembly in such a way that assembly will force the connector together.

**Verifications:** Item 8 in the pre-flight section of the deployment checklist will ensure that the breakaway wire is properly connected during the final assembly immediately prior to launch.

- **Risk:** Deployment timing is incorrect.

**Causes:** Sensor failure, programming errors, radio failure, or accidental black powder activation.

**Effects:** Effects range from mostly inconsequential late deployment to disastrous early deployment. If the deployment event occurs too early, it can affect the trajectory of the launch vehicle, influence future rover actions, result in the rover failing to eject, or possible damage to equipment and bystanders.

**Severity/Likelihood:** E1

**Mitigations:** Design of deployment systems will be mitigated through redundant systems for verification of deployment conditions. Specifically, the combination of an accelerometer and an altimeter will verify that the payload has landed before deployment is initiated. Additionally, the deployment command is locked out until a period of time significantly longer than anticipated flight time. The black powder will be properly isolated and contained to ensure no early activation.

**Verifications:** Base-level verifications can be completed through the use of ground testing and flight simulations, but conclusive testing cannot be completed until a full launch of the launch vehicle is performed.

- **Risk:** Deployment fails to provide enough impulse to completely push the rest of the payload systems far enough away from the rest of the launch vehicle.

**Causes:** Too little black powder is activated or the black powder is of poor quality.

**Effects:** The force applied to the section is sufficient to break the shear pins but is not sufficient to fully separate the transition section from the payload tube.

**Severity/Likelihood:** D1

**Mitigations:** Similar to mitigations stated just above, slow increase of black powder usage until the force applied is enough that usual variation in black powder quality will not hinder the success of payload deployment.

**Verifications:** Due to LEUP restrictions, it is unlikely that testing will be possible prior to the first test launch date; development of a backup payload system and availability of black powder at the launch site will allow for testing procedures as described above.

#### 5.4.6 Ejection of the Rover

- **Risk:** Signal is not accurately broadcast from the ejection electronics sled in the nosecone.

**Causes:** Battery is insufficient, ejection electronic sled is not securely mounted inside of the nosecone.

**Effects:** The ejection event will never happen and the rover will be stuck in the airframe of the rocket.

**Severity/Likelihood:** C3

**Mitigations:** Use standoffs in order to fully secure the ejection electronics sled and check the structural integrity of the entire mechanism.

**Verifications:** This failure mode will be mitigated through the new assembly of the ejection electronics sled.

- **Risk:** Scissor lift fails catastrophically.

**Causes:** Too much force is applied to the bottom links of the scissor lift.

**Effects:** The bottom links can snap or break off and prevent the ejection mechanism from working at all.

**Severity/Likelihood:** C3

**Mitigations:** The scissor lift will be designed with an additional margin of safety to account for unexpected forces encountered by the lift.

**Verifications:** The ejection system will be fully tested at the launch site as stated by checklist item 1 in phase 3 of the pre-flight section of the ejection checklist.

- **Risk:** Improper assembly leads to ejection system failure.

**Causes:** Ejection mechanism is jostled before the nosecone is fully attached.

**Effects:** Ejection might fail to completely push the rover out of the launch vehicle tube and onto the ground.

**Severity/Likelihood:** C3

**Mitigations:** The ejection mechanism will be double checked immediately prior to final assembly. Additionally, the ejection mechanism will be loaded into the nosecone and the nosecone onto the rest of the launch vehicle with extreme care.

**Verifications:** Adhering to checklist item 1 of the immediately pre-flight section of the ejection checklist will double check the construction of the scissor lift.

- **Risk:** Scissor lift is unable to eject rover.

**Causes:** The scissor lift does not generate enough force to eject the rover.

**Effects:** The rover is not ejected.

**Severity/Likelihood:** C3

**Mitigations:** The scissor lift system will undergo FEA and significant lab testing prior to flight.

**Verifications:** The ejection system will be fully tested at the launch site as stated by checklist items 1 and 2 in phase 3 of the pre-flight section of the ejection checklist.

- **Risk:** Scissor lift shears.

**Causes:** Turbulent forces during launch may exert too much pressure on the scissor lift mechanism.

**Effects:** The rover fails to eject.

**Severity/Likelihood:** C2

**Mitigations:** The scissor lift will be properly reinforced and structured to endure the stress of launch.

**Verifications:** A finite element analysis (FEA) has been conducted to make sure the scissor lift can handle much more than the expected forces from the launch. Laboratory testing will then be completed to verify the FEA.

- **Risk:** Friction-derived rover ejection failure

**Causes:** The friction between the wheel and the interior airframe or the friction between the ejection plate and the interior airframe is too strong for the ejection mechanism.

**Effects:** The rover fails to eject fully from the payload.

**Severity/Likelihood:** C2

**Mitigations:** The scissor lift will be designed to produce more force than is necessary to eject the rover. Additionally, the wheels will be manufactured such that they are slightly smaller than the inner diameter of the airframe. The wheels will be fit-tested with the airframe in isolation and after attachment to the rover.

**Verifications:** The friction from the ejection system will be fully tested at the launch site as stated by checklist item 3 in phase 3 of the pre-flight section of the ejection checklist.

- **Risk:** 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.

**Severity/Likelihood:** C3

**Mitigations:** 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. Specifically, the scissor lift arms laterally constrain the lift in such a way that the top and bottom plates will remain perpendicular, thus reducing the potential of binding forces between the top plate and the sides of the airframe.

**Verifications:** The fit within the airframe will be fully tested at the launch site as stated by checklist item 2 in phase 3 of the pre-flight section of the ejection checklist.

#### 5.4.7 Movement of the Rover

- **Risk:** Wheels do not have sufficient torque and traction 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 proper torque.

**Effects:** Rover has difficulty moving and may especially struggle with obstacles. Minimum distance of 5ft possibly not achieved.

**Severity/Likelihood:** C2

**Mitigations:** Tests will be conducted on a wide variety of terrains, including mud, and motors will be oversized to provide a buffer.

**Verifications:** The rover will be tested on the terrain at launch per checklist items 14 and 18 on the pre-flight section of the rover checklist.

- **Risk:** Skid fails to deploy.

**Causes:** Servos fail to work, or the skid is obstructed by an obstacle during its deployment.

**Effects:** The rover may have difficulty climbing hills or approaching uneven ground not perpendicular to rover movement. Additionally, rover orientation might be affected.

**Severity/Likelihood:** B2

**Mitigations:** Test skid deployment multiple times and have two separate servos, so there is a backup if one fails.

**Verifications:** Servos will be tested per item 12 on the pre-flight section of the rover checklist.

- **Risk:** Skid prevents movement.

**Causes:** Skid gets caught on unusually steep and abnormal terrain.

**Effects:** Rover is unable to move well or at all.

**Severity/Likelihood:** D2

**Mitigations:** The type of terrain that would cause this issue is unlikely to be present at the site. Extensive testing will take place to ensure the rover operates well in rough terrain.

**Verifications:** If the skid is caught, or close to getting caught during the rover trial per item 12 of the pre-flight section in the rover checklist, the code can be modified so the skid deploys to a lesser extent or not at all depending on the situation.

- **Risk:** Battery disconnects from essential components of rover.

**Causes:** The battery or other electronics are jostled during previous phases.

**Effects:** The rover is unable to move or complete the objective.

**Severity/Likelihood:** D2

**Mitigations:** Ensure that all connections are secure and can sustain movement during tests and practice launches. The design will reduce risk of disconnection by reinforcing connection points and using lockable latching connectors.

**Verifications:** All electronics will be inspected prior to launch per items 1 and 6 of the pre-flight section in the rover checklist.

- **Risk:** Collision detection fails.

**Causes:** Sensors do not recognize, or recognize incorrectly a divot, hill, or anything abnormal not planned for in the code. Rover does not move perfectly smoothly.

**Effects:** Rover is unable to detect obstacles in front of it, may cause the rover to be impeded.

**Severity/Likelihood:** B3

**Mitigations:** Sensors will repeatedly be tested and are programmed around possible issues to reduce their impact during the competition. Additionally, wheels will be designed to move over rugged terrain.

**Verifications:** Sensors will be tested per item 13 of the pre-flight section in the rover checklist.

- **Risk:** Wheel tears or deforms excessively during movement.

**Causes:** A sharp object or edge comes into contact with moving wheels or the rover's weight is greater than the wheels can support without significant deformation.

**Effects:** Wheels are uneven and movement is affected.

**Severity/Likelihood:** C3

**Mitigations:** The wheels will be made out of a material that is not easily torn and will be relatively wide to mitigate any damage during movement. If necessary, the material of the wheels can be changed to a more dense foam or PLA.

**Verifications:** By design, these mitigations will be followed.

- **Risk:** 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.

**Effects:** Rover could be misaligned during ejection or affect trajectory of launch vehicle.

**Severity/Likelihood:** D1

**Mitigations:** Deployment mechanism makes sure the rover is secured prior to deployment. Additionally, redundant sensors (physical, light) ensure that movement happens at the proper time.

**Verifications:** By design, the deployment mechanism secures the rover. The sensors will be tested per items 10 and 15 of the pre-flight section in the rover checklist.

#### 5.4.8 Deployment of the Solar Panels

- **Risk:** Panels are damaged.

**Causes:** Panels are damaged and/or detached during previous phases.

**Effects:** The objective is not completed.

**Severity/Likelihood:** B2

**Mitigations:** The current chassis design protects the solar panels from the environment when not deployed. The individual solar cells are encased by polycarbonate while hood remains closed, which is ensured by the use of magnets.

**Verifications:** These mitigations are fully achieved through the design of the rover.

- **Risk:** Panel deployment fails.

**Causes:** The servo locks up, actuation is obstructed, or the servo does not apply enough power are all possible mechanical failures. Additionally, the rover may not recognize the correct time to actuate the hood due to issues with the sensors that measure distance from the launch vehicle.

**Effects:** The panels never deploy.

**Severity/Likelihood:** B2

**Mitigations:** Multiple tests will be done to ensure consistency in servo actuation and distance verification in a wide variety of possible environments.

**Verifications:** The proper deployment of the solar panels will be tested and verified in the launch environment.

- **Risk:** Solar panels open before rover reaches the 5ft minimum distance.

**Causes:** Vibration during launch vehicle flight and/or rover navigation lead to the solar panels opening prematurely.

**Effects:** Following the scoring guidelines, the 5ft minimum distance will not be achieved.

**Severity/Likelihood:** C3

**Mitigations:** Magnets will be used as a redundant latch to keep the hood closed. These magnets should provide enough force to prevent the hood from opening unintentionally due to vibrations. Only once the rover sensors confirm that it is at least 5ft from the launch vehicle will the servo actuate the hood, overcoming the force of the magnets.

**Verifications:** The proper deployment of the solar panels will be tested and verified in the launch environment through item 12 in the pre-flight section of the rover checklist. Magnet and servo effectiveness will be tested and verified in the launch environment in item 16 of the pre-flight section of the rover checklist.

## 5.5 Environmental 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 (Al<sub>2</sub>O<sub>3</sub>), 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.

#### 5.5.1 Environmental Hazards Analysis:

- **Risk:** The transition section of the launch vehicle is obstructed by an obstacle.  
**Causes:** The launch vehicle lands in such a way that a rock, branch, or other obstacle is in the path of the transition section as it is blown away from the rover section of the airframe.  
**Effects:** The deployment subsystem does not generate enough force to clear enough space for the ejection subsystem to expel the rover from the payload section of the airframe.

**Severity/Likelihood:** D2

**Mitigations:** The deployment subsystem should be equipped with enough black powder to push past obstacles of reasonable size.

**Verifications:** Tests will be performed with various obstacles; however, due to LEUP restrictions, it is unlikely that testing will be possible before the first test launch date.

- **Risk:** The launch vehicle lands in a tree.

**Causes:** A tree close to the launch site could end up becoming the landing spot of the launch vehicle.

**Effects:** Deployment may not be successful if the transition tube is wedged in between branches or otherwise stuck, and ejection may not be successful if the scissor lift is unable to push past branches. Moreover, even if deployment and ejection are successful, the rover would still either be stuck in the tree or fall to the ground, potentially damaging the rover.

**Severity/Likelihood:** E2

**Mitigations:** The nearest trees to the Huntsville launch site are approximately a mile away, which means that the recovery systems need to minimize drift.

**Verifications:** Testing of the recovery system during launches prior to Huntsville should give a good estimate for how much the launch vehicle is expected to drift, with modifications being made if the launch vehicle drifts too far.

- **Risk:** Rover gets stuck in mud.

**Causes:** Residual moisture on the ground from previous rainfall results in muddy terrain.

**Effects:** The mud decreases the traction in the rover wheels, which could compromise the rover's ability to move away from the launch vehicle. It may get stuck and fail to reach the minimum 5ft distance requirement outlined in the scoring guidelines.

**Severity/Likelihood:** D3

**Mitigations:** The gear-like design of the wheels promotes increased traction and durability so as to help prevent the wheels from getting stuck.

**Verifications:** Ground tests will be performed with the rover moving over soil with various amounts of moisture to determine that it does not get stuck.

- **Risk:** Damage to rover due to rain.

**Causes:** Poor weather such as rain or hail occurs on the day of launch.

**Effects:** Moisture enters the airframe of the rocket or the rover and damages the electronics, which could potentially incapacitate both vehicles.

**Severity/Likelihood:** D3

**Mitigations:** Not launching in the rain or when there is bad weather.

**Verifications:** Launch Commit Criteria will include requirements regarding lack of rain.

- **Risk:** The rover gets stuck behind an obstacle.

**Causes:** A rock, branch, hole, or other obstacle is in the path of the rover as it moves away from the launch vehicle.

**Effects:** The rover's path is blocked, it gets stuck, and the rover fails to meet the minimum 5ft distance requirement outlined in the scoring guidelines.

**Severity/Likelihood:** C3

**Mitigations:** The gear-like design of the wheels promotes increased traction and durability so as to help the rover roll over obstacles in its path. Additionally, ultrasonic sensors will allow the rover to avoid large obstacles.

**Verifications:** Run ground tests with the rover having various obstacles of different sizes in its path to determine that it does not get stuck.

- **Risk:** The rover is damaged by a sharp obstacle.

**Causes:** A rock, branch, or other sharp object is in the path of the rover as it moves away from the launch vehicle.

**Effects:** The wheels or chassis are cut, leading to decreased mobility or the rover veering off of its original path and potentially failing to meet the minimum 5ft distance requirement outlined in the scoring guidelines.

**Severity/Likelihood:** D3

**Mitigations:** The wheels are made out of sturdy, high-density foam and are fairly large so as to decrease the effects of wear and tear from the environment. The fully enclosed chassis design also promotes improved environmental protection

**Verifications:** Run ground tests with the rover having various sharp obstacles of different sizes in its path to determine that its movement is not seriously impeded or that its wheels are not seriously torn.

- **Risk:** Launch vehicle goes out of sight.

**Causes:** Low-lying clouds over launch site.

**Effects:** Cannot see falling objects, so personnel are less likely to have situational awareness during launch.

**Severity/Likelihood:** D2

**Mitigations:** Do not launch vehicle if there are clouds beneath 6000ft AGL.

**Verifications:** Finalized Launch Commit Criteria will include a minimum cloud height requirement.

- **Risk:** Launch vehicle is pushed off course.

**Causes:** High wind speeds.

**Effects:** Vehicle lands outside of launch site.

**Severity/Likelihood:**

**Mitigations:** Do not launch vehicle if there are sustained wind speeds above 15mph at ground level or aloft.

**Verifications:** Finalized Launch Commit Criteria will include a maximum wind speed requirement.

- **Risk:** Airframe becomes damaged.

**Causes:** Hail, due to impact. Rain, due to water softening the airframe material.

**Effects:** Launch vehicle is unable to fly correctly. Stability of both structure and flight may be compromised, and the vehicle becomes less aerodynamic.

**Severity/Likelihood:** D2

**Mitigations:** Do not launch the vehicle in hail or rain conditions, even if clouds are high-level.

**Verifications:** Finalized Launch Commit Criteria will include requirements that there is no rain or hail.

- **Risk:** Electronics become damaged.

**Causes:** Rain entering launch vehicle components and reaching active electronic components.

**Effects:** Recovery and/or payload may fail to deploy.

**Severity/Likelihood:** D2

**Mitigations:** As before, do not launch the vehicle in rain conditions.

**Verifications:** Finalized Launch Commit Criteria will include requirements that there is no rain.

- **Risk:** Electronics overheat.

**Causes:** High-temperature weather.

**Effects:** Electronics may work in undefined ways when out of rated temperature range.

**Severity/Likelihood:** D2

**Mitigations:** Place electronics in shade when not in use, and install electronics into launch vehicle as late as possible in order to avoid overheating

**Verifications:** Test electronics using TEST MODE to verify they still work.

- **Risk:** Recovery system becomes damaged.

**Causes:** Hail.

**Effects:** Parachutes may be punctured or ripped by collision with hail.

**Severity/Likelihood:** D2

**Mitigations:** Do not launch the vehicle in hail conditions.

**Verifications:** Finalized Launch Commit Criteria will include requirements that there is no hail.

- **Risk:** Parts melt or become too brittle or malleable.

**Causes:** Extreme temperatures, especially summer heat.

**Effects:** Payload fails to deploy as parts undergo significant bending or break. Soldered joints may weaken if the temperature is significantly higher than average.

**Severity/Likelihood:** E1

**Mitigations:** Do not launch (or even prepare) the vehicle if temperature conditions are extreme.

**Verifications:** Finalized Launch Commit Criteria will include requirements that the temperature falls within a certain safe range.

## 6 Launch Day Operations & Procedures

- Any darkened region bordered in black is an important step of the procedures:

This is an important step.

- Any safety warning/caution will have the following format:

If you do not perform this step properly, bad things may happen.

- Any procedure step which must be witnessed or verified by specific personnel will have a notice with a checkbox, and the names/titles of the required personnel will be placed in square brackets. For example:

[Logistics Officer] Verify that all required personnel have transportation to launch site:

### 6.1 Materials, Components, & Tools

The following items must be brought to the launch site.

#### Safety Equipment:

[Safety Officer] Safety Equipment is brought to launch site:

1. Safety glasses
2. Face shields
3. Respirators (all sizes)
4. Latex gloves
5. First-aid kit
6. Fire extinguisher

#### Food & Water:

1. Lunch/snacks, as necessary
2. Plenty of extra water

## **Tools:**

The following tools and extra materials may be useful for adjustments and repairs.

1. Screwdrivers
2. Allen wrenches
3. Pliers
4. Extra electrical wire
5. Extra screws, bolts, and nuts
6. Extra (unused, fresh) batteries: 9V Duracell
7. 5-minute epoxy
8. Electric drill and drill bits
9. Dremel
10. Measuring tape/ruler
11. Blue scotch tape
12. Electrical tape
13. Sandpaper of various roughness
14. Rip-stop nylon repair tape

## **Vehicle Components & Spares:**

1. Airframe components:

[Airframe Lead] Verify airframe components are brought to launch site: <input type="checkbox"/>
---

- (a) Nose cone
- (b) Payload section
- (c) Transition section
- (d) Recovery section
- (e) Avionics section and external door
- (f) 4x mounting screw for avionics section external door
- (g) Booster section
- (h) Short length of 1010 launch rail
- (i) Shear pins x4, and some extra

- (j) Metal screws x6, and some extra
2. Electrical components, tools, & miscellaneous:
- [Electrical Lead] Verify electrical components are brought to launch site and components are ready:
- (a) Ensure correct firmware is loaded to *all* boards:
- i. Deployment (x2)
  - ii. Ejection (x2)
  - iii. Rover (x2)
  - iv. Ground station (x2)
- (b) All computers going to launch should be on the latest git commit of the master branch.
- (c) Charge batteries. (Note: charger has capacity for one battery at a time.)
- (d) Components to bring:
- i. 2x Deployment board.
  - ii. 2-Pin latching connector to stripped-wire connector for black powder.
  - iii. Mounting screws and standoffs for deployment board.
  - iv. 2x Ejection board.
  - v. Mounting screws and standoffs for ejection board.
  - vi. 2x Rover board.
  - vii. Mounting screws and standoffs for rover board.
  - viii. LOTS of 2-pin jumpers.
  - ix. Breakaway wire connectors.
  - x. Onboard antenna.
  - xi. Yagi antenna.
  - xii. Radio board.
  - xiii. Radio board box.
  - xiv. Radio board UART-USB cable.
  - xv. Radio board mounting screws.
  - xvi. Spare UART-USB cable for testing.
- (e) Electrical tools:
- i. All 6 screwdrivers (and in particular, the smallest flathead).
  - ii. Soldering iron and solder.
  - iii. Electrical tape.
  - iv. Wire strippers.
  - v. Needle-nose pliers.
  - vi. AVR Programmer.
  - vii. UART USB cable.

- viii. Multimeter.
  - ix. LiPosack Firesafe Bag.
  - x. Laptops (of multiple people) with some serial port program (e.g. PuTTY or RadioSerial) and the full AVR toolchain and the current calstar-electronics Git repository downloaded. Charge it overnight!
3. Payload components:
- [Payload Lead] Verify payload components are brought to launch site:
- (a) 2x 0.25in wood centering rings, in nose cone, with 6 #6-32 hex nuts glued on aft side of centering ring holes
  - (b) 24x #6-32 pan-head phillips slotted machine screws
  - (c) 3d printed base plate
    - i. 3d printed crossbar
    - ii. 3d printed base rail
    - iii. Laser-cut wood slot
    - iv. Laser-cut wood hinge
    - v. Laser-cut acetal rack, with two #6-32 hex nuts glued into the rack
    - vi. HS-645MG servo, with servo gear and gear mount (screw and washer)
    - vii. 4x #6-32 servo screws
    - viii. 4x #6-32 servo nuts
    - ix. 4x servo washers
  - (d) 3d printed top plate
    - i. Laser-cut wood slot
    - ii. Laser-cut wood hinge
  - (e) 12x 2in-long aluminum standoffs
  - (f) 4x 1/8in aluminum spacers
  - (g) 24x #6-32 machine screws
  - (h) 8x #6-32 hex nuts
  - (i) 4x #4-40 machine screws
  - (j) 4x #4-40 hex nuts
  - (k) 24x laser-cut acetal scissorlift links
  - (l) Ejection battery and battery charger
  - (m) Rover (boards and electronics should be attached)
  - (n) Rover battery
  - (o) Zip-ties
  - (p) Nomex cover

- (q) 5-minute epoxy
- (r) Loctite 242 threadlocker

4. Recovery components:

[Recovery Lead] Verify recovery components are brought to launch site:

- (a) Main parachute
- (b) Drogue parachute
- (c) Avionics sled
- (d) Two PerfectFlite StratoLoggerCF altimeters
- (e) Eight mounting screws for the altimeters
- (f) Two L2 Tender Descenders
- (g) Kevlar shock cord
- (h) Kevlar shock cord sleeves
- (i) Four quicklinks
- (j) Drogue blanket
- (k) Complete parachute blanket
- (l) Two fresh & unused Duracell 9V batteries, and extra
- (m) Rolls of 20-22 gauge wire

5. Propulsion components:

[Propulsion Lead] Verify propulsion components are brought to launch site:

- (a) Motor casing
- (b) Motor retainer
- (c) PTFE/Teflon spray
- (d) Wet wipes
- (e) White lithium gel/grease

## 6.2 Launch Commit Criteria

The vehicle may only be launched if the following Launch Commit Criteria are satisfied at the launch site:

1. Temperature is between 32 degrees and 110 degrees Fahrenheit.
2. There is no cloud cover beneath 6000ft AGL (Above Ground Level).
3. There are not sustained winds of over 15mph at ground level or aloft (up to 6000ft AGL).

4. It is not raining or hailing.
5. It has not rained in the past day.
6. The ground is not excessively damp or moist from previous rain.

## 6.3 Assembly & Preparation

### 6.3.1 Airframe Assembly

For any of these steps, if a fit between two sections is too loose, then add tape to the coupler until the fit is tight. If a fit is too tight, then remove tape and/or sand the coupler or inner surface of the outer tube.

Safety goggles and a respirator are required when sanding tubing, fins, or the nose cone.

1. Screw together the booster and avionics sections with metal screws.
2. Screw together the avionics and recovery sections with metal screws.
3. Screw together the nose cone and the payload section with metal screws.
4. When the recovery team has finished preparing the parachute system, screw together the transition and recovery sections with shear pins.
5. When the payload team has finished preparing the payload and the payload section, screw together the payload and transition sections with shear pins.
6. Verify, by picking up the launch vehicle solely by each section in turn, that all sections are securely mounted together. Make sure that sections do not wobble or bend.

### 6.3.2 Electronics Preparation & Testing

- Troubleshooting:
  - Radio not working when inside the nose cone:
    1. Test the radio outside of the nose cone and debug accordingly.
    2. Try reinserting board with minimal bending.
  - Accidentally shorting a circuit board:
    1. Use the other circuit board.
  - Deployment not buzzing when turned on:
    1. Take apart launch vehicle, check battery connection, make sure black powder is connected.
  - GUI not responsive:
    1. Restart the GUI.

- **Electrical Testing Common Procedure:** The appendix contains board annotations and more detailed test instructions, if further information is desired.

All deployment, ejection, radio, and sensor tests can be run through the GUI. In terminal, navigate to the “~/Software/RadioSerial/bin/Debug” directory. Run RadioSerial.exe.

The program should look like the following:

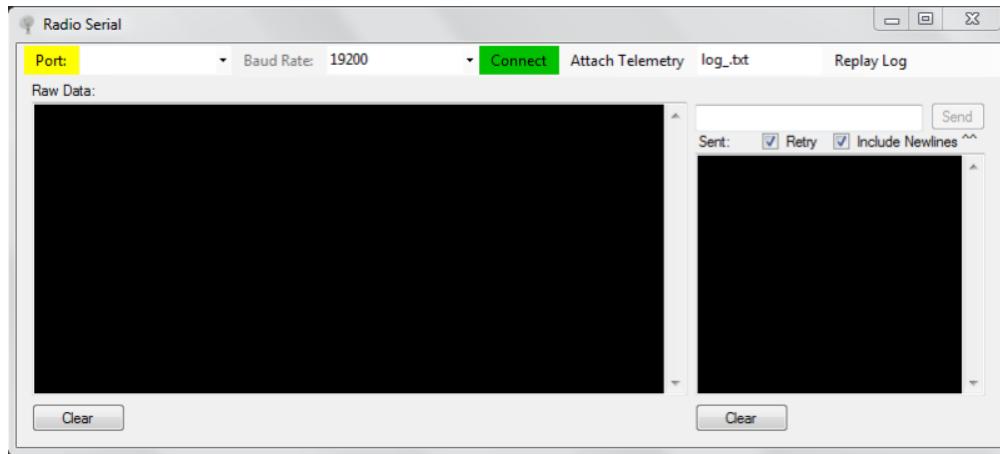


Figure 17: Radio Serial Program

1. Set up the ground station:
  - (a) Make sure the ground station has the USB-UART cable (blue USB part) connected, with the red wire going to the positive terminal of J1.
  - (b) Unscrew the two front/top screws of ground station. Remove the panel and screw in the Yagi antenna.
  - (c) Replace the panel.
  - (d) Connect the blue USB part to a computer. The red LED on the ground station should turn on.
2. Connect the ground station to the computer via USB. This should show up as a COM port. In the left corner, the menu labelled "Port" lists which port the program is reading from. Pressing the "Port" button refreshes the list of available ports. Using Device Manager, look under "Ports (COM & LPT)", and check which COM port is the ground station. This may look something like "Prolific USB-to-Serial Comm Port (COMx)", where the 'x' is what you want. Select the COMx port in RadioSerial. If the COMx port does not appear in RadioSerial, close RadioSerial and open it again.
3. In the box for "Baud Rate:", make sure to enter 19200.
4. The box that says "log\_.txt" logs data. Remove the text for testing so that it does not log data. For launches, put a filename in the box, so that it will log all the data sent and received. It can be replayed later with the Replay Log button.

- Press the green Connect button. Raw data should show up on the left, and any signals sent should show up on the right.
- The Attach Telemetry button opens the following window:

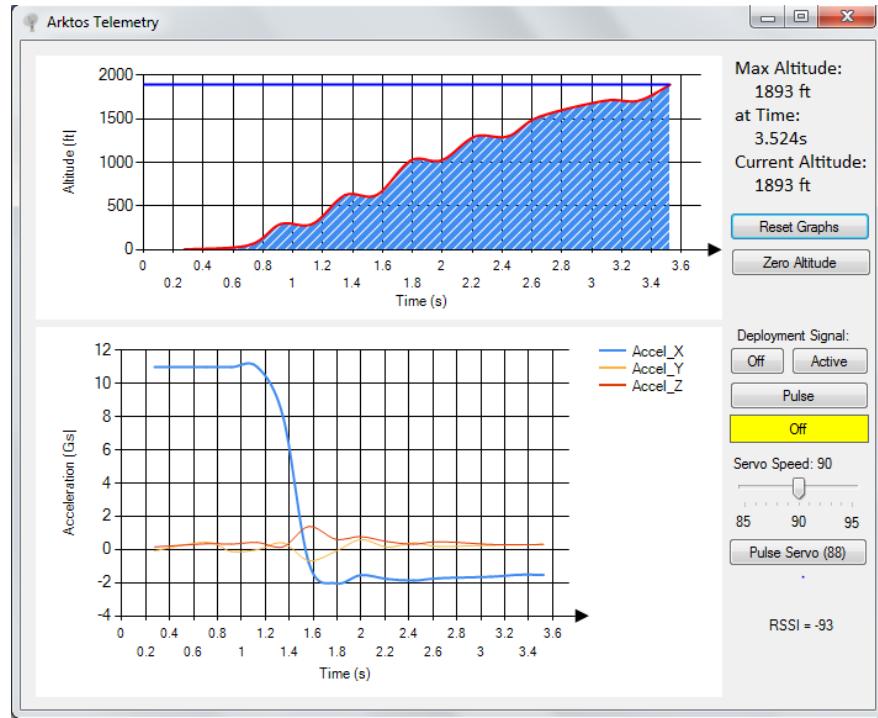


Figure 18: Arktos Telemetry Program

- Make sure to reset the graphs before launch after done with testing!
- No magnets are expected at the launch site, but make sure that magnets are never brought near any electrical components.
- To run sensor tests:
  - Make sure the boards are turned on.
  - For the ejection board: press the Attach Telemetry button to start the test.
  - For the deployment board: put the deployment board into test mode and start sensor data streaming. Attach the UART cable and press the Attach Telemetry button to start test.
  - While the test is running, move the accelerometer along every axis, and confirm that reasonable values are output in the graph.
  - Hold the board above your head and then near the ground, watching to confirm accurate change in altitude in the graph.
- To test the radio:
  - Make sure that the ejection board is on.
  - Put the ejection board in test mode over radio (if possible), and otherwise over UART.

- (c) Use the first screen to type a command in the box next to the "Send" button. Commands should follow the format "radio *text*". The ejection board should broadcast back "*text*".
11. To test servos:
- (a) Make sure that the ejection board is on.
  - (b) Put the ejection board in test mode over radio (if possible), and otherwise over UART.
  - (c) Use the first screen to enter integer values between 0 and 180 in the box next to the "Send" button. This should move the servo the specified number of degrees.
12. To test breakaway wire connectivity (LVDS):
- (a) Make sure the ejection and deployment boards are in test mode.
  - (b) Turn the deployment signal on and off with the buttons on the right.
  - (c) A successful result lights a red LED on the Ejection board, and switches the green LED to cyan on the Deployment board.
13. To test breakaway wire disconnection (LVDS):
- (a) Make sure the ejection and deployment boards are in test mode.
  - (b) Disconnect the breakaway wires.
  - (c) The LED on the ejection board should turn yellow.
  - (d) When asked, the ejection board should report that it detects disconnection.
14. To test black powder continuity:
- (a) Make sure the deployment board is on and in test mode and that the black powder wires are connected.
  - (b) Listen for beeps from the board that indicate the wires are connected.
  - (c) Disconnect the wires. The beeping should stop.
15. To test black powder detonation:
- (a) Connect a low value ( $20\Omega$  or less), 1/4-watt axial resistor across the black powder wires.
  - (b) Turn on the deployment board.
  - (c) Turn on the black powder port.
  - (d) Verify that the resistor begins to melt and vaporize.
  - (e) Quickly remove the resistor.
  - (f) Turn off the black powder port.
16. To test the functionality of the ejection and deployment connection:
- (a) Turn on both the deployment and ejection boards. Ejection should be in test mode and deployment should not be.
  - (b) Send the deployment signal through the radio.
  - (c) Board LEDs should remain red. Nothing changes.

- (d) Switch deployment into test mode and ejection off test mode.
- (e) Send the deployment signal through the radio.
- (f) Board LEDs should remain red. Nothing changes.
- Deployment board assembly:
  1. Remove the jumper from J12.
  2. Be sure that J6,7,8,9 are in the correct position for [LVDS] or [Single-ended voltage signaling]. This can be verified with the annotated boards in the appendix.
- Ejection board assembly:
  1. Remove the jumper from J3.
  2. Be sure that J13,8,9,12 are in the correct position for [LVDS] or [Single-ended signaling]. This can be verified with the annotated boards in the appendix.
- Final electrical assembly:
  1. Connect the deployment-side breakaway wires.
  2. Connect the ejection-side breakaway wires.
  3. Attach the breakaway wire connectors to complete the signal pathways.
  4. Add PowerPole clips to all PowerPole connectors, minus breakaway wire connectors.

### 6.3.3 Payload Assembly

- Deployment system assembly:

Since the deployment system contains black powder, safety goggles and face shields are required when assembling the deployment system.

1. Required materials and components:
  - Payload tube.
  - Transition section.
  - Electronics sled.
  - Deployment board.
  - D-04: transient bulkhead.
  - 4-40x0.25” nylon standoffs.
  - 4-40x0.625” button head cap screws.
  - 4-40 nylon lock nuts.
  - 14 gauge breakaway connectors (without Anderson Powerpoles attached).
  - 4s LiPo battery.
  - 10-32 knurled hand nuts, or 10-32 wing nuts.
  - Velcro strap.

- Zip ties.
  - Nomex blanket.
2. Verify with the electrical subteam that the deployment board is functional. In particular, ultrasonic sensors should be tested with calibrated distances to ensure readout accuracy.
  3. Check deployment battery voltage. It should be around 16.8V.
  4. Insert the velcro Strap into the two vertical slots on the electronics sled such that the plastic buckle is on the side opposite the face with serial number and part identification.
  5. Assemble the deployment board onto the electronics sled:
    - (a) Insert the 4-40 button head cap screws into the board such that the side with connectors is facing away from the sled.
    - (b) Place the 4-40 nylon standoffs onto the screws.
    - (c) Insert the exposed screw threads into the corresponding holes on the electronics sled.
    - (d) Install the nylon lock nuts so as to prevent the deployment board from falling free.
  6. Connect the battery to the deployment board such that the smaller end (without connectors) is flush with the face opposite the D-01 label. Tighten the Velcro strap, and verify board initialization: listen for an audible click and tactile feedback.
  7. Visually check the connection to breakaway plugs.
  8. Route the 14 gauge breakaway connectors through the holes labeled "Wire Passthrough" on D-01 and D-04 after connecting the large connectors to the deployment board, ensuring about 10" of slack between the D-01 and D-04 plates.
  9. Attach the Anderson Powerpole connectors to their color coded wires.
  10. Insert the electronics sled into the transition section such that the battery and deployment board are hidden from sight beneath the bulkhead. **Ensure that the insertion of the electrical sled is done vertically and slowly: binds should be corrected early, not pushed through.**
  11. Install thumb screws onto the exposed threads of the 10-32 mounting screws visible through the D-01 bulkhead.
  12. [Payload Lead] Verify that the deployment key switch is in the "off" configuration.
 

If the deployment key switch is in the "on" position, then the deployment system is armed, which can cause inadvertent ignition of black powder during installation.
  13. [Team Mentor] Fill and seal a black powder charge capsule containing a mass of black powder within 0.05 grams of 6 grams.
  14. Connect E-match to the deployment board.
  15. [Team Mentor] Install the black powder capsule, and verify a secure fit.

16. Place the Nomex shielding on top of the D-01 bulkhead.
17. Place the D-04 transient bulkhead on top of the Nomex shielding.
18. Assemble the payload tube on top of the transition section, ensuring that the shoulder section of the transition section is sandwiched between the space created by the supports in the payload tube.

- Ejection system assembly:

1. Required materials and components:
  - (a) Electronics sled.
  - (b) Ejection battery.
  - (c) Zip ties.
  - (d) Ejection board.
  - (e) Scissor lift assembly (separated into top and bottom pieces).
  - (f) 8x 4-40 screws.
  - (g) 6x 6-32 machine screws.
2. Integration of electrical components:
  - (a) Ensure ejection battery has sufficient charge, and place the ejection battery into the battery holder in the ejection sled, located nose cone-side of the ejection baseplate.
  - (b) Zip-tie the battery in place, using the notches in the sled as guides.
  - (c) Connect the battery to the ejection board.
  - (d) Mount the ejection board onto the sled by aligning the four screw holes of the board to the four drilled holes of the sled.
  - (e) Screw four #4-40 screws into the screw holes on the ejection board. On the underside of the ejection sled, screw four #4-40 hex nuts onto the screw threads.
  - (f) Zip-tie the top half of the ejection board.
  - (g) Connect the servo connector to the ejection board.
  - (h) Connect the power switch, which is already mounted in the nose cone, to the ejection board.
  - (i) Ensure the two radio antennas run lengthwise along the ejection board, and secure them against the sled and the battery with zip-ties.
  - (j) Ensure all cables are as compact as possible. Tie them down with electrical tape and/or zip-ties.
3. Physical integration into nose cone:
  - (a) If the full scissorlift assembly is assembled (i.e. the base plate is fully connected to the top plate with the scissor links), remove the top plate by unscrewing the top two aluminum standoffs from the scissor. Set aside the top plate.

- (b) With the nose cone horizontal, begin inserting the bottom plate assembly into the nose cone, aligning the width of the ejection board with the cut-out slots of the centering ring. Ensure that the base plate assembly is fully horizontal or aligned with the nose cone for proper insertion.
- (c) Begin slowly rotating the nose cone assembly to vertical, and push on the baseplate assembly to ensure that it rests upon the six hex nuts of the centering ring.
- (d) Screw in six #6-32 machine screws into the six mounting holes above the centering ring hex nuts. The heads of the machine screws must fully contact the base plate assembly.
- (e) At this point, test full ejection scissor lift functionality.
- (f) If test is successfully, reassemble the top-plate onto the rest of the scissorlift assembly. Manual extension of the scissorlift links at this point may be necessary - gently pull on the scissorlift links until enough clearance is attained. Reassemble the top two aluminum standoffs.

4. Final integration tests:

- (a) Make sure to keep fingers and hands clear of the scissor lift system during testing.
- (b) Ensure that scissor lift can push entire rover through payload section by running a systems test with electronics.
- (c) Test friction/functionality inside airframe.
- (d) Ensure entire assembled scissor lift can slide freely through airframe. If not, sand/ lubricate until possible.

5. Final checks:

- (a) Check all fasteners on the ejection system:
  - Six screws from the base plate into the centering ring.
  - our screws from servo to the base plate.
  - One red 3d printed rail glued at fixed points on the base plate.
  - Two screws and nuts on the fixed-hinge side of the base plate. Ensure the nuts are not loose! Use blue Loctite if they are.
  - Twenty aluminum standoffs.
  - One threaded rod affixed inside slots of the top plate. Ensure that there are four nuts present on the rod holding the links to the slot, and that they are not loose.
  - Two screws and nuts on the fixed-hinge side of the top plate.
- (b) Perform a final inspection for any damage. This includes checking for cracks or breaks in the top plate, broken top plate legs, the base plate slider rack being worn, and misalignment of the servo gear and rack mechanism.

• Rover system preparation:

1. Make sure to not put eyes near the rover skids. Also, do not place fingers or hands near the wheels during any tests.

2. Install the rover battery, using velcro straps on the bottom and top of the battery.
3. Ensure the rover battery is charged; Check rover battery voltage. Use a multimeter to check the terminals of the battery, ensuring that voltage is approximately 14.8V.
4. Ensure the rover board is securely fastened to the top plate using #8-32 socket head screws. Inspect and manually check tightness of screws.
5. Connect the battery to the rover board. Verify the rover board is powered on: the rover board LED should turn on.
6. Flash the rover board with electronics test firmware using the 3.3V programmer. Connect the programmer to appropriate port on main board.
7. Connect the serial UART cable to monitor serial output during the test. Ensure that Rx, Tx and GND wires are connected to appropriate pins on the board.
8. Check servo functionality during the test. Ensure full range of motion and correct speed for each servo, as defined in test program.
9. Check sensor accuracy during test. Place objects at a variety of ranges in front of the sensors and ensure the serial readout from the sensors is accurate.
10. Check motor functionality during test. Ensure that the motors rotate at the speeds and directions defined in the test program.
11. Flash the rover board with movement test firmware using the 3.3V programmer. Using the same port as above, upload test firmware that executes basic movement commands such as driving straight and turning.
12. Test rover movement on terrain on-site. This is a basic motion software run. Ensure that the rover moves at the appropriate speeds and turns at the angles defined in the test firmware.
13. Flash the rover board with launch firmware using the 3.3V programmer. This uploads the program that will be used for the actual launch/rover sequence to the board.
14. Verify breakaway cable integrity with the rover deployment subteam.
15. Secure the connection of breakaway cables to connectors in payload tube. There should be an audible click and tactile feedback.
16. Visually check the interior rover electronics for any damage. Make sure no wires are pinched and the chamber interior is void of debris.
17. Verify with the electrical subteam regarding functionality of all sensors. Test ultrasonic sensors with calibrated distances to ensure readout accuracy; test encoder to ensure distance readout accuracy; test potentiometer to ensure angle corresponds to correct hood angle.
18. Verify with the electrical subteam that all servos are functional, by running test software verifying actuation of servos.
19. Verify functionality of all solar cells, by confirming voltage input on rover computer corresponds to solar panel output.

20. Inspect structural supports within the payload tube.
21. Verify the motors are mounted to the rover chassis using screws. Inspect and manually check tightness of screws.
22. Verify servos are securely fastened using screws. Inspect and manually check tightness of screws.
23. Check magnet strength. Ensure magnets keep hood closed under a good shaking.
24. Inspect motor shafts and rover body for deformation and substantial blemishes.
25. Check and ensure integrity of structure and fasteners: check for damage and deformation of the rover chassis and manually verify that the fasteners connecting the chassis plates are secure.
26. Insert the rover into the payload section airframe. Visually and physically check for impediments and rotational constraints.

#### **6.3.4 Recovery Preparation**

1. Assembly of avionics bay:
  - (a) Ensure that both batteries are completely fresh. If not, replace with two fresh 9-V batteries.
  - (b) Verify that both Perfectflite Stratologger CF altimeters are secured onto the altimeter sled with four 2-56 screws together. Also verify that both 9V batteries are secured in their zip-ties, and confirm that it is secured onto the altimeter sled with four 2-56 screws each.
  - (c) Connect wires to altimeters on altimeter sled. After connecting, VERIFY that they are the correct wires by checking that the ports correspond to the tape labels.
  - (d) Tug on every wire to ensure that they are all securely fastened.
  - (e) Slide the altimeter sled into the bulkheads and ensure it is secure.
  - (f) Close the aft end of the avionics bay with the bottom bulkhead (the one that has two different diameters) and secure with washers, o-rings, and wing nuts. O-rings precede washers, which precede the wing nuts when adding them on.
  - (g) Place the door into the airframe and insert the four screw. Then place a vinyl sticker over each screw head
  - (h) Use silicone to Fill any gaps between bulkhead and airframe tube.
  - (i) Perform Anderson Connector stress connectivity checks. Check to see that it is easy to disconnect. Ensure all the wires are connected to the Anderson Connectors.
  - (j) Check altimeters for functionality:
    - i. Check main parachute altitude on both.
    - ii. Check drogue delays on both.

- iii. For both of the StratoLoggerCFs, switch it on (ensure there is no siren indicating error codes). Wait for it to sound off the 1 digit preset, 2 second pause, and then ensure that the 3 digit number representing the main parachute deployment altitude is 800 (ft) on the altimeter on side 1 and 850ft on the altimeter on side 2. This number is read off through the beeps on the altimeter (1 long beep to signal a number, pause, then it will beep out each digit, 10 beeps represent 0)
  - (k) Check switches to verify that they work and correspond to the correct on/off mode.
- 2. Parachute deployment system assembly:
  - (a) Verify that bulkheads and doors are airtight by looking for cracks of light/air/silicone.
  - (b) Turn altimeters on to ensure they are functioning.
  - (c) Attach parachutes to corresponding quicklinks:
    - i. Main chute to QL3
    - ii. Drogue chute to QL4
  - (d) Verify dual deployment orientation:
    - i. Two L2 Tender Descenders (TD) linked together in series
      - A. Grease Tender Descenders with WD 40
      - B. Will be designated as TD1 for the TD located closest to the Av-Bay and TD2 for the TD located after the TD1
      - C. Contains two small quick links on each side of the quick link
      - D. Will eventually contain an E-Match in each
      - E. Contains 1/2 g of Black Powder in each
    - ii. Shock Cords
      - A. Use one very long length of 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 48.75 ft.
      - 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 Booster section separation stage when the drogue chute catches air. Its length is 24.58 ft.
      - D. DROGUE-to-BOOSTER (D2B): This refers to the length of shock cord between the Drogue Chute/QL3, and QL4, which is directly attached to the Booster section of the rocket. Like the M2B, it is also pulled out during the first two stage separation. Its length is 12.00 ft.
    - iii. 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, 5) Beige parachute blanket
  - B. QL2 - the one connected to the main chute; connected to the following:  
 1) TD2, 2) B2M connection, 3) Main Chute, 4) M2D
  - C. QL3 - the one connected to the drogue chute; connected to the following:  
 1) M2D, 2) Drogue chute, 3) D2B, 4) Orange parachute blanket
  - D. QL4 - the one connected to the booster; connected to the following: 1)  
 D2B, 2) U-Bolt on the Booster Section Bulkhead
- iv. Parachutes
- A. Drogue Chute: 24 Elliptical parachute from Fruity Chutes; the red and white one
  - B. Main Chute: 72 Toroidal parachute from Fruity Chutes; the orange and black one
- v. 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 D2B
- (e)
- i. Attach parachute bag to QL1
  - ii. Attach QL1 to the U-Bolt on the Av-Bay side
  - iii. Verify that TD1 is connected to TD2 and that the B2M is looped through the aft-end smaller quicklink on TD1
  - iv. Verify that TD2 is connected to QL2
  - v. Verify that QL2 is connected to the following four components: 1) TD2, 2) B2M, 3) Main Chute, 4) M2D
  - vi. Verify that Main Chute is not tangled
  - vii. Verify that Drogue chute is not tangled
  - viii. Verify that QL3 is attached to the following components: 1) M2D, 2) D2B, 3) Drogue Chute, 4) Orange parachute blanket
  - ix. Verify everything once more.
  - x. Fold Parachutes:
    - A. Main Chute: Starts at folded in half in front of you
    - B. Fold in left and right 1/4 parts towards the center
    - C. Fold in shroud lines neatly
    - D. Repeat left and right folds to it desired size (based on parachute deployment bag)
    - E. Roll parachute up
    - F. Stuff gently into the parachute bag

- G. Drogue Chute: Starts at folded in half in front of you
- H. Fold in left and right 1/4 parts towards the center
- I. Fold in shroud lines neatly
- J. Repeat left and right folds to its desired size (based on parachute deployment bag)
- K. Roll parachute up
- L. Wrap carefully in orange parachute cloth
- xi. Fold shock cords
  - A. B2M: Take full length, and fold in half. Repeat until the bundle is in 10-12 in. loops, but still neat, tape for now, but will be REMOVED later.
  - B. M2D: Neatly zig zagged into 10-12 in. loops and taped
  - C. D2B: Neatly zig zagged into 10-12 in. loops and taped
- xii. Turn altimeters to the OFF position. This IS VERY IMPORTANT.
 

[Recovery Lead] Verify altimeters are OFF:

If the altimeters are on, then the black powder deployment charge may unexpectedly explode on installation.
- xiii. Connect two e-matches to two 4g black powder ejection charges for drogue deployment.
- xiv. Cut and strip ends of e-matches and insert and tighten into the corresponding altimeter ports.
- xv. Pull e-matches through tender descenders for main deployment.
- xvi. Use a piece of masking tape to cover the bottom of the tender descender.
- xvii. Add 0.5g of black powder to each tender descender. Cover and ensure the tender descenders are fastened.
- xviii. Carefully push the deployment system into the parachute tube from the fore-end. Ensure the drogue charges are packed below the main parachute.
- xix. Visually inspect that the parachutes and shroud lines are protected from the black powder explosion.
- xx. Interface with the transition tube bulkhead once completed.

### 6.3.5 Propulsion Preparation

1. Verify that the motor mount is secured to outer tubing: the motor mount should not be able to shift or move at all inside the booster section.
2. Verify that the motor retainer can hold the weight of the booster section: screw the motor retainer onto the motor mount, and lift the booster by the motor retainer.
3. Test fit the motor casing inside the motor mount, and verify that any ballast is placed high enough in the launch vehicle.
4. Spray PTFE/teflon onto the inside surface of the motor casing.

5. [Team Mentor] Collect the motor from the Bay Area Rocketry truck, and follow instructions on the motor manual to assemble the motor.

### 6.3.6 Launch Commit

- Record wind speed: \_\_\_\_\_
- Record temperature: \_\_\_\_\_
- Record humidity: \_\_\_\_\_

[Safety Officer] Verify that all the launch commit criteria are satisfied:   
If the launch commit criteria are not satisfied, launch may not proceed.

## 6.4 Launch Setup

1. Determine the stability of the launch vehicle: find the center of gravity by balancing the vehicle on a point, then determine how far the center of gravity is from the center of pressure, and divide this distance by the vehicle's largest radius [6in]. (Center of pressure is marked on the vehicle's outer surface with a marker line, labeled with the text "CP".)

Vehicle stability: \_\_\_\_\_ cal

[Safety Officer] Verify that vehicle stability is between 2.0 and 2.5 cal:

If the vehicle is under-stable, its flight path may be chaotic.

2. Get permission from the Range Safety Officer to carry the vehicle to the launch rail.
3. Carry the vehicle to the launch rail: at least one team member must hold near the top of the vehicle, and at least one member must hold near the bottom.

Bring white lithium grease.

[Team Mentor] Bring the motor.

### 6.4.1 Vehicle Setup at Launch Rail

1. Ensure that the launch rail is very stable and secure: it does not move when pulled or yanked, especially when pulled vertically up. Make sure there is a hold-down device (such as a pin) mounting the launch rail to the launch mount.

If the rail is not stable and secure, then inform the Range Safety Officer and have another launch rail assigned.

[Safety Officer] Verify that the launch rail is secure and stable:

If the launch rail is not secure, friction from the vehicle's rail buttons may lift the launch rail off its mount at liftoff.

2. Lower the launch rail.

3. Lubricate the internal surfaces of the launch rail with white lithium grease.
4. Slide the launch vehicle onto the launch rail, making sure that the rail buttons move smoothly along the entire rail.
5. Raise the launch rail.
6. Perform a final visual/physical examination of the launch vehicle: is it ready to fly?
  - (a) Fins are undamaged, firmly mounted, and well-aligned. They will not collide with the launch rail during liftoff.
  - (b) Shear pins are in place, mounting the transition section to the payload section and to the recovery section.
  - (c) Metal screws mount the nose cone to the payload section, the recovery section to the avionics section, and the avionics section to the booster section.
  - (d) Motor retainer is secure and firmly attached to the motor mount.
  - (e) Entire airframe exterior is free of damage. This includes: nose cone, payload section, transition tube, recovery section, avionics section, booster section.
  - (f) Gaps between tubing of different sections are minimal.

[Airframe Lead] Verify that the launch vehicle appears ready for flight:

7. [Safety Officer] Verify that the launch rod is nearly vertical, and will not aim the launch vehicle towards any people or prohibited areas:

8. [Safety Officer] Ensure that no person is at the pad except safety personnel and those required for arming and disarming operations:

9. Arm both altimeters by turning on their external key switches, located on the recovery section. Turn them on one at a time. Listen for three beeps from each altimeter. This indicates continuity.
10. Arm the payload section by turning on the deployment and ejection external key switches, located on the transition section and nose cone.
11. The electrical team must verify signal from the ejection radio. If there is no signal, then disarm the payload section by turning off the deployment and ejection external key switches. At this point, either remove the vehicle from the launch rail for inspection, or launch with payload disarmed.

If no ejection signal is received, then the ejection computer is damaged or in an otherwise undefined state. Launching with the ejection computer on and armed could cause inadvertent payload deployment mid-flight, with catastrophic results.

#### **6.4.2 Motor & Igniter Installation**

The Team Mentor performs these steps.

1. Unscrew the motor retainer if it is already installed.
2. Insert the motor into the motor casing.
3. Insert the motor casing into the motor mount.
4. Screw the motor retainer onto the motor mount, and ensure the retainer is secure.
5. Create a bend in the ignitor, and push the ignitor through the hole in the plastic motor cap.
6. Install the ignitor by pushing it as far up into the motor as possible.
7. Retain the ignitor by fitting the plastic motor cap over the motor nozzle.
8. Verify that the ignition system leads are unpowered by shorting their alligator clips together. Stop if there is any spark: inform the Range Safety Officer and wait for the Range Safety Officer to unpower the ignition system, and then repeat this step again.

If the ignition system is powered, then attaching the alligator clips to the ignitor may ignite the motor. DO NOT PROCEED if there is any spark.

9. Connect the alligator clips to the leads on the ignitor.

#### **6.5 Launch**

The steps of this section most likely will be executed by the Range Safety Officer or other launch official.

1. [Safety Officer] Ensure that the launch vehicle has been on the launch rail for less than one hour. DO NOT LAUNCH if the vehicle has been on the rail for at least an hour.  
If the launch vehicle has been on the launch rail for at least an hour, there is a possibility that recovery batteries are dead, which would cause parachute deployment failure and the launch vehicle to impact the ground at high velocity.
2. Ensure all personnel are a safe distance from the launch vehicle, as specified in the NAR High Power Rocket Safety Code.
3. Count down at least 5 seconds, and then launch the vehicle.
4. In case of misfire, remove the launchers safety interlock and wait at least 60 seconds before approaching the launch vehicle. Wait also for the range to be cleared by the Range Safety Officer.

## 6.6 Post-Flight

### 6.6.1 Rover Deployment

1. Wait for the range to open (with RSO approval).
2. Report to the Rover Deployment Officer (RDO).
3. Verify that there are no personnel near the launch vehicle, particularly the payload section.
4. Obtain approval from the RDO to deploy the rover.
5. Send the rover deployment command by clicking the relevant button in the ground support software GUI.

### 6.6.2 Vehicle Safing & Recovery

This section should be followed by the vehicle recovery group, i.e. the team members who find the launch vehicle after its flight, disarm it, and bring it back to the rest of the team.

Safety glasses and face masks are required.

[Recovery Lead] Bring a key for the external key switches.

[Safety Officer] bring a fire extinguisher.

1. Wait until the rover has either (a) failed to deploy, or (b) has stopped moving after being deployed. Wait for the range to open, and obtain approval from the Range Safety Officer to approach the vehicle & rover, since they may be in the launch range.
2. [Recovery Lead] Approach the launch vehicle, making sure to not stand along the axis of the payload or recovery section.
3. [Recovery Lead] Turn off the two external key switches on the recovery section. This disarms the recovery system.
4. [Recovery Lead] Turn off the external key switch on the transition section. This disarms the rover deployment system.
5. [Recovery Lead] Turn off the external key switch on the nose cone. This disarms the rover ejection system.
6. [Payload Lead] To avoid causing damage to the rover, inspect the rover's battery pack for physical damage or visible expansion of the outer casing before disconnection. If the battery is at risk of electrical short or is otherwise compromised, it must be placed into a large LiPo fire-safe bag for transport before controlled decommission to reduce the risk of fire.
7. At this point every component of the launch vehicle is disarmed.

8. Measure the location of the rover and solar panels, and the distance travelled by the rover:

- (a) Rover distance to launch vehicle: \_\_\_\_\_
- (b) Solar panels status: \_\_\_\_\_
- (c) Distance travelled by rover: \_\_\_\_\_

9. Bring the components back to the team's work area for post-flight inspection.

### **6.6.3 Post-Flight Inspection & Cleanup**

This section should be followed once the launch vehicle has been returned to the team's work area. Inspection results should be noted digitally or on paper.

- Propulsion:

1. Unscrew motor retainer cap.
2. Remove motor casing from motor mount.
3. Screw motor retainer cap back onto the motor mount.
4. Remove o-rings and the nozzle from the motor casing.
5. Clean the internal surfaces of the motor casing with wet wipes.

- Recovery:

1. Detach quicklinks and isolate the deployment system.
2. Inspect for any tears or holes in the parachutes. If there are, take photos, clean, and patch immediately using ripstop nylon tape in bag.
3. Separate avionics bay from booster section by unscrewing.
4. Check for any damage on the avionics bay exterior.
5. Clean exterior with a wet cloth to remove black powder residue.

- Payload:

1. Payload section inspection:
  - (a) Visually inspect the payload section for damage resulting from the deployment event or from terrain.
  - (b) Take pictures to document the physical status of the payload section and internals.
2. Rover inspection:
  - (a) Visually inspect the solar panel deployment, potentiometer rotation, and servo rotation. Ensure the solar panel position corresponds to the expected position.
  - (b) Visually inspect the rover for heat damage from the deployment event.

- (c) Visually inspect the rover for damage resulting from terrain.
  - (d) Take pictures to document the physical status of the rover.
3. Ejection inspection:
- (a) Check for damage to links and link fasteners.
  - (b) Check for cracks/damage to the top and bottom plates.
  - (c) Check for damage to the mounting ring inside the airframe, and to the connection between the airframe and the plate.
  - (d) Check for damage to the servo mechanism: the gear, wooden teeth, sliding pins, and screws holding the servo.
  - (e) Check for damage to the electrical sled, including to soldered connections and wire connectors.
- Electronics:
    1. Visually check for damage to any boards.
    2. Inspect all connectors: are they still secure?
    3. Verify that the breakaway wire has successfully broken.
    4. Verify LED indicators are as expected.
    5. Disconnect batteries.
  - Airframe:
    1. Visually inspect fins for surface damage, cracks, etc.; press against the fins to determine if they are still firmly mounted.
    2. Visually inspect all airframe tubing, looking at both outer and inner surfaces. Note any damage from black powder charges, from terrain, and from zippering.

## 7 Project Plan

### 7.1 Testing

Consult CDR [here](#) for details on what each test is. Payload tests start on page 81.

#### 7.1.1 Payload Electronics Tests

##### P.L.1 Board Bench Tests

**Test Objective:** The transmitted signal from the ground station must be properly received by the ejection board via radio, which must then transmit a signal via breakaway wires to the deployment board, which actuates the deployment mechanism.

**Verification Method:** Inspection using LED indicators

**Testing Plan:** The primary method of testing shall be a bench test, wherein all electronics will be assembled and powered in a laboratory setting. The deployment and ejection

boards are both equipped with RGB LEDs, and the firmware designates a different LED state for each stage of the program (radio signal received, deployment signal transmitted, deployment mechanism actuated). The deploy and reset commands shall be sent several times in sequence, to ensure the whole system reacts quickly and consistently. The output of the deployment board, which shall be connected to the actuator (a black powder explosive mechanism), will be measured using an ammeter.

**Success Criteria:** All three stages (radio signal transmission, deployment signal transmission, and deployment mechanism actuation) should occur quickly and consistently. In a successful test, the LED on the ejection board should change colors after the radio signal is received, and the LED on the deployment board should change colors after the signal to deploy is received from the ejection board. Furthermore, measuring the actuation output on the deployment board with an ammeter will show a current in excess of 1 amp.

**Justification:** The signaling and actuation must perform very consistently in order to reliably begin the payload sequence.

---

### P.L.2 Deployment Board Independent Bench Test

**Test Objective:** Signals sent to the deployment board must be properly received by the deployment board via serial cable, which should then respond properly to test commands sent over the serial connection.

**Verification Method:** Inspection using LED indicators and serial monitor

**Testing Plan:** All electronics in the deployment board will be assembled and powered in a laboratory setting, as with the aforementioned test of both the ejection and deployment boards. The deployment board is equipped with an RGB LED, and the firmware can set these LEDs in response to commands received over a serial connection. In addition to setting LEDs, commands will also be sent to test that the deployment board properly receives LVDS signal from the ejection board, the transmission of signals to the black powder mechanism, and the detection of the presence of a black powder charge.

**Success Criteria:** The LEDs on the deployment board change colors correctly, and the serial monitor displays the expected values for the other testing commands.

**Justification:** The deployment board must function properly in order to reliably begin the deployment of black powder charges.

---

### P.L.3 Board Airframe Integration Test

**Test Objective:** Once boards are assembled in the airframe, the transmitted signal from the ground station must be properly received and processed by the ejection board via radio.

**Verification Method:** Inspection using LED indicators, inspection of buzzer

**Testing Plan:** Once the launch vehicle is assembled, a sequence of test commands will be sent to the ejection board over radio, similar to the procedure performed during bench tests. RGB LEDs on the ejection and deployment boards should, as before, change to reflect changes in the state of the program. The buzzer should also sound to properly reflect the presence of a black powder charge.

**Success Criteria:** The LED on the ejection board change color after the radio signal is received, and LED on the deployment board should change color after a deployment signal is received from the ejection board, and a buzzer should be heard going off at a regular interval if a black powder charge is present.

**Justification:** The ejection board failed during the first full-scale launch, likely as a consequence of mechanical damage that occurred during the mounting of the board. This test would help detect and recover from such failures after launch vehicle assembly.

---

### P.S.1 Solar Cell Integration

**Test Objective:** The panels chosen must interface with the rover computer such that they do not produce too much current at their input to the computer.

**Verification Method:** Inspection

**Testing Plan:** The leads of all the individual solar cells will be electrically chained together such that they serve as one effective solar panel. Current production will be monitored across the panel using a multimeter in bright lighting conditions (a very sunny day). The range of currents produced by the solar panels over a range of lighting conditions will be compared to the maximum current the rover computer analog input can handle. If these currents fall outside of the range of acceptable current values, a resistive load will be placed in series with the panels to dissipate some current. The resistive load will most likely take the form of a ceramic resistor to effectively dissipate any heat as a result of current dissipation. The panel and resistive load, if necessary, will then be connected to an analog input on the rover computer and the test will be run again to ensure that the current produced by the panel does not fry the rover computer.

**Success Criteria:** The solar panel current input to the rover computer should not short the computer in the sunniest conditions.

**Justification:** The rover computer should operate after panel deployment. If too much current from the solar panels is passed into it, it may be ruined.

**Status:** Successfully completed. Solar panels interface with the rover computer such that the computer is not damaged by too much current.

---

### P.S.2 Servo Integration

**Test Objective:** The servo must be able to actuate the rover hood under all conditions.

**Verification Method:** Inspection

**Testing Plan:** The servo will be mounted to the full rover system, as if to prepare for flight. The whole rover system will also be assembled. The servo will then be electrically actuated to a particular setpoint, such as would be done to deploy the solar panels. It will be verified that the hood rotates appropriately without major strain through visual inspection. If this test is a success, a tiny amount of extra weight will be added to the hood and the system will be reset. The actuation of the servo will be repeated. This test ensures that torque due to hood on the servo arm is not near or beyond the servo's realized torque. This will give us a reasonable safety margin for panel deployment, ensuring that the servo can deploy the hood under a variety of slopes which may alter the effective torque from the hood on the servo. If the servo does not give a reliable safety margin, another servo with a higher torque specification will be selected and will undergo the same tests outlined above.

**Success Criteria:** The servo should actuate the rover hood under all conditions.

**Justification:** The servo needs to actuate the hood in order to deploy the solar panels.

**Status:** Partially completed. Servo was successfully fit and integrated with the chassis but tests on lifting the hood are ongoing.

---

### P.M.1 Manufacturing Testing

**Test objective:** Create a smaller version of the parts as a proof of concept for the manufacturing techniques that will be used to manufacture the rover.

**Verification Method:** Demonstration.

**Testing Plan:** Using OMAX Layout create cutting paths for the wheels without using tabs. Set the cutting type to water only. Attach a 24 x 12in sheet of cross-linked polyethylene to a 0.125in plywood sheet using double sided tape. Fasten down the sheet to the OMAX 2626 waterjet cutter cutting table using three clamps, two on the 24in side and one on the 12in side. Export the OMAX Layout file to OMAX Make, set the cut quality to 3, and following all safety procedures attempt the cut. Assess if the wheels cut through this method are cut without blemishes. Then prepare the polycarbonate parts for cutting. Using OMAX Layout create cutting paths for the rover top sheet and bottom sheet without using tabs. Fasten down a 24 x 12in polycarbonate sheet to the OMAX 2626 waterjet cutter cutting table using three clamps, two on the 24in side and one on the 12in side. Export the OMAX Layout file to OMAX Make, set cut quality to 3, and following all safety procedures attempt the cut. Assess if the cut was successful and verify that the lack of tabs did not compromise the integrity of the cut. If the cut is unsuccessful due to interference add tabs in the OMAX Layout file attaching the center hole to the rover body and then repeat the cut. The 3D-printed parts for the rover will be sliced in the appropriate slicing software using the default recommended settings and 30 percent infill. The parts will then be printed on an Ultimaker 2+ and a Type A printer to determine which printer produces higher quality parts for the rover. If the parts fail then the slicing will be redone with slower print speeds until each part prints and is functional.

**Success criteria:** All parts are manufactured without defects and can be assembled into a sub-scale version of the rover.

**Justification:** The rover must be manufactured for the competition thus this is a necessary step to demonstrate that it can be manufactured using the methods thought to be appropriate. Should a part not be able to be manufactured using the current design then the part will either need to be redesigned or the current manufacturing style will need to be changed.

**Status:** Successfully completed. When manufacturing the wheels and the rover sheets the OMAX 2626 waterjet cutter cut out both without issue and without using tabs. The 3D-printed parts were higher quality when printed on the Ultimaker 2+ using the default settings and 30 percent infill.

---

### P.M.2 Terrain Testing

**Test Objective:** See if the rover is capable of traversing the rugged terrain of the launch area.

**Verification Method:** Demonstration

**Testing Plan:** The rover will be placed on the ground in front of a patch of each terrain. The terrains emulated will be grassy field, a dirt path, dirt mixed with grass tufts, mud, small slopes of an incline up to 20 degrees, and small holes in the ground less than half the size of the rover. Each terrain will be tested three times in a variety of different but similar areas appropriate to each terrain type. The terrains tested will be verified by members who have been to Huntsville previously as conditions similar to those at Huntsville. During each

trial, mark the start position of the rover. Activate the rover so that it is movement mode, then measure the distance traveled by the rover when it stops. Connect the rover to a serial monitor and record the measured distance.

**Success criteria:** The rover is able to independently travel at least 10ft in each trial. The rover's measured distance traveled does not deviate from the actual distance by more than 50 percent.

**Justification:** The rover will need to move 5ft away from the launch vehicle on unknown terrain, thus it must be able to travel across a variety of terrains to be certain that the rover will operate at the launch site. The test is primarily targeted toward the wheels, as they will be the deciding factor in if the rover has enough traction to traverse the terrain.

**Status:** Partially completed. Rover was successfully able to traverse over flat ground and uniform slopes but has not yet been tested on more rugged terrain.

---

### P.M.3 Electronics Resilience Testing

**Test objective:** To verify that electronics can survive the vibrations and other forces from launch, recovery, and deployment.

**Verification Method:** Observation

**Testing Plan:** First the rover will be fully assembled with electronics integrated. Then electronics will undergo a full test, verifying that each electronic part works before launch. Then the rover will be loaded into the launch vehicle. A full payload sequence will be run on the group prior to launching the rocket. Upon recovery of the rover a full electronics test will be run and all electronics parts will be inspected for possible damage.

**Success criteria:** The test is a success if the electronics of the rover work as intended and the rover is fully operational after a launch.

**Justification:** This test is necessary because if the electronics do not operate due to damage from the forces from launch and deployment then the rover will not be able to complete its objective. If not all of the rover's electronics are operational after the test then additional shielding will be added to dampen the forces of deployment and ejection on the rover.

**Status:** Successfully completed. Movement board successfully completed all nominal test cases.

---

#### 7.1.2 Deployment

All 4 tests for deployment (ignition, remote triggering, separation, and rover shielding) were conducted concurrently prior to full-scale launch. The rocket was placed horizontally on the ground, and the black powder inside was remotely triggered in a ground test. Not only was the ignition and remote detonation successful, but the separation distance was over the desired 15 inches. Finally, the nomex blanket placed in between the rover and the charge was able to protect the rover with great effectiveness, leaving only slight ash and char marks on the wheel after the test, and no structural or functional damage was observed.

#### 7.1.3 Ejection

P.E.1: Frame Load-bearing Capacity

P.E.2: Lift Actuation Force  
P.E.3: Linkage Lateral Flex  
P.E.4: Linkage Vertical Flex  
P.E.5: Lift Range of Motion

#### 7.1.4 Movement

P.M.1: Manufacturing Testing  
P.M.2: Terrain Testing  
P.M.3: Electronics Resilience Testing  
P.M.4: Hill Climb Test  
P.M.5: Rover Actuation Test  
P.M.6: Distance Measurement Test  
P.M.7: Obstacle Avoidance Test

#### 7.1.5 Solar

P.S.1: Solar Cell Integration  
P.S.2: Servo Integration  
P.S.3: Panel Deployment

## 7.2 Requirements Compliance

### 7.2.1 NSL Handbook 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).

Verification Method: Demonstration

Plan: We will continue the practice followed for the past two years of using our mentor for design and manufacturing guidance alone, as well as motor and black powder handling.

---

**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.

Verification Method: Demonstration

Plan: Thorough project documentation has been kept on the STAR Google Drive folder.

---

**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.

Verification Method: Demonstration  
Plan: All FN's were identified by the PDR.

---

**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.

Verification Method: Demonstration

Plan: All team members attending launch were identified by email in the specified way. Our mentor, David, will be attending.

---

**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.

Verification Method: Demonstration

Plan: 1716 students have been reached through outreach events.

---

**1.6:** The team will develop and host a Web site for project documentation.

Verification Method: Demonstration

Plan: The team website is [stars.berkeley.edu](http://stars.berkeley.edu) and project documentation can be found under the "SL Doc" tab.

---

**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.

Verification Method: Demonstration

Plan: The team Historian and the Reports Team Lead are responsible for ensuring this is done.

---

**1.8:** All deliverables must be in PDF format

Verification Method: Demonstration

Plan: The team Historian and the Reports Team Lead are responsible for ensuring this is done.

---

**1.9:** In every report, teams will provide a table of contents including major sections and their respective sub-sections.

Verification Method: Demonstration

Plan: The Reports Team Lead is responsible for ensuring this is done. L<sup>A</sup>T<sub>E</sub>X has functionality that automatically creates and updates a table of contents.

---

**1.10:** In every report, the team will include the page number at the bottom of

the page.

Verification Method: Demonstration

Plan: The Reports Team Lead is responsible for ensuring this is done. L<sup>A</sup>T<sub>E</sub>X has functionality that automatically creates page numbers.

---

**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.

Verification Method: Demonstration

Plan: The President and Vice-President are responsible for ensuring this is done. Campus rooms with much of this equipment are able to be reserved in advance.

---

**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 8 ft. 1010 rails, and 8 and 12 ft. 1515 rails available for use.

Verification Method: Demonstration

Plan: The launch vehicle has been designed to use a 1515 rail. The pre-launch checklist includes a fit check on the rail buttons to ensure there will be no launch rail issues.

---

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

Subpart B-Technical Standards (<http://www.section508.gov>):

- **1194.21 Software applications and operating systems.**
  
- **1194.22 Web-based intranet and Internet information and applications.**

Verification Method: Demonstration

Plan: The President and team Safety Officer are responsible for ensuring this requirement continues to be met.

---

**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.

Verification Method: Demonstration

Plan: Our mentor has been identified in section 1.1 of this report, has sufficient experience/certification, and will travel with the team to launch week.

---

**2.1: The vehicle will deliver the payload to an apogee altitude of 5,280 feet above ground level (AGL).**

Verification Method: Demonstration

Plan: A full-scale test flight in conditions with little wind recorded an apogee of 5360ft. From this figure, there is confidence that the apogee of the rocket will be near 5280ft over the expected range of wind conditions. Simulations using OpenRocket have provided predicted apogee of near the goal of 5280 as well.

---

**2.2: The vehicle will carry one commercially available, barometric altimeter for recording the official altitude used in determining the altitude award winner. Teams will receive the maximum number of altitude points (5,280) if the official scoring altimeter reads a value of exactly 5280 feet AGL. The team will lose one point for every foot above or below the required altitude.**

Verification Method: Inspection

Plan: The design has been made to meet this requirement.

---

**2.3: Each altimeter will be armed by a dedicated arming switch that is accessible from the exterior of the rocket airframe when the rocket is in the launch configuration on the launch pad.**

Verification Method: Inspection

Plan: The design has been made to meet this requirement.

---

**2.4: Each altimeter will have a dedicated power supply.**

Verification Method: Inspection

Plan: The design has been made to meet this requirement.

---

**2.5: Each arming switch will be capable of being locked in the ON position for launch (i.e. cannot be disarmed due to flight forces).**

Verification Method: Inspection.

Plan: The design has been made to meet this requirement. The purchased arming switched can be locked in the ON position.

---

**2.6: The launch vehicle will be designed to be recoverable and reusable. Reusable is defined as being able to launch again on the same day without repairs or modifications.**

Verification Method: Demonstration

Plan: Components and materials were selected that were either previously flight proven, or made to be strong enough to withstand the forces experienced during flight and landing.

---

**2.7: The launch vehicle will have a maximum of four (4) independent sections.**  
An independent section is defined as a section that is either tethered to the main vehicle or is recovered separately from the main vehicle using its own parachute.

Verification Method: Inspection

Plan: The design has been made to meet this requirement. There are only 2 independent sections.

---

**2.8: The launch vehicle will be limited to a single stage.**

Verification Method: Inspection

Plan: The design has been made to meet this requirement. The vehicle has single stage propulsion.

---

**2.9: The launch vehicle will be capable of being prepared for flight at the launch site within 3 hours of the time the Federal Aviation Administration flight waiver opens.**

Verification Method: Demonstration

Plan: The launch vehicle was able to be prepared in under 3 hours at our initial full-scale test flight.

---

**2.10: The launch vehicle will 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 components.**

Verification Method: Demonstration

Plan: Test R.3 has been designed to demonstrate compliance.

---

**2.11: The launch vehicle will be capable of being launched by a standard 12-volt direct current firing system. The firing system will be provided by the NASA-designated Range Services Provider.**

Verification Method: Inspection

Plan: The design has been made to meet this requirement. The Cesaroni L730 motor is ignitable in this way and has been sufficiently flight proven.

---

**2.12: The launch vehicle will require no external circuitry or special ground support equipment to initiate launch (other than what is provided by Range Services).**

Verification Method: Inspection

Plan: The design has been made to meet this requirement. The Cesaroni L730 motor requires only equipment typically used by Range Services.

---

**2.13: The launch vehicle will use a commercially available solid motor propulsion system using ammonium perchlorate composite propellant (APCP) which is approved and certified by the National Association of Rocketry (NAR), Tripoli**

Rocketry Association (TRA), and/or the Canadian Association of Rocketry (CAR).

2.13.1. Final motor choices must be made by the Critical Design Review (CDR).

2.13.2. Any motor changes after CDR must be approved by the NASA Range Safety Officer (RSO), and will only be approved if the change is for the sole purpose of increasing the safety margin.

Verification Method: Inspection

Plan: The Cesaroni L730 motor meets these requirements and we understand the restrictions place on further changing the motor choice.

---

**2.14:** Pressure vessels on the vehicle will be approved by the RSO and will meet the following criteria:

2.14.1. The minimum factor of safety (Burst or Ultimate pressure versus Max Expected Operating Pressure) will be 4:1 with supporting design documentation included in all milestone reviews.

2.14.2. Each pressure vessel will include a pressure relief valve that sees the full pressure of the valve that is capable of withstanding the maximum pressure and flow rate of the tank.

2.14.3. Full pedigree of the tank will be described, including the application for which the tank was designed, and the history of the tank, including the number of pressure cycles put on the tank, by whom, and when.

Verification Method: N/A

Plan: There are no pressure vessels on the vehicle.

---

**2.15:** The total impulse provided by a College and/or University launch vehicle will not exceed 5,120 Newton-seconds (L-class).

Verification Method: Inspection

Plan: The design has been made to meet this requirement. The Cesaroni L730 motor has a total impulse of 2764 N-s.

---

**2.16:** The launch vehicle will have a minimum static stability margin of 2.0 at the point of rail exit. Rail exit is defined at the point where the forward rail button loses contact with the rail.

Verification Method: Analysis

Plan: The center of gravity and center of pressure were found using OpenRocket and the stability was calculated to be 2.57 calibers, well above the required margin of 2.0.

---

**2.17:** The launch vehicle will accelerate to a minimum velocity of 52 fps at rail exit.

Verification Method: Analysis

Plan: OpenRocket simulations provided a rail exit velocity of 80.2 ft/s.

---

**2.18:** All teams will successfully launch and recover a sub-scale model of their rocket prior to CDR. sub-scales are not required to be high power rockets.

2.18.1. The sub-scale model should resemble and perform as similarly as possible

to the full-scale model, however, the full-scale will not be used as the sub-scale model.

**2.18.2.** The sub-scale model will carry an altimeter capable of reporting the models apogee altitude.

Verification Method: Demonstration

Plan: The sub-scale model was flown December 9th and met these requirements. It was scaled down to a 2/3 size as near as possible given tubing availability and parachute sizing and included a mock payload to mimic flight as closely as possible.

---

**2.19:** All teams will successfully launch and recover their full-scale rocket prior to FRR in its final flight configuration. The rocket flown at FRR must be the same rocket to be flown on launch day. The purpose of the full-scale demonstration flight is to demonstrate the launch vehicles stability, structural integrity, recovery systems, and the teams ability to prepare the launch vehicle for flight. A successful flight is defined as a launch in which all hardware is functioning properly (i.e. drogue chute at apogee, main chute at a lower altitude, functioning tracking devices, etc.). The following criteria must be met during the full-scale demonstration flight: (excluded for brevity: see handbook)

Verification Method: Demonstration

Plan: The full-scale rocket is schedule for a test launch on February 3rd. It will be flown exactly as we intend to fly it in Huntsville, with the exception of anticipated payload modifications that will have insignificant effects on flight.

---

**2.20:** Any structural protuberance on the rocket will be located aft of the burnout center of gravity.

Verification Method: Inspection

Plan: The design has been made to meet this requirement. The only structural protuberances are the fins, which are aft of burnout center of gravity.

---

## **2.21: Vehicle Prohibitions**

Verification Method: Inspection

Plan: The design has been made to meet these requirements.

---

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## **7.3 NASA Requirements**

**3.1 :** The launch vehicle will stage the deployment of its recovery devices, where a drogue parachute is deployed at apogee and a main parachute is deployed at a lower altitude. Tumble or streamer recovery from apogee to main parachute deployment is also permissible, provided that kinetic energy during drogue-stage descent is reasonable, as deemed by the RSO.

Verification Method: Inspection of recovery subsystem design

Plan: The launch vehicle has a duel deployment recovery system in which a drogue chute is deployed at apogee and a main chute is deployed at 600 ft .

---

**3.2 : Each team must perform a successful ground ejection test for both the drogue and main parachutes. This must be done prior to the initial subscale and full-scale launches.**

Verification method: Demonstration before launch

Plan: A black powder charge will be placed at the point of separation within the airframe. The charge will then be detonated manually to ensure the airframe can successfully separate. The subscale launch vehicle has already successfully completed a ground ejection test.

---

**3.3 : At landing, each independent sections of the launch vehicle will have a maximum kinetic energy of 75 ft-lbf.**

Verification method: Kinetic energy calculations

Plan: Using a custom-built kinetic energy program written in Matlab along with the weights of the various launch vehicle sections and desired kinetic energies, the necessary parachute sizes can be calculated for each section to obtain a kinetic energy below 75 ft-lbf.

---

**3.4 : The recovery system electrical circuits will be completely independent of any payload electrical circuits.**

Verification method: Inspection of design

Plan: The avionics bay containing the recovery electrical circuits is completely independent of the payload electrical circuits, as they are located in separate sections of the airframe, separated by several bulkheads.

---

**3.5 : All recovery electronics will be powered by commercially available batteries.**

Verification method: Inspection of design

Plan: 9V Duracell batteries will power all of the recovery electrical systems.

---

**3.6 : The recovery system will contain redundant, commercially available altimeters. The term altimeters includes both simple altimeters and more sophisticated flight computers.**

Verification method: Inspection of design

Plan: Two PerfectFlite StratologgerCF altimeters are housed in the avionics bay to provide redundancy to the deployment system. They are both fully connected to the recovery system and are powered by their own 9V battery.

---

**3.7 : Motor ejection is not a permissible form of primary or secondary deployment.**

Verification method: Inspection of design

Plan: A dual deployment recovery system triggered by a redundant system of altimeters is used instead of a motor ejection system.

---

**3.8 : Removable shear pins will be used for both the main parachute compartment and the drogue parachute compartment.**

Verification method: Inspection of design

Plan: Both the drogue and main chutes are located in the same compartment. The parachute section of airframe will be connected to the payload section of the airframe via shear pins.

---

**3.9 : Recovery area will be limited to a 2500 ft. radius from the launch pads.**

Verification method: Drift calculations

Plan: The total flight time can be calculated using the weights of the launch vehicle sections, the sizes and drag coefficients of the parachutes, and the parachute deployment altitude. This time can be multiplied by the wind speed to estimate maximum drift distance.

---

**3.10 : An electronic tracking device will be installed in the launch vehicle and will transmit the position of the tethered vehicle or any independent section to a ground receiver.**

Verification method: Inspection of design

Plan: The GPS module will be placed in the nose cone of the launch vehicle.

- **3.10.1 : Any launch vehicle section, or payload component, which lands untethered to the launch vehicle, will also carry an active electronic tracking device.**

Verification method: Inspection of design

Plan: Each independent section of the launch vehicle has a GPS module in it.

- **3.10.2 : The electronic tracking device will be fully functional during the official flight on launch day.**

Verification method: Inspection on launchpad

Plan: Each GPS module will be inspected before the launch vehicle is launched to ensure they are functional.

---

**3.11 : The recovery system electronics will not be adversely affected by any other on-board electronic devices during flight (from launch until landing).**

Verification method: Inspection of design

Plan: The recovery system electronics are located in the avionics bay, a separate section of the launch vehicle, away from the payload electronics.

- **3.11.1 : The recovery system altimeters will be physically located in a separate compartment within the vehicle from any other radio frequency transmitting device and/or magnetic wave producing device.**

Verification method: Inspection of design

Plan: The recovery system electronics are located in the avionics bay, a separate section of the launch vehicle, away from the payload electronics.

- **3.11.2 : The recovery system electronics will be shielded from all onboard transmitting devices, to avoid inadvertent excitation of the recovery system electronics.**

Verification method: Inspection of design

Plan: The recovery system electronics are located in the avionics bay, a separate section of the launch vehicle, away from the payload electronics.

- **3.11.3 : The recovery system electronics will be shielded from all onboard devices which may generate magnetic waves (such as generators, solenoid valves, and Tesla coils) to avoid inadvertent excitation of the recovery system.**

Verification method: Inspection of design

Plan: The recovery system electronics are located in the avionics bay, a separate section of the launch vehicle, away from the payload electronics.

- **3.11.4 : The recovery system electronics will be shielded from any other onboard devices which may adversely affect the proper operation of the recovery system electronics.**

Verification method: Inspection of design

Plan: The recovery system electronics are located in the avionics bay, a separate section of the launch vehicle, away from the any other electronics.

---

#### **4.5 : Deployable Rover.**

Verification method: N/A

Plan: This requirement is covered in great detail by the Team Derived Requirements (see the following section).

---

#### **5.1 : Each team will use a launch and safety checklist. The final checklists will be included in the FRR report and used during the Launch Readiness Review (LRR) and any launch day operations.**

Verification method: Demonstration

Plan: Checklists were created prior to, and used for, the sub-scale launch. Any necessary additions were noted for the full-scale checklists and are included in this report.

---

#### **5.2 : Each team must identify a student safety officer who will be responsible for all items in section 5.3.**

Verification method: N/A

Plan: Our student safety officer, responsible for all items in section 5.3, is Grant Posner.

---

#### **5.3 : The role and responsibilities of each safety officer will include, but not limited to: (excluded for brevity, see Student Launch Handbook)**

Verification method: Demonstration

Plan: Per our club's constitution, safety officer is a yearly elected position whose duties include those listed by this requirement. There is also a safety team to assist in these duties.

---

**5.4 :** During test flights, teams will abide by the rules and guidance of the local rocketry clubs RSO. The allowance of certain vehicle configurations and/or payloads at the NASA Student Launch Initiative does not give explicit or implicit authority for teams to fly those certain vehicle configurations and/or payloads at other club launches. Teams should communicate their intentions to the local clubs President or Prefect and RSO before attending any NAR or TRA launch.

Verification method: Demonstration

Plan: Our team mentor is the president of the Livermore Unit of NAR, which is where we typically perform our test flights. The team always checks with him before flying any vehicles or payloads

---

**5.5 : Teams will abide by all rules set forth by the FAA.**

Verification method: N/A

Plan: The safety officer has explained the rules to team members and will ensure this requirement is complied with.

---

### 7.3.1 Team Requirement Derivation

**A.1:** While there is no Handbook lower limit for apogee, the team imposed limit is 4800ft AGL.

**A.2:** A motor with less thrust than the Aerotech L1150 (the motor the team used last year) shall be used. The team recognizes that much of the challenge of rocketry is sending a payload to a desired height/location for as little power as possible. This requirement was imposed to challenge the team to reduce mass and drag of the launch vehicle. **P.1.1** The deployment subsystem should not initiate until on the ground after being given the command by the main flight computer.

**P.1.2** The deployment subsystem should not cause serious personal safety concerns.

**P.1.3** The deployment subsystem should not damage the rover or ejection subsystem.

**P.1.4** The black powder charge is successfully triggered.

**P.2.1** In order to maximize the ability to eject the rover successfully in a variety of unpredictable terrain, the team has decided that the payload ejection scissor lift must be able to successfully eject the rover on a horizontal slope of up to 20 degrees.

**P.2.2** In order to maximize testing efficiency and reduce operating costs, the team has decided that the payload ejection subsystem must be easily reusable.

**P.2.3** In order to ensure successful rover deployment and the correct sequencing of events, the team has decided that processes of the payload ejection subsystem must only occur after complete and successful separation of the transition and payload airframe sections.

**P.2.4** In order to protect rover functionality and integrity, the team has decided that the payload ejection subsystem shall not in any way damage the rover.

**P.2.5** In order to comply with overall launch vehicle stability requirements and payload weight limits, the team has decided that the payload ejection subsystem must have a maximum weight of 1lb.

**P.2.6** As the scissor lift rack and pinion drive mechanism is the most critical and vulnerable element of the payload ejection subsystem, the team has decided that the drive mechanism

must continue to function under severe conditions such as when encountering abnormal resistance to scissor lift extension.

**P.3.1** In order to traverse rough terrain, the team has decided that a solid toothed wheel made out of 2lb. crosslinked polyethylene must optimize weight, cost, and durability.

**P.3.2** In order to maximize testing efficiency and reduce operating costs, the team has decided that the rover materials must be resilient to launch and terrain conditions.

**P.3.3** In order to counteract the torque from the motors, the team has decided that skids must deploy after ejection of the rover.

**P.3.4** In order avoid collisions during navigation, the team has decided that ultrasonic sensors must provide accurate measurements and detection of obstacles in the direct path of the rover.

**P.4.1** 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.

**P.4.2** 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.

**P.4.3** The system should measure the extent of panel deployment with minimal additional hardware and power.

**P.4.4** The solar panel system should work under a realistic range of weather and lighting conditions, such as nighttime, sunny, overcast.

**P.4.5** The solar panel system should communicate with the rover's main computer.

**P.4.6** The system will require multiple measurements in order to confirm solar panel deployment status.

**P.4.7** The solar panel system should fully fit inside the launch vehicle before solar panel deployment.

**P.4.8** The solar panel system should be robust such that it survives launch, flight, touchdown, rover deployment, and rover movement.

**P.4.9** The solar panel system should be reusable and able to be folded back into place, preferably electromechanically. No parts should need to be replaced.

**P.4.10** The solar panel system should not deploy nor should the panels unfold unless intentional.

**R.1:** All scenarios of parachute deployment must result in all rocket components landing under 75ft-lbf. This is done so that the rocket lands safely even if all separations and payload parachute deployments do not take place.

**R.2:** Parachutes are not damaged by black powder charges - there are no holes or burn marks.

**R.3:** Wires to tender descenders are broken upon successful deployment of main parachute.

**R.4:** The vehicle shall use a removable door on avionics bay that allows for easy access and adjustment of altimeters on the launch pad if necessary.

**G1:** There will be a sub-report document for all sections within a report. This will be done to minimize clutter on a master report document that all members have access to.

**G.2:** All reports have consistent style, formatting, and elements. Failure to do this will result in a less professional and more difficult to read report. With many authors of any given report, it can be challenging to prevent contrasting styles without conventions set in

place that all will follow, and sufficient time to edit.

### 7.3.2 Team Requirement Compliance

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#### A.1 The launch vehicle shall reach an apogee of above 4800ft AGL.

Verification Method: Analysis

Plan: OpenRocket simulations and Matlab calculations have been performed to ensure the vehicle will exceed 4800ft in any anticipated weather condition.

---

#### A.2: A motor with less thrust than an Aerotech L1150 shall be used.

Verification Method: Inspection

Plan: A Cesaroni L730 is being used and meets this requirement.

---

#### P.1.1 The deployment subsystem should not go off prematurely.

Verification Method: Demonstration

Plan: To address this requirement, STAR 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.

---

#### P.1.2 The deployment subsystem will not harm people.

Verification Method: Design Modification

Plan: To address this requirement, the method of deployment was changed to a black powder charged system from the previous pneumatic piston system to minimize the threat that the pressurized launch vehicle could pose on bystanders, especially considering that some of the original pneumatic piston system parts, such as the solenoid, were not rated at a high enough psi in comparison to the air cartridges, which could potentially lead to a very dangerous and harmful explosion.

---

#### P.1.3 The deployment subsystem will not harm the rover or ejection subsystem.

Verification Method: Design Modification

Plan: To address this requirement, the deployment subsystem features a protective Nomex blanket in between the transition and payload compartments of the airframe to seal off the rover and ejection subsystem from hot exhaust fumes and a loose bulkhead that pushes against wooden posts in the payload section that are glued to the airframe and go in between the gears in the wheels when the black powder is ignited to direct some of the force of the black powder from the rover to the airframe.

---

#### P.1.4 The black powder charge is successfully triggered.

Verification Method: Demonstration

Plan: To address this requirement, the black powder charge will be connected to the deployment computer with low gauge stranded wire and triggered once touchdown is confirmed through 2 point verification from ejection and deployment computers.

---

**P.2.1 The payload ejection scissor lift must be able to successfully eject the rover on a horizontal slope of up to 20 degrees.**

Verification Method: Demonstration

Plan: The payload ejection subsystem, mounted inside the vehicles nosecone and payload tube sections, will be placed onto an artificial slope constructed to be 20 degrees from the horizontal with the nosecone facing down. An artificial mass that is two times the rovers weight or greater will be placed inside the payload tube at the exact position of where the rover would be. The payload ejection subsystem will then be commanded to perform the ejection sequence and eject the mass up the sloped payload tube section and out of the opening. A successful ejection is indicated by the weighted mass fully clearing the opening of the payload tube section. If the weighted mass is unable to be ejected from the tube, it will be removed, the ejection subsystem will be inspected, and adjustments will be made. After ten consecutive and successful ejections, the verification will be considered complete.

---

**P.2.2 The payload ejection subsystem must be easily reusable.**

Verification Method: Demonstration.

Plan: The condition of easily reusable is hereby defined as the ejection subsystem being able to reset itself via a radio command to a state where it can successfully run through the full ejection sequence again, without outside intervention. To verify this requirement in a worst-case scenario, the ejection subsystem, mounted inside the airframe nosecone and payload tube sections, will be placed on the same artificial slope used in the slope test. The rover will then be positioned into the payload tube in the launch-ready position. The full ejection sequence will then commence via a radio trigger, and after the full extension of the scissor lift another radio trigger will command the ejection subsystem to reset compressing the scissor lift. At this point, if the rover successfully cleared the opening, it will then be placed back into the payload section and the entire sequence will run again. This cycle will be repeated ten times. During these cycles, if the rover fails to clear the opening or the scissor lift fails to fully compress, then the ejection subsystem will be removed, inspected, and adjusted. After ten successful cycles, the requirement is verified.

---

**P.2.3 The payload ejection subsystem must only occur after complete and successful separation of the transition and payload airframe sections.**

Verification Method: Demonstration and Inspection

Plan: The proper sequencing and activation of the ejection subsystem will be verified in a combined test of both the ejection and deployment subsystems. The entire payload system, consisting of the deployment and ejection subsystems along with the rover, will be assembled and mounted inside the vehicle airframe. Via a radio trigger, the deployment subsystem sequence commences and separate the transition section from the payload tube section. At this point, the separation of a breakaway cable connecting from the payload tube section to the transition section will signal a completed separation of the two sections. Upon confirmation of the signal, the ejection subsystem will be signaled to commence, and eject the rover. If during this test, the separation signal is not received, or received at an incorrect time, then the test sequence will be stopped. Critical elements of both the deployment and ejection subsystems will be inspected, particularly both electrical boards, the radio antenna, batter-

ies, and the breakaway wire connection. This testing sequence will be repeated 5 times, and if all test cycles succeed then the requirement will be considered verified. Furthermore, the inspection of the aforementioned critical elements of the payload system will be integrated into checklists to ensure successful sequencing in each launch.

---

#### **P.2.4 The payload ejection subsystem shall not in any way damage the rover.**

Verification Method: Inspection

Plan: This requirement will be verified via the same test detailed in P.2.2. After each test cycle of the ejection subsystem reusability test, critical elements of the rover will be inspected in detail, paying special attention to the motors, electronics, solar panels, skids, ultrasonic sensors, wheels, and structural components. Subsequently, the rover will be commanded to travel a distance of 5ft. After inspection and a successful test of rover movement, it will be placed back into the payload section, and the test procedures detailed in P.2.2 will continue. After ten successful tests of the ejection subsystem and rover movement, verification will be considered complete.

---

#### **P.2.5 The weight of the payload ejection subsystem must be equal to or below 1lb or 450g.**

Verification Method: Demonstration

Plan: Each individual component of the ejection subsystem will be placed onto a scale that is accurate to at least a hundredth of a gram. The weights of each individual component will then be tabulated into a bill of materials, and the final weight of the ejection subsystem will be computed and compared against the weight limit. If the calculated weight exceeds the limits, then one of two actions will take place: a) non-critical elements of the ejection subsystem will be modified to reduce the overall weight, or; b) if no element in the ejection subsystem can be further reduced, then the weight of elements in the remaining payload subsystems will be modified and reduced in order to increase the weight allowance of the ejection subsystem. If the pre-assembled weight test succeeds, then the verification is partially successful. After the entirety of the ejection subsystem is assembled, the full assembly will be placed onto the same scale to be weighted. This is to account for parts used in the assembly process that cannot be weighted, such as epoxy. If the weight of the full assembly exceeds that of the weight limit, then the same two remediation procedures detailed previously will be performed. If the assembled weight test is successful, then the verification will be considered complete.

---

#### **P.2.6 The payload ejection scissor lift drive mechanism must continue to function under severe conditions such as encountering abnormal resistance to scissor lift extension.**

Verification Method: Demonstration

Plan: The requirement will be verified via the same test detailed in P.2.1. In the ejection subsystem slope test, the weighted mass that is at least 2 times the weight of the rover is used in order to represent the worst-case scenario that the scissor lift mechanism encounters significant resistance. Furthermore, detailed inspections to the drive system, and specific elements such as the servo, pinion, and rack, will be made after each cycle of the slope test. If degradation is found in any of the aforementioned elements, then the test will stop and the

drive mechanism will be modified. If the slope test detailed in P.2.2 succeeds and inspections reveal no damage, then the verification of this requirement is also considered complete.

---

### **P.3.1 The wheels will allow the rover to navigate rough terrain.**

Verification Method: Demonstration

Plan: To address this requirement, in order to verify that the wheels must be able to move over rugged terrain and small obstacles the rover will be tested in a variety of environments to determine the efficacy of the wheel design by observing the rover's ability to navigate those surfaces in a timely manner.

---

### **P.3.2 The rover materials must be resilient to launch and terrain conditions.**

Verification method: Demonstration

Plan: To address this requirement, the materials and electronics of the rover will be checked for damage before and after flight to determine the durability of each part.

---

### **P.3.3 Skids must deploy after ejection of the rover.**

Verification method: Demonstration

Plan: To address this requirement, a light sensor will detect when the rover is clear of the payload section of the airframe and will trigger the deployment of the skids.

---

### **P.3.4 Measurements from an ultrasonic sensor will detect obstacles to prevent any possible collisions.**

Verification Method: Demonstration

Plan: To address this requirement, the ultrasonic sensor and the software will be tested in different light and weather conditions to determine efficacy in regular use.

---

### **P.4.1 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.**

Verification Method: Demonstration and Inspection

Plan: 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. After deployment occurs, the rover will be inspected to ensure that no part of the system lays within 5ft of any part of the airframe.

---

### **P.4.2 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.**

Verification Method: Demonstration

Plan: To address this requirement, the voltage output of the solar panels will be monitored. This output will be passed as an input to the rover computer. Thus, this ensures that the functionality of the solar panels is always monitored. The solar system will be folded via a servo which will open the rover hood. The servo will be controlled by the rover computer,

allowing for autonomous deployment once the rover is at least 5ft away from the airframe of the launch vehicle.

---

**P.4.3 The system should measure the extent of panel deployment with minimal additional hardware and power.**

Verification Method: Demonstration

Plan: 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 hinge of the hood. Any changes in hood position will correspond to a change in rod rotation angle.

---

**P.4.4 The solar panel system should work under a realistic range of weather and lighting conditions, such as nighttime, sunny, overcast.**

Verification Method: Demonstration

Plan: 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.

---

**P.4.5 The solar panel system should communicate with the rovers main computer.**

Verification Method: Demonstration

Plan: To address this requirement, the computer will communicate with the servo to deploy the hood when it has verified that the rover has traveled at least 5ft from the airframe.

---

**P.4.6 The system will require multiple measurements in order to confirm solar panel deployment status.**

Verification Method: Demonstration

Plan: To address this requirement, a potentiometer will be used on top of monitoring the servo rotation angle. These give us two independent verifications of panel deployment.

---

**P.4.7 The solar panel system should fully fit inside the launch vehicle before solar panel deployment.**

Verification Method: Inspection

Plan: To address this requirement, the components of the solar array will be recessed within the housing of the rover.

---

**P.4.8 The solar panel system should be robust such that it survives launch, flight, touchdown, rover deployment, and rover movement.**

Verification Method: Demonstration and Inspection

Plan: 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. The solar system will be inspected after every launch and subsequent panel deployment to ensure that the system does not sustain any damage.

---

**P.4.9 The solar panel system should be reusable and able to be folded back into place, preferably electromechanically. No parts should need to be replaced.**

Verification Method: Demonstration and Inspection

Plan: To address this requirement, a servo arm 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. The solar system will be inspected after every launch and subsequent panel deployment to ensure that the system does not sustain any damage and that no parts need to be replaced.

---

**P.4.10 The solar panel system should not deploy nor should the panels unfold unless intentional.**

Verification Method: Demonstration and Inspection

Plan: 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). The rover will be monitored after ejection from the airframe until the point of solar panel deployment to ensure that the panels will not unfold prematurely.

---

**R.1: All scenarios of parachute deployment must result in all rocket components landing under 75ft-lbf.**

Verification Method: Analysis

Plan: Simulating possible scenarios in OpenRocket and the resulting landing kinetic energy for each.

---

**R.2: Parachutes are not damaged by black powder charges - there are no holes or burn marks.**

Verification Method: Demonstration

Plan: Tested at full scale ground tests and full scale test flight.

---

**R.3: Wires to tender descenders are broken upon successful deployment of main parachute.**

Verification Method: Demonstration

Plan: Full scale test flight.

---

**R.4: The vehicle shall use a removable door on avionics bay.**

Verification Method: Inspection

Plan: The design meets this requirement.

---

**G1: There will be a sub-report document for all sections within a report.**

Verification Method: Demonstration

Plan: 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.

---

**G.2: All reports have consistent style, formatting, and elements.**

Verification Method: Demonstration

Plan: 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.

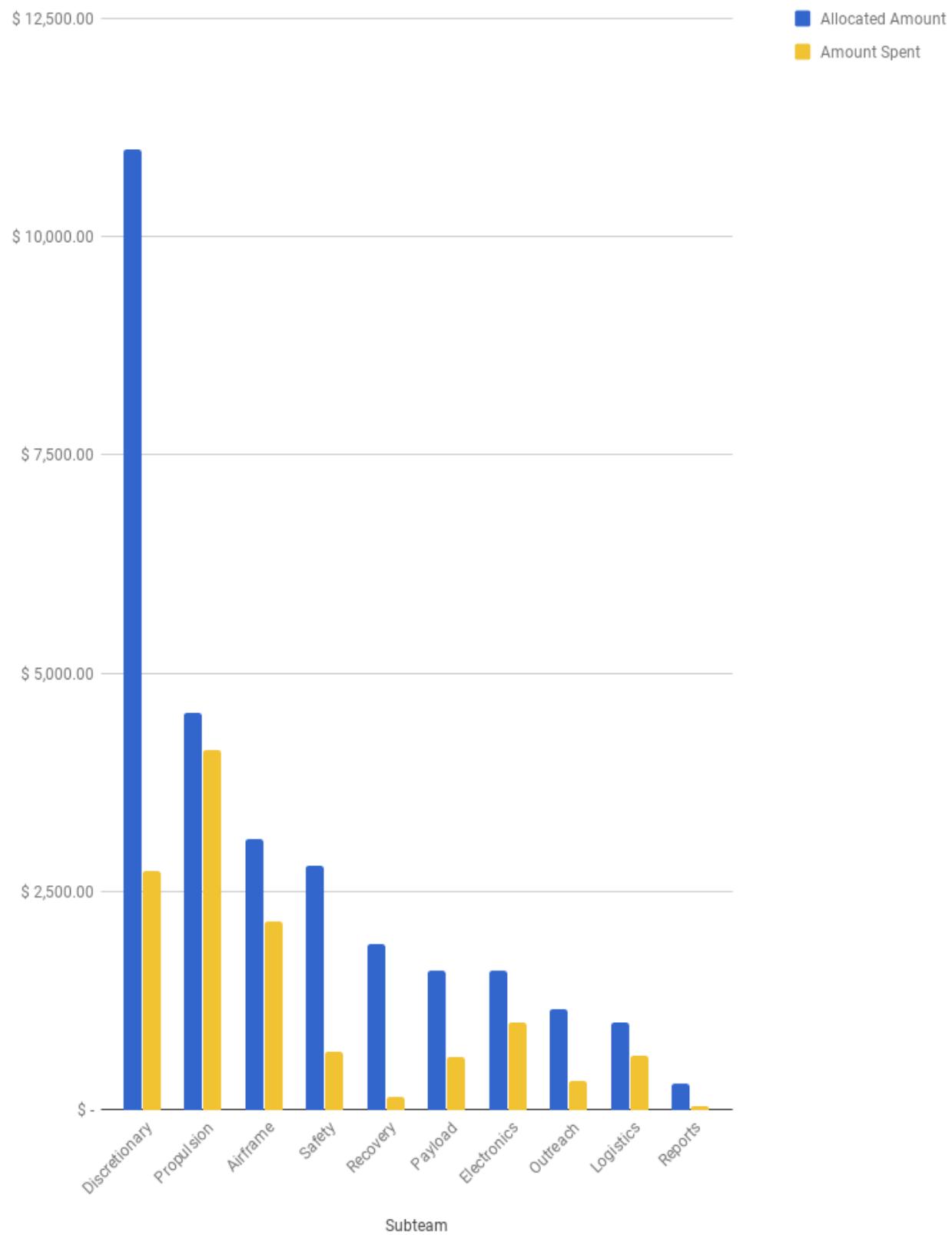
---

## 7.4 Budget

For the team's detailed budget, see the CDR at <https://stars.berkeley.edu/>.

There are no significant changes to our funding from the CDR. Of our pre-expense \$27,389.39 (including Boeing transfer), \$12,883.28 was raised 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 received a \$2,500 initial allocation from the school (pulled from campus wide student activity fees). The remaining \$12,006.11 comes from a few private sponsors including corporations like Boeing, Aragon Research, Google, and Northrop Grumman. The total breakdown for the how these funds were allocated and spent by the various sub-teams are provided by the graph on the following page. Pending funding applications mentioned in the CDR have either been successful, or remain pending.

## Allocated Amounts vs Total Spent



## Appendix A List of Project Leaders

Name	Primary Duties
Aaron Togelang	Logistics Officer
Adam Huth	Acting Vice President, 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
Ryan O'Gorman	Reports
Sean Pak	Outreach, Website Management
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.

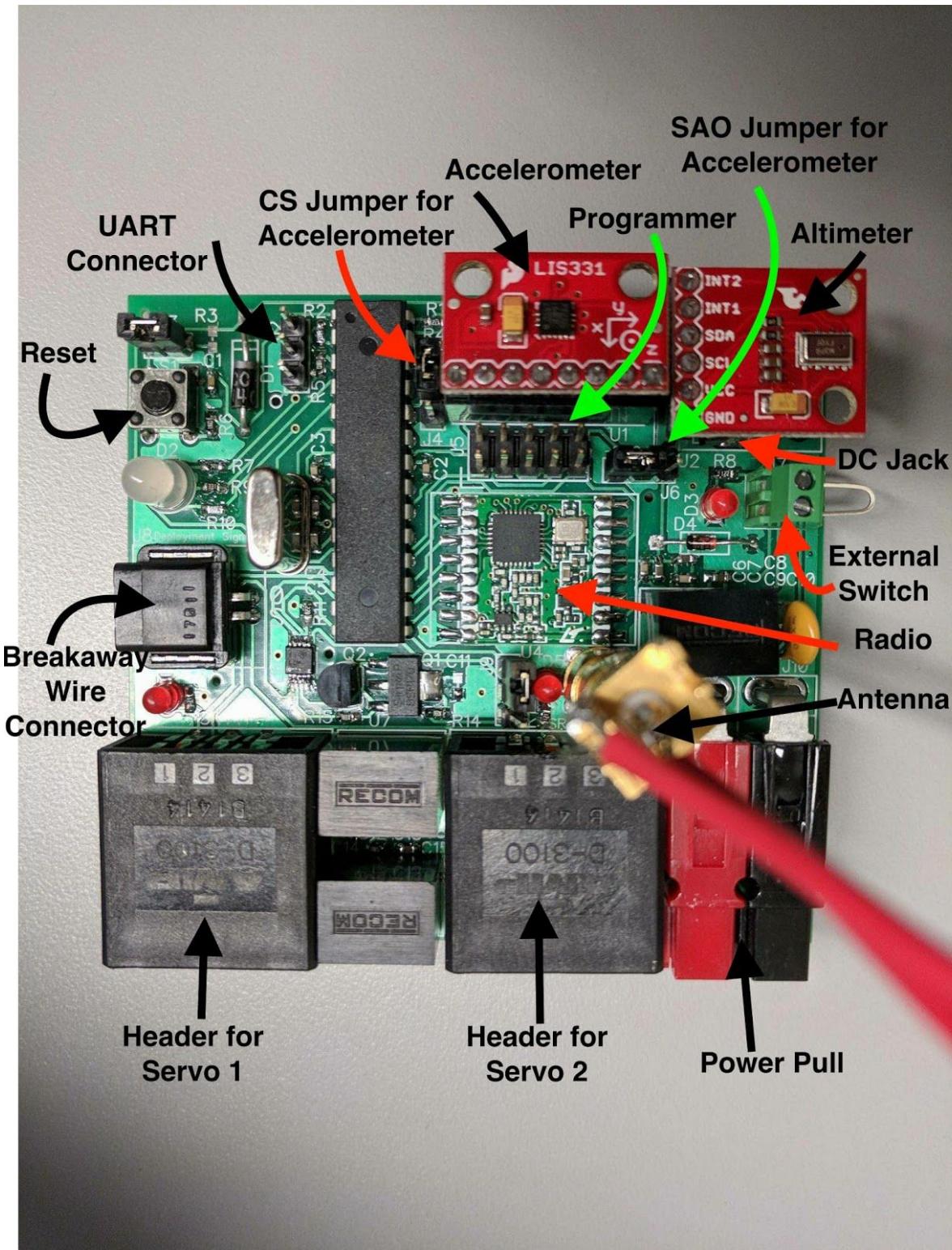
8. Size. My rocket will not contain any combination of motors that total more than 40,960 N-sec (9208 pound-seconds) of total impulse. My rocket will not weigh more at liftoff than one-third of the certified average thrust of the high power rocket motor(s) intended to be ignited at launch.
9. Flight 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.

<b>Installed Total Impulse (Newton-Seconds)</b>	<b>Equivalent High Power Motor Type</b>	<b>Minimum Diameter of Cleared Area (ft.)</b>	<b>Minimum Personnel Distance (ft.)</b>	<b>Minimum Personnel Distance (Complex Rocket<sup>1</sup>) (ft.)</b>
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 Annotated Electrical Boards**

The following pages offer diagrams of all electrical boards used in the launch vehicle and rover.

## Ejection board:



**PLEASE READ THE FOLLOWING CAREFULLY**  
**BEFORE ATTEMPTING TO RUN TESTS**

Above is the annotated ejection board. Note that the DC jack is underneath the altimeter. This usually connects to a computer. Keep the external switch shorted (as shown in the picture) in order to power the board. The board will not be powered if the U-shaped pin that is shorting the switch is removed.

Important notes about the header pins:

- The UART connector has 3-header pins but the jumper cables have 4. This is because we do not use the red power pin. The other three cables are ground (black), receiver (green), and transmitter (white), which connect to the ground, receiver, and transmitter pins respectively. From the diagram, the top pin is ground, the middle pin is the receiver, and the bottom pin is the transmitter.
- The CS jumper for accelerometer goes on 2 of a given 3 pins. Looking at the diagram, the top pin is the 3.3V pin, and the bottom pin is ground. The CS signal should be set high, which means the jumper (pictured below - the top part should be facing out of the board) should slide over the top and middle pins.
- The SAO jumper for accelerometer also goes on 2 of a given 3 pins. Looking at the diagram, the left pin is the ground pin, and the right pin is 3.3V. The SAO signal should be set low, which means the jumper (pictured below - the top part should be facing out of the board) should slide over the left and middle pins.

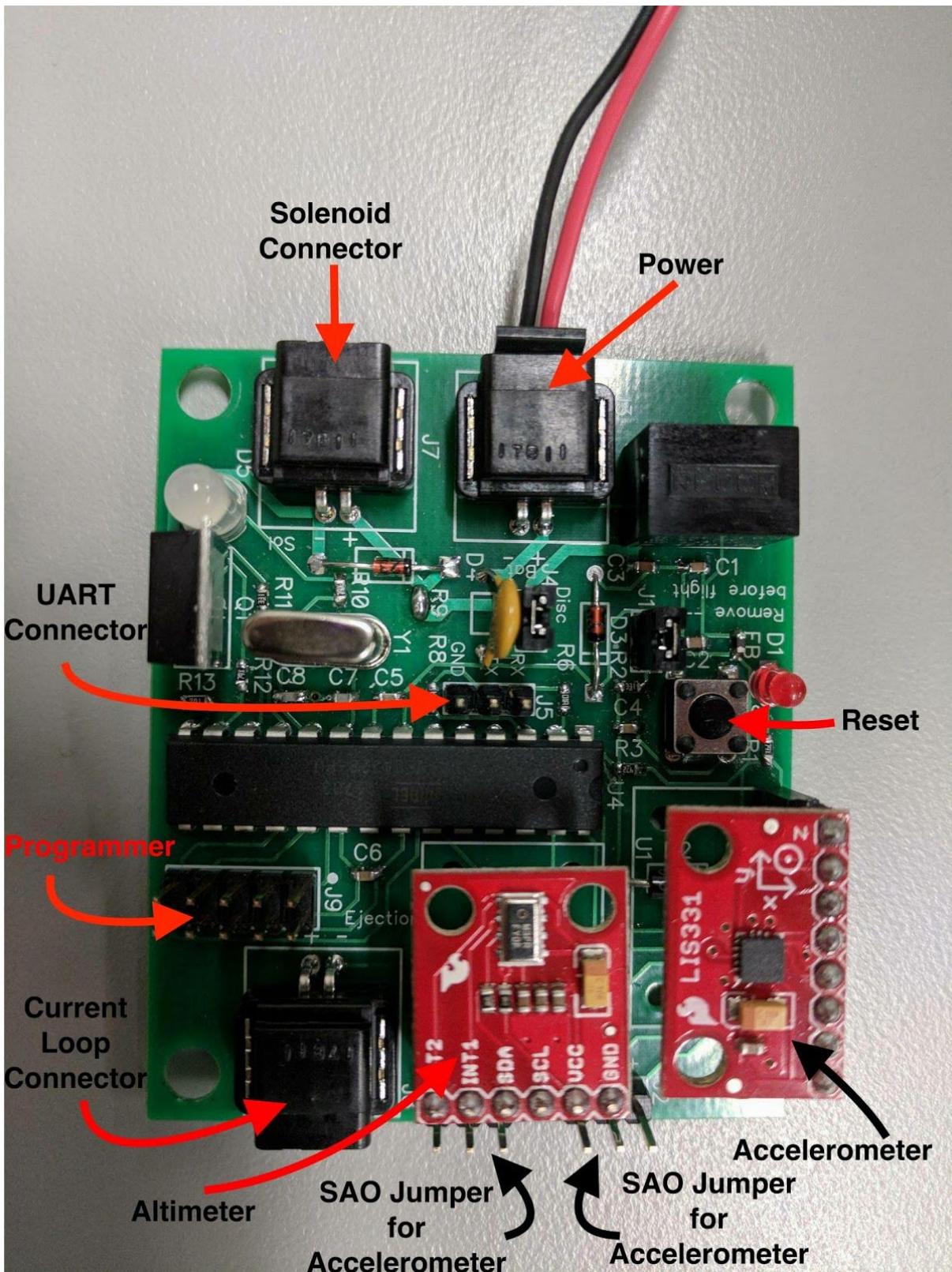


- The programmer has 10 cable holes that slide over the 10 pins.

The instructions for running the following tests should be listed in the checklist:

1. The Servo Test
1. The Accelerometer Test
2. The Altimeter Test
3. The Radio Test
4. Breakaway Wire Test

Deployment board:



## **PLEASE READ THE FOLLOWING CAREFULLY**

## **BEFORE ATTEMPTING TO RUN TESTS**

Above is the annotated deployment board. Note that the current loop connector is the signal connection between the ejection and deployment boards.

Important notes about the header pins:

- The UART connector has 3-header pins but the jumper cables have 4. This is because we do not use the red power pin. The other three cables are ground (black), transmitter (green), and receiver (white), which connect to the ground, transmitter, and receiver pins respectively. From the diagram, the left pin is ground, the middle pin is the transmitter, and the right pin is the receiver. You can double check the order of the pins as printed on the actual circuit board, next to the pins. NOTE: If you tested the ejection board, the UART cable is connected in a different order on this board. The order of the UART cable colors in this bullet is correctly listed, not a typo. Read each of the instructions carefully.
- The CS jumper for accelerometer goes on 2 of a given 3 pins. Looking at the diagram, the left pin is the ground pin, and the right pin is 3.3V. The CS signal should be set high, which means the jumper (pictured below - the top part should be facing out of the board) should slide over the right and middle pins.
- The SAO jumper for accelerometer also goes on 2 of a given 3 pins. Looking at the diagram, the left pin is the ground pin, and the right pin is 3.3V. The SAO signal should be set low, which means the jumper (pictured below - the top part should be facing out of the board) should slide over the left and middle pins.



- The programmer has 10 cable holes that slide over the 10 pins.

The instructions for running the following tests should be listed in the checklist:

1. The Ejection Signal/Breakaway Wire Test
2. The Accelerometer Test
3. The Altimeter Test
4. The Solenoid Test

# Appendix E Additional Electrical Drawings and Schematics

## E.1 Deployment

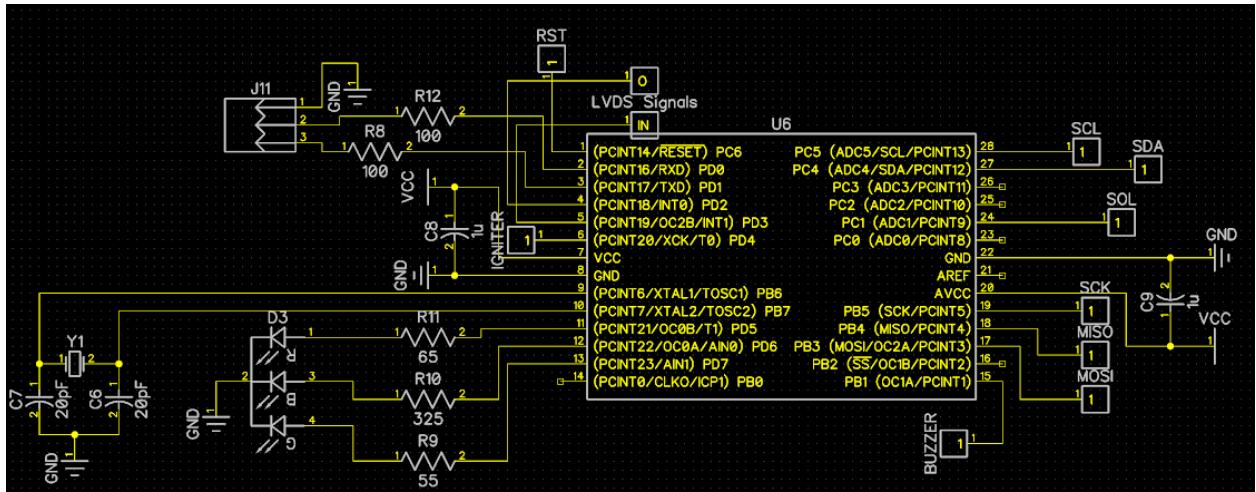


Figure 1: Deployment Processor: Atmega 328p processor with 16 MHz clock (Y1), testing LEDs, programmer, and decoupling capacitors

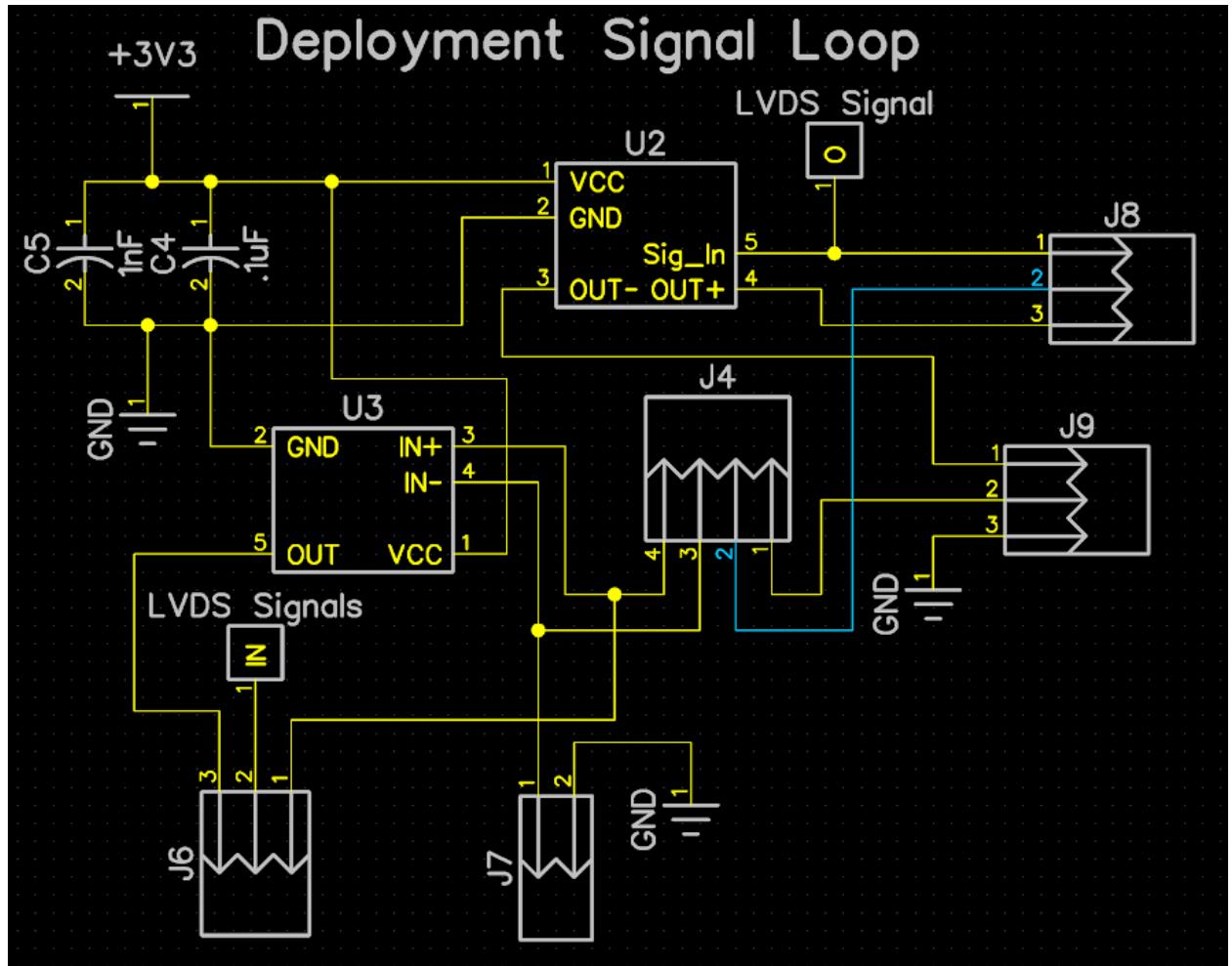


Figure 2: Deployment Signal Loop: LVDS transmitter and receiver with decoupling capacitors. LVDS Signal Net Port O is signal from Deployment board and LVDS Signals Net Port IN is signal from Ejection board.

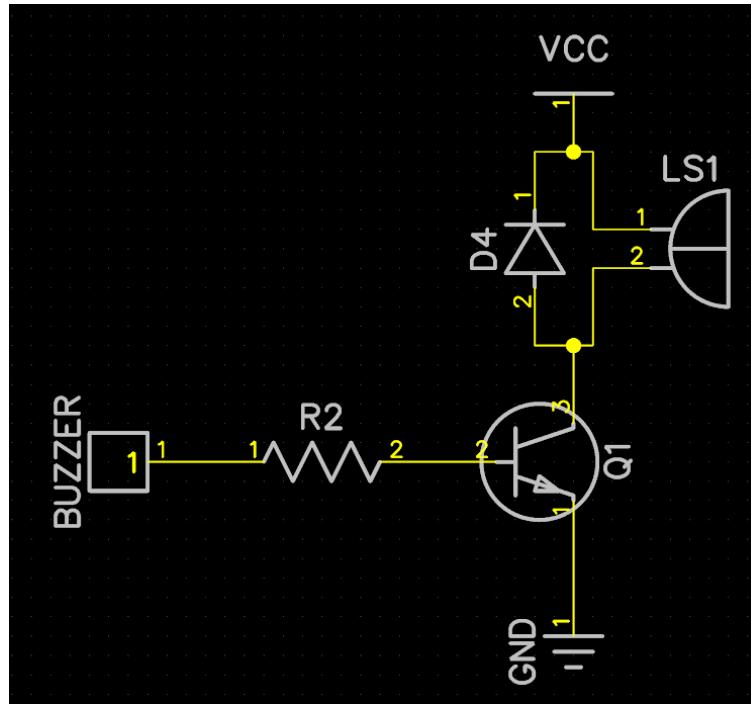


Figure 3: *Deployment Buzzer*: Net Port Buzzer is the signal from the processor to the buzzer (LS1)

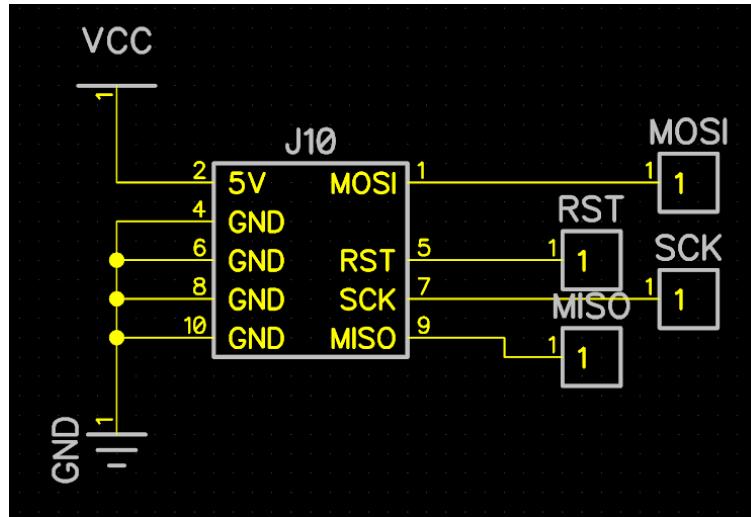


Figure 4: *Deployment Programmer*: The 10-pin header used to flash programs onto the deployment board.

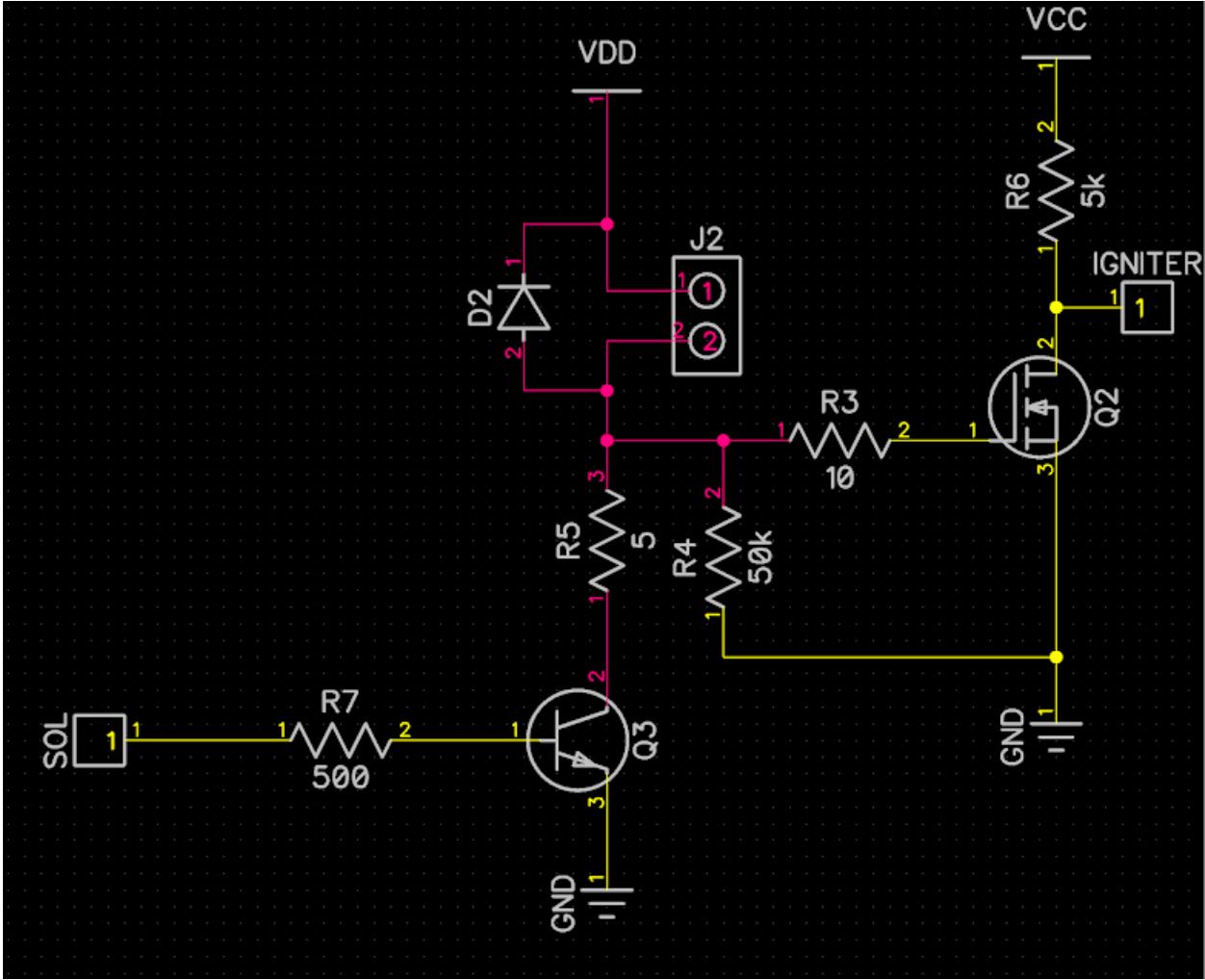


Figure 5: Deployment Black Powder:  $J_2$  is connected to black powder. Signal from Net Port SOL ignites the black powder. Before ignition, Net Port Igniter acts as a discontinuity detector.

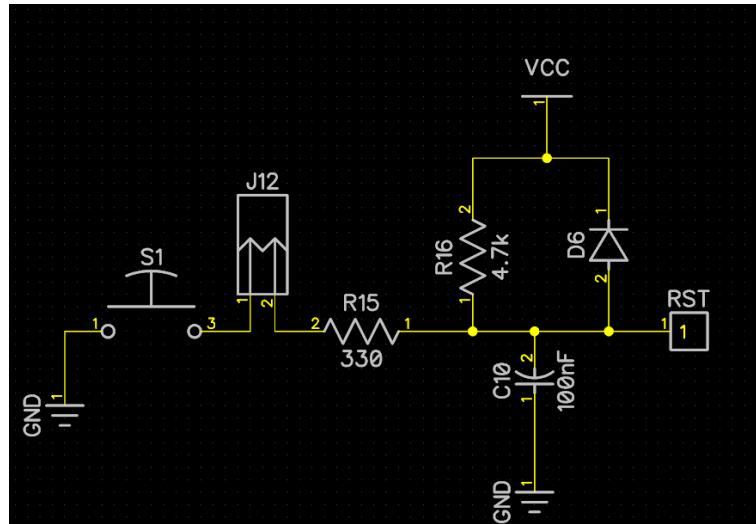


Figure 6: Deployment Reset: Active low reset line with a jumper disconnected for flight to prevent accidental reset.

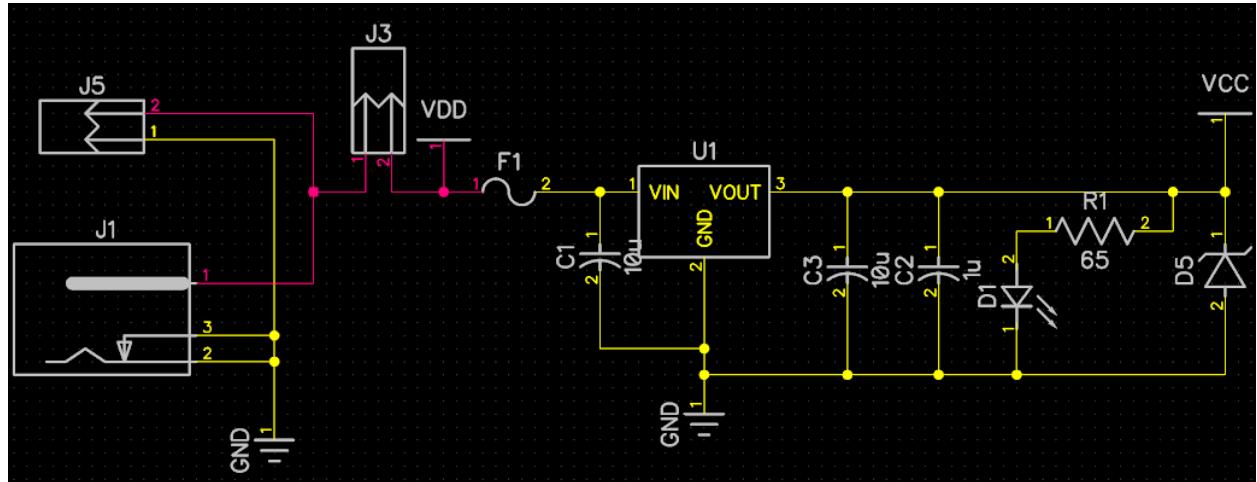


Figure 7: Deployment Power: VCC power line with J5 representing a battery connector, J3 a terminal block switch, and LEDs for debugging.

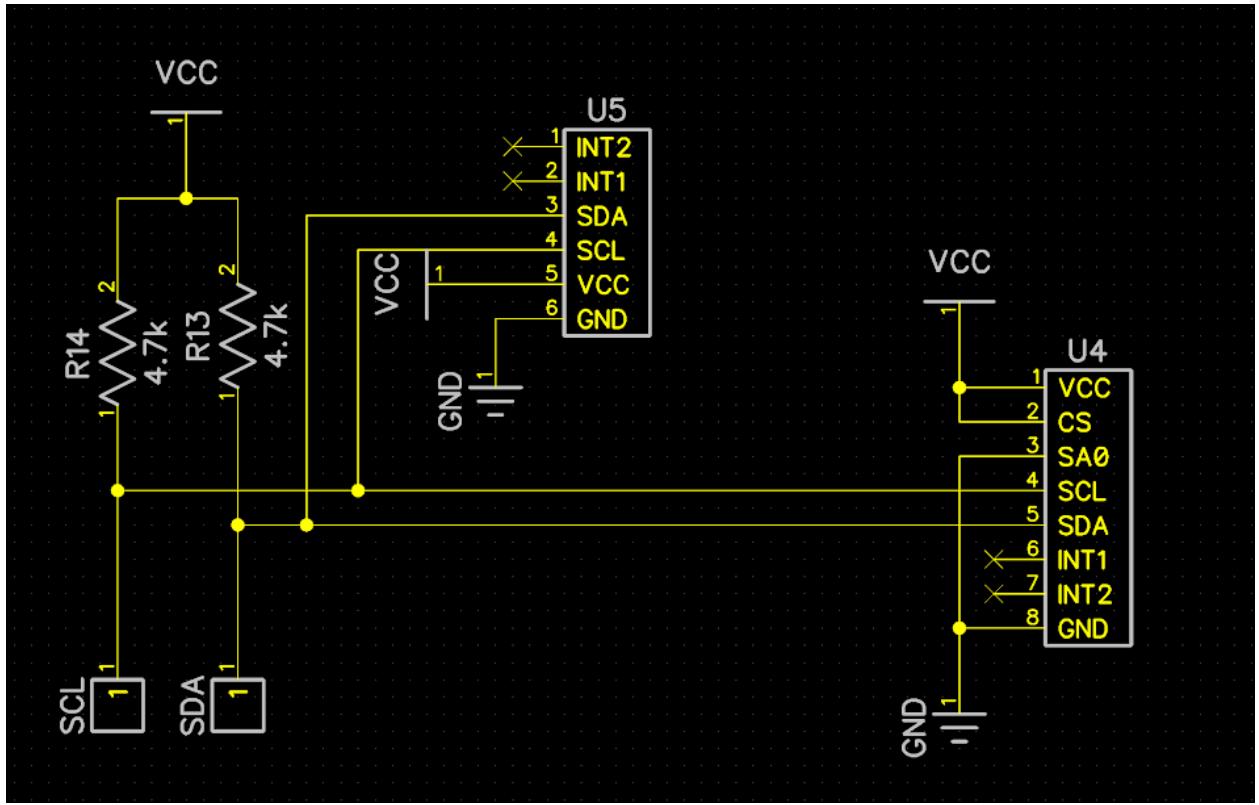


Figure 8: Deployment Sensors: Altimeter and accelerometer sensors that communicate via I2C to the processor.

## E.2 Ejection

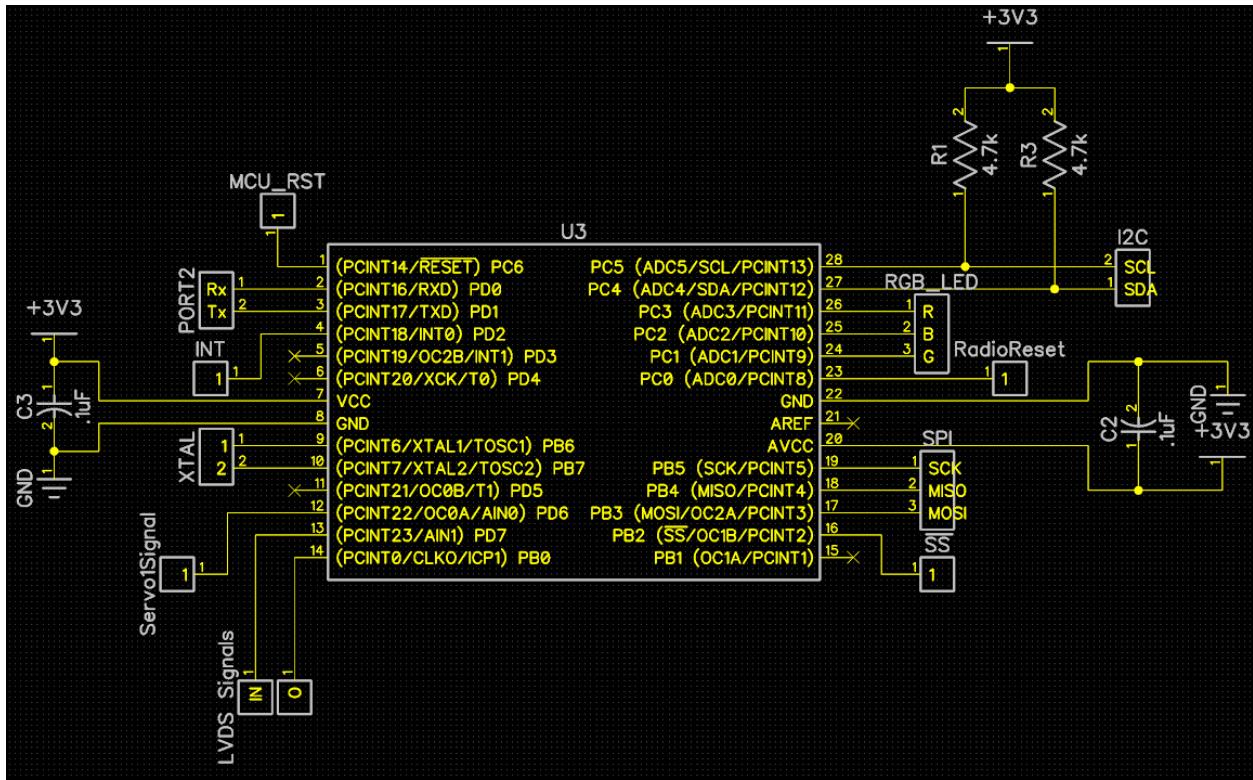


Figure 9: *Ejection Processor*

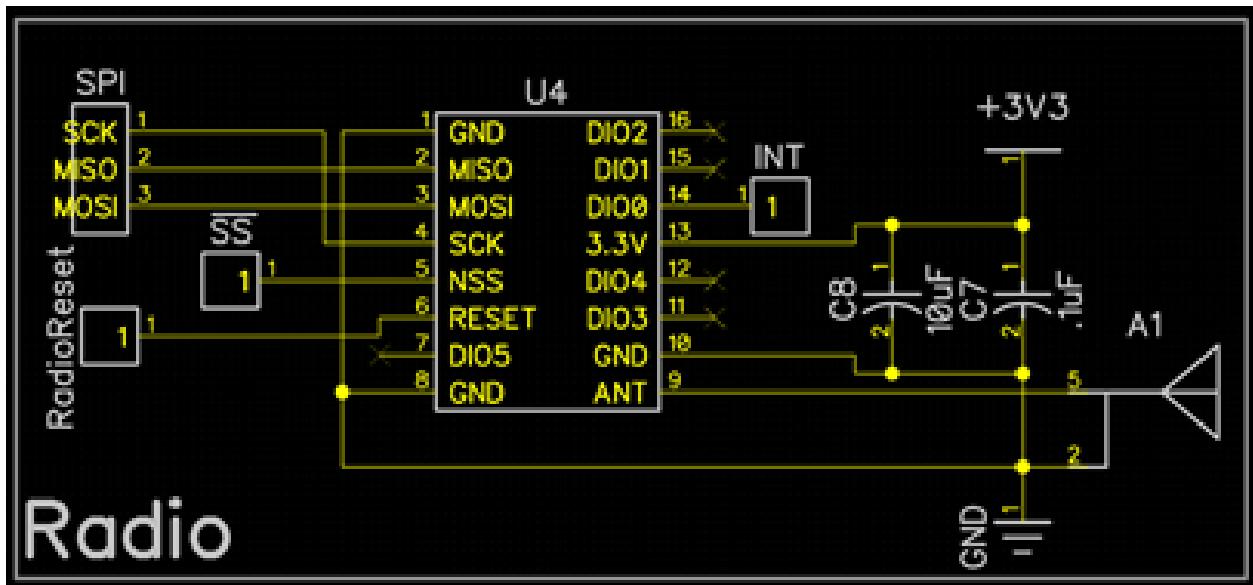


Figure 10: *Ejection Radio*

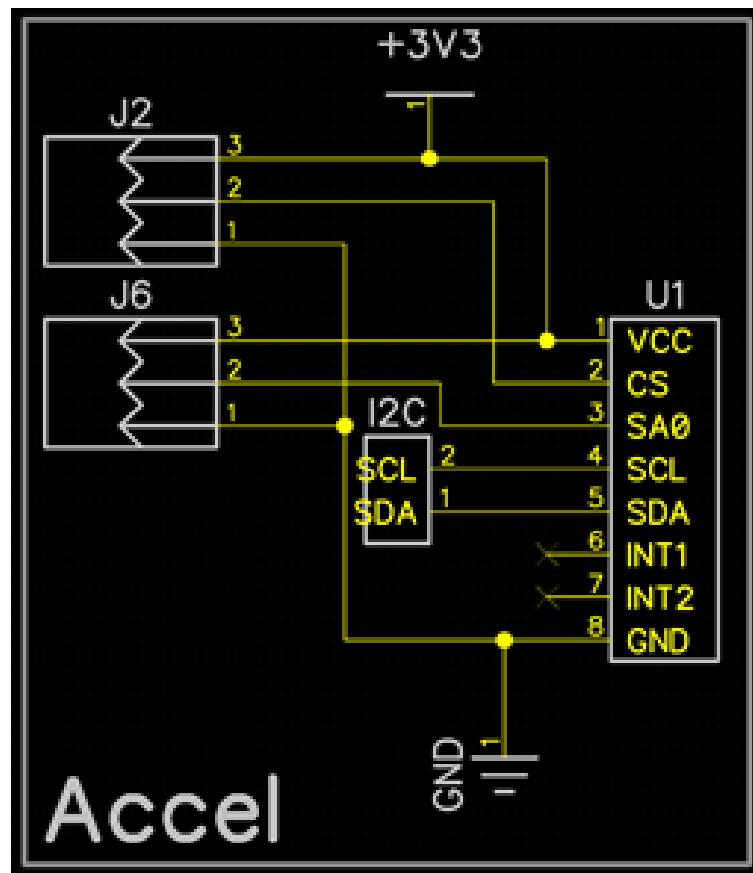


Figure 11: Ejection Accelerometer: *J2* and *J6* used for hardware select to ensure accelerator is using *I2C*

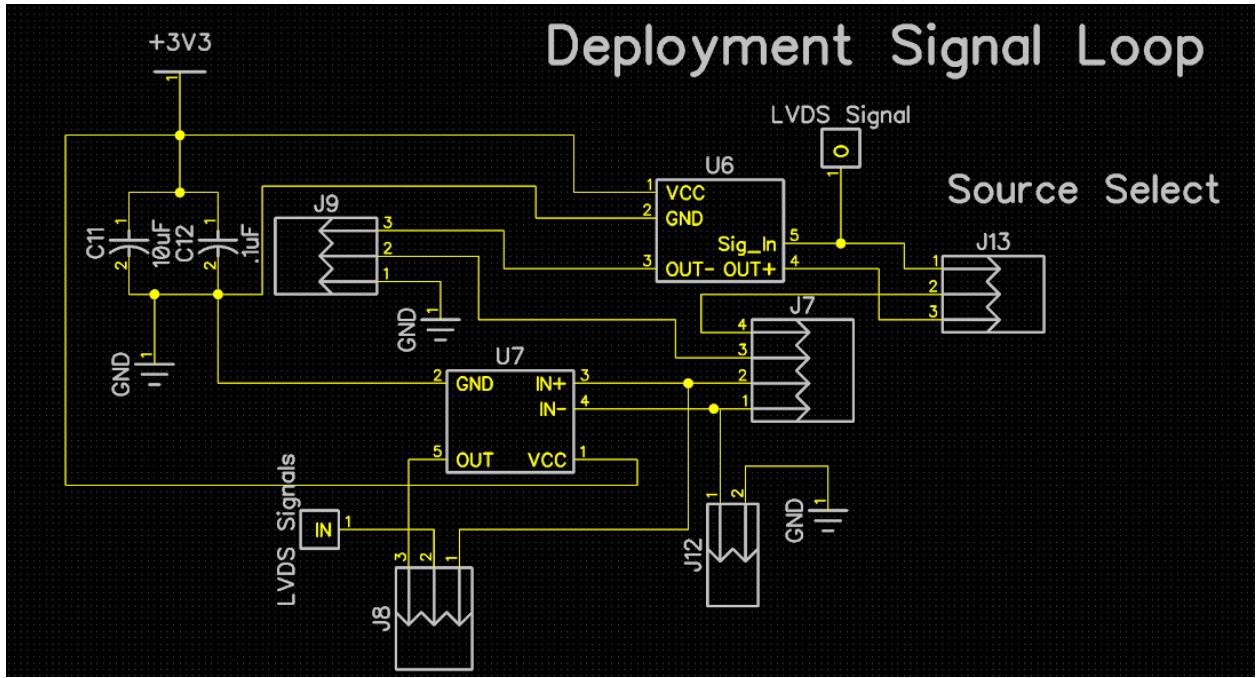


Figure 12: *Ejection Signal Loop: LVDS transmitter and receiver with decoupling capacitors. LVDS Signal Net Port O is signal from Ejection board and LVDS Signals Net Port IN is signal from Deployment board.*

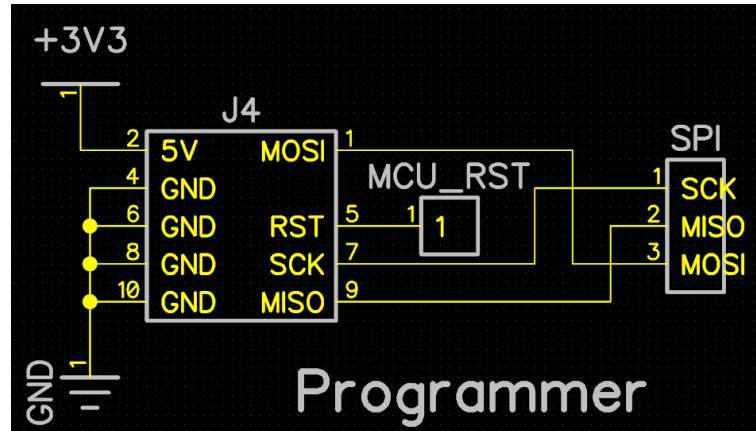


Figure 13: *Ejection Programmer*

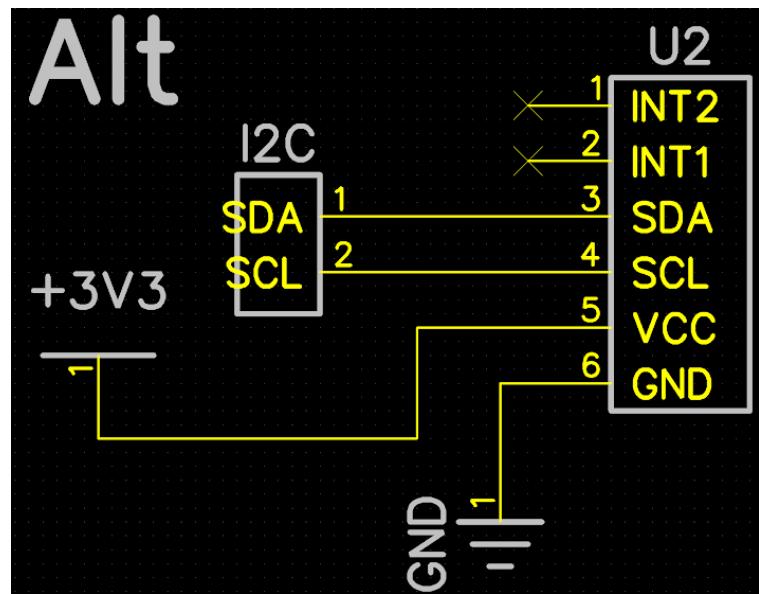


Figure 14: *Ejection Altimeter*

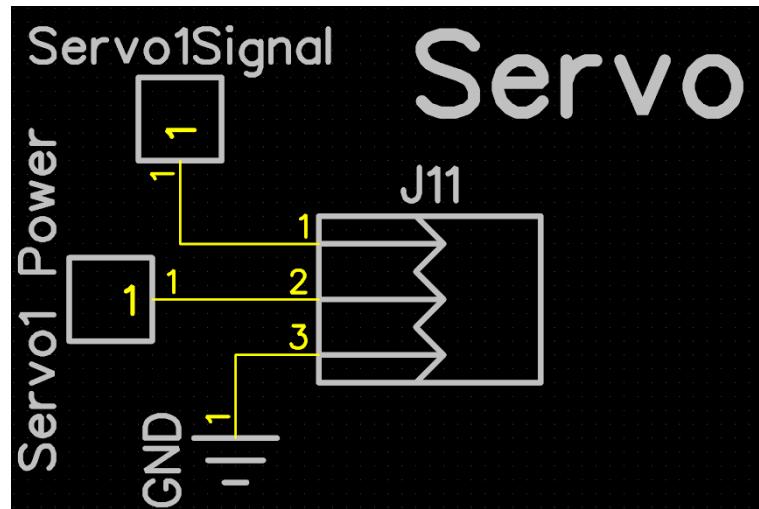


Figure 15: *Ejection Servo*

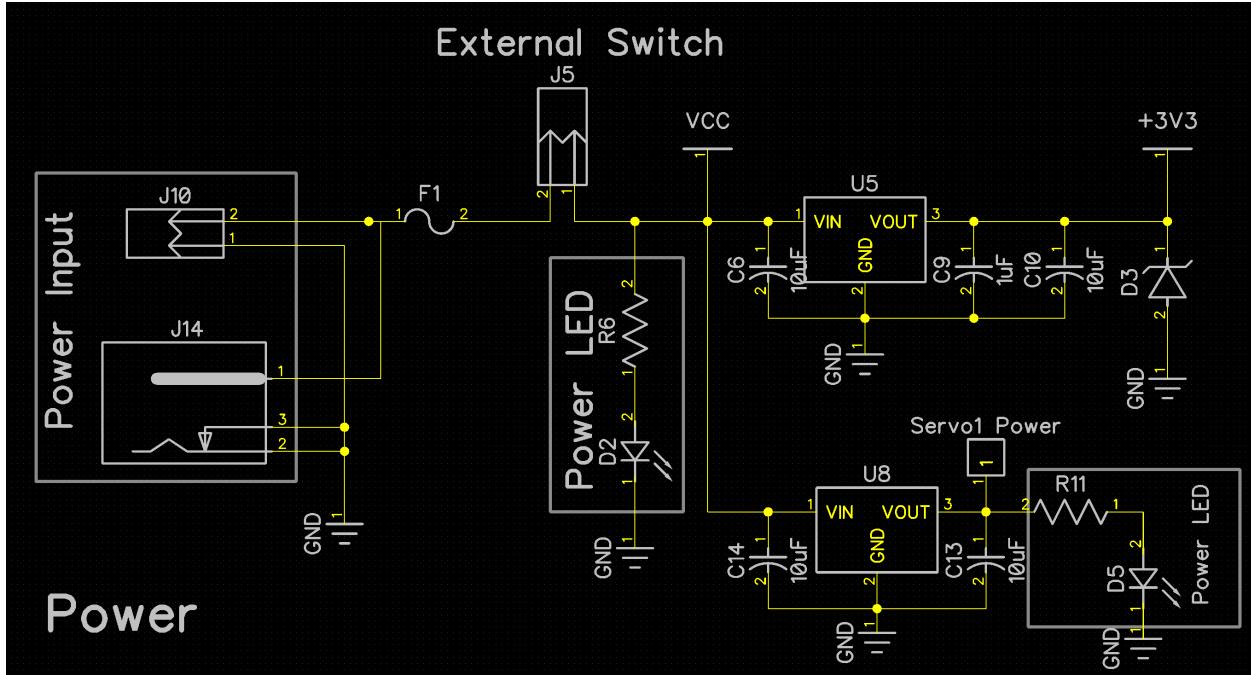


Figure 16: *Ejection Power: Power line with J10 representing a battery connector, J5 a terminal block switch, and LEDs for debugging. Bottom line supplies 5V to the scissor-lift servo.*

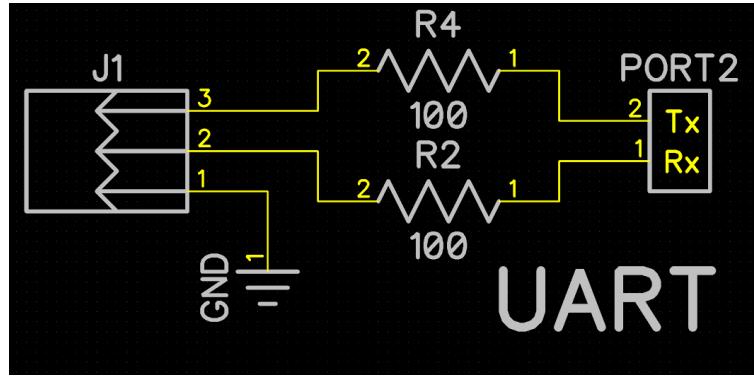


Figure 17: *Ejection UART*

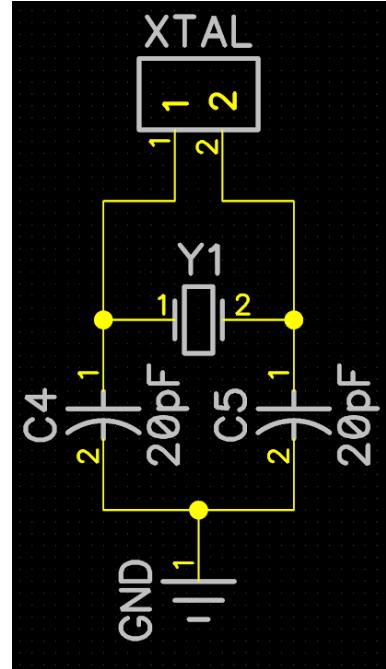


Figure 18: *Ejection Clock*

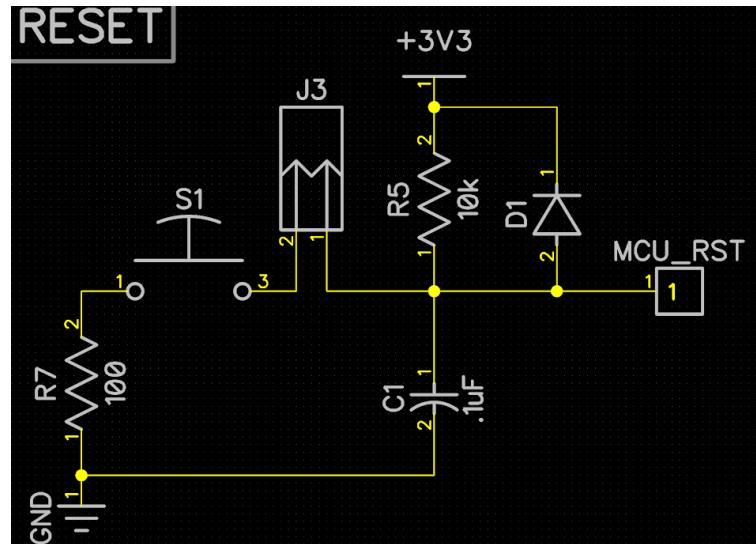


Figure 19: *Ejection Reset*

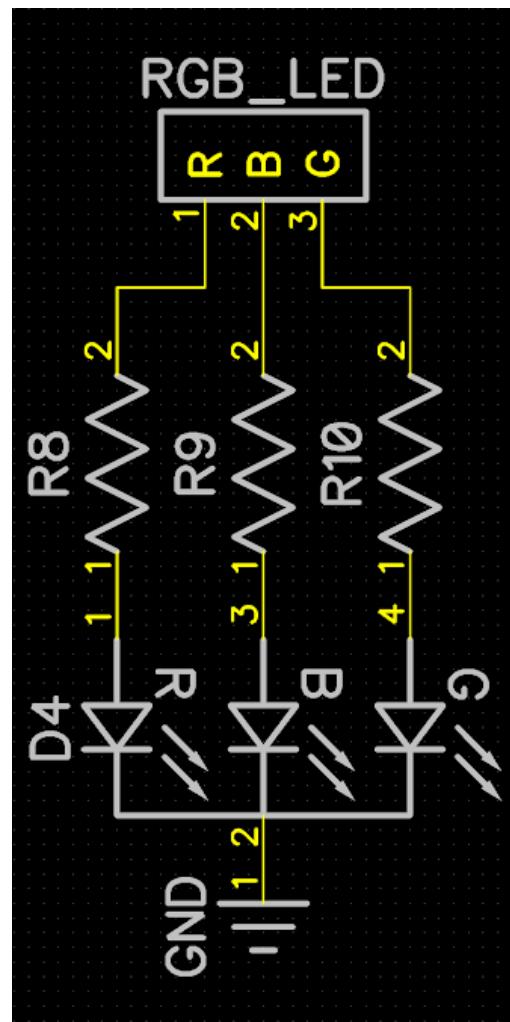


Figure 20: *Ejection RGB LED*

### E.3 Rover

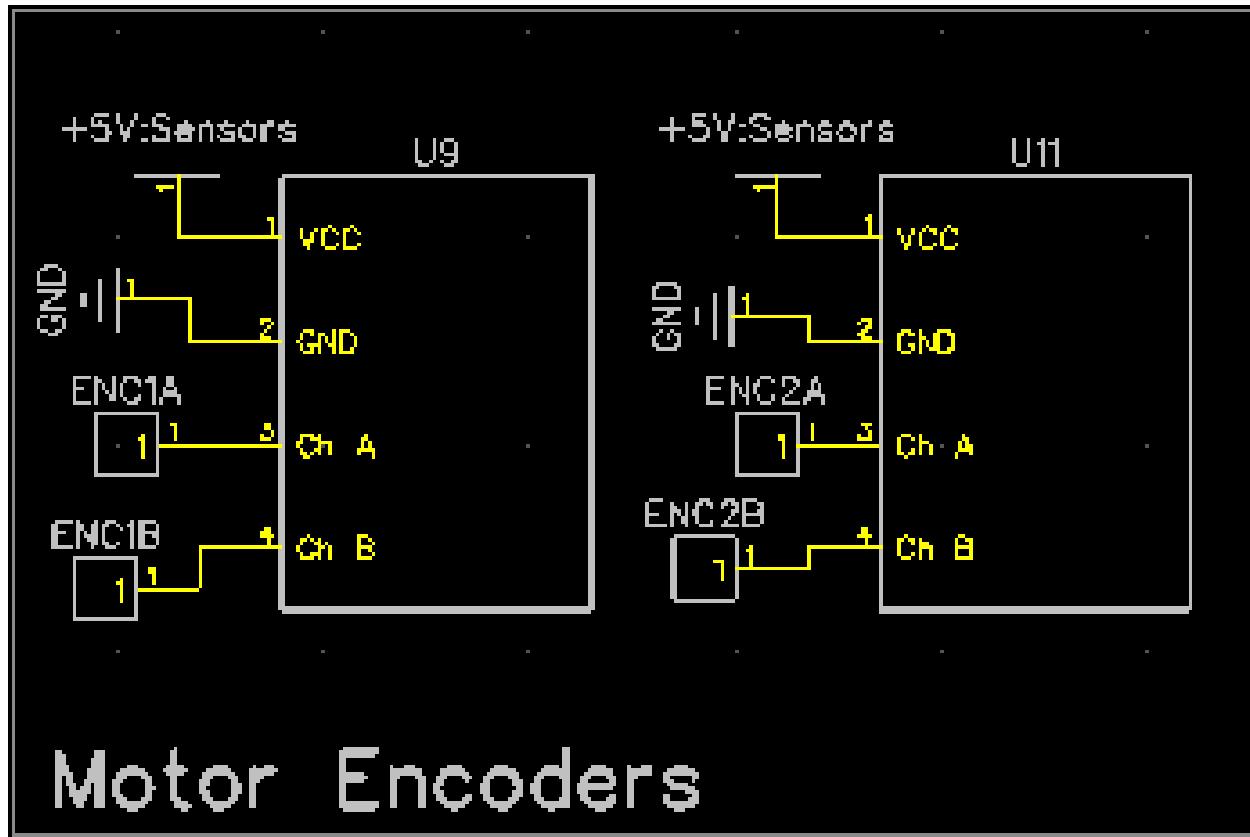


Figure 21: *Rover Motor Encoders*

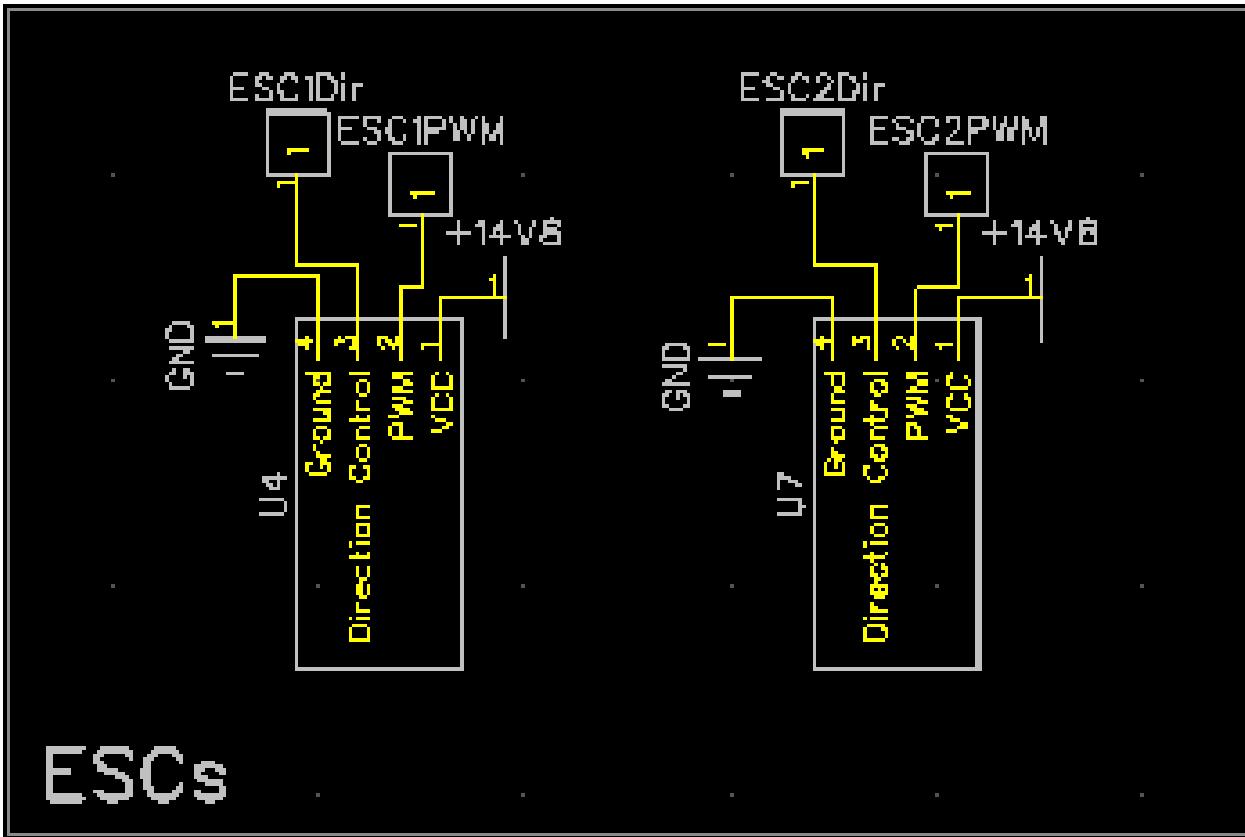


Figure 22: *Rover ESCs*

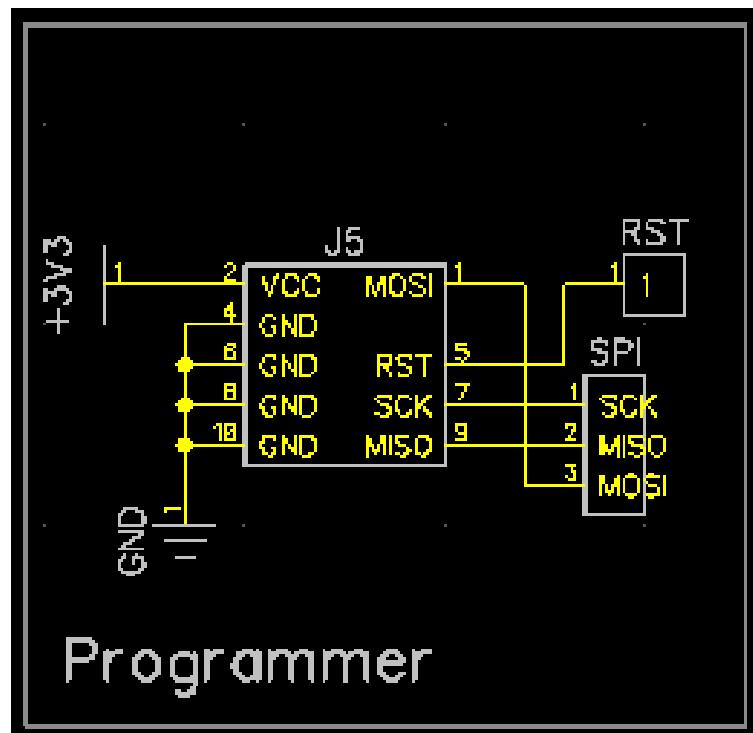


Figure 23: *Rover Programmer*

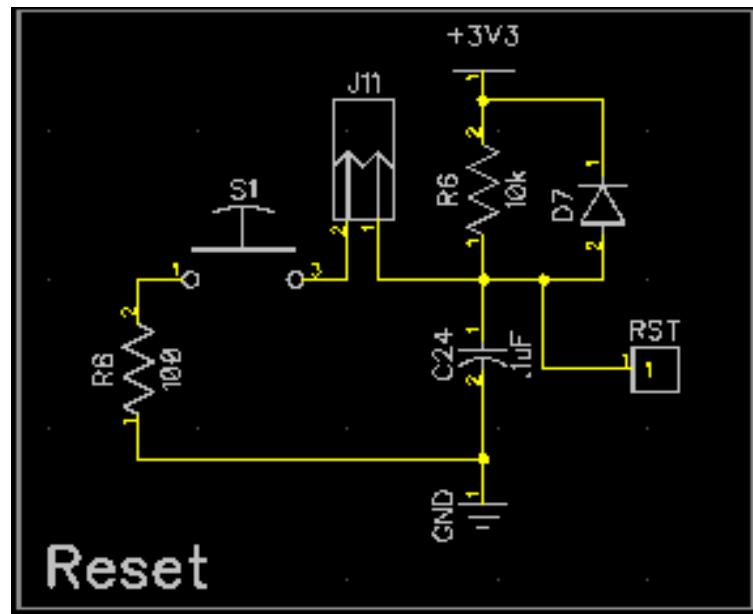
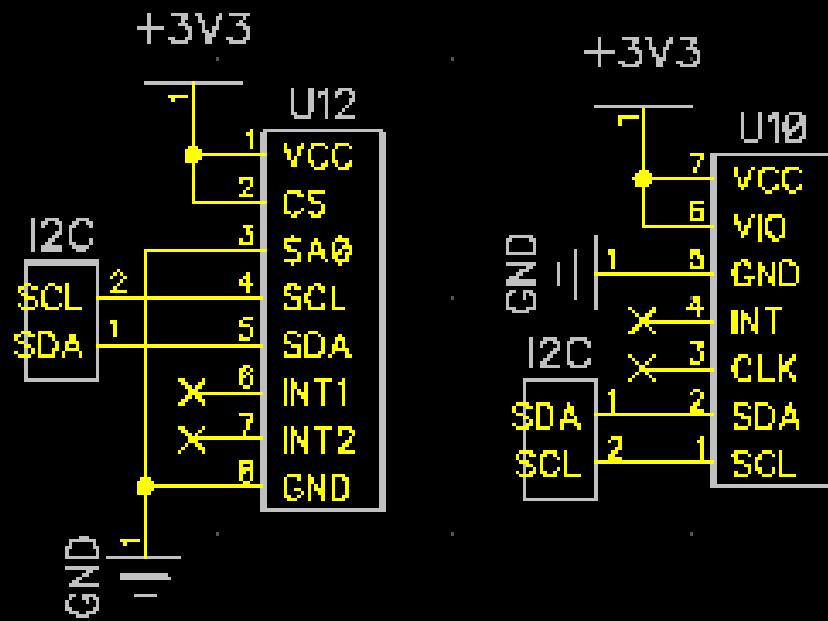


Figure 24: *Rover Reset*



## Motion Sensors

Figure 25: Rover Motion Sensors

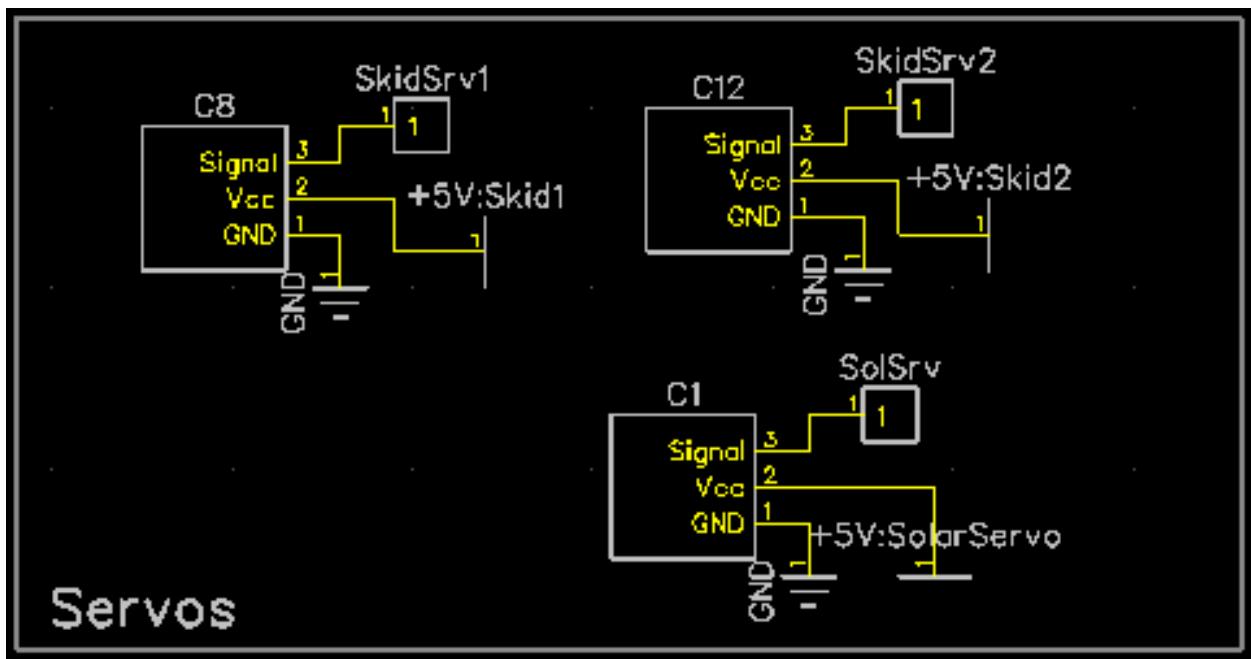


Figure 26: *Rover Servos*

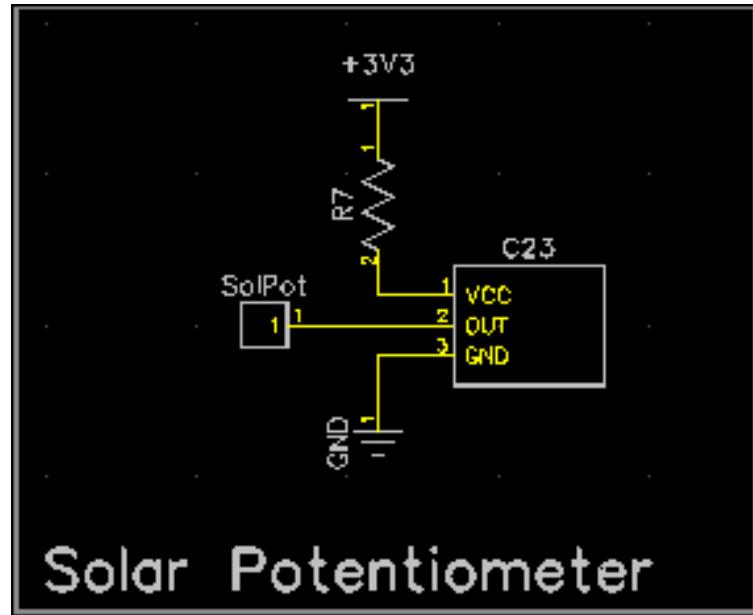
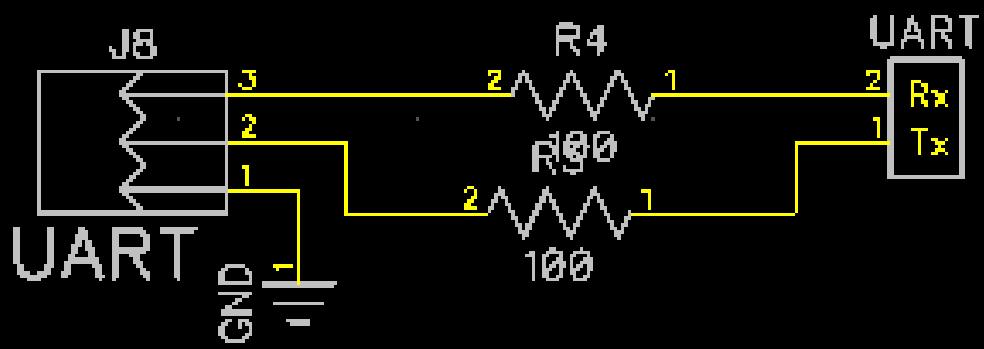


Figure 27: *Rover Solar Potentiometer*



## Serial UART

Figure 28: Rover UART

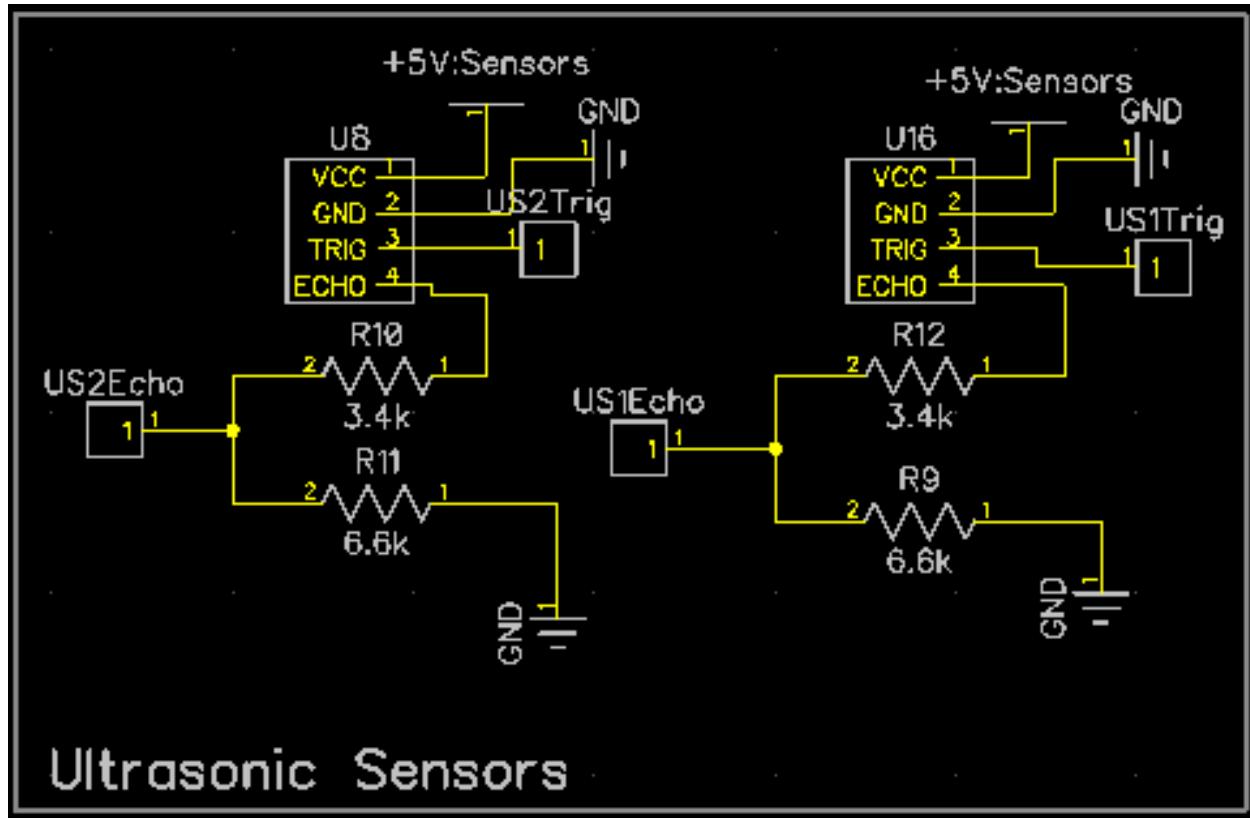


Figure 29: *Rover Ultrasonics*

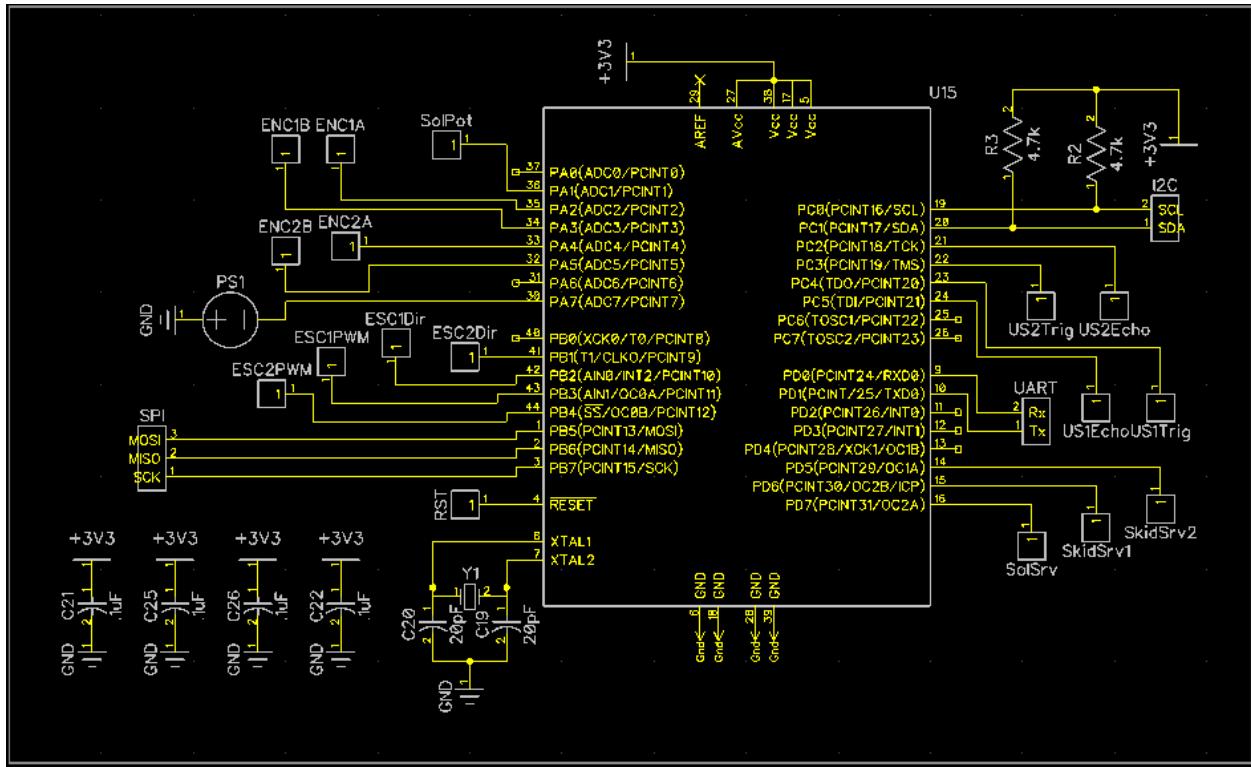


Figure 30: *Rover Processor*

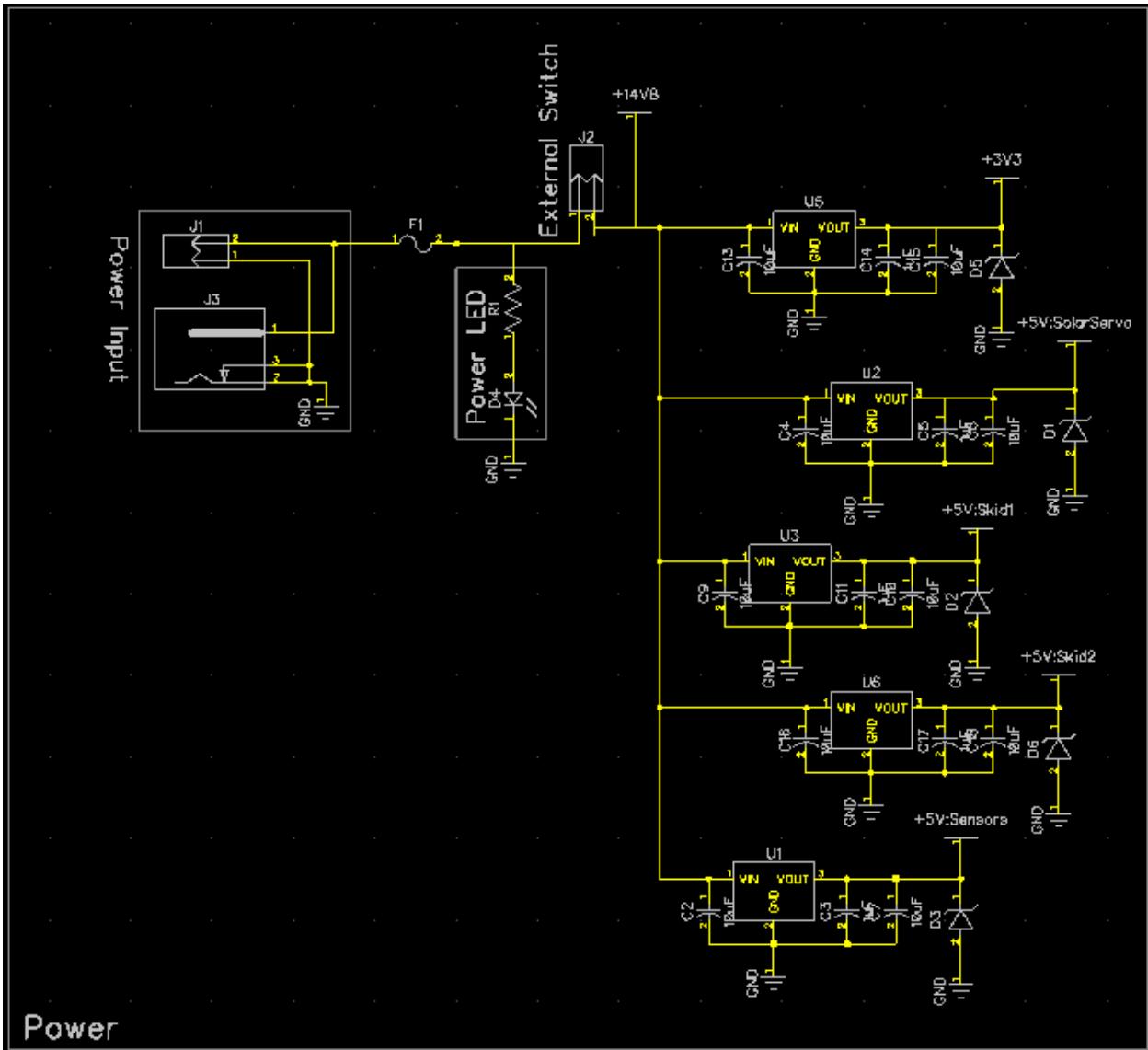


Figure 31: *Rover Power*

## Appendix F Matlab Code for Kinetic Energy Calculations

```

global rho;
rho = 0.0765;
global g;
g = 32.174; % ft/s ^2
global ftlf_to_lbmf2persec2;
ftlf_to_lbmf2persec2 = 32.174049; % conversion factor of ft-lbf

drogue_main()

```

```

function area = para_area_v_cd(mass, vmax, cd)
% takes mass, velocity , and coefficient of drag to calculate the
    necessary parachute area (in ft ^2)
global g
global rho
area = ((mass * g) / (.5 * (vmax .^ 2) * rho * cd )); % returns ft
    ^2
end

function vmax = KEmax_to_vmax(KEmax, mass)
% for a given mass, returns the landing velocity (ft/s) to land
    with a given Kinetic Energy
global ftlfbf_to_lbmft2persec2
vmax = ((2 * KEmax * ftlfbf_to_lbmft2persec2) / mass) .^ .5;
end

function v = terminal_v(m, cd1, a1, cd2, a2) % lbm, cd, ft ^2, cd,
    ft ^2
global g
global rho
v = ((m * g) / (.5 * rho * (cd1 * a1 + cd2 * a2))) .^ .5;
end

function e = v_fts_to_ke_ft_lbf(v_ft, m_lbm)
global ftlfbf_to_lbmft2persec2
e = ((.5 * m_lbm) * (v_ft .^ 2)) / ftlfbf_to_lbmft2persec2 ;
end

function drogue_main()
global g
global rho
% upper_w = input('Rocket upper half weight (lbm) -->');
% lower_w = input('Rocket lower half weight (lbm) -->');
upper_w = 11.12;
lower_w = 10.61;
cords_parachute_weights = 2.04;
total = upper_w + lower_w + cords_parachute_weights;
fprintf('WEIGHTS: %f lbm | %f lbm\n', upper_w, lower_w)
fprintf('WEIGHT: %f lbm\n', cords_parachute_weights)
fprintf('TOTAL WEIGHT: %f lbm\n', total)
fprintf('_____ \n')

```

```

%%%%%
% drogue parachute

Cd1 = 1.5; % coefficient of drag for Drogue
fprintf('Drogue_coefficient_of_drag_is_%f\n', Cd1)
drogue_vmax = 73 + (1 / 3);

drogue_area = para_area_v_cd(total, drogue_vmax, Cd1);
drogue_radius = (drogue_area / pi) .^ .5; % given in ft
fprintf('Drogue_is_designed_to_slow_the_rocket_to_%f_ft/s\n',
drogue_vmax)
fprintf('Drogue_diameter_must_be_at_least_%f_inches\n',
drogue_radius * 12 * 2)
final_drogue_diameter_in = input('Decide_on_final_drogue_parachute
_size_(diameter_inches)-->'); % inches
final_drogue_area_ft = ((final_drogue_diameter_in / (12 * 2)) .^
2) * pi;

%%%%%
% vmax for landing with a KE less than 75 ft-lbf with detaching
payload

KEmax = 75; % ft-lbf
fprintf('Max_landing KE is %f ft-lbf\n', KEmax)
safety_factor = input('Safety_factor_of_(should_be_between_0_and_
1)-->');
KEmax = safety_factor * KEmax;

hv = input('HEAVIEST_SECTION_put_"upper_w" or "lower_w"(no_quotes
) or a number-->');
vmax = KEmax_to_vmax(KEmax, hv);

fprintf('Maximum_velocity_is_%f_ft/s\n', vmax)

%%%%%
Cd2 = 2.2;
fprintf('Main_coefficient_of_drag_is_%f\n', Cd2)

main_area = (((total * g) / (.5 * (vmax .^ 2) * rho)) - (Cd1 *
final_drogue_area_ft)) / Cd2;
main_radius = (main_area / pi) .^ .5;
main_diameter_in = main_radius * 2 * 12;
fprintf('Main_diameter_must_be_at_least_%f_inches\n',
main_diameter_in)

```

```

fprintf( 'Decided_on_drogue_of_%f_inches\n' ,
    final_drogue_diameter_in)

main_radius_ft = input( 'Main_diameter_(inches)--->' ) / (2 * 12);
main_area_ft2 = ( main_radius_ft .^ 2) * pi;

t_velocity = terminal_v(total, Cd1, final_drogue_area_ft, Cd2,
    main_area_ft2);

fprintf( 'The_final_terminal_velocity_is_%f_ft/s\n' , t_velocity)
fprintf( 'The_final KE for the_upper_half is_%f_ft_lb\n' ,
    v_fts_to_ke_ft_lbf(t_velocity, upper_w))
fprintf( 'The_final KE for the_lower_half is_%f_ft_lb\n' ,
    v_fts_to_ke_ft_lbf(t_velocity, lower_w))

end

```