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

432 Eshleman Hall, MC 4500

Berkeley, CA 94720-4500

January 12, 2018

Contents

1 Summary of CDR Report **5**
- 1.1 Team Summary 5
- 1.2 Launch Vehicle Summary 5
- 1.3 Payload Summary 5

2 Changes made since PDR **6**
- 2.1 Vehicle Criteria 6
- 2.2 Payload 6
- 2.3 Deployment 6
  - 2.3.1 Black Powder Separation 6
  - 2.3.2 Pneumatic Separation 7
- 2.4 Ejection 7
- 2.5 Movement 7
- 2.6 Solar 7
- 2.7 Project Plan 8

3 Design and Verification of Launch Vehicle **8**
- 3.1 Unique Mission Statement & Success Criteria 8
- 3.2 Design Alternatives from PDR 8
  - 3.2.1 Transition Piece 8
  - 3.2.2 Fins 9
  - 3.2.3 Motor Tube 9
  - 3.2.4 Motor 9
  - 3.2.5 Boat Tail 9
  - 3.2.6 Nose Cone 10
- 3.3 Demonstration of Complete Design 10
  - 3.3.1 Nose Cone 10
  - 3.3.2 Transition Piece 10
  - 3.3.3 Fins 10
  - 3.3.4 Boat Tail 10
  - 3.3.5 Motor Tube 11
  - 3.3.6 Motor Retainer 11
  - 3.3.7 Airframe Tubing 11
  - 3.3.8 Coupler Tubing 11
  - 3.3.9 Bulkheads 11
  - 3.3.10 Centering Rings 11
- 3.4 CAD Drawings 12
- 3.5 Integrity of Design 13
  - 3.5.1 Fin Shape and Size 13
  - 3.5.2 Materials for Fins, Bulkhead, and Transition Tube 14
  - 3.5.3 Motor Mounting and Retention 14
  - 3.5.4 Mass Estimates 14

3.6 Justification of Design Aspects . . . 14
3.6.1 Nose cone . . . 14
3.6.2 Transition . . . 15
3.6.3 Boat Tail . . . 15
3.6.4 Websites for Research . . . 15

4 Sub-scale Flight Results **16**
4.1 Scaling Factors . . . 16
4.1.1 Body Tube . . . 17
4.1.2 Transition Piece . . . 17
4.1.3 Nose Cone . . . 17
4.1.4 Fins . . . 17
4.2 Launch Day Conditions and Analysis . . . 17
4.3 Flight Analysis . . . 18
4.4 Impact on Full-Scale Design . . . 18

5 Recovery Subsystem **19**
5.1 Sub-scale Modifications and Results . . . 19
5.2 Design Alternatives . . . 19
5.2.1 Avionics Bay . . . 19
5.2.2 Avionics Bay Door . . . 21
5.2.3 Bulkheads . . . 22
5.2.4 Centering Rods . . . 23
5.2.5 Bolts . . . 24
5.2.6 Shock Cords . . . 24
5.3 Deployment System . . . 25
5.4 Part Drawings . . . 28

6 Mission Performance Predictions **34**
6.1 Motor Metrics . . . 34
6.2 Stability . . . 34
6.3 Flight Metrics . . . 34
6.4 Kinetic Energy Recovery Calculations . . . 35
6.5 Drift Calculations . . . 35

7 Safety **36**
7.1 Responsibilities . . . 36
7.2 Checklists . . . 36
7.3 Personnel Hazards Analysis . . . 36
7.4 Failure Modes and Effects Analysis . . . 41
7.4.1 Airframe Failures Modes . . . 42
7.4.2 Recovery Failures Modes . . . 45
7.4.3 Electronics Failures Modes . . . 49
7.4.4 Payload Failure Modes . . . 50
7.4.5 Deployment of the Payload . . . 50

7.4.6 Ejection of the Rover . . . 52
7.4.7 Movement of the Rover . . . 54
7.4.8 Deployment of the Solar Panels . . . 56
7.5 Environmental Analysis . . . 57
7.5.1 Environmental Hazards Analysis: . . . 59

8 Payload Criteria **62**
8.1 Designs chosen from PDR . . . 62
8.2 System level design review . . . 62
8.2.1 Deployment subsystem . . . 62
8.2.2 Ejection subsystem . . . 64
8.2.3 Movement subsystem . . . 65
8.2.4 Solar subsystem . . . 65
8.3 Electronics . . . 66
8.3.1 Ejection . . . 66
8.3.2 Deployment . . . 66
8.3.3 Rover . . . 67
8.4 Justification for unique aspects . . . 68
8.4.1 Deployment . . . 68
8.4.2 Ejection . . . 69
8.4.3 Movement . . . 69
8.4.4 Solar . . . 70
8.5 CAD & Drawings . . . 71
8.5.1 Deployment . . . 71
8.5.2 Ejection . . . 73
8.5.3 Movement and Solar . . . 76
8.5.4 Summary . . . 78

9 Project Plan **80**
9.1 Testing . . . 80
9.1.1 Airframe Tests . . . 80
9.1.2 Recovery Tests . . . 81
9.1.3 Payload Deployment Tests . . . 81
9.1.4 Payload Ejection Tests . . . 83
9.1.5 Payload Movement Tests . . . 85
9.1.6 Payload Solar Tests . . . 88
9.1.7 Payload Electronics Tests . . . 90
9.2 Requirements Compliance . . . 90
9.2.1 NSL Handbook Requirement Compliance . . . 90
9.2.2 Team Requirement Derivation . . . 100
9.2.3 Team Requirement Compliance . . . 102
9.3 Budgeting and Timeline . . . 108
9.3.1 Airframe Budget . . . 108
9.3.2 Recovery Budget . . . 109
9.3.3 Payload Budget . . . 109

9.3.4 Outreach Budget 112
9.3.5 Funding 113
9.3.6 GANTT Charts 114

Appendix A List of Project Leaders **115**

Appendix B Safety Agreement **116**

Appendix C NAR High Power Rocket Safety Code **117**

Appendix D Launch Checklists & Procedures **120**
D.1 Materials, Components, & Tools 120
D.2 Launch Commit Criteria 124
D.3 Assembly & Preparation 124
D.3.1 Airframe Assembly 124
D.3.2 Electronics Preparation & Testing 125
D.3.3 Payload Assembly 127
D.3.4 Recovery Preparation 131
D.3.5 Propulsion Preparation 134
D.3.6 Launch Commit 135
D.4 Launch Setup 135
D.4.1 Vehicle Setup at Launch Rail 135
D.4.2 Motor & Igniter Installation 136
D.5 Launch 137
D.6 Post-Flight 137
D.6.1 Rover Deployment 137
D.6.2 Vehicle Safing & Recovery 137
D.6.3 Post-Flight Inspection & Cleanup 138
D.7 Annotated Electrical Boards 139
D.8 Post-Flight Inspection Notes 144

Appendix E Matlab Code for Kinetic Energy Calculations **145**
E.1 Matlab Code for Black Powder Calculations 147

1 Summary of CDR Report

1.1 Team Summary

Team Name:
UC Berkeley Space Technologies and Rocketry (STAR)
Team Contact Address
432 Eshlemann Hall, MC 4500
Berkeley, CA 94720-4500
Team Mentor
David Raimondi
President: Livermore Unit. National Association of Rocketry (LUNAR)
NAR #82676, Level 3

1.2 Launch Vehicle Summary

The length of the launch vehicle is 113in. The wet weight of the launch vehicle is 27.2 lbs and the dry weight is 22.2 lbs. The launch vehicle utilizes a Cesaroni L730 motor to achieve a simulated apogee of approximately 5328ft. The launch rail will be a 12ft 1515 rail. The recovery system implements a same-side dual deployment method, with drogue chute deployment at apogee and main chute deployment at 800ft AGL. The 24in elliptical drogue chute and 72in toroidal main chute are systematically integrated with a series of two L2 tender descenders and black powder ejection charges. The ejection is controlled by two altimeters, which sit on an avionics sled design. Furthermore, the avionics bay will be accessible from the airframe exterior via a small door. Further launch vehicle details can be found on our Flysheet at https://stars.berkeley.edu/sl.html.

1.3 Payload Summary

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 two 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 — radio link and subsystem for separating the payload section from the lower airframe
- Ejection — subsystem for ejecting the rover from the payload airframe section

- Movement — rover subsystem
- Solar — solar panel subsystem on the rover

2 Changes made since PDR

2.1 Vehicle Criteria

The internal layout of the airframe has stayed primarily the same since the PDR for NASA SL 2018. One of the minor changes made to the vehicle since the PDR is the thickening of the fins. Upon suggestion from the NASA SL staff, they are now 1/8in as opposed to the 1/16in thickness previously. The transition piece will now also be constructed by 3D printing as opposed to a traditional fiberglass layup. This method was tested during the sub-scale launch and was successful. The final change will be the construction of the boattail. The boattail will be constructed from 3D printed material and inlaid with fiberglass. Furthermore, the issue of the rail buttons has now been solved. There will be two standoffs that will be extruded from the 4in tubing to the rail.

There have been no major changes since the Preliminary Design Review. Both the avionics bay layout and door design remain unchanged, as no design flaws have been discovered so far. One small change is that the screws holding the door in place will be countersunk. In addition, vinyl stickers will then be placed over the screw heads. These measures will help to reduce any drag created by the protruding screw heads. All other aspects of the recovery subsystem have not been altered since the PDR.

2.2 Payload

2.3 Deployment

2.3.1 Black Powder Separation

The payload deployment subsystem was revised in the interest of safety and reliability based upon setbacks encountered in manufacturing the previous design and data from sub-scale launch testing.

To achieve the linear force required to sufficiently separate the airframe, the primary design was shifted from a pneumatic system to a system utilizing black powder for section separation. The benefits of a pneumatic system, namely lower operating temperature and cleaner re-usability, are outweighed by the design constraints imposed by the system, particularly the weight of the system and the impulse of the force delivery. The precedent offered by a black powder design lends itself to a lower-risk, lighter-weight design at the expense of a more involved refurbishing process. The current design relies upon: (1) a semi-permanent bulkhead to isolate the electrical components controlling the deployment process; (2) a transient bulkhead which will be the primary mechanism through which force is applied to the upper sections of the airframe; (3) a Nomex shield to isolate the remainder of the payload from the heat of detonation, and; (4) radially oriented structural supports attached to the upper stages to direct the applied force away from the more sensitive payload components.

2.3.2 Pneumatic Separation

Due to time constraints, no rigorous tests of the new black powder design have been completed; if test data show that no amount of shielding is adequate to ensure low-risk operation of the remainder of the payload, a backup design has been prepared which parallels the pneumatic system initially pursued. This design utilizes: (1) a 250 PSI rated stainless steel vessel; (2) a high impulse linear piston; (3) 500 PSI fittings and 2000 PSI reinforced tubing, and; (4) radially oriented structural supports similar to those mentioned above to achieve the expansion force required to separate the airframe. This design is intended to operate between 175 and 200 PSI. This option sacrifices weight for cleaner operation and cooler operating temperatures and is only intended to be used in the event that the design mentioned above is insufficient to isolate combustion temperatures.

2.4 Ejection

The payload ejection subsystem has undergone minor revisions to improve reliability and to accommodate results gathered from sub-scale launch testing; However, the fundamental design of a scissor lift system remains unchanged. The primary design change is reducing the planned number of servos used in the scissor lift drive mechanism from two servos to one servo. It was concluded that the benefit of a multi-servo system, namely greater operating redundancy, is outweighed by major complications including the need to precisely synchronize the movements of all servos. Further changes to the PDR design include improvements to structural rigidity by adding aluminum cross-members to the scissor links and switching from a primarily 3D-printed design to a design that makes extensive use of laser-cut plastics to reduce binding characteristics inherent in 3D-printed parts and to improve manufacturing tolerances. The changes are visible in Figure 13.

2.5 Movement

The rover chassis was changed from a partially-enclosed frame design to a fully-enclosed frame design. The new design offers superior environmental protection and is easier to design and manufacture. While the new design weighs more, those negative effects are mitigated by the use of a single, light, 3D-printed polylactic acid (PLA) piece for the side paneling that encloses the rover. This 3D-printed piece allows for the placement of holes in the front for ultrasonic sensors and a hole in the back for the skids without major manufacturing difficulties. The design from PDR and the current design are presented side-by-side in Figure 23. The PLA part can be identified as the blue paneling on the sides absent in the PDR design.

2.6 Solar

The basic design of the solar subsystem remains the same as detailed in the PDR. A few minor modifications were made, primarily on the basis of weight and volume restrictions. The top and bottom effective solar panels are now composed of individual 2in x 1in cells. These will be inserted into the top and hood of the rover such that they do not peek above the encompassing polycarbonate. The polycarbonate pieces that form the rover body and hood shall lay flush against each other with the longer edge of the panels oriented perpendicular to the longer edge of the rover body. Only one servo, instead of two, will be used to actuate the panel deployment. This was chosen after verifying that the torque from one servo is adequate to lift the hood. Additionally, the hood will be smaller in area, such that it will not intersect with the servo or potentiometer attached to it. This was decided in order for the hood to fit inside the volume enclosed by the two rover wheels. The solar system is displayed in its pre-deployment configuration in Figure 19 and its fully-deployed configuration in Figure 20.

2.7 Project Plan

Our initial projections had our total pre-expense budget at $24,000. Our current pre-expense budget is $25,389.39, with a pending $2,000 transfer from Boeing. We have spent about $3,000 (approximate as some members still have not submitted reimbursements for purchases on our bill of materials).

3 Design and Verification of Launch Vehicle

3.1 Unique Mission Statement & Success Criteria

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

- Airframe is defined as any of the external tubing, coupler tubing, motor tubing, fins, nose cone, and transition piece. There will be no cracks in the airframe.
- There will be no unwanted separation between the pieces of the rocket.
- The stress in the airframe will not exceed acceptable levels. Acceptable is defined as below the yield strength for the specific member of tubing in question.
- Meets all vehicle requirements set from NASA SL 2018 Handbook.

3.2 Design Alternatives from PDR

3.2.1 Transition Piece

The alternatives available to the transition piece were only differences in length/angle. The midpoint (8in) of possible length values (4-12in) was chosen as it maximized apogee while providing a desired stability. Other length values could have worked, but they would have been sub-optimal.

3.2.2 Fins

The major alternatives for fins have been shape and dimensions. The finalized geometry, which was chosen to provide ideal stability for minimum weight, is made of an 8in root chord, and a 6in tip chord, at a height of 5in. Additionally, we have refined the geometry of the fins, making them thicker, from 0.118in to 0.1875in. This decision was necessary to decrease susceptibility to damage and fin fluttering. The material of fiberglass was readily chosen over other options as it offers the best combination of strength and weight that also fits our budget. A trapezoidal shape was chosen over others like triangular as it is the optimal shape for ease of manufacturing and reducing drag.

3.2.3 Motor Tube

The motor tube choice was heavily governed by the motor choice, as the motor tube has to adequately fit the specific chosen motor. That is how we chose the specific length of 26in and outer diameter of 2.276in and inner diameter of 2.152in. The alternatives for motor tube composition were kraft phenolic, Blue Tube, carbon fiber, and fiberglass. Blue Tube was ruled out due to low heat resistance. Carbon fiber and fiberglass were too expensive for the budget. So kraft phenolic was chosen as it offered the best heat resistance and strength while also being affordable for our organization.

3.2.4 Motor

Some of our motor alternatives were the Cesaroni L730, L990-BS, and the Animal Works L777. Motor choice was largely determined by the rest of the rocket, as we had to choose what motor would get our specific rocket to desired apogee. The chosen alternative is the L730. The L990-BS gave too high of an acceleration (30% greater than the L730), even though both motors gave similar apogee of about 5400 feet. The AMW L777 results in an apogee of about 5500 feet, but our local supplier does not carry Animal Works motors, so that leaves the L730 as the optimal motor.

3.2.5 Boat Tail

The alternatives for the boat tail were among dimension, shape, and material. The dimensions (forward diameter: 4.014in, aft diameter: 2.465in, length: 4.7in, thickness: .062in) were chosen over others as the inner diameter has to fit around the motor retainer and the length has to fit a transition angle of around 9 degrees (which serves to minimize base drag).

The shape was chosen to be conical over other options like ogive. The other options seemed to be better for a longer/wider rocket, but conical was calculated to minimize drag/-maximize apogee; ogive reduced apogee by a few feet.

The material was chosen as 3D printed PET-G with a fiberglass reinforcement on the inside. This was chosen over other options such as aluminum or just plastic. Aluminum is difficult and expensive to manufacture, and by themselves plastics do not have sufficient heat resistance to survive in such close proximity to the thrust exhaust. Thus, a use of both plastic and fiberglass offers fairly simple manufacturing, decent cost, and sufficient heat resistance.

3.2.6 Nose Cone

The nose cone alternatives consisted mainly in shape and dimensions. There is less room for alternatives as nose cones must be purchased/not manufactured. All of the alternatives were made of fiberglass due to its high compressive strength and low weight. An ogive nose cone with 6in diameter and a tip-to-shoulder length of 24in was selected as it is the lightest commercially available, has an ideal 4:1 length to diameter ratio, and minimizes drag. Alternatives for nose cone choice are conical, fiberglass nose cones of 6in diameter and 30in length, and ogive, fiberglass nose cones of 6in diameter and 30in length. However, as these nose cones significantly increase overall mass (by roughly 8oz), as well as reduce apogee (by roughly 150 and 100ft respectively), the first nose cone was selected.

3.3 Demonstration of Complete Design

3.3.1 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.

3.3.2 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.

3.3.3 Fins

The launch vehicle's 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.

3.3.4 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.

3.3.5 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.

3.3.6 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.

3.3.7 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.

3.3.8 Coupler Tubing

Except for on the nose cone, boat tail, and either side of the transition piece, all coupler lengths will be purchased blue tube manufactured to fit inside the outer tubing.

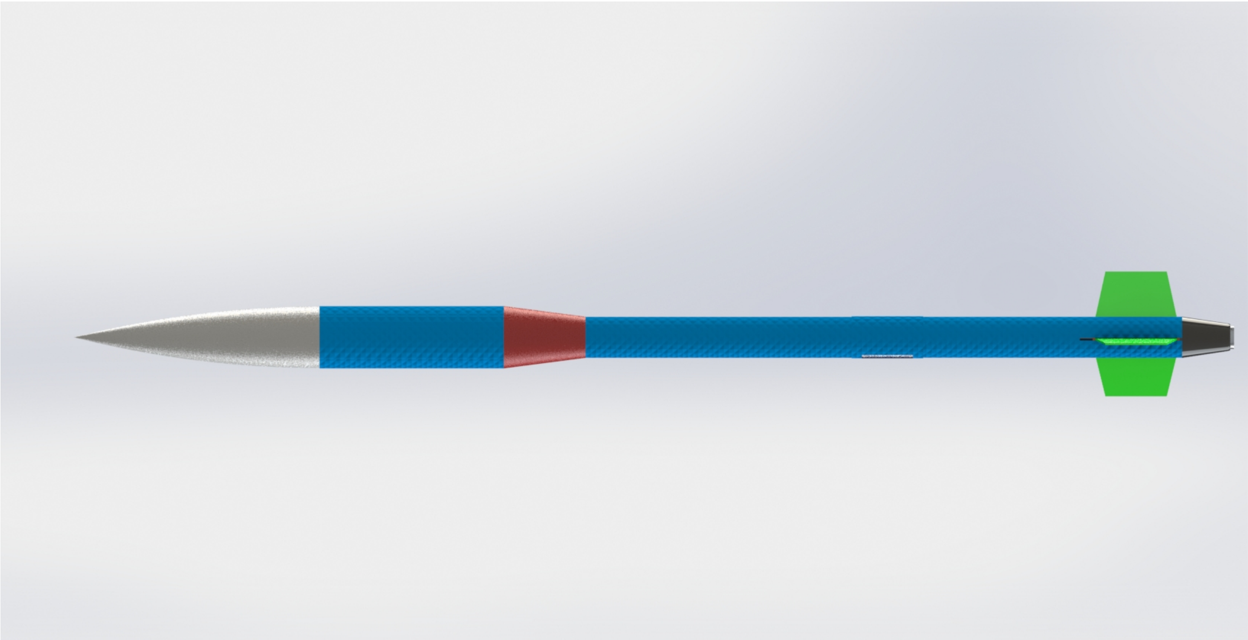
3.3.9 Bulkheads

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.

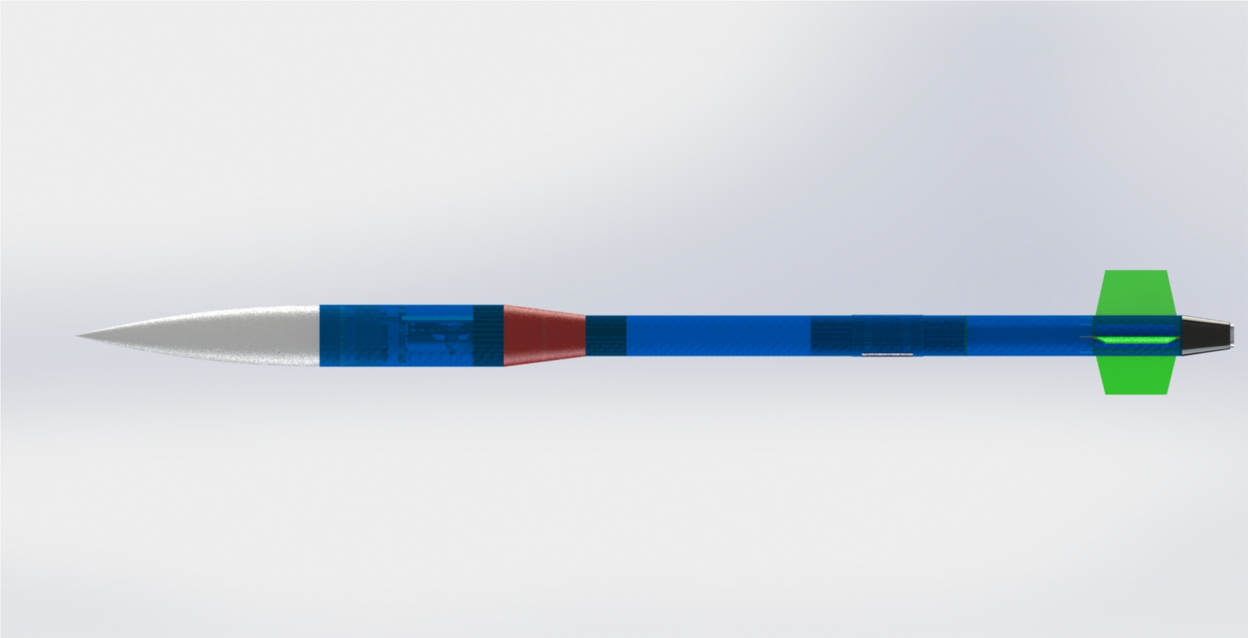
3.3.10 Centering Rings

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 vehicle's vertical axis. They will be secured to the airframe and inner tubing with JB Weld steel reinforced epoxy.

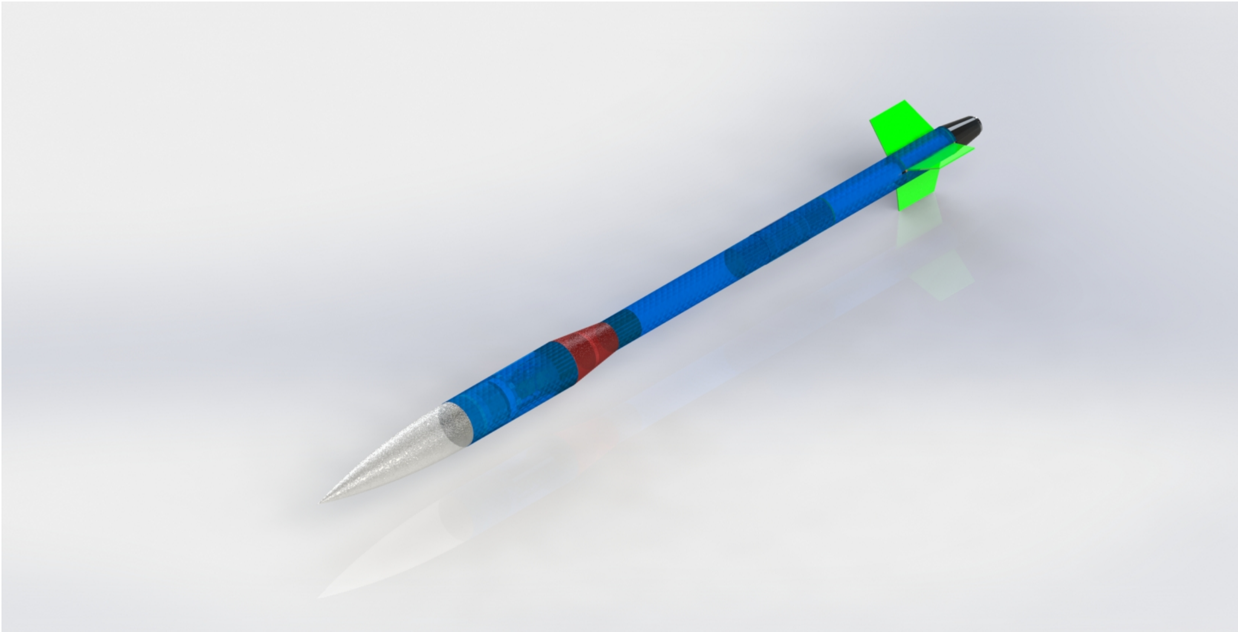
3.4 CAD Drawings



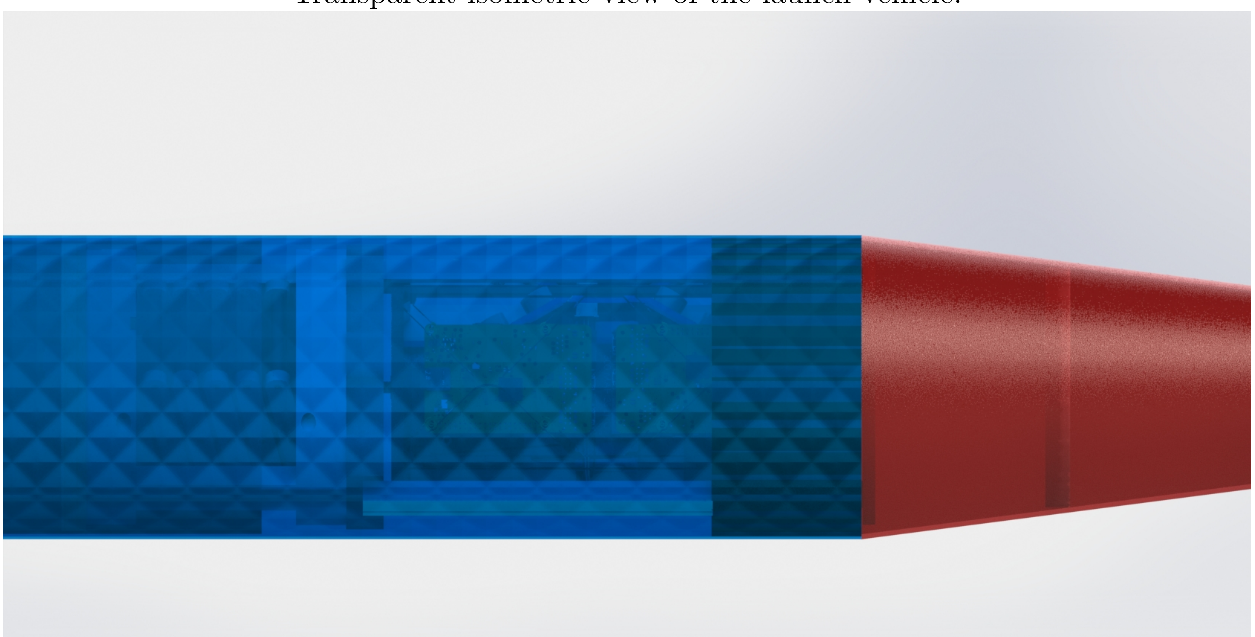
Opaque side view of the launch vehicle.



Transparent side view of the launch vehicle.



Transparent isometric view of the launch vehicle.



Transparent close-up view of the payload section and transition piece.

3.5 Integrity of Design

3.5.1 Fin Shape and Size

The fins have a trapezoidal shape, as that is the optimal shape for reducing drag. The sides of the fins will be sanded down such that their edges are rounded, creating the illusion of an airfoil. The size of the fins has been chosen at a 8in root chord and a 6in top chord, with a height of 5in and thickness 0.1875in. These dimensions were decided because they offer the best compromise between stability, aerodynamics, and ease of production.

3.5.2 Materials for Fins, Bulkhead, and Transition Tube

The fins are made of G10, a compressed fiberglass epoxy laminate. G10 is a very strong material and impact resistant, while being thin. Because of this, it wont break easily and reduces drag. The bulkheads are made out of plywood. Plywood is sturdy and light. Since the bulkheads are internal in the launch vehicle, they wont take the bulk of the forces upon impact, so stronger materials would add unnecessary weight. The transition piece is 3D printed with PETG filament. PETG is cheap and stronger than other cheap alternatives, such as ABS and PLA. It is also easier to manufacture with and reliable to get the desired shape. A layer of fiberglass on the inside provides reinforcement.

3.5.3 Motor Mounting and Retention

The motor retainer is the Aero Pack 54 mm retainer P bought from a reliable retailer, Apogee Rockets. The retainer is epoxied onto the motor mount, preventing it and the motor from slipping off during flight.

3.5.4 Mass Estimates

The mass estimates for the rocket are below. The values for each subsystem are shown, along with the standalone estimate of the tubing:

Section	**Weight(lb)**
Nose cone	2.2
Payload	6
Recovery Tube	2.2
Avionics Bay	2
Booster (including fins)	8.5
Tubing	6.3
Total	**27.2**

3.6 Justification of Design Aspects

3.6.1 Nose cone

The length is 24in and the base diameter is 6in The shape of the cone is Ogive, which is optimal for this launch vehicle's design because it smoothly passes through the air, providing reduced drag.

A nose cone shaped like an ellipsoid can be useful for smooth airflow. However, it would not penetrate the air as well as the ogive design. Due to its curved tip, the ellipsoid nose cone would allow more air to pass smoothly over, but it would go at a slower speed. The Ogive nose cone has a curved surface and a tip, resulting in more speed and a little more drag than the Ellipsoid nose cone.

A conical nose tip would have the fastest speed due to its triangular shape, but it would generate the greatest amount of drag force as it has no curved surfaces. Also, including OpenRocket Data, by transforming the current Ogive nose cone to a Conical Nose Cone, the stability goes up by .22 cals and the apogee is decreased by 156 feet. With Ogive Nose Cone, the Rocket has a lower probability of weather cocking into the wind and gains a higher apogee. Since the Ogive nose cone is for high speed rockets and it has proven effective in previous launch vehicles, so the vehicle is equipped with that specific nose cone as well. 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. For Subsonic speeds, the ideal nose cone would be the parabolic shape because it more more air molecules pass smoothly, resulting in less drag at lower altitudes. According to this source: https://www.apogeerockets.com/education/downloads/Newsletter376.pdf, an ellispoid nose cone has much less drag than the Ogive nose cone.

3.6.2 Transition

Transition: A key element in the design of the vehicle is the addition of a transition piece, which serves the purpose of reducing the rockets diameter which reduces drag on the launch vehicle, resulting in increased apogee. This causes a shift up in the center of gravity, which improves the launch vehicles stability, giving us more leeway in other parts of the design to add different kinds of elements that are not necessarily optimal for stability. The length of the transition piece is 8 inches, the Fore diameter is 6 and the aft diameter is 4 inches. We simulated both extremes in OpenRocket, we to see which is better. After both Simulations, the data showed that the longer transition had a much more gradual slope than shortest transition, but the margin between the two was small and not something on which we could base a decision.

3.6.3 Boat Tail

Boat Tail: The dimensions: the length of the boat tail is 4.7 inches, while the Fore diameter is 4.014 inches and the aft diameter is 2.465 inches. The boat tail has an upper limit placed on its size due to its impact on the stability. The Boat Tail aft diameter is the same diameter as the motor mount because that is the smallest diameter that will not have any interference from the motor. With the boat tail dimensions, the rocket gains an extra 50 feet in apogee and it lowers the stability by .20 cals. This design reduces the amount of Turbulence on the rocket because the final diameter of the launch vehicle is now less.

3.6.4 Websites for Research

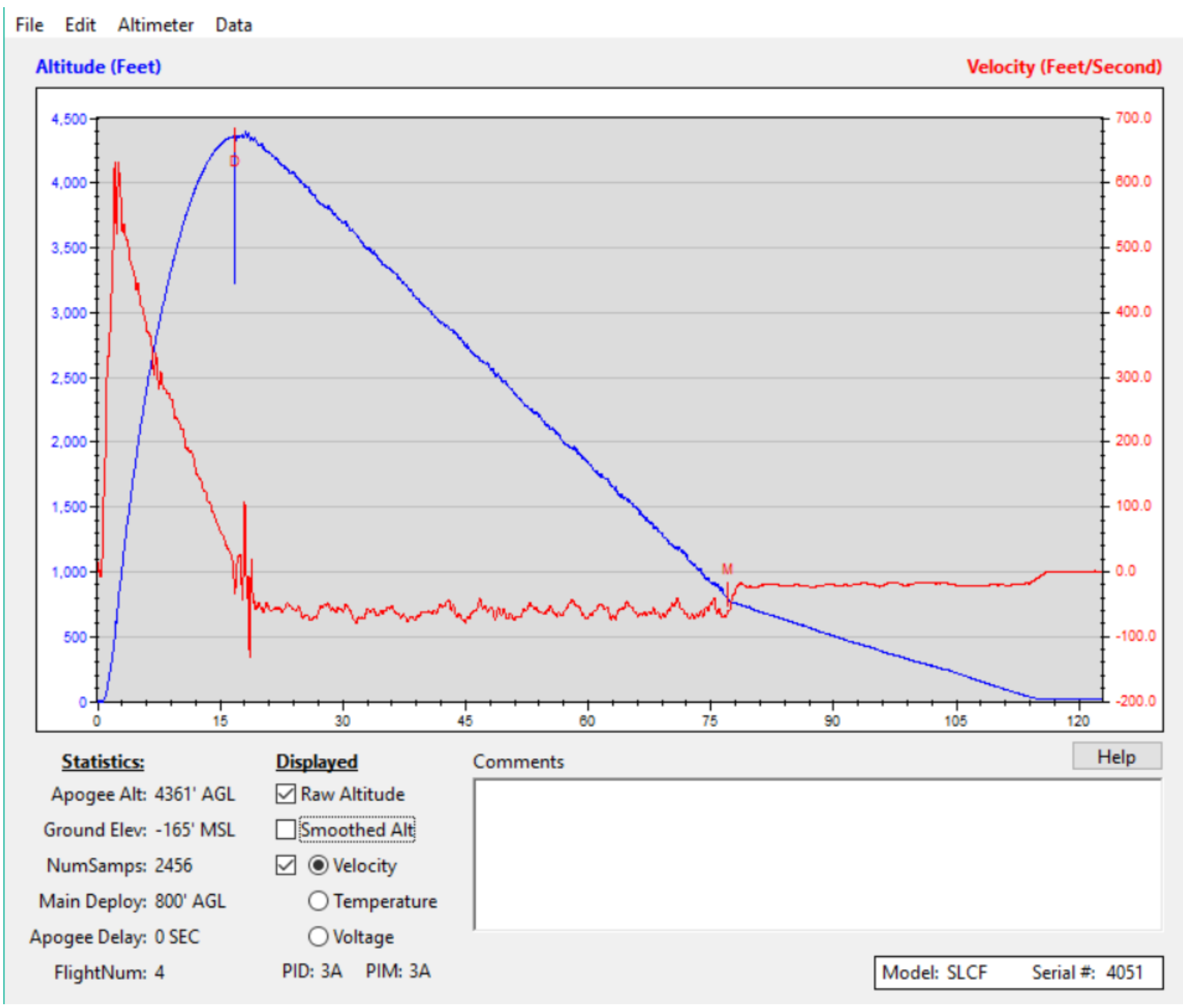
- https://www.apogeerockets.com/education/downloads/Newsletter376.pdf
- http://www.aerospaceweb.org/question/aerodynamics/q0151.shtml
- https://spaceflightsystems.grc.nasa.gov/education/rocket/shaped.html
- http://www.nar.org/landing/building-rockets-preview-of-member-guidebook/

4 Sub-scale Flight Results

Sub-Arktos flew successfully on December 9, 2017. Two altimeters were flown on its avionics bay, each recording altitudes of 4361 ft and 4371 ft, respectively. The average of these two values was taken to estimate a flight apogee of 4366 ft.

4.1 Scaling Factors

Sub-Arktos is a 2/3 scale of the full-scale Arktos launch vehicle, intended to fly a non-functional scaled version of TARS as the payload. Scaling design considerations and choices for each airframe section is described in more detail in the following subsections. Flight data from one of the altimeters is given in the figure below.



Acceleration and velocity recorded from one of the altimeters

4.1.1 Body Tube

An important feature of Arktos is its two different diameter body tubes. The full-scale Arktos launch vehicle design includes two body tube diameters of 4 in and 6 in. For Sub-Arktos, body tube diameters of 2.56 in and 4 in were chosen because they are nominal Blue Tube diameter sizes and match a 2:3 ratio.

4.1.2 Transition Piece

The transition piece had to be scaled down to accommodate the new diameter differences. This was achieved by scaling the length of the transition piece by a factor of 2/3. The diameters of the two ends were then readjusted to fit within the two smaller body tubes. Using these values, the angle of change was calculated for both the full-scale and sub-scale transition pieces: 7.125° and 7.689°, respectively. This minimal difference in transition piece shape made these dimensions ideal for a 2/3 sub-scale vehicle.

4.1.3 Nose Cone

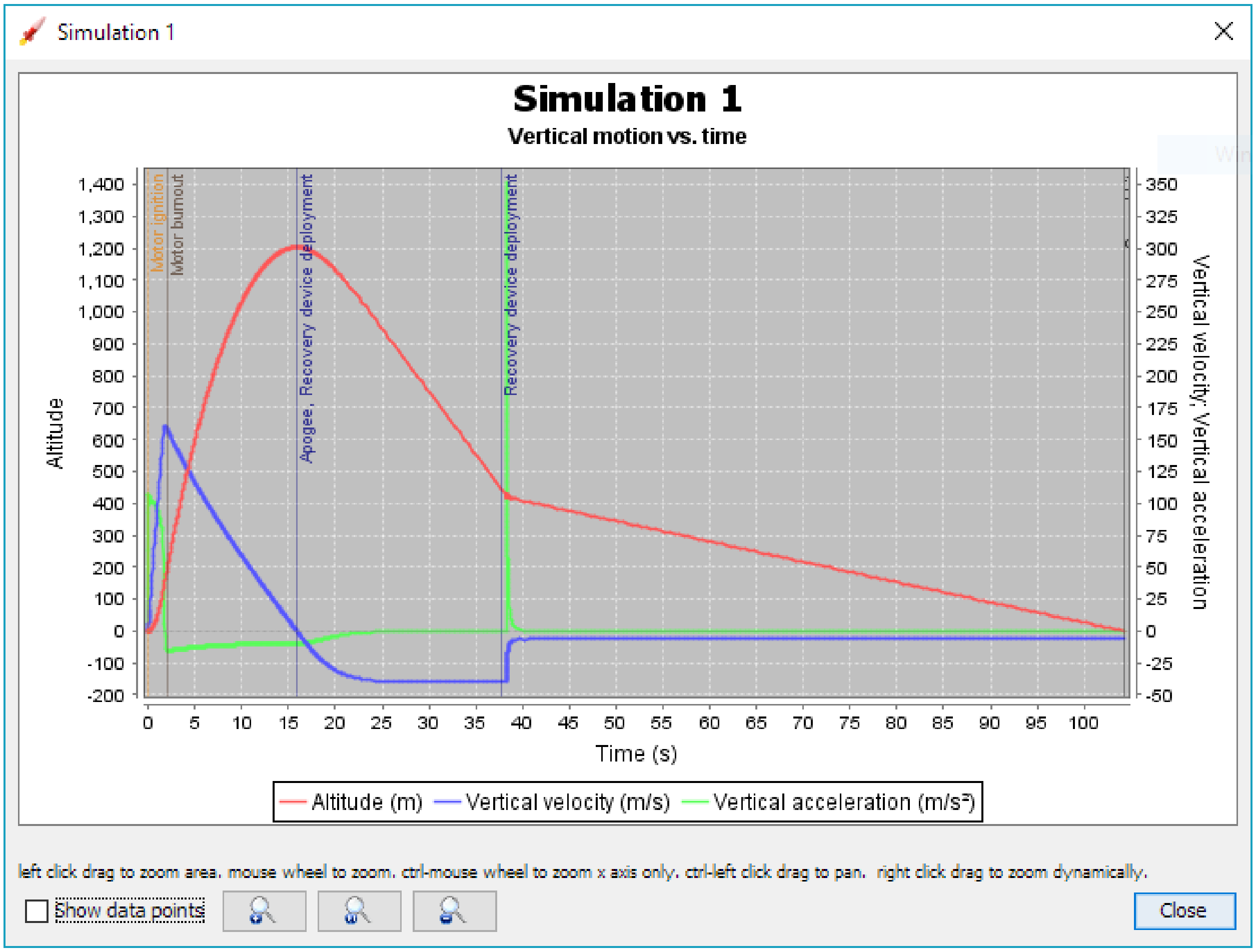
The nose cone was scaled down to fit the new diameter of 4 in. Because it is sold in nominal sizes as well, the nose cone could also be scaled down constantly, as long as the length to diameter ratio is kept at the same 4:1 ratio.

4.1.4 Fins

A large factor in determining the center of pressure of the launch vehicle, and thus the stability, are the fins, and the shape and size of the fins were adjusted to match the simulated stability of the full-scale launch vehicle.

4.2 Launch Day Conditions and Analysis

Sub-Arktos was launched on December 9, 2017 at the LUNAR launch site in Snow Ranch, CA. Launch conditions were near optimal, with 5 MPH wind speeds, partially cloudy skies, and moderate temperature and humidity levels. Using these conditions, the sub-scale OpenRocket simulations were run and are given below.



OpenRocket simulation with 5 MPH crosswinds

Given the conditions on launch day, OpenRocket returned a simulated apogee of 3946 ft, a maximum acceleration of 352 ft/s^2, and a maximum velocity of 527 ft/s.

4.3 Flight Analysis

The recorded flight data from the two altimeters aboard Sub-Arktos gave an average maximum altitude of 4366 ft while the OpenRocket simulations estimated an apogee of 3946 ft, resulting in a 420 ft difference between simulated and recorded data. The disparity between simulated and recorded apogee can be attributed to differences in weight between the OpenRocket simulation and the actual weight of the launch vehicle.

4.4 Impact on Full-Scale Design

The difference in apogee in the sub-scale launch vehicle flight provides a benchmark for the error on the simulated full-scale launch vehicle flight. According to the data, ballast can be added to the full-scale launch vehicle to achieve a more accurate apogee.

5 Recovery Subsystem

5.1 Sub-scale Modifications and Results

For the subscale recovery system, many modifications were made in order to adapt to the different physical constraints. As a result of the decrease in airframe diameter from 4in to 2.56in, the I-beam sled design simply could not be scaled down, especially since the length of the altimeters took up nearly the entire airframe diameter lengthwise. As a result, the sled design was consolidated into an elongated vertical sled that fit one altimeter and 9V battery lengthwise on each side. The sled itself was lasercut out of .25in birch plywood and pieced together. Two steel rods also ran the length of the avionics bay, similar to the fullscale design, providing axial support. The batteries were ziptied around the sled itself. All other aspects of the design were the same.

A significant innovation is that the door was cut using a new technique developed on the laser cutter, and this technique will be adapted and applied to the full-scale design. Learning this new method would improve the accuracy and efficiency with which the door will be cut, decreasing the drag created by protruding burrs.

The parachute deployment system also was simplified due to the decrease in volume. In order to pack all the parachutes within the given space constraint, a system was created that did not use tender descenders for dual deployment, but rather, depended on the main chute's bulkiness to separate the two events. The main chute had such girth such that it would essentially act as a bulkhead between the two adjacent areas. This simplified the deployment system and helped to reduce mass and decrease necessary volume.

As a result, the subscale flight was very successful overall. With an apogee of 4366ft AGL, The main goal was met and both the main and drogue chutes deployed successfully. Minor holes were sustained on both parachutes, but both were patched using ripstop nylon tape. No further damage to the launch vehicle was recorded.

5.2 Design Alternatives

5.2.1 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.

Design	Benefits	Costs

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

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

Final Decision: The I-Beam sled design will be used for the avionics bay. There will be two one-half in. bulkheads on the top and of the bay. Then, there will be an additional two one-fourth in. bulkheads glued together mounted within the existing bulkheads, as shown by Figure 5. These bulkheads will have section removed from them, with their edges cut at a 45° angle in order to create a triangular slot. The I-Beam sled will then slide into these slots and be held in by the door.

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

5.2.2 Avionics Bay Door

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

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

5.2.3 Bulkheads

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

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

Table 3: Bulkhead Analyses

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

5.2.4 Centering Rods

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

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

Table 4: Center Rod Analyses

‘

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

5.2.5 Bolts

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

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

Table 5: Bolts Analyses

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

5.2.6 Shock Cords

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

Designs	Benefits	Costs
1in Tubular Nylon [Final Design]	1. Cheaper per length (1.87 Dollars/yard) 2. More flexible, can withstand initial impact better 3. Requires less shock cord length	1. Not as durable and more massive 2. Not heat resistant 3. Lower strength rating: slightly greater than 1000lb
Tubular Kevlar	1. Very durable 2.Can hold high amounts of strain 3. Lighter than strap nylon 4. 3600lb strength rating	1. More expensive per length (4.34 Dollars/yard) 2. More inelastic, hard to know when it will shear

Table 6: Shock Cord Analyses

Final Decision: The launch vehicle will use 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 will be covered with kevlar shock cord sleeve, at least for the 3ft closest to the black powder, to ensure that the shock cord will not be damaged.

5.3 Deployment System

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

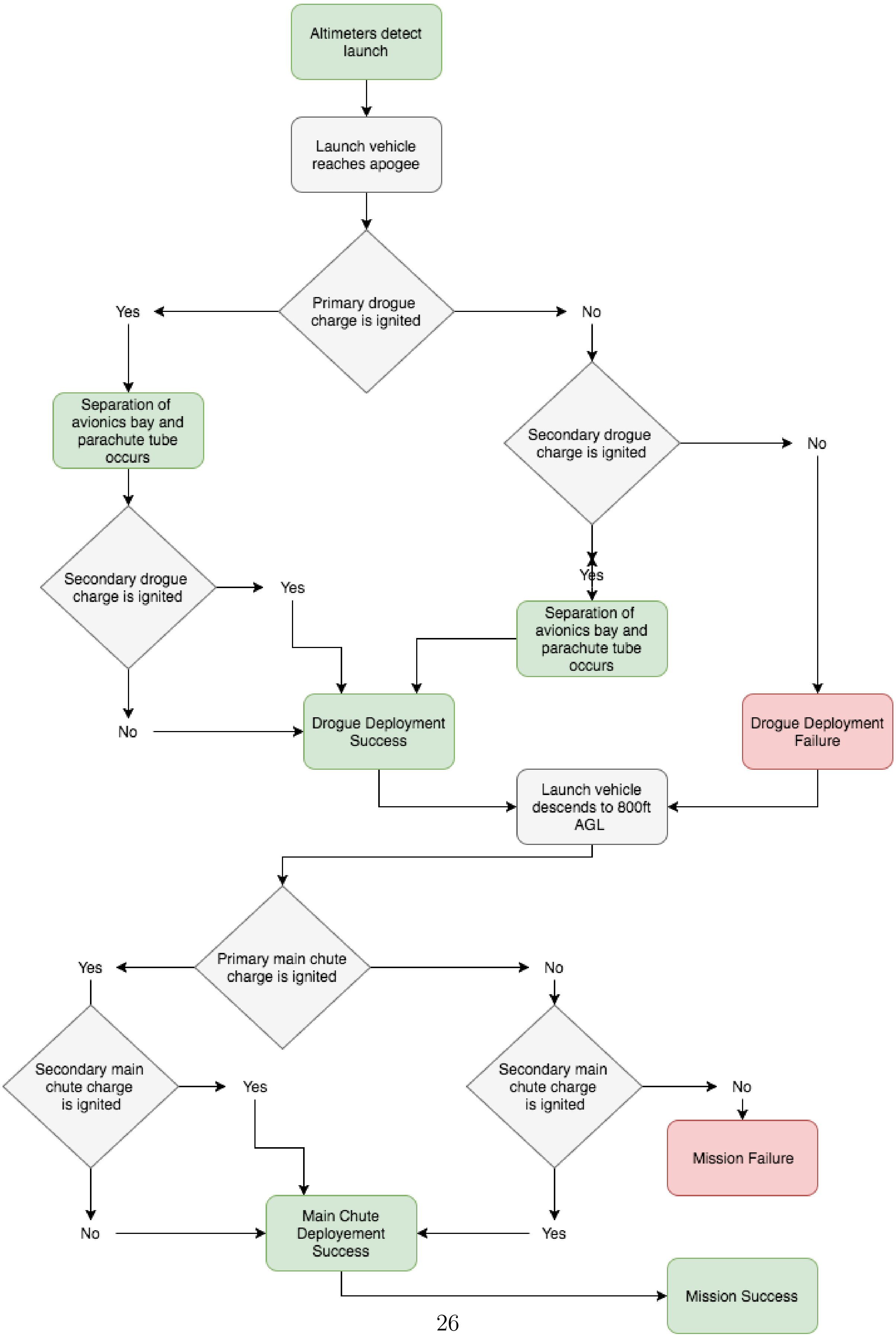


Figure 1: A flowchart of the deployment process

To ensure that the launch vehicle will safely land for every launch, the deployment system must have redundancy. This is to maximize the probability of success. First and foremost, two vials of black powder will be used, rather than one, for the separation of the launch vehicle during drogue chute deployment. Each would have enough to separate the launch vehicle on its own, and the launch vehicle is designed to withstand such structural loads. Furthermore, there are two altimeters to ensure the firing of the e-matches at the detection of the correct barometric reading. The two altimeters will simultaneously and independently read the barometric data and deploy the black powder ejection charges. These, in turn, are each powered by their own 9V-Duracell battery. Finally, in order to ensure the success of the same-side dual deployment procedure, a system of two Tender Descenders in series was developed. More details are found in Figure 2.

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

1. The following orientation will be described in order beginning from the avionics bay to the transition tube.
2. Altimeters: PerfectFlite StratoLoggerCF
   - Dual deployment
   - Data storage after power shut-off
   - Audible continuity checks
   - Relays flight data via a series of beeps
   - Tolerant to 2 seconds of power loss during flight
   - Resistant to false readings due to wind gusts up to 100mph
3. Two L2 Tender Descenders (TD) linked together in series
   (a) Will be designated as TD1 for the TD located closest to the Av-Bay and TD2 for the TD located after the TD2
   (b) Contains two small quick links on each side of the quick link
   (c) Will eventually contain an E-Match in each
   (d) Contains 0.5 g of Black Powder in each
4. Shock Cords
   (a) Use one length of 0.5in nylon shock cord, coated with shock cord sleeves, 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 28.25ft.

(c) MAIN-to-DROGUE (M2D): This refers to the length of shock cord between the Main Chute and the Drogue Chute. It is pulled out during the first Av-Bay and Transition section separation stage when the drogue chute catches air. Its length is 37.67ft.

(d) DROGUE-to-TRANSITION (D2T): This refers to the length of shock cord between the Drogue Chute and QL3, which is directly attached to the Transition section of the launch vehicle. Like the M2B, it is also pulled out during the first two stage separation. Its length is 3ft.

5. Quicklinks

   (a) QL1 - the one closest to the avionics bay; is connected to the following: 1) U-Bolt connected to Av-Bay, 2) Stingray Main Chute Bag, 3) B2M, 4) TD1

   (b) QL2 - the one connected to the main chute; connected to the following: 1) TD2, 2) Shock Cord to QL1, 3) Main Chute, 4) M2D

   (c) QL3 - the one connected to the drogue chute; connected to the following: 1) M2D, 2) Drogue chute, 3), D2T

   (d) QL4 - the one connected to the Transition; connected to the following: 1) D2T, 2) U-Bolt on the Transition Section Bulkhead

6. Parachutes

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

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

7. Parachute Bag

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

8. Parachute Blankets

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

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

5.4 Part Drawings

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

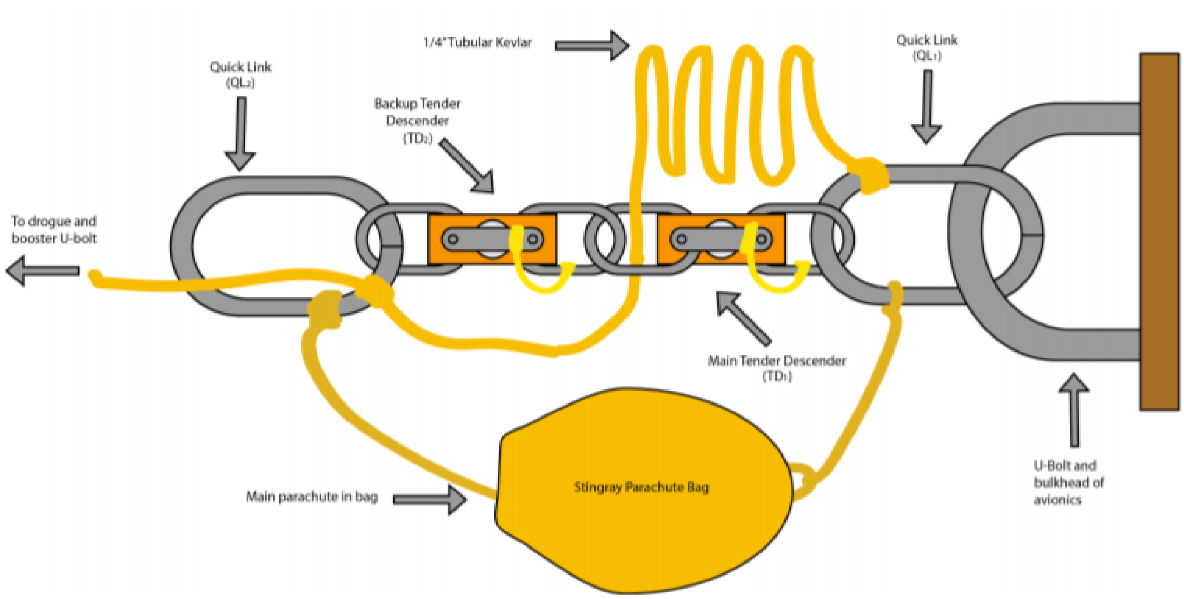


Figure 2: *Dual Deployment Orientation*

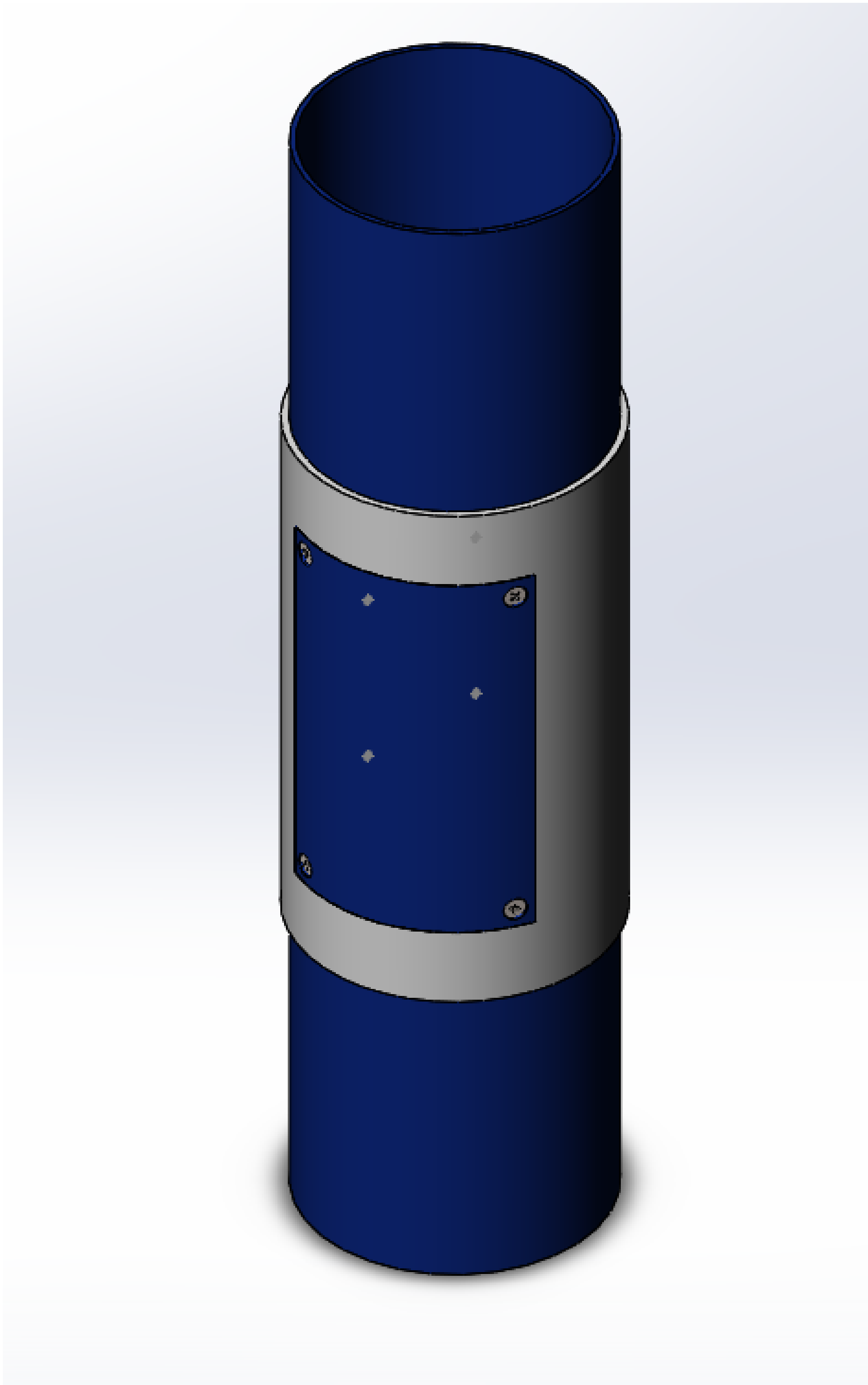


Figure 3: *Avionics Bay External Isometric View*

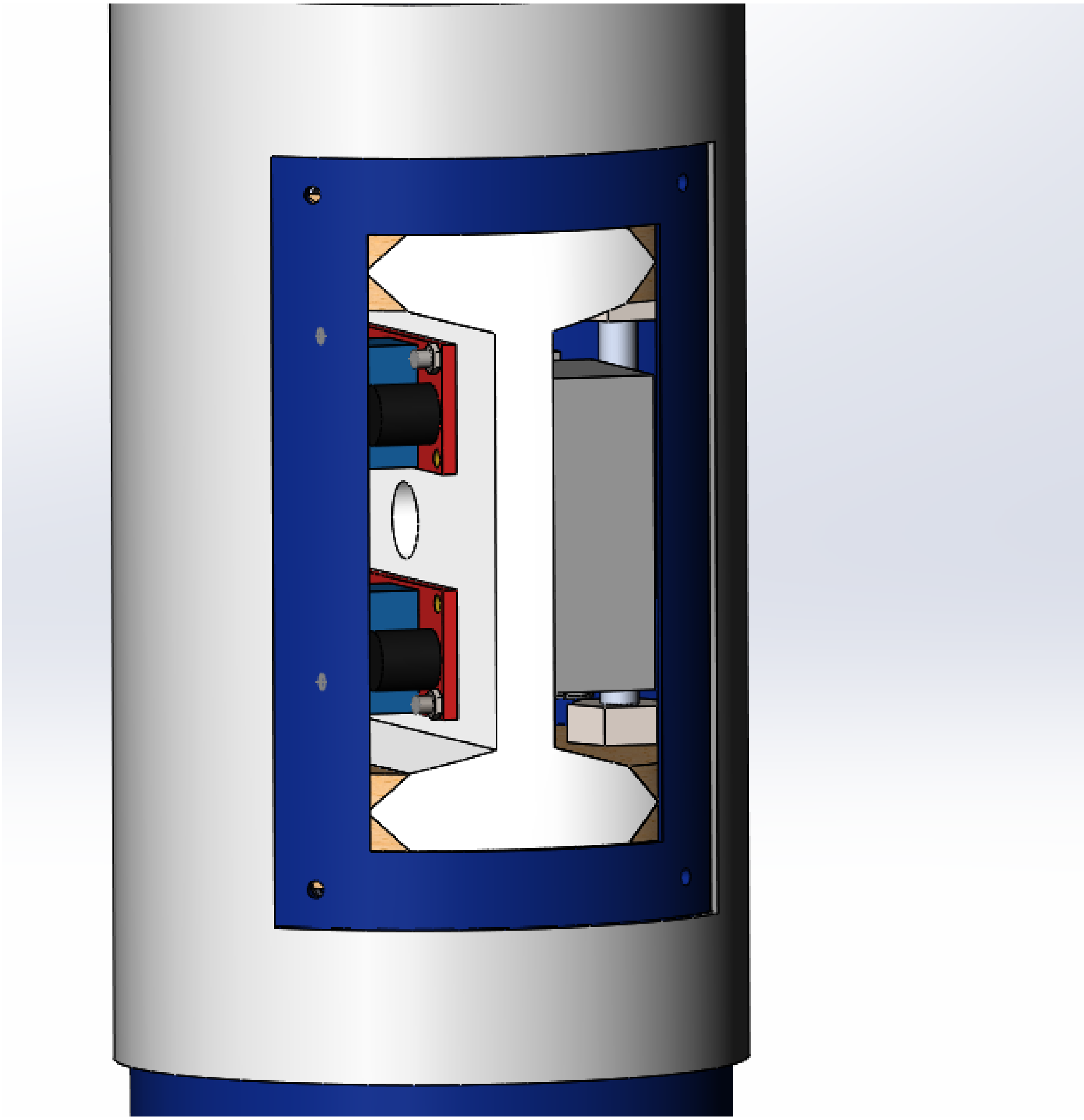


Figure 4: *Avionics Bay External View with Open Door*

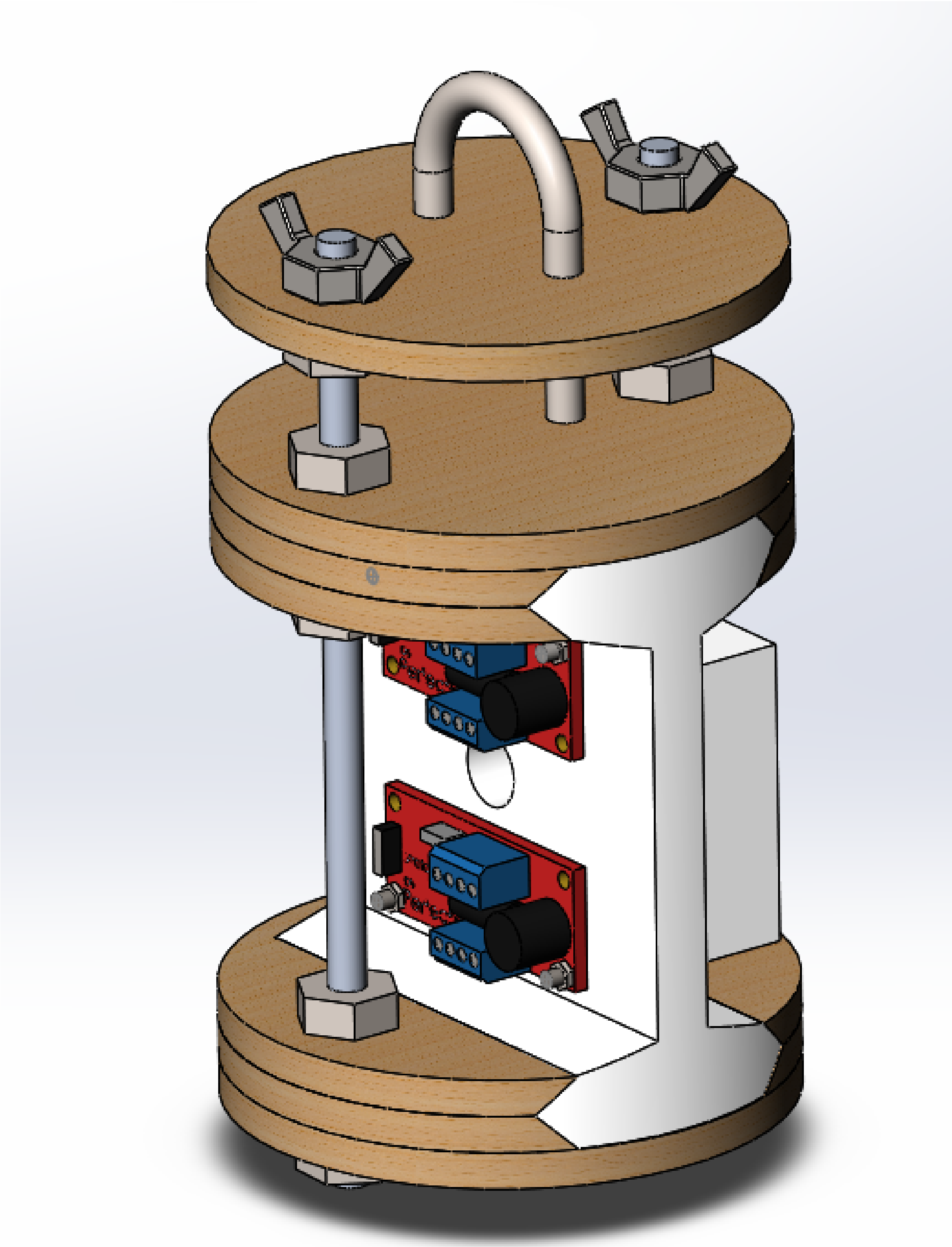


Figure 5: *Avionics Bay Internal Altimeters*

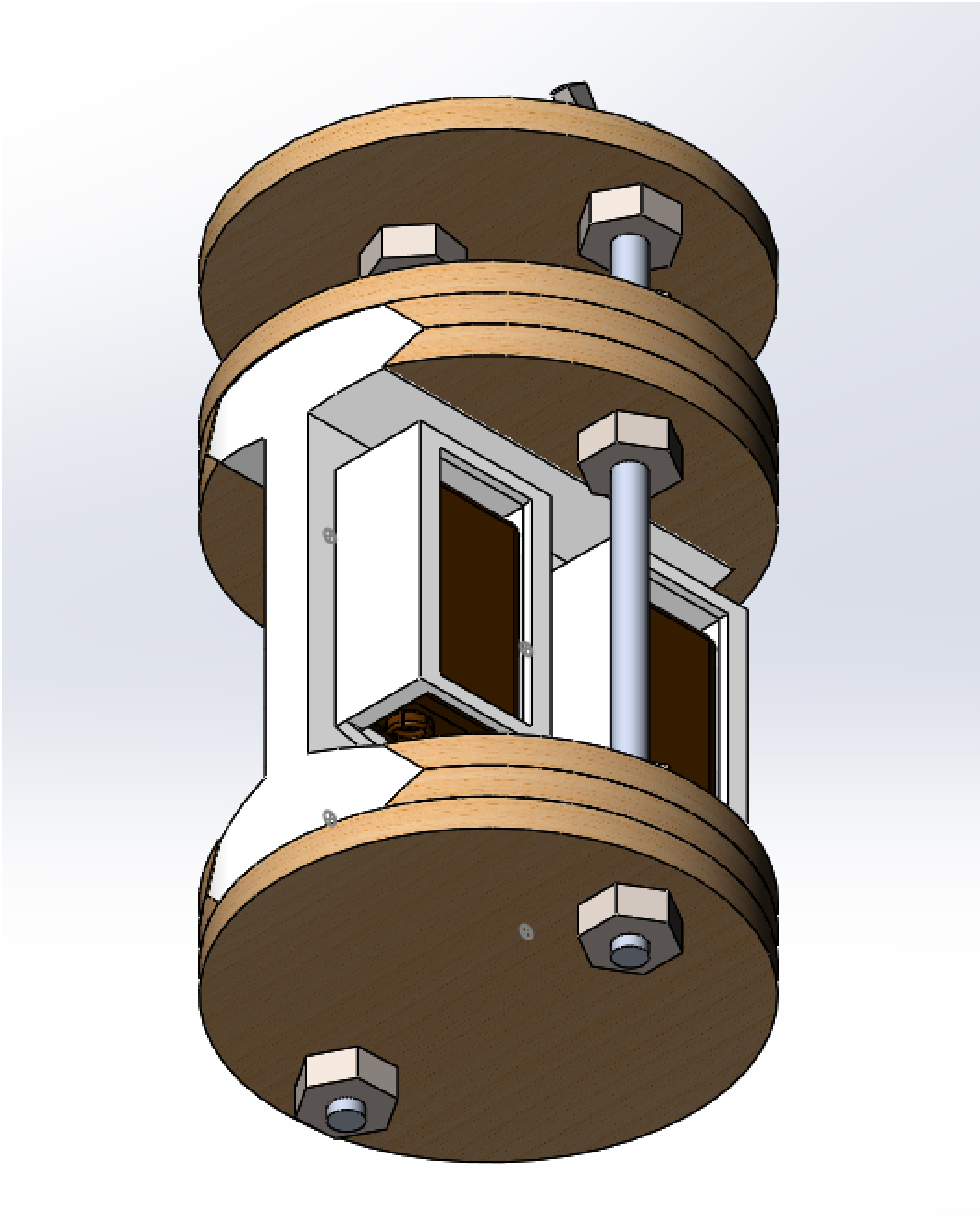
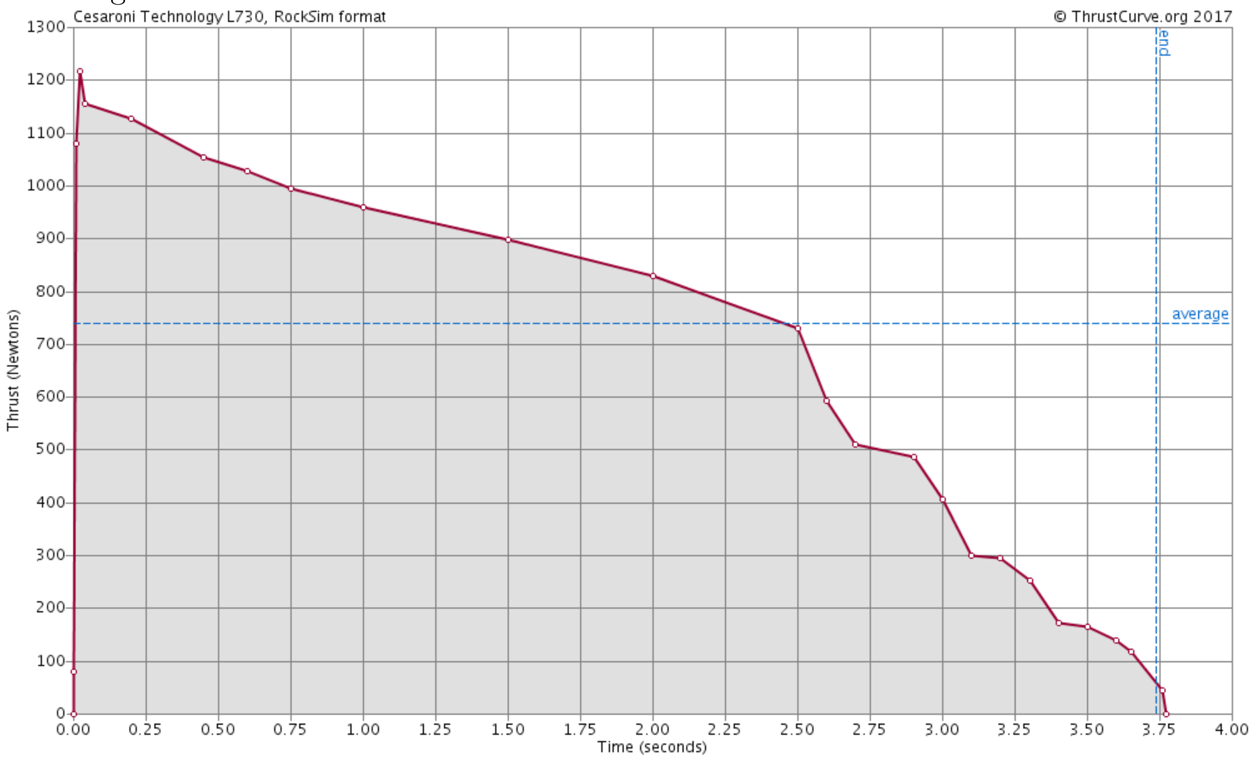


Figure 6: *Avionics Bay Internal Batteries*

6 Mission Performance Predictions

6.1 Motor Metrics

The selected motor is the Cesaroni L730-P with diameter of 54mm, length of 64.9cm total thrust of 2763.2 N, a burn time of 3.8 seconds, and a thrust profile as follows in the below figure.



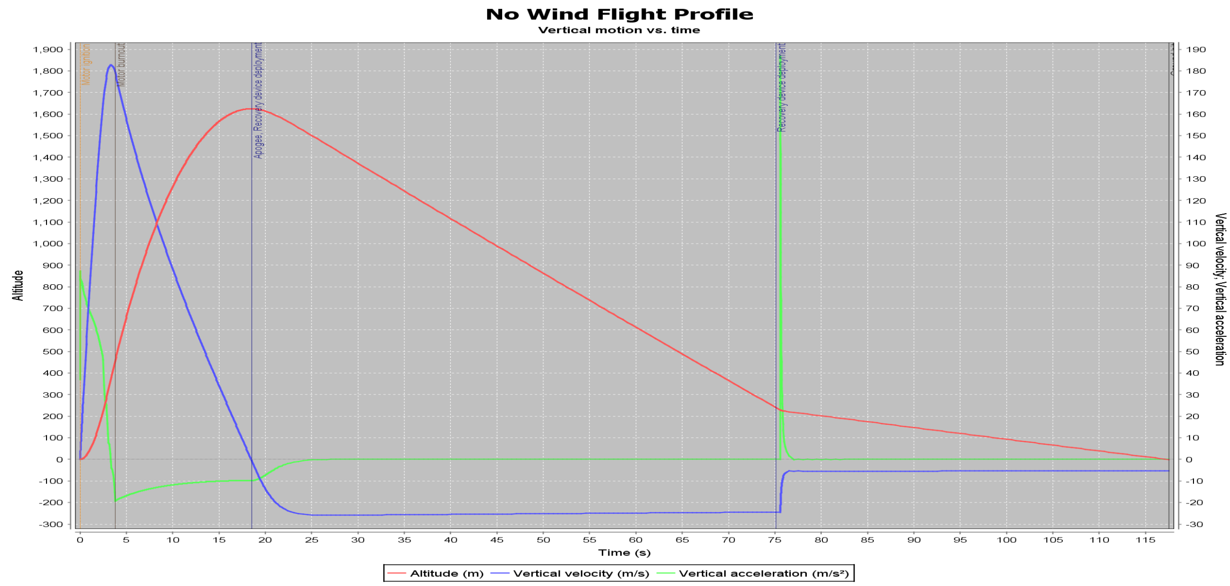
6.2 Stability

The CG and CP of the launch vehicle were both found using OpenRocket calculations. The CG is 63.8in from the nose cone and the CP is 78.3in from the nose cone. The resulting stability is 2.37 calibers, which is above the minimum stability of 2.0 specified by the Student Launch Handbook.

6.3 Flight Metrics

Under no wind conditions the vehicle reaches an apogee of 5328ft AGL and at wind speeds of 20mph the vehicle reaches an apogee of 5105 ft AGL. Therefore, the vehicle can be expected to reach an apogee very close to the optimal 5280ft AGL under any conditions. Multiple OpenRocket simulations were run to verify that these apogee values were precise.

Below is the flight profile for the condition of no wind. The maximum speed is Mach 0.54, the maximum acceleration is 8.8 G's, and the velocity off the rail is 82ft/s.



6.4 Kinetic Energy Recovery Calculations

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 24 in and a drag coefficient of 1.5, and the main parachute has a diameter or 72 in and a drag coefficient of 2.2. Using these numbers, it was calculated the launch vehicle would descend with a terminal velocity of 65.18ft/s after drogue deployment and 17.29 ft/s after main deployment. The final energy for the upper part of the launch vehicle would be 51.63 ft-lbf, and the final energy for the lower part of the launch vehicle would be 49.27 ft-lbf. This is significantly lower than the maximum allowed energy of 75 ft-lbf, so descent using these parachutes should be safe. The code used can be found in the appendix.

6.5 Drift Calculations

Upon request from the PDR presentation, drift calculations were revised and simplified. 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 a descent time of 117s.

Wind Speed (mph)	**Drift (ft)**
5	858
10	1716
15	2574
20	3432

7 Safety

7.1 Responsibilities

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

- Ensuring that construction is carried out safely. In particular, the Safety Officer will maintain MSDS documentation for various chemicals and materials that team members may be working with, will ensure that the relevant team members understand the risks and procedures involved in these materials, will identify construction risks, and will design and implement procedures for minimizing these risks.
- Ensuring that all tests and launches abide by relevant codes and regulations. In particular, the Safety Officer will design and implement procedures to abide by the NAR High Power Rocket Safety Code; NFPA 1127; FAR 14 CFR, Subchapter F, Part 101, Subpart C; and CFR 27 Part 55; and verify team compliance through observation, instruction, and team agreement to the 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.

7.2 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 Appendix D for the complete listing of launch-day procedures.

7.3 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 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					
Likelihood		Trivial	Minor	Moderate	High	Critical
	Rare	A1	B1	C1	D1	E1
	Unlikely	A2	B2	C2	D2	E2
	Moderate	A3	B3	C3	D3	E3
	Probable	A4	B4	C4	D4	E4
	Very Likely	A5	B5	C5	D5	E5

Figure 7: *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: A3

  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 possiblity of software issues.

  Verifications: Finalized procedures will have a caution message regarding scissor lift operation.

- **Risk:** Unexpected 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: D2

  Mitigations: Before any launch vehicle component has block 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 parallel to 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: Finalized procedures will 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 deplomement 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: A3

  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. Test that skid deployment operates correctly in isolation.

  Verifications: Finalized procedures will have a warning message regarding skid operation, and personnel working with the rover will be required to wear safety goggles.

- **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: A3

  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. Test that each motor and wheel assembly operates correctly; perform unit testing on movement software.

Verifications: Finalized procedures will have a warning message regarding wheel activation.

- **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:** 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 will be recorded in finalized 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: Finalized procedures will have 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: Finalized procedures will 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 to due 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: Finalized procedures will include several (redundant) steps for verifying that all attachments are properly mounted and secured.

7.4 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.

7.4.1 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; compormised 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; researh 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.

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

  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: Have thorough pre-launch and launch checklists; practice during sub-scale and full-scale launches.

  Verifications: Run a manual test and check tolerances prior to launch; conduct ground tests with black powder charges.

- **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:** Failed parachute deployment.

  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: D1

  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:** 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 bystandards, 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.

7.4.2 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 travels at too high of 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; Tender L2 Descender fails.

  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: Finalized procedures will 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 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.

Severity/Likelihood: E2

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

Verification: Ground tests.

- **Risk:** Magnetic disruption of electronics (detected pre-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: Finalized procedures will specify isolation of magnets from electronics.

- **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 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: Finalized procedures will 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.

7.4.3 Electronics Failures Modes

- **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: Finalized procedures will 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. Finalized procedures will 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: Finalized procedures will 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: Finalized procedures will 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: Finalized procedures will specify testing program for verification of gyroscope data.

7.4.4 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: Checklist item X, which ensures that the battery before installation is sufficiently charged.

7.4.5 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: C2

Mitigations: A 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: Checklist item X 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: E2

  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.

7.4.6 Ejection of the Rover

- **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: C2

  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 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: C2

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 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: C2

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

  Verifications: The ejection system will be fully tested with the rover on ground in a controlled laboratory environment before any launch testing is done.

- **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: D2

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

  Verifications: An 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 is too strong for the ejection mechanism.

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

  Severity/Likelihood: D2

  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 ejection system will be fully tested with the rover on ground in a controlled laboratory environment before any launch testing is done.

- **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 ejection system will be fully tested with the rover on ground in a controlled laboratory environment before any launch testing is done.

7.4.7 Movement of the Rover

- **Risk:** Wheels do not have sufficient torque for terrain.

  Causes: The site may have varied terrain, fine loose dirt, or mud due to rain. Other slippage can arise from disjointed contact between the axles and the wheels or motors not geared for 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 item 2e on the movement subsystem 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: C3

  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 2f on the movement 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: D3

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 2e of the movement 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 latching connectors.

  Verifications: All electronics will be inspected prior to launch per item 2c of the movement 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: C3

  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 1a of the movement checklist. The sensors and the wheels will be further tested per item 2e of the movement 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: E2

  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 item 1a of the movement checklist.

7.4.8 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: D2

  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: D2

  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. Magnet and servo effectiveness will be tested and verified in the launch environment.

7.5 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 (Al2O3), Chloro-fluoro-carbons (CFCs) and chlorine gas (Cl(g)). Although Level 2 rockets aren't comparable in emissions to (sub-orbital) rockets, they still have an impact on the local environment and the deployment envelope.
- **Launch area:** Before doing any rocket launch, it is critical to inspect the site of launch for potential fire risks, ecological environments and nearby water sources. Rocket launches can damage local ecological environments by affecting soil quality, and local ecosystems.

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

  There also should be an animal impact assessment to consider any negative impacts to animals in the blast or deployment area. (The launch site shall not be near any animal habitats.)
- **Electrical systems and batteries:** The performance characteristics of any electrical systems, including batteries shall be documented, per their manufacturers, in order to contain any malfunction. In addition, any electrical systems should be protected against human contact, even in a malfunction. Any chemical runoff from a malfunction of an electric system will have serious negative impacts to the local environment. The chemical runoff shall be immediately picked up and contained, and disposed of in an appropriate waste bin.

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

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

7.5.1 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:** 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:** Aiframe 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:** 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.

8 Payload Criteria

8.1 Designs chosen from PDR

The deployment subsystem design was altered completely from the one proposed in PDR due to safety and feasibility concerns and now consists of a black powder system as opposed to the previously proposed pneumatic piston system. A loose bulkhead in between the transition and payload sections of the airframe will push up against two 3D-printed bars glued inside the payload section once the black powder is ignited, effectively separating the two sections without damaging the payload. Next, the ejection subsystem design maintains the same scissor lift design described in PDR, with minor changes such as removing a servo, adding metal cross-members to the scissor links, and using laser-cut plastics to promote ease and improvement of assembly. The current movement subsystem design also features essentially the same rectangular prism rover model outlined in PDR, with slight variations like moving from a partially to fully-enclosed frame made for improved durability and easier manufacturing. Finally, the solar subsystem design described in PDR remains mostly unchanged, with modifications in sizing of solar cells and panels, polycarbonate pieces, and the hood of the rover as well as removing a servo due to weight and volume restrictions.

8.2 System level design review

8.2.1 Deployment subsystem

The payload deployment subsystem is contained within the 8in body portion of the airframe transition tube, which is secured to the payload section via two 4-40 shear pins. The system consists of an isolated electronics bay and an ignition chamber. A CAD drawing of the deployment subsystem can be viewed in Figure 11.

Electronics Bay

The electronics bay is located in the aft section of the transition tube. It is isolated on the aft end of the launch vehicle by the recovery bulkhead that separates the transition tube from the parachute section. The bay is isolated on the fore end via a removable bulkhead secured to a permanent centering ring with four 1/4-20 socket head cap machine screws and nuts. The permanent centering ring on the fore end and the permanent bulkhead on the aft end are secured to the airframe using JB Weld epoxy. The removable bulkhead on the fore end will have four cutouts which will each contain an Anderson PowerPole connector secured to the bulkhead with JB Weld epoxy. Each connector contains a wire that connects the ejection computer in the nosecone to the deployment computer in the electronics bay. A terminal block will be glued to the fore end of the removable bulkhead using JB Weld epoxy. A 3D-printed electronics sled will be glued to the aft end of the removable bulkhead using five minute epoxy. The sled will contain compartments for the deployment lithium polymer battery and the custom deployment electrical board. The battery will be secured to the sled using cable ties, and the board will be secured to the sled using four 4-40 machine screws.

Ignition Chamber

The ignition chamber, which is contained in fore end of the transition tube contains a loose bulkhead, a black powder charge, and a Nomex parachute blanket. The black powder charge consists of 1.5 grams of black powder and is connected to the deployment electronics computer via an e-match. The leads of the e-match are screwed to the terminal block on the fore end of the removable bulkhead of the electronics bay. The ignition chamber is isolated on the fore end via a loose bulkhead and a Nomex parachute blanket. Two 3D-printed PLA bars are glued to the interior of the payload tube 180 degrees from each other. These bars run the length of the payload tube and slot between the teeth of the rover wheels. The Nomex blanket is placed between the loose bulkhead and the two bars.

Deployment Subsystem Procedure

Once the launch vehicle has landed, a radio signal will be sent by the ground station to the ejection computer. The ejection computer will then send a signal to the deployment computer along the four wires that connect the two. Once the deployment computer receives the signal from the deployment computer, it uses an accelerometer and altimeter to verify that the launch vehicle is on the ground and stationary. If this is confirmed, the deployment computer will send a quick burst of current to the black powder charge in the ignition chamber through the terminal block on the removable bulkhead. The black powder ignites, and the rapidly expanding exhaust gases push the loose bulkhead against the 3D-printed bars glued to the payload section. The pressure from the exhaust gases exert a force on these bars, shearing the two 4-40 shear pins that connect the transition tube to the payload tube, pushing the payload section away from the transition section. The purpose of the 3D-printed bars in the deployment procedure is to mitigate the force of the black powder exhaust gases away from the rover and onto the airframe in order to prevent any damage to the rover. Additionally, the rover will be protected from the hot exhaust gases by the Nomex blanket in between the loose bulkhead and the 3D-printed bars, which will insulate and seal the payload section from the transition tube. Once the two sections are pushed apart from each other, the connectors connecting the ejection computer and deployment computer break away from each other, which will trigger the beginning of the ejection sequence. Section 8.3.2 describes the deployment computer and electrical sequences in more detail.

8.2.2 Ejection subsystem

The payload ejection subsystem consists of the scissor lift section and the electronics section. The scissor lift section of the subsystem is located in the upper half of the 18in payload tube while the electronics section is attached to the fore of the scissor lift base and protrudes into the nosecone tube. The scissor lift, when compressed, is a compact 5.5in long and extends to a length of 19.5in, therefore allowing the full ejection of the rover from the payload tube plus a 1.5in safety margin. The electronics section consists of the ejection board, radio system, and a lithium-polymer battery. An overview of the ejection subsystem can be seen in Figure 13.

Scissor Lift Section

The scissor lift section of the ejection subsystem is secured to the vehicle airframe by six 6-32 machine screws and nuts that mount into a 0.5in thick wooden centering ring. The centering ring is secured using JB Weld epoxy flush at the seam between the nosecone and payload tubes. The positioning of the scissor lift within the payload tube is seen in Figure 14. Additionally, the centering ring contains 4 cutouts at the quadrants of the ring in order to accommodate wires that need to pass through the ejection subsystem. The scissor lift itself consists of two 3D-printed PLA base and pusher plates that are connected by 24 laser-cut acetal copolymer scissor-links forming 6 sets of scissors in total. The sets of scissors are connected to each other via 40 6-32 machine screws and 20 2in long aluminum standoffs. The scissor lift is driven by a rack and pinion mechanism fabricated largely from laser-cut acetal copolymer and powered by a Hitec HS-645MG servo motor. This can be seen in Figure 15. The servo motor is mounted to the base plate using four 6-32 machine screws and nuts. The pusher plate of the scissor lift has a 5.5in diameter circular surface that pushes against the rover wheels. This surface is flat in order to evenly distribute the force onto the rover. Integrated into the pusher plate are two 4in long support structures located 180 degrees apart from each other. These supports rest on the base plate when the scissor lift is compressed, providing additional structural strength. The supports have a U-shaped cross section in order to accommodate the 3D-printed bars needed for the deployment subsystem seen in Figure 11.

Electronics Section

The electrical control components of the ejection subsystem are mounted to a laser-cut wood sled and is located inside the vehicle nosecone tube. The ejection board is secured to the sled via four 4-40 machine screws, and the sled itself is mounted on the fore side of the scissor lift base plate using four 6-32 machine screws and nuts. The sled assembly fits through the 4in diameter opening of the centering ring. Since the sled and all the electrical components are mounted to the scissor lift section, and the scissor lift section is mounted to the centering ring via screws, the entire ejection subsystem can be removed from the vehicle by removing the six screws mounting the scissor lift base to the centering ring. This allows for easy servicing of expendable electrical components such as the lithium polymer battery.

Ejection Procedure

The coordination and proper sequencing of the deployment subsystem and the ejection subsystem is crucial for successful rover deployment. As such, the signal for scissor lift extension is the separation of a breakaway wire connecting the ejection and deployment boards that occurs when the deployment subsystem separates the payload tube from the transition section. Once the signal is received, the ejection board will command the servomotor to drive the rack and pinion mechanism and extend the scissor lift. The board will then stop the lift at maximum extension as the servo motor reaches its set position. Further details of this process can be found in Section 8.3.1.

8.2.3 Movement subsystem

The payload movement subsystem consists of the rover components necessary for autonomous movement of the rover, including the wheels, chassis, motors, servos, skids, and electronics. The wheels are water-jet cut from 2lb density closed-cell cross-linked polyethylene foam in the shape of gear-like, toothed, solid wheels. Each wheel is attached to the drive shaft of its respective motor via an aluminum mounting hub; cap screws perpendicular to the mounting hub and the wheel face ensure each wheel moves following the rotation of the drive shaft. The chassis is constructed from two water-jet cut rectangular plates of polycarbonate separated by aluminum standoffs at each corner and secured with 8-32 cap screws; the top plate and screw heads can be seen in Figure 19. The aluminum standoffs are embedded in a 3D-printed PLA enclosure that serves as the rover's walls and protects the electronics from environmental hazards. Two servos—one per skid—will engage the skids once the rover is clear of the payload section of the airframe. During movement, the payload will appear as in Figure 22. Once the rover is ejected from the payload section of the airframe, a breakaway wire will trigger the autonomous navigation.

8.2.4 Solar subsystem

The payload solar subsystem consists of the individual solar cells on the hood and top of the rover and the servo, potentiometer, and magnets used to deploy these panels. Once the movement logic has executed, driving the rover forward at least 5ft and communicating this to the rover computer, the computer will drive the servo to a deployed position. The magnets on the hood will prevent the hood from opening before instructed. A potentiometer on the rod used to rotate the hood open will independently verify that the rover hood is at the proper angle. These components can be seen in Figure 20 to the side of the deployed solar panel assembly. The rover computer will also read the voltage of the panels, verifying that they are fully functional.

8.3 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 nosecone, 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 nosecone 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.

In the PDR, it was proposed that these signals would be transmitted by a current loop driver and corresponding receiver. However, after manufacturing the original ejection PCB, it was revealed that the current loop plan was unfeasible. LVDS signalling is almost as noise-resistant and is likely to be easier to implement.

8.3.1 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 receive a live stream of telemetry data from the ejection board and to send the initial remote signal to the payload to start the entire deployment and ejection process.

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

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, and then activates the scissor lift via the attached servo to push the rover out of the airframe.

8.3.2 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

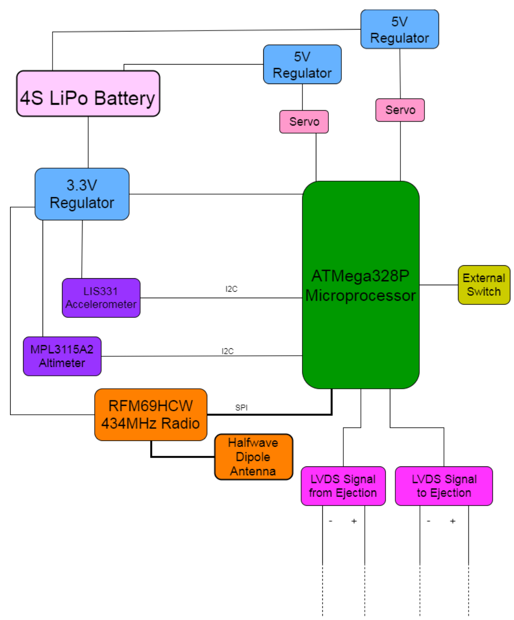


Figure 8: Ejection Board Block Diagram

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, and then allows 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.

8.3.3 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.

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 I2C-controlled gyroscope and accelerometer, and has connections for two ultrasonic distance sensors. These sensors, along with the encoders,

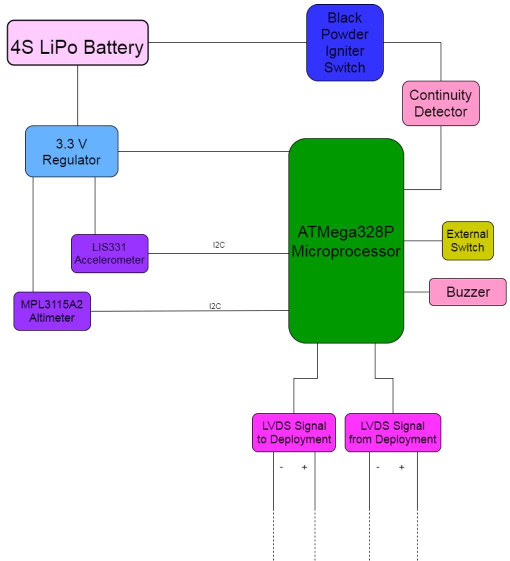


Figure 9: Deployment Board Block Diagram

allow the rover control program to detect and avoid obstacles in the rover's path and to accurately estimate its distance travelled from the airframe.

The rover board is able to control three servos: two to control the rover's 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 Figure 17.

8.4 Justification for unique aspects

8.4.1 Deployment

The proposed design for payload deployment is a result of an approach focused on risk analysis. As discussed in Section 2.3, the focus on a black powder based design alongside an alternative pneumatic design was determined to be the best strategy to ensure safe operation for both the payload and operators. Emphasis was placed on the black powder design as it presents lower risk failure modes than the alternate. Due to the large applied force required to separate the sections, the force is directed away from the payload by means of several latitudinally oriented supports radially surrounding the rover, these supports are secured to the airframe via an epoxy bond. The expected applied should be well within (>3 FoS) the load capacity of an epoxy application method. The transient bulkhead which applies the separation force will consist of a wooden layer bonded to a thin aluminum plate with JB

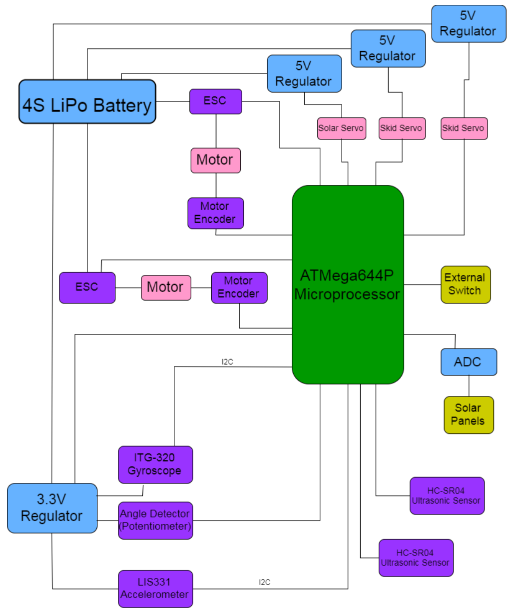


Figure 10: Rover Board Block Diagram

Weld; this allows the bulkhead to resist torsion due to thickness and to resist fracture due to the malleability of the aluminum while minimizing weight and manufacturing difficulty.

8.4.2 Ejection

The scissor lift design proposed is the result of several iterations of designs. As discussed in the PDR, the choices for the ejection subsystem fell into two categories—explosive actuation and constant-force actuation. Since a goal is to minimize the risk in the event of failure, it was decided to abandon the two explosive designs (black powder, springs), in favor of the constant-force designs. Between a telescoping plate and a scissor lift, it was decided that the scissor lift is both more robust and easily manufactured, since the actuation mechanism in a telescoping arm is much more difficult to engineer.

8.4.3 Movement

The wheel shape was chosen based on how much traction and ability to go over small obstacles. The wheels have rounded gear-like teeth to be able to grip uneven surfaces; the teeth do not have sharp corners to minimize possible tearing (between the teeth and body of the wheel) and to increase the stability of the ride. The wheel material was chosen based on expected durability and insulation of the electronics from vibrations during flight. The 2lb closed-cell polyethylene foam was chosen to reduce weight and was considered to be durable enough to survive the stresses of flight and landing. The chassis design is rectangular to provide ample mounting surface while also being easy to design and manufacture. The top and bottom plates of the chassis are constructed from polycarbonate to minimize weight, maintain structural integrity, and improve ventilation. A 12V Cytron SPG30 series motor with 120:1 gearbox was chosen because it requires DC, which can be easily sourced and is more compact and cost effective than comparable planetary gear motors. The gearbox also provides a good tradeoff between RPM and torque because high torque is necessary to navigate over obstacles, while high speed is not necessary to traverse a short distance. The skids are designed to be stored inside the rover until ejection and will unfold, one on each side of the rover. This process was chosen because it allowed the skids to be longer and more effectively counteract the torque of the motors.

8.4.4 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.

8.5 CAD & Drawings

8.5.1 Deployment

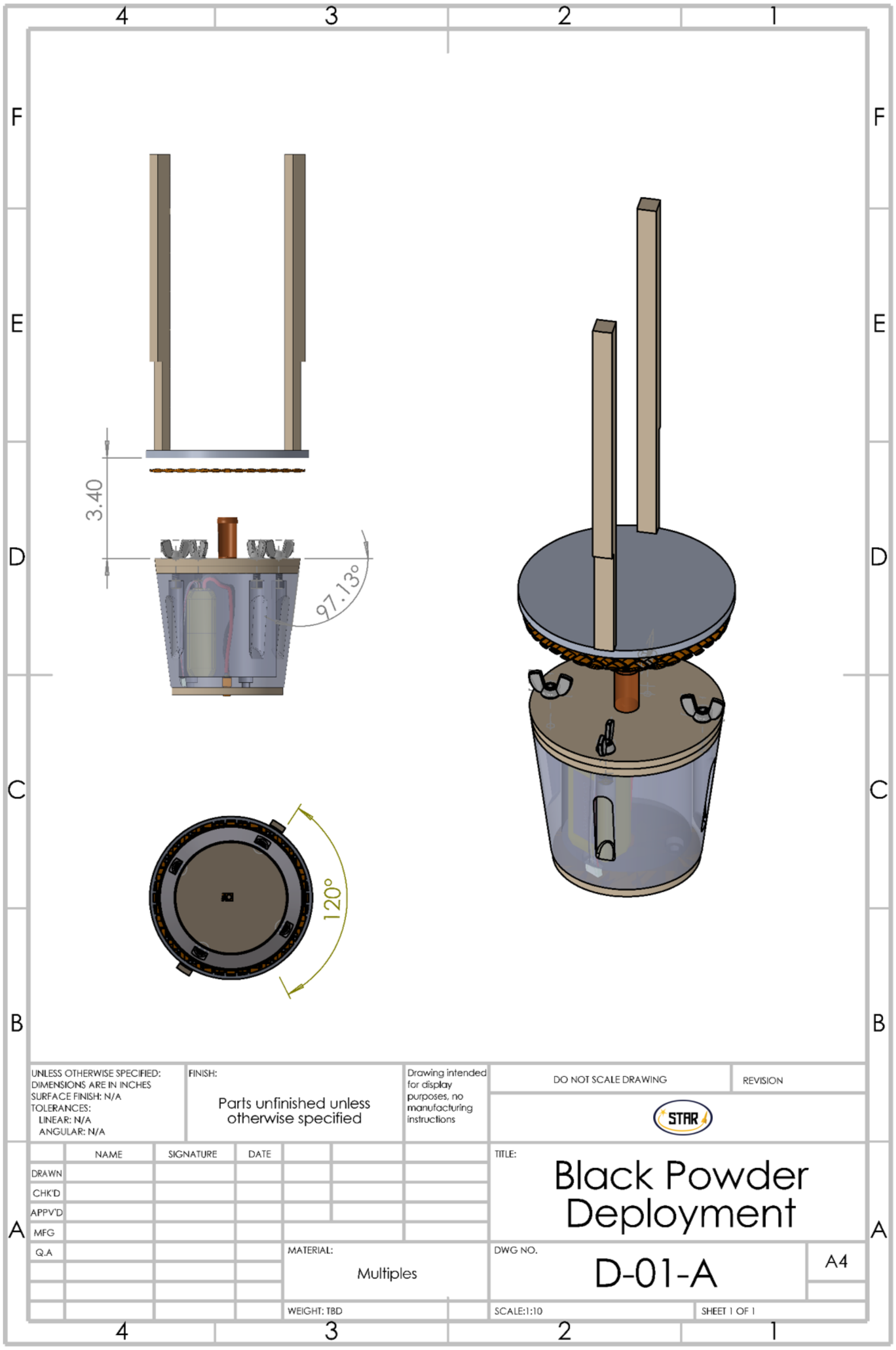


Figure 11: A view of the deployment subsystem with the airframe hidden

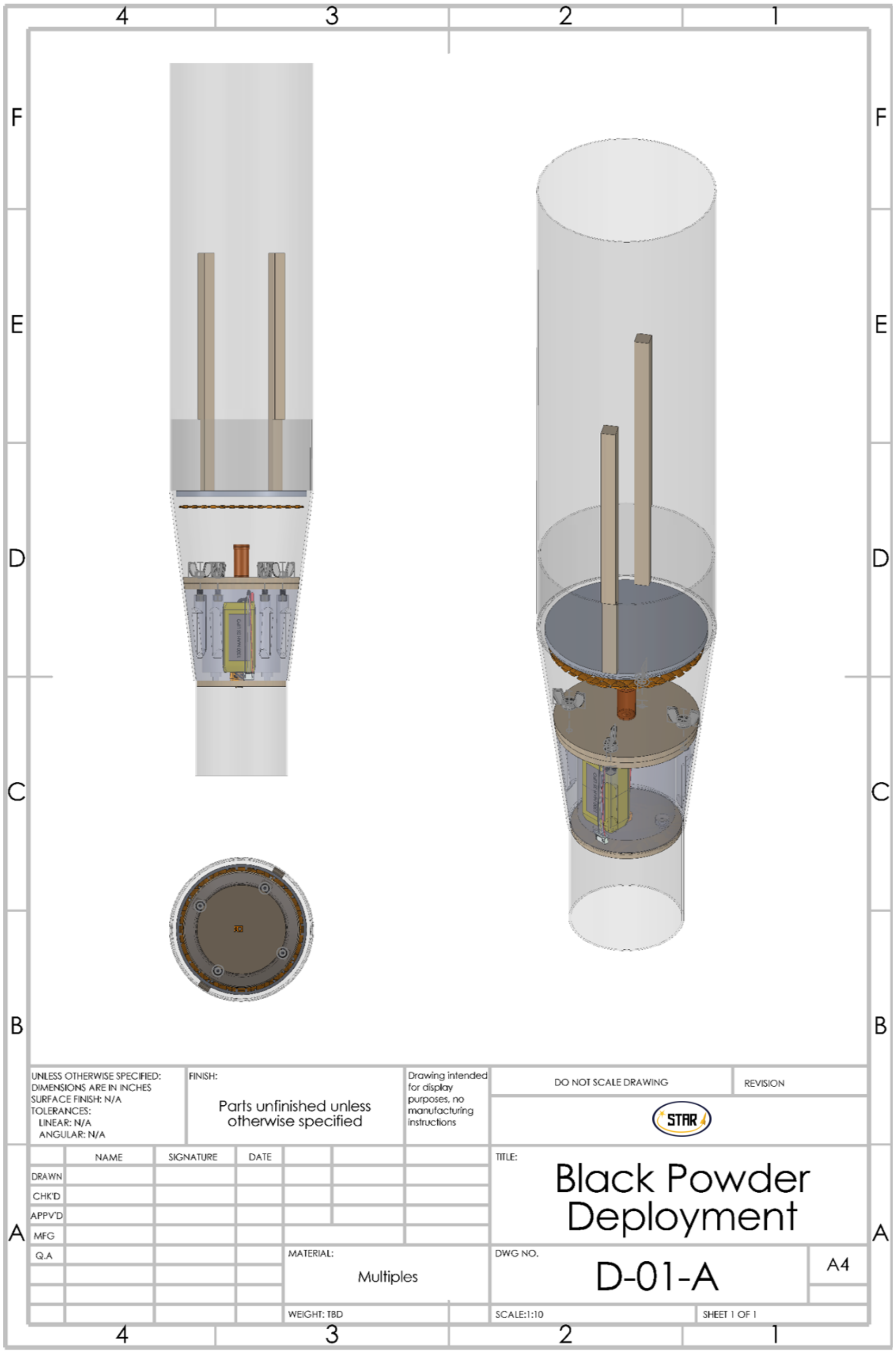


Figure 12: Payload deployment subsystem with airframe tubing visible

8.5.2 Ejection

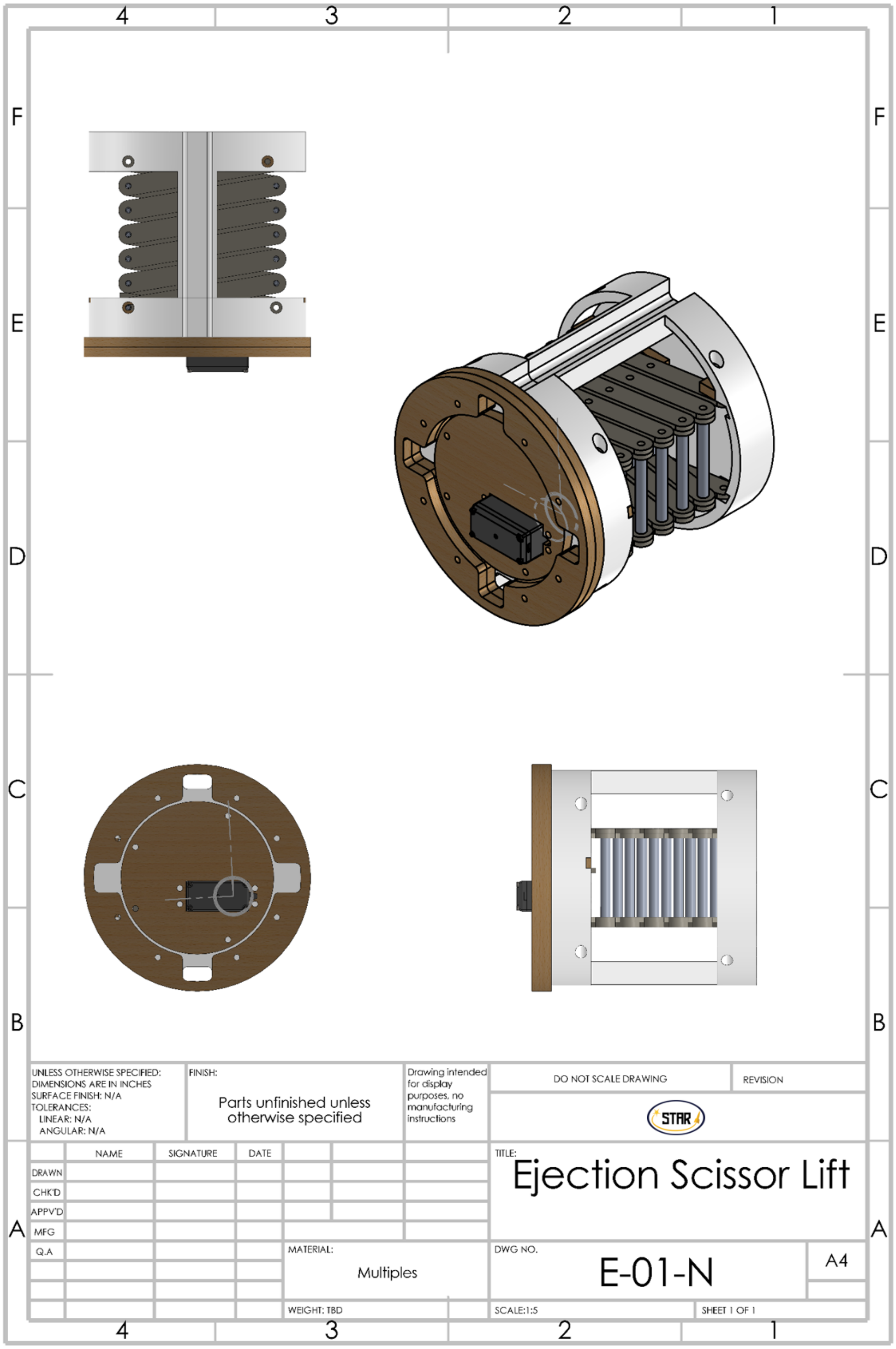


Figure 13: The scissor lift mechanism for ejection as seen from various angles

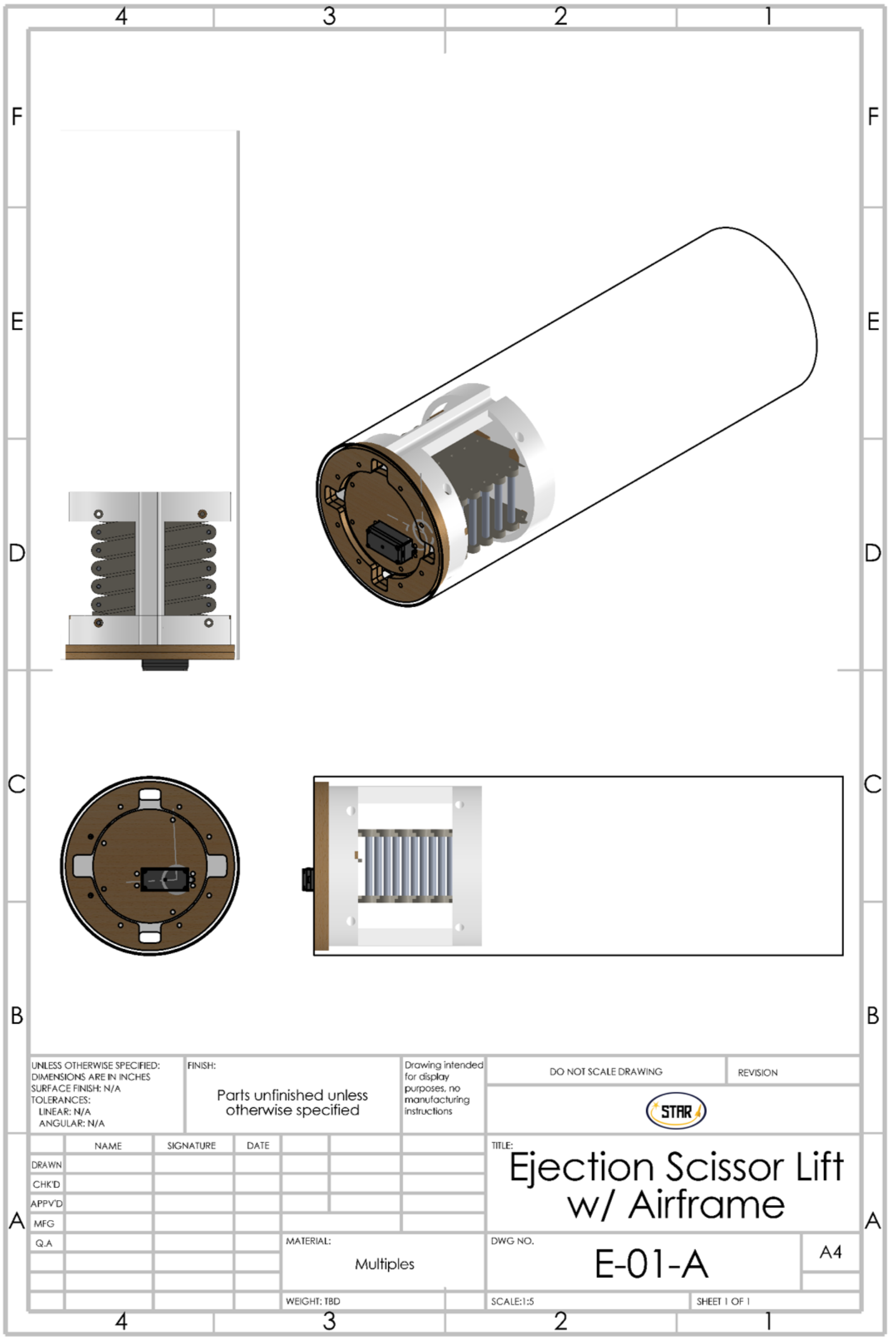


Figure 14: Payload ejection subsystem with airframe tubing visible

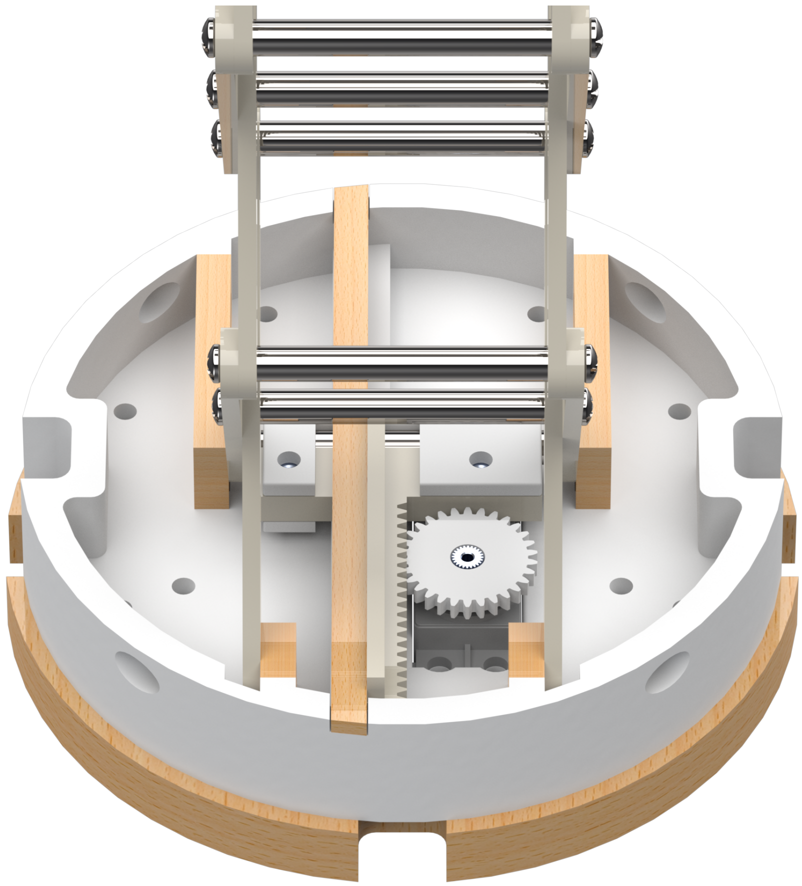


Figure 15: View of the scissor lift drive mechanism

8.5.3 Movement and Solar

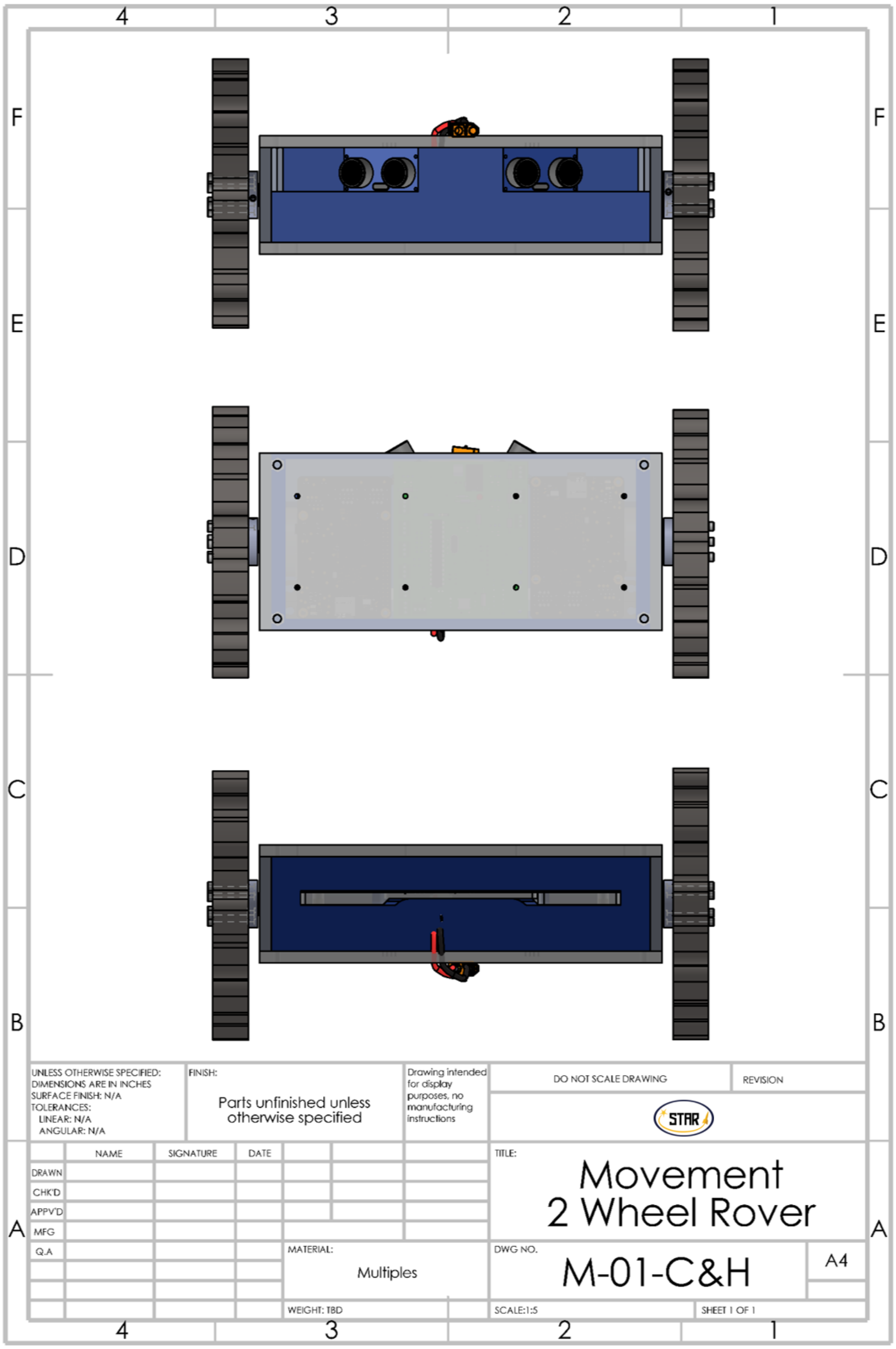


Figure 16: An overview of of the ultrasonic sensor layout and a view of the slot from which the skids deploy

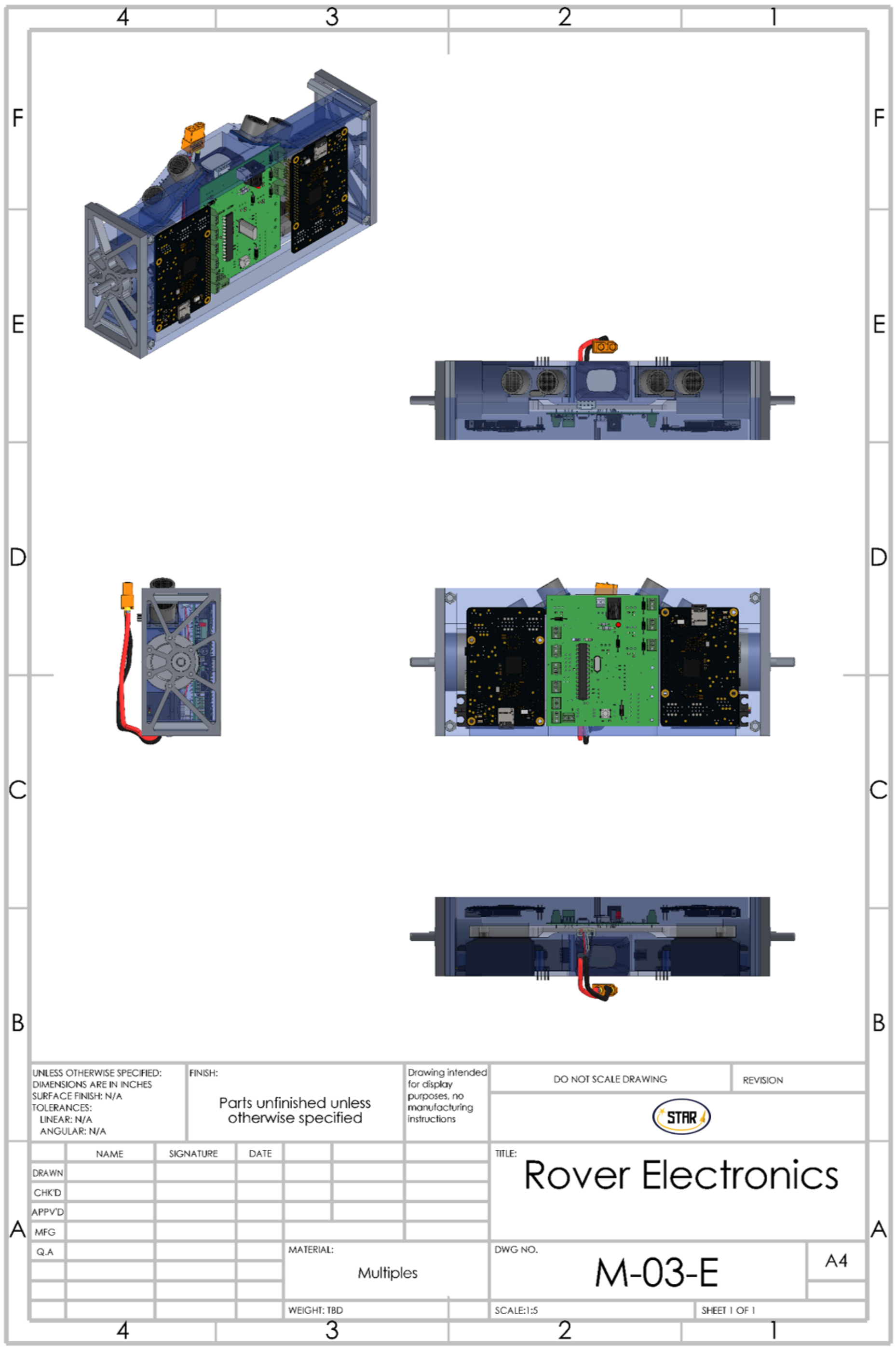


Figure 17: Internal layout of electronic rover components

8.5.4 Summary

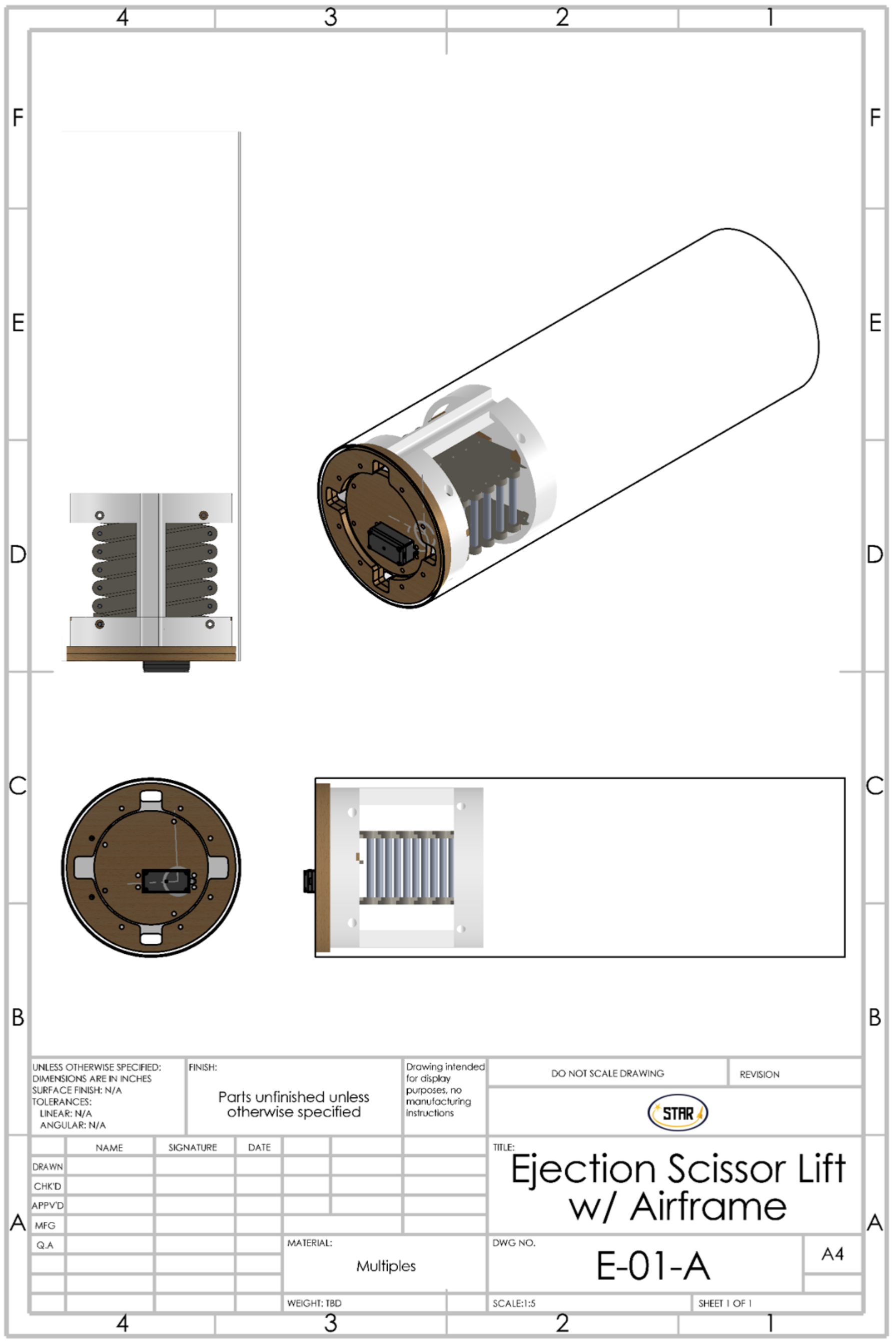


Figure 18: Full Payload Assembly

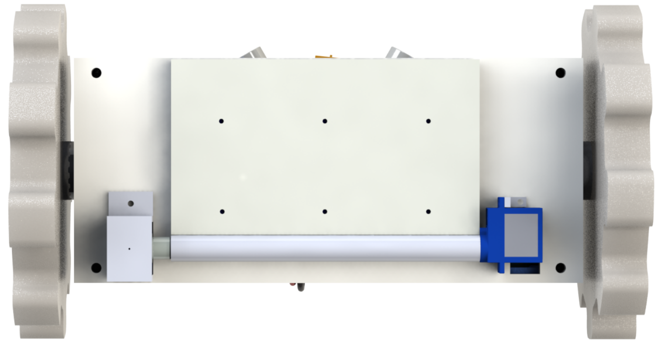


Figure 19: Top view of payload with hood closed

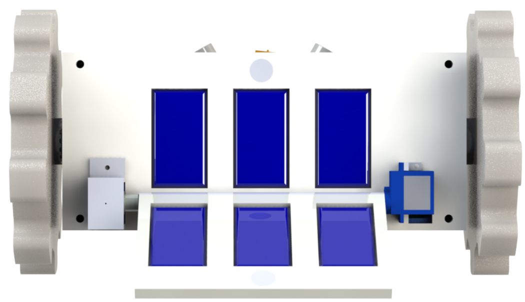


Figure 20: Top view of payload with hood open

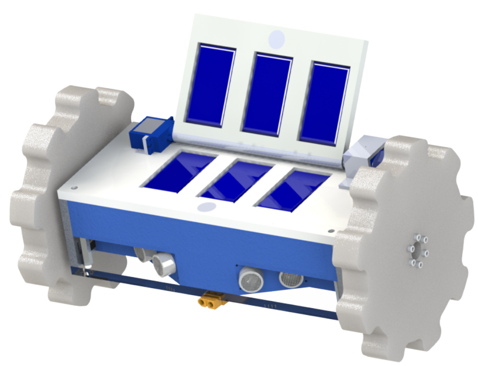


Figure 21: Isometric view of payload with hood open

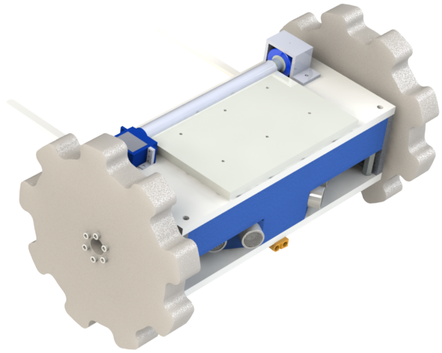


Figure 22: Isometric view of payload in movement configuration with hood closed and skids deployed

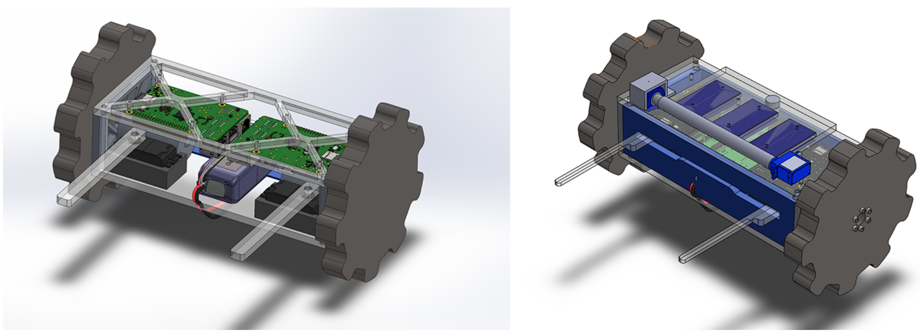


Figure 23: Comparison of rover design from PDR (left) and current (right)

9 Project Plan

9.1 Testing

9.1.1 Airframe Tests

A.1 Transition Impact Test
Test objective: Verify the transition piece is sufficiently strong to withstand landing forces.
Verification Method: Demonstration
Testing Plan: Drop transition alone from height that will allow it to experience the impulse it is expected to see in a worst case landing situation.
Success criteria: Transition survives the test with negligible structural and surface damage.
Justification: This test is necessary to ensure that Handbook requirement 2.6 (re-usability) is met.

9.1.2 Recovery Tests

R.1 Static Load Test
Test objective: Ensure the avionics bay can survive a static load
Verification Method:Demonstration
Testing Plan: Place weights incrementally on top of avionics bay.
Success criteria: Avionics bay survives the test
Justification: This test is necessary to ensure that the avionics bay will not collapse or suffer from any structural weaknesses during the launch

---

R.2 Ground Ejection Test
Test objective: Separation of the launch vehicle
Verification Method: Demonstration
Testing Plan: Place a black powder charge at the point of separation in the launch vehicle. Then put the shear pins into position and manually detonate the charge.
Success criteria: The launch vehicle separates into two different sections when the black powder is detonated
Justification: This test is necessary to ensure that the launch vehicle can successfully separate and that the proper amount of black powder is used.

R.3 Electronics Test
Test objective: Proper function of recovery system electronics
Verification Method: Inspection.
Testing Plan: Wire up and power all recovery system electronics, then wait an hour.
Success criteria: All electronics function after one hour
Justification: This test is necessary to ensure that all electronics systems will not fail during the standby period before launch. Will demonstrate compliance with Handbook Req. 2.10.

9.1.3 Payload Deployment Tests

P.D.1 Detonation testing
Test Objective: The goal of this test is to verify that the ignition method for the black powder ignites the black powder.
Verification Method: Inspection
Testing Plan: The launch vehicle will be loaded into flight configuration without the motor installed. A black powder charge and e-match will be loaded into the deployment section with the e-match leads protruding from the side of the launch vehicle through a pre-drilled hole. A 9V battery will be used to attempt to ignite the black powder. The launch vehicle will be inspected after waiting for a safety period of one minute. The black powder intended for detonation will be inspected to see if any of it remains or if it all exploded.
Success Criteria: Success is if all of the black powder explodes as intended when triggered.
Justification: This test is necessary because the separation relies upon the detonation of

the black powder. As such the black powder must detonate reliably and completely to ensure separation and safety when recovering the launch vehicle.

P.D.2 Remote Trigger Radio testing
Test Objective: The goal is to ensure that the remote trigger radio effectively ignites the black powder immediately after the signal is sent.
Verification Method: Demonstration
Testing Plan: This will be tested at the full-scale launch prior to launching the rocket. The payload will be loaded into the payload section and attached to the rocket using two 4-40 shear pins. The black powder will also be loaded into the rocket. A radio signal will be sent from the ground station to the rocket and team members will visually confirm or deny that the radio signal successfully triggered the deployment sequence. In order to verify that the radio link detonation does not have a delay, a member will remain in contact with members at the radio detonation station via cell phone and will visually verify that the detonation occurs upon the signal. The observing member will be standing at a safe distance of at least 30ft and will be located perpendicular to the main axis of the launch vehicle such that the nose cone is facing 90 degrees away from them.
Success Criteria: This test is considered a success if detonation occurs after the signal is sent over the radio.
Justification: In order for the launch vehicle to separate deployment must work across the radio gap which will exist on the launch site. Additionally, this is needed to ensure that when the launch vehicle is recovered there will not be any black powder left in the launch vehicle, which could pose a safety hazard.

P.D.3 Separation Distance testing
Test Objective: The objective of this test is to measure how far the payload section separates from the rest of the launch vehicle upon detonation in various conditions.
Verification Method: Demonstration and Inspection
Testing Plan: The launch vehicle will be loaded into flight configuration without the motor installed. The launch vehicle will then be placed on flat ground. A black powder charge and e-match will be loaded into the deployment section with the e-match leads protruding from the side of the launch vehicle through a pre-drilled hole. A 9V battery will be used to attempt to ignite the black powder. After detonation of the charge the distance between the aft end of the payload and the fore end of the transition section will be measured.
Success Criteria: This test is considered successful if the payload section separates at least 15in from the rest of the launch vehicle. This distance is the 150 percent of the rover length which ensures that there is enough clearance for the rover to exit the payload tube without interfering with the remainder of the rocket.
Justification: This test is needed to verify that the rover will have enough space to be pushed all the way out of the launch vehicle without interfering with the transition section. This is needed so the scissor lift designed to push the rover out of the launch vehicle will have minimal load.

P.D.4 Rover Shield testing
Test Objective: The objective of this test is to confirm that the Nomex blanket rover

shield protects the rover from the hot black powder exhaust gases.
Verification Method: Demonstration and Inspection
Testing Plan: The deployment sequence will be fully run with the sub-scale dummy rover in the payload section instead of the full-scale rover. A black powder charge will be placed into the transition section and will be manually ignited using a 9V battery. After detonation occurs, the dummy rover will be removed from the payload section and inspected for burn marks and damage.
Success Criteria: This test is considered successful if there are no burn marks and there is no visible damage to the dummy rover.
Justification: This test is needed to verify that the deployment sequence will not physically harm the rover and its internal electronics.

9.1.4 Payload Ejection Tests

P.E.1 Frame Load-bearing Capacity
Test objective: The objective of the test is to measure the amount of force the scissor lift can withstand directly before collapsing.
Verification Method: Analysis and Demonstration
Testing Plan: Finite element analysis will be conducted on the 3D model of the frame in SolidWorks. Furthermore, a physical test will be conducted on the flight spare scissor lift. The scissor lift will be placed vertically resting on the base plate and in the compressed position. Individual 100g weights will then be placed onto the scissor lift. As each mass is placed, the 3D-printed supports will be inspected, focusing on the layer integrity of the supports and the alignment of the supports and the base plate. The masses will be added until a factor of safety of 2 is reached.
Success Criteria: 3D-printed support structures between top and bottom plates are intact and correctly aligned with the base plate after force is applied.
Justification: It is important that the scissor lift be able to withstand compressive forces applied onto it. Although it is anticipated that there will be little to no force coming from the deployment subsystem, the scissor lift must still withstand compressive forces resulting from in flight motion and vibrations. Furthermore, the scissor lift must demonstrate some resilience in the event the deployment subsystem support bars fail.

P.E.2 Lift Actuation Force
Test objective: The objective of the test is to measure the amount of direct force the scissor lift can apply to the payload during the ejection stage.
Verification Method: Demonstration
Testing Plan: The flight spare scissor lift will be mounted inside the payload tube. The payload tube will then be placed on a 20 degree incline, with the nosecone facing down. This is to represent the worst-case ground conditions and ejection scenario. A weight equal to 2 times the weight of the rover, 8lb, will then be placed into the payload tube. The scissor lift will then be commanded to fully extend and eject the mass out of the payload tube. A mass of 2 times the rover weight is again used to represent the worst-case scenario. This test will

then be repeated 5 times in succession.
Success Criteria: The scissor lift, positioned on a 20 degrees incline, is able to completely eject a mass two times the rover weight, 8lb, in 5 consecutive test trials.
Justification: Since it is impossible to accurately estimate the force generated on the plate purely by the torque generated by the servo (due to the uncertainty in frictions, moments, and mechanical advantage) it is simpler to quantitatively test the ejection lifting capabilities directly.

P.E.3 Linkage Lateral Flex
Test Objective: The objective of the test is to measure potential lateral deflection of the linkages within the scissor lift.
Verification Method: Inspection
Testing Plan: The scissor lift will be positioned horizontally on the edge of a table, in the extended position. The base plate will be mounted and secured to the table, while the pusher plate will be cantilevered over the ground. A ruler measuring vertically from the surface of the table to the ground will measure the amount of deflection in the extended scissor lift at the pusher plate. The entire scissor lift assembly will then be rotated along its axis in increments of 90 degrees in order to obtain 4 total deflection measurements. The rotation is needed because the amount of deflection will vary depending on the orientations of the scissor links to the ground.
Success Criteria: Maximum deflection in any orientation does not exceed 2in.
Justification: During the construction and testing of the sub-scale ejection mechanism, it was noticed that the two columns of linkages in the scissor lift could flex laterally (towards and away from each other). To mitigate this, crossbeams have been placed between each set of linkages to maintain a constant width. This test measures the effectiveness of the crossbeams in mitigating deflection and flex.

P.E.4 Linkage Vertical Flex
Test objective: The objective of the test is to measure potential vertical extension of the linkages without actuation.
Verification Method: Inspection.
Testing Plan: The scissor lift will be positioned horizontally in the compressed position. The base will be secured, leaving the pusher plate free to move. A ruler will then be positioned horizontally, starting from pusher plate. With the servo motor powered off, the pusher plate will then be pulled away from the base plate until the powered off servo begins to turn. The distance that the pusher plate is pulled away from the base will then be measured by the ruler. This test will be repeated ten times, and the measured distance will be averaged.
Success criteria: The average distance of separation must not be greater than 2in.
Justification: During the construction and testing of the sub-scale ejection mechanism, it was noticed that the lift was able to extend and retract a certain amount from the "completely retracted" position without the actuation of the servo or the movement of the bottom linkages. Furthermore, upon actuation of the servo, the links closer to the bottom would move more than those at the top, due to friction lost in each joint. The intention in the new design is to increase stiffness, thereby mitigating the amount of flex present in the scissor. The friction in each joint is reduced by changing the fastener type and applying WD-40 to

each joint.

P.E.5 Lift Range of Motion
Test objective: Measure the total distance between the minimum and maximum extension of the scissor lift.
Verification Method: Inspection.
Testing Plan: The scissor lift will be positioned horizontally, first in the compressed position. The base will be secured, leaving the pusher plate free to move. A ruler will then be positioned horizontally, starting from base plate and extending towards the pusher plate. The compressed length of the scissor lift will then be recorded. The scissor lift will then be commanded to fully extend. The extension length of the scissor lift will then be recorded. From the extended and compressed lengths, the difference between the two lengths will be calculated.
Success criteria: Distance between minimum and maximum extension of scissor lift is enough to cover the length of the rover, 10in, plus a 20% margin of safety for a total difference of 12in.
Justification: For the lift to be able to completely push the rover out of the payload tube, it is necessary for the lift to extend the length of the rover. However, this assumes that the rover is completely flush with the opening in the payload section. Since this may not be the case, due to in flight motions and vibrations, it would be prudent for the lift to have a factor of safety on the distance it can push the rover.

9.1.5 Payload Movement Tests

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 succesful 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 the 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.
Results: 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.

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.

P.M.4 Hill Climb Test
Test objective: To evaluate the rover's ability to climb slopes.
Verification Method: Observation
Testing Plan: The rover will be placed at the base of a 10 degree inclined ramp, and will be programmed to attempt to drive up the ramp. Upon a successful trial, the angle of the ramp will be increased by 5 degrees. When the rover is no longer able to traverse the incline, record the highest incline angle that the rover was able to traverse.
Success criteria: The test is a success if a maximum incline angle for the rover is determined.
Justification: This test is necessary because the rover may have to traverse uneven terrain in addition to rough terrain and small obstacles. Determining the rover's hill climbing ability is important in case modifications must be made in order to successfully traverse terrain like the launch area.

P.M.5 Rover Actuation Test
Test objective: To verify the robustness and reliability of the rover actuation process.
Verification Method: Observation
Testing Plan: The rover will be turned on and flashed with the program to be used during the competition launch, and placed on the ground while connected to a serial monitor. The external tactile switch will be depressed and released, simulating the ejection sequence. The response of the rover will be observed, noting whether it successfully outputs an activation message on the serial monitor and deploys its skids.
Success criteria: Upon the correct actuation of the switch, the rover enters its movement state and deploys skids over at least five trials.
Justification: This test is necessary because the successful activation of the rover relies on accurately detecting switch activation. This system must be made as reliable as possible, and modifications to the activation process may have to be made if it is not.

P.M.6 Distance Measurement Test
Test objective: To verify the rover's ability to successfully detect when it has met the distance goal.
Verification Method: Observation
Testing Plan: Begin with the rover successfully activated and in its movement mode. Mark its starting position. Allow the rover to move on its own until it comes to a rest, or fails to stop after travelling 20ft. Measure the distance the rover travelled. Connect the rover to a serial monitor and observe the distance it has measured. Additionally, verify that the rover

has entered its solar deployment mode by checking the serial output and observing panel deployment.
Success criteria: The rover stops after travelling over 5ft, reaching its goal measured distance, and enters its solar deployment mode over at least five trials.
Justification: This test is necessary because the rover must accurately ensure it has met its goal, and respond appropriately to meeting this goal, in order to complete its task.

P.M.7 Obstacle Avoidance Test
Test objective: To verify the rover's ability to detect and avoid obstacles.
Verification Method: Observation
Testing Plan: Place a soda can sized object on the ground in front of the rover. Activate the rover so that it is in its movement mode. Observed whether the rover successfully halts in front of the obstacle, turns and moves clear of it, and continues moving forward.
Success criteria: The rover stops in front of the obstacle, avoids it, and continues moving toward clearing the 5ft radius.
Justification: The rover may encounter large obstacles it cannot traverse during the competition. It must be able to avoid these obstacles or it will not be able to meet its distance goal.

9.1.6 Payload Solar Tests

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.

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.

P.S.3 Panel Deployment
Test Objective: The solar panels must not deploy unintentionally.
Verification Method: Inspection
Testing Plan: The rover will be subjected to higher than expected accelerations and vibrations to ensure the magnets will hold the hood closed until the solar panels are supposed to deploy. The rover system will be fully assembled. First, the rover will be placed on a shake table in the configuration it would be in after being ejected from the payload tube (both wheels touching the ground). The rover will be subjected to accelerations up to 15m/s. The rover will be visually inspected to make sure the hood did not deploy prematurely. If the hood does not deploy prematurely, then the rover will be placed in the payload tube and the full deployment and ejection system will be assembled and attached to the payload section of the launch vehicle. A full rover launch will be performed, involving the activation of the deployment and ejection systems. When the rover emerges from the payload tube, it will be visually inspected to make sure the hood has not deployed prematurely. The proper sequencing and reliability of this series of events will be tested by running the autonomous rover commands at least several times. The rover will be activated to drive as if it has just been ejected from the payload tube. It will drive its minimum 5ft distance over a variety of rocky, sandy, and flat terrains. After driving each time, the hood will be visually inspected to make sure it deploys only after the rover has traversed at least 5ft. The exact angle of hood rotation will be monitored with the potentiometer to verify that a consistent solar deployment is achieved.
Success Criteria: The rover hood does not rotate unless it is intentional. The panels should remain undeployed under all test stresses except when actuated by the servo.
Justification: The solar deployment will not receive points unless the panels deploy when all parts of the rover are at least 5ft away from the launch vehicle. Thus, the panel deployment system should be reliable as possible to prevent deployment prior to the fulfillment of this distance criterion.

9.1.7 Payload Electronics 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.

9.2 Requirements Compliance

9.2.1 NSL Handbook Requirement Compliance

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 student 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` 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. LaTeX 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. LaTeX 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: Simulations using OpenRocket have been used to predict the apogee of the vehicle to a reliable range. Comparing sub-scale flight results and simulations was also used to determine if any design modifications would be needed to reach this target. Further simulation methods using ANSYS software and Matlab calculations are being developed.

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: This will be verified during vehicle preparation at test launches.

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 2.37 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 82.8 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.

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 rocket has a duel deployment recovery system in which a drogue chute is deployed at apogee and a main chute is deployed at 1000ft .

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 sub-scale 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 sub-scale rocket 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 rocket sections and desired kinetic energies, we can calculate the necessary parachute sizes 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 duel 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: N/A
Plan: Using the kinetic energy calculation program, the parachutes will be effectively sized to minimize kinetic energy, but not make the parachutes too large as to allow the rocket sections to drift outside the target area.

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 rocket.

- **3.10.1 : Any rocket 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 rocket 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 rocket 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 rocket, 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 rocket, 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 rocket, 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 rocket, 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 rocket, 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 hime 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.

9.2.2 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.

9.2.3 Team Requirement Compliance

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, batteries, 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 within5ft, 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

additionalhardware 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.

9.3 Budgeting and Timeline

9.3.1 Airframe Budget

Sub-scale				
Component	Vendor	Component Cost	Taxes and Shipping	Total Cost
nose cone	Apogee Components	\$37.95	\$5.67	\$43.62
Payload Tubing	Apogee Components	\$38.95	\$5.67	\$44.62
Aft Tubing	Apogee Components	\$26.95	\$5.67	\$32.62
Transition	Fibre Glast	\$18.12	\$4.98	\$23.10
Boat tail	Fibre Glast	\$18.12	\$4.98	\$23.10
Forward Couplers	Apogee Components	\$10.95	\$5.67	\$16.62
Aft Couplers	Apogee Components	\$18.50	\$5.67	\$24.17
Motor Tubing	Public Missiles	\$14.99	\$4.95	\$19.94
Motor Retainer	Apogee Components	\$31.03	\$5.67	\$36.70
Glue/Expoxy	Fibre Glast	\$44.95	\$9.95	\$54.90
Aerotech J800T Motor	Bay Area Rocketry	\$92.99	\$0	\$92.99
Fiberglass Fins (3)	Public Missiles Ltd.	\$38.00	\$3.27	\$41.27
			Subtotal	\$453.65
Full-scale				
nose cone	Public Missiles	\$104.99	\$7.48	\$112.47
Payload Tubing	Apogee Components	\$66.95	\$6.84	\$73.79
Aft Tubing	Apogee Components	\$77.90	\$6.84	\$84.74
Transition	Fibre Glast	\$18.12	\$4.98	\$23.10
Boat tail	Fibre Glast	\$18.12	\$4.98	\$23.10
Forward Couplers	Apogee Components	\$19.95	\$6.84	\$26.79
Aft Couplers	Apogee Components	\$39.95	\$6.84	\$46.79
Motor Tubing	Public Missiles	\$18.99	\$7.48	\$26.47
Motor Retainer	Apogee Components	\$58.85	\$6.84	\$65.69
Glue/Expoxy	Fibre Glast	\$44.95	\$9.95	\$54.90
Rail Button Material	Metals Depot	\$3.87	\$8.05	\$11.92
Cesaroni Pro54-6XL Casing	Bay Area Rocketry	\$106.95	\$15.00	\$121.95
Cesaroni L730 Motor	Bay Area Rocketry	\$165.95 x 2	\$62.00	\$393.90
Fiberglass Fins (3)	Public Missiles Ltd.	\$38.00	\$3.27	\$41.27
			Subtotal	\$1106.88
			Total	\$1560.53

9.3.2 Recovery Budget

Component	Vendor	Unit Cost	Quantity	Total Cost
Main Altimeter	N/A	$0	2	$0
Back-up Altimeter	N/A	$0	2	$0
Duracell 9V Battery	N/A	$3	5	$15
TeleGPS	N/A	$0	1	$0
L2 Tender Descender	N/A	$0	2	$0
Large Heat Blanket	Apogee Rockets	$70	1	$70
24in Torodial Drougue	N/A	$0	1	$0
72in Torodial Main	N/A	$0	1	$0
Sub-scale drougue	N/A	$0	1	$0
Sub-scale main	N/A	$0	1	$0
$\frac{1}{4}$in tubular kevlar	N/A	$0	150ft	$0
Small heat blanket	Apogee Rockets	$50	1	$50
5.5" Parachute deployment bag	Fruity Chutes	$40	1	$40
Marlinespike	Jig Pro Shop	$29.99	1	$29.99
Rip-stop nylon repair tape	N/A	$15	1	$15
Black powder	N/A	$.13	40g	$5
$\frac{1}{4}$in Threaded Aluminum Rods	N/A	$0	2	$0
U-bolt	N/A	$0	1	$0
Plywood 18inx24in	Jacob's Hall (campus)	$3	1	$3
High Fidelity 3D Prints	Jacob's Hall (campus)	$50	2	$100
Wire	Ace Hardware	$2	5ft	$10
$\frac{1}{4}$-20 Screws	N/A	$0	4	$0
$\frac{1}{4}$-20 Nuts	N/A	$0	4	$0
2-56 Screws	N/A	$0	16	$0
2-56 Nuts	N/A	$0	16	$0
Misc		N/A	N/A	$30
			Total	$367.99

9.3.3 Payload Budget

Deployment: Sub-scale				
Component	Vendor	Component Cost	Taxes and Shipping	Total Cost
Accelerometer	Sparkfun	$10.00	$2.00	$12.00
Altimeter	Sparkfun	$15.00	$2.00	$17.00
Schrader Valve to NPT	McMaster-Carr	$4.00	$1.00	$5.00
Pressure Relief Valve	McMaster-Carr	$6.00	$1.00	$7.00
3D Printed Pressure Plates	Manufactured	$0.00	$0.00	$0.00

Breakaway Connector	Molex	$0.50	$0.50	$1.00
NPT piping and Connectors	Pre-owned	$0.00	$0.00	$0.00
PVC Tubing and Caps	ACE	$20.00	$0.00	$20.00
			Subtotal	$62.00
Ejection: Sub-scale				
Component	Vendor	Component Cost	Taxes and Shipping	Total Cost
Push-in rivets	McMaster-Carr	$10.00	$2.00	$12.00
3D Printed Lift Structure	Pre-owned	$0.00	$0.00	$0.00
Servo	Servo City	$30.00	$5.00	$35.00
Servo gear	Servo City	$4.00	$1.00	$5.00
Accelerometer	Sparkfun	$10.00	$2.00	$12.00
Altimeter	Sparkfun	$15.00	$2.00	$17.00
Radio	Sparkfun	$4.00	$1.00	$5.00
			Subtotal	$86.00
Movement: Sub-scale				
Component	Vendor	Component Cost	Taxes and Shipping	Total Cost
Polyethylene Wheels	EPlastics	$12.00	$3.00	$15.00
Lexan Plate	EPlastics	$18.00	$2.00	$20.00
Washers and Locking Nuts	Pre-owned	$0.00	$0.00	$0.00
			Subtotal	$35.00
Solar: Sub-scale				
Component	Vendor	Component Cost	Taxes and Shipping	Total Cost
Solar Panels	AMX3D	$33.00	$2.00	$35.00
Servo	Hobby King	$3.00	$1.00	$4.00
Potentiometer	Digikey Electronics	$12.00	$2.00	$14.00
			Subtotal	$43.00
Deployment: Fullscale				
Component	Vendor	Component Cost	Taxes and Shipping	Total Cost
Laser Cut Plates	Pre-owned	$0.00	$0.00	$0.00
Nomex Shield	Sunward	$14.00	$1.00	$15.00
Nuts and bolts	Pre-owned	$0.00	$0.00	$0.00
Printed Circuit Board	Bay Area Circuits	$55.00	$5.00	$60.00
Polyethylene Tubing	PureSec	$7.00	$2.00	$9.00
Battery	Hobby King	$14.00	$1.00	$15.00
Pneumatic Piston	Fabco	$15.00	$2.00	$17.00
Solenoid Valve	AOMAG	$10.00	$2.00	$12.00
Pneumatic Pipes and Fittings	Pre-owned	$0.00	$0.00	$0.00
			Subtotal	$130.00

Ejection: Fullscale				
Component	Vendor	Component Cost	Taxes and Shipping	Total Cost
Servo	Servo City	$25.00	$5.00	$30.00
Servo Gear	Servo City	$3.00	$2.00	$5.00
Aluminum Standoffs	McMaster-Carr	$20.00	$5.00	$25.00
Machine Screws	McMaster-Carr	$7.00	$3.00	$10.00
Delrin Sheet	EPlastics	$20.00	$5.00	$25.00
Aluminum spacer	McMaster-Carr	$1.00	$1.00	$2.00
Hex Nuts	McMaster-Carr	$6.00	$2.00	$8.00
			Subtotal	$105.00
Movement: Fullscale				
Component	Vendor	Component Cost	Taxes and Shipping	Total Cost
Drive Motor	Cytron	$42.00	$8.00	$50.00
Motor Controller	Cytron	$25.00	$5.00	$30.00
Rover Body	EPlastics	$5.00	$1.00	$6.00
Mounting Screws	McMaster-Carr	$0.50	$0.50	$1.00
Wheel Mounting Hubs	Pololu	$3.00	$2.00	$5.00
Ultrasonic Sensors	Sparkfun	$7.00	$2.00	$9.00
Battery	Turnigy	$20.00	$4.00	$24.00
Microcontroller	ATMega	$28.00	$2.00	$30.00
Socket Head Cap Screws	McMaster-Carr	$1.00	$1.00	$2.00
Standoffs	Sparkfun	$8.00	$2.00	$10.00
Accelerometer	Sparkfun	$10.00	$2.00	$12.00
Gyroscope	Sparkfun	$20.00	$5.00	$25.00
			Subtotal	$229.00
Solar: Fullsace				
Magnets	MicroGeoCache	$18.00	$2.00	$20.00
			Subtotal	$20.00
			Total	$710.00

9.3.4 Outreach Budget

Ohlone College Night of Science				
Component	Vendor	Component Cost	Taxes and Shipping	Total Cost
Film Canisters	Amazon	$25.00	$1.06	$26.06
Coffee Stirrers	Amazon	$8.00	$0.91	$8.91
Construction Paper	Amazon	$9.85	$0.56	$10.41
Alka-Seltzer	Costco	$40.00	$2.76	$42.76
Glue Guns	Michael's	$28.00	$1.90	$29.90
Glue Sticks	Michael's	$19.00	$0.98	$19.98
Fiber Board	Home Depot	$5.15	$0.80	$5.95
Pine Board	Home Depot	$6.00	$0.72	$6.72
Misc. Hardware	Home Depot	$9.50	$1.00	$10.50
Sand	Home Depot	$4.00	$0.63	$4.63
Spray Paint	Home Depot	$6.00	$0.85	$6.85
Scissors	Amazon	$24.50	$0.70	$25.20
			Subtotal	$197.87
High School Engineering Program				
Coffee Stirrers	Amazon	$8.00	$0.91	$8.91
			Subtotal	$8.91
Discovery Days, CSU East Bay				
Film Canisters	Amazon	$50.00	$2.12	$52.12
Alka-Seltzer	CVS	$12.00	$1.00	$13.00
3D Printed parts	UC Berkeley	$2.50	$0.00	$2.50
Lunch for Volunteers	Trader Joe's	$27.50	$2.50	$30.00
			Subtotal	$97.63
Discovery Days, AT&T Park				
Film Canisters	Amazon	$96.24	$8.00	$104.24
Alka-Seltzer	Costco	$60.00	$4.14	$64.14
3D Printed parts	UC Berkeley	$26.00	$0.00	$26.00
			Subtotal	$97.63
Expanding Your Horizons				
Unknown Materials	Unknown	$100.00	$0.00	$100.00
			Subtotal	$100.00
Bay Area Teen Science Conference				
Unknown Materials	Unknown	$100.00	$0.00	$100.00
			Subtotal	$100.00
Space Day				
Unknown Materials	Unknown	$400.00	$0.00	$400.00
			Subtotal	$400.00
			Total	$1098.78

9.3.5 Funding

As of now, the bulk of our funds are from crowdfunding campaigns. Of our pre-expense \$27,389.39 (including Boeing transfer), \$12,883.28 was raised through three crowdfuning campaigns (two through the school as part of the Big Give and Berkeley Crowdfunding, and one from our own GoFundMe page).

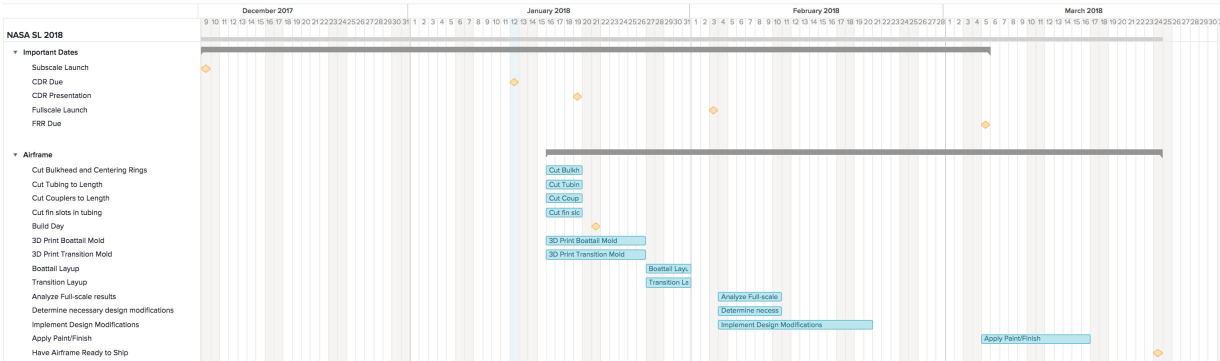
We also recieved a \$2,500 initial allocation from the school (pulled from campus wide student activity fees). The remaining \$12,006.11 comes from a few private sponsors including corporations like Boeing, Aragon Research, Google, and Northrop Grumman.

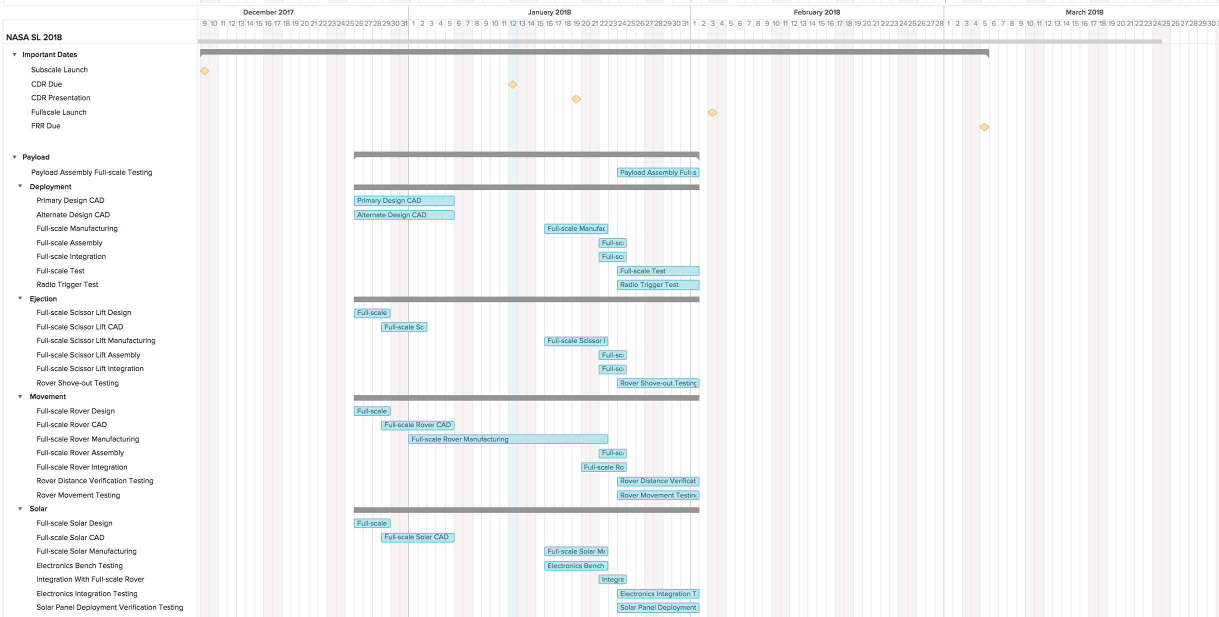
Previously mentioned in our PDR, our outreach team is now selling 3d-printed rocket kits on a recommended donation pricing scheme (e.g. we recommend a donation of \$5 dollars for the kit, but feel free to give us less or more for the kit.). This has turned out to be very successful, and we sold out all of our kits at our Discovery Days AT&T Park event. Our Outreach team is now mostly self-sufficient.

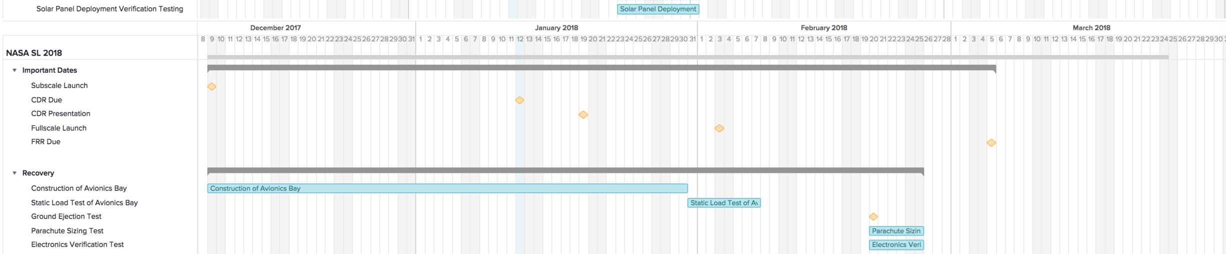
Also previously mentioned in our PDR, we applied for a \$5,000 grant from our school's Student Technology Fund. Our application was approved, and we now have access to the full amount requested.

We currently still have pending applications for \$2,000 from SpaceX, and other school funds (\$750 from the Academic Oppurtunity Fund, and \$750 from the Intellectual Community Fund).

9.3.6 GANTT Charts







Appendix A List of Project Leaders

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

Appendix B Safety Agreement

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

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

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

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

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

1. Range safety inspections of each rocket before it is flown. Each team shall comply with the determination of the safety inspection or may be removed from the program.
2. The Range Safety Officer has the final say on all rocket safety issues. Therefore, the Range Safety Officer has the right to deny the launch of any rocket for safety reasons.
3. Any team that does not comply with the safety requirements will not be allowed to launch their rocket.

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

Appendix C NAR High Power Rocket Safety Code

1. Certification. I will only fly high power rockets or possess high power rocket motors that are within the scope of my user certification and required licensing.

2. Materials. I will use only lightweight materials such as paper, wood, rubber, plastic, fiberglass, or when necessary ductile metal, for the construction of my rocket.

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

4. Ignition System. I will launch my rockets with an electrical launch system, and with electrical motor igniters that are installed in the motor only after my rocket is at the launch pad or in a designated prepping area. My launch system will have a safety interlock that is in series with the launch switch that is not installed until my rocket is ready for launch, and will use a launch switch that returns to the off position when released. The function of on-board energetics and firing circuits will be inhibited except when my rocket is in the launching position.

5. Misfires. If my rocket does not launch when I press the button of my electrical launch system, I will remove the launcher's safety interlock or disconnect its battery, and will wait 60 seconds after the last launch attempt before allowing anyone to approach the rocket.

6. Launch Safety. I will use a 5-second countdown before launch. I will ensure that a means is available to warn participants and spectators in the event of a problem. I will ensure that no person is closer to the launch pad than allowed by the accompanying Minimum Distance Table. When arming on-board energetics and firing circuits I will ensure that no person is at the pad except safety personnel and those required for arming and disarming operations. I will check the stability of my rocket before flight and will not fly it if it cannot be determined to be stable. When conducting a simultaneous launch of more than one high power rocket I will observe the additional requirements of NFPA 1127.

7. Launcher. I will launch my rocket from a stable device that provides rigid guidance until the rocket has attained a speed that ensures a stable flight, and that is pointed to within 20 degrees of vertical. If the wind speed exceeds 5 miles per hour I will use a launcher length that permits the rocket to attain a safe velocity before separation from the launcher. I will use a blast deflector to prevent the motor's exhaust from hitting the ground. I will ensure that dry grass is cleared around each launch pad in accordance with the accompanying Minimum Distance table, and will increase this distance by a factor of 1.5 and clear that area of all combustible material if the rocket motor being launched uses titanium sponge in the propellant.

8. Size. My rocket will not contain any combination of motors that total more than 40,960 N-sec (9208 pound-seconds) of total impulse. My rocket will not weigh more at liftoff than one-third of the certified average thrust of the high power rocket motor(s) intended to be ignited at launch.

9. Flight Safety. I will not launch my rocket at targets, into clouds, near airplanes, nor on trajectories that take it directly over the heads of spectators or beyond the boundaries of the launch site, and will not put any flammable or explosive payload in my rocket. I will not launch my rockets if wind speeds exceed 20 miles per hour. I will comply with Federal Aviation Administration airspace regulations when flying, and will ensure that my rocket will not exceed any applicable altitude limit in effect at that launch site.

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

11. Launcher Location. My launcher will be 1500 feet from any occupied building or from any public highway on which traffic flow exceeds 10 vehicles per hour, not including traffic flow related to the launch. It will also be no closer than the appropriate Minimum Personnel Distance from the accompanying table from any boundary of the launch site.

12. Recovery System. I will use a recovery system such as a parachute in my rocket so that all parts of my rocket return safely and undamaged and can be flown again, and I will use only flame-resistant or fireproof recovery system wadding in my rocket.

13. Recovery Safety. I will not attempt to recover my rocket from power lines, tall trees, or other dangerous places, fly it under conditions where it is likely to recover in spectator areas or outside the launch site, nor attempt to catch it as it approaches the ground.

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

Appendix D Launch Checklists & 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: ☐

D.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: ☐

   (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 both boards.

(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. Deployment board.
  ii. PowerPole to 2-pin latching connector power adapter cable.
  iii. Ejection board.
  iv. Mounting screws for deployment board.
  v. Mounting screws for ejection board.
  vi. Many 2-pin jumpers.
  vii. Breakaway wire connectors.
  viii. Onboard antenna.
  ix. Yagi antenna.
  x. Radio board.
  xi. Radio board box.
  xii. Radio board UART-USB cable.
  xiii. Radio board mounting screws.

(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

D.2 Launch Commit Criteria

The vehicle may only be launched if the following Launch Commit Critera 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 5mph at ground level or aloft (up to 6000ft AGL).
4. It is no 1t raining or hailing.
5. It has not rained in the past day.
6. The ground is not excessively damp or moist from previous rain.

D.3 Assembly & Preparation

D.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.

D.3.2 Electronics Preparation & Testing

- **Electrical Testing:**

  All deployment, ejection, radio, and sensor tests can be run through the GUI. In terminal, navigate to " /Software/RadioSerial" directory. Run RadioSerial.exe in the Debug folder.

  The program should look like the following:

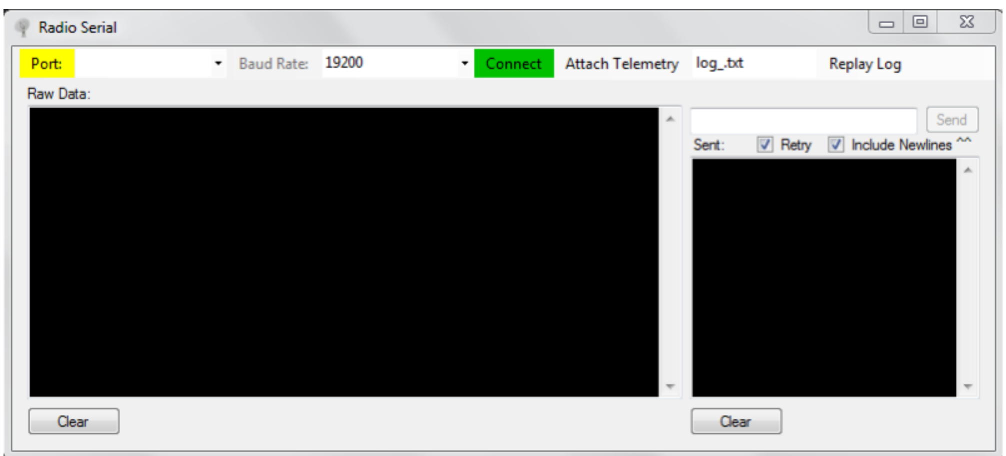


Figure 24: Radio Serial Program

1. First connect the base station to the computer via USB. This should show up as a COM port. In the left corner, the menu labelled "Port" should list the correct port number. Pressing the Port button refreshes the list of available ports.
2. Press the green Connect button. Raw data should show up on the left, and any signals sent should show up on the right.
3. The box that says "log_.txt" logs data. Remove the text for testing so that it does not log data. Note: for actual launches, put a filename in the box, so that itll log all the data sent and received. It can be replayed later with the Replay Log button

4. The Attach Telemetry button opens the following window:

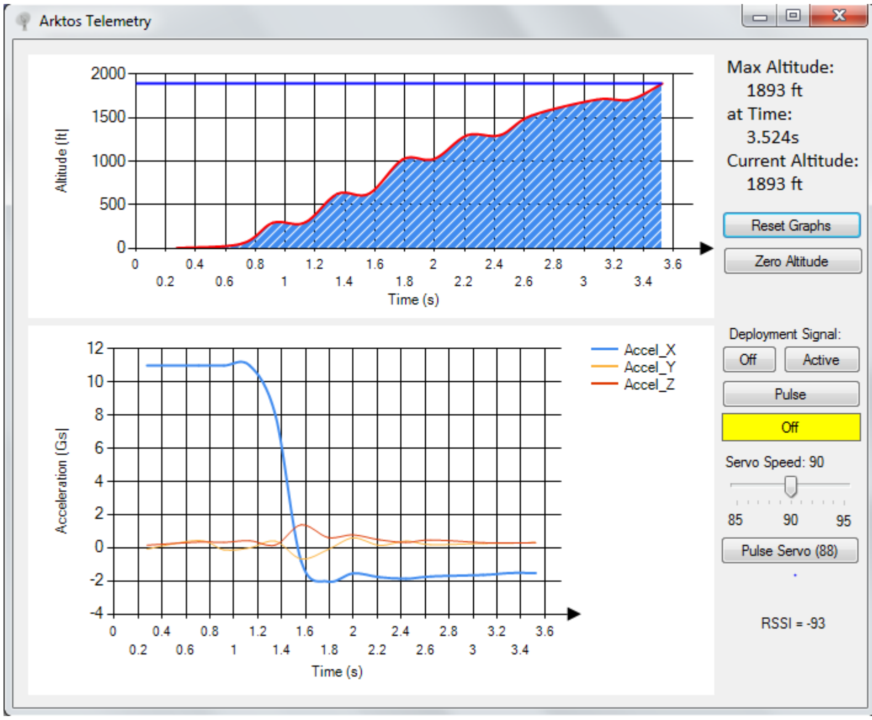


Figure 25: Arktos Telemetry Program

5. To run sensor tests for BOTH deployment and ejection boards:
   (a) To calibrate the altimeter: in terminal, navigate to "~/Firmware/Arktos_deployment" directory.
   (b) Open the Makefile and verify that TARGET=altitude_calibration and PSRC=altitude_calibr
   (c) Run "make basic_test".
   (d) While test is running, move accelerometer along every axis, and confirm that reasonable values are output on serial monitor.
   (e) Hold board above your head and then near the ground, watching to confirm accurate change in altitude on serial monitor.
6. To test the radio and servos:
   (a) Flash the test program to the ejection board by navigating to "~/Firmware/Arktos_ejection" and run "make servo_test".
   (b) Click "Pulse Servo" and adjust the angle using the slider (~90 is no movement, 0-89 is backward, 91-180 is forward) and verify that the servo is moving appropriately.
7. To test the continuity in breakaway wires (LVDS):
   (a) Turn the deployment signal on and off with the buttons on the right. Listen for beeps from the board that indicate the wires are connected. A successful result lights a red LED on the Ejection board, and switches the red LED to green on the Deployment board.

8. Important: Make sure to zero the altitude and reset the graphs before launch after done with testing.

- Deployment assembly:

1. Check the Makefile in Arktos_deployment to make sure TARGET=deployment and PSRC=deployment.cpp.
2. Run "make".
3. Remove the jumper on J1.
4. Be sure that J8,10,13,14,16 are in the correct position for [LVDS] or [Direct voltage signaling].

- Ejection assembly:

1. Remove the jumper on J3.
2. Be sure that J7,8,9,11,12 are in the correct position for [LVDS] or [Direct voltage signaling].

- 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.

D.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. 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.
2. Check deployment battery voltage. It should be around 16.8V.
3. Fasten the deployment board to its 3d printed carrier by screwing four mounting screws in the corners.
4. Securely install the deployment battery by using the velcro straps on the bottom and top of the battery.
5. Connect the battery to the deployment board, and verify board initialization: listen for an audible click and tactile feedback.
6. Visually check the connection to breakaway plugs.
7. Tighten the three thumb screws to fasten the electrical bulkhead tightly.

8. Visually check the bulkhead and deployment chamber: there should be no wires pinched, the bulkhead should be fastened, and the interior of the chamber should be void of severe blemishes.
9. Install breakaway cables. Four colors will be present; match the deployment side to the deployment connectors.
10. [Team Mentor] Fill and seal a black powder charge capsule containing a mass of black powder within 0.05 grams of the intended amount.
11. Connect E-match to the deployment board.
12. [Team Mentor] Install the black powder capsule, and verify a secure fit.
13. Install Nomex shielding.

- Ejection system assembly:

  1. 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.
  2. 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 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.

3. Final integration tests:
   (a) Ensure that scissor lift can push entire rover through payload section by running a systems test with electronics.
   (b) Test friction/functionality inside airframe.
   (c) Ensure entire assembled scissor lift can slide freely through airframe. If not, sand/ lubricate until possible.
4. 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. 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.
  2. 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.

3. Verify with the electrical subteam that all servos are functional, by running test software verifying actuation of servos.
4. Verify functionality of all solar cells, by confirming voltage input on rover computer corresponds to solar panel output.
5. Ensure the rover battery is charged.
6. Check rover battery voltage. Use a multimeter to check the terminals of the battery, ensuring that voltage is approximately 14.8V.
7. Ensure the rover board is securely fastened to the top plate using #8-32 socket head screws. Inspect and manually check tightness of screws.
8. Verify the motors are mounted to the rover chassis using screws. Inspect and manually check tightness of screws.
9. Verify servos are securely fastened using screws. Inspect and manually check tightness of screws.
10. Inspect motor shafts and rover body for deformation and substantial blemishes.
11. Inspect structural supports within the payload tube.
12. Visually check the interior rover electronics for any damage. Make sure no wires are pinched and the chamber interior is void of debris.
13. Install the rover battery, using velcro straps on the bottom and top of the battery.
14. Connect the battery to the rover board. Verify the rover board is powered on: the rover board LED should turn on.
15. Flash the rover board with electronics test firmware using the 3.3V programmer. Connect the programmer to appropriate port on main board.
16. 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.
17. Check servo functionality during the test. Ensure full range of motion and correct speed for each servo, as defined in test program.
18. 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.
19. Check motor functionality during test. Ensure that the motors rotate at the speeds and directions defined in the test program.
20. 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.
21. Check magnet strength. Ensure magnets keep hood closed under a good shaking.
22. Install the lower panel of the rover using thumb screws. Ensure the screws are securely fastened.
23. 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.

24. 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.
25. Insert the rover into the payload section airframe. Visually and physically check for impediments and rotational constraints.
26. Verify breakaway cable integrity with the rover deployment subteam.
27. Secure the connection of breakaway cables to connectors in payload tube. There should be an audible click and tactile feedback.
28. Confirm with the electrical subteam that all connections are secure.

D.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 1and 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 TD2

         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 it 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.

D.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.

D.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.

D.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 graviy 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.

D.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.

D.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.

D.5 Launch

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

1. Ensure all personnel are a safe distance from the launch vehicle, as specified in the NAR High Power Rocket Safety Code.

2. Count down at least 5 seconds, and then launch the vehicle.

3. 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.

D.6 Post-Flight

D.6.1 Rover Deployment

1. Verify that there are no personnel near the launch vehicle, particularly the payload section.

2. Obtain approval from the Range Safety Officer to deploy the rover.

3. Send the rover deployment command by clicking the relevant button in the ground support software GUI.

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

D.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 geear, 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:

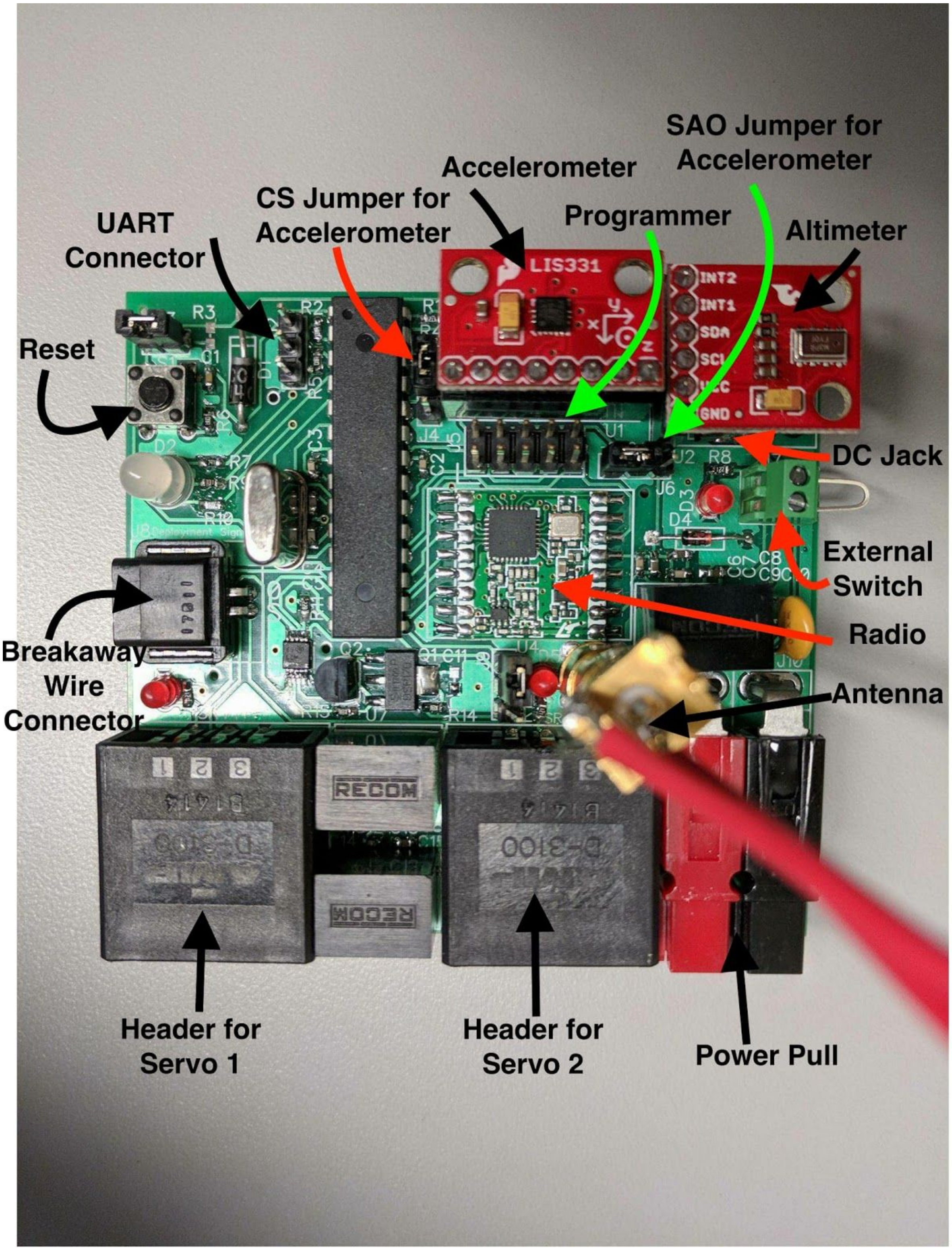
  1. Visually check for damage to any boards.
  2. Inspect all connectors: are they still secure?
  3. Verify that the breakaway wire has successfully broken.
  4. Verify LED indicators are as expected.
  5. Disconnect batteries.

- 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.

D.7 Annotated Electrical Boards

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:

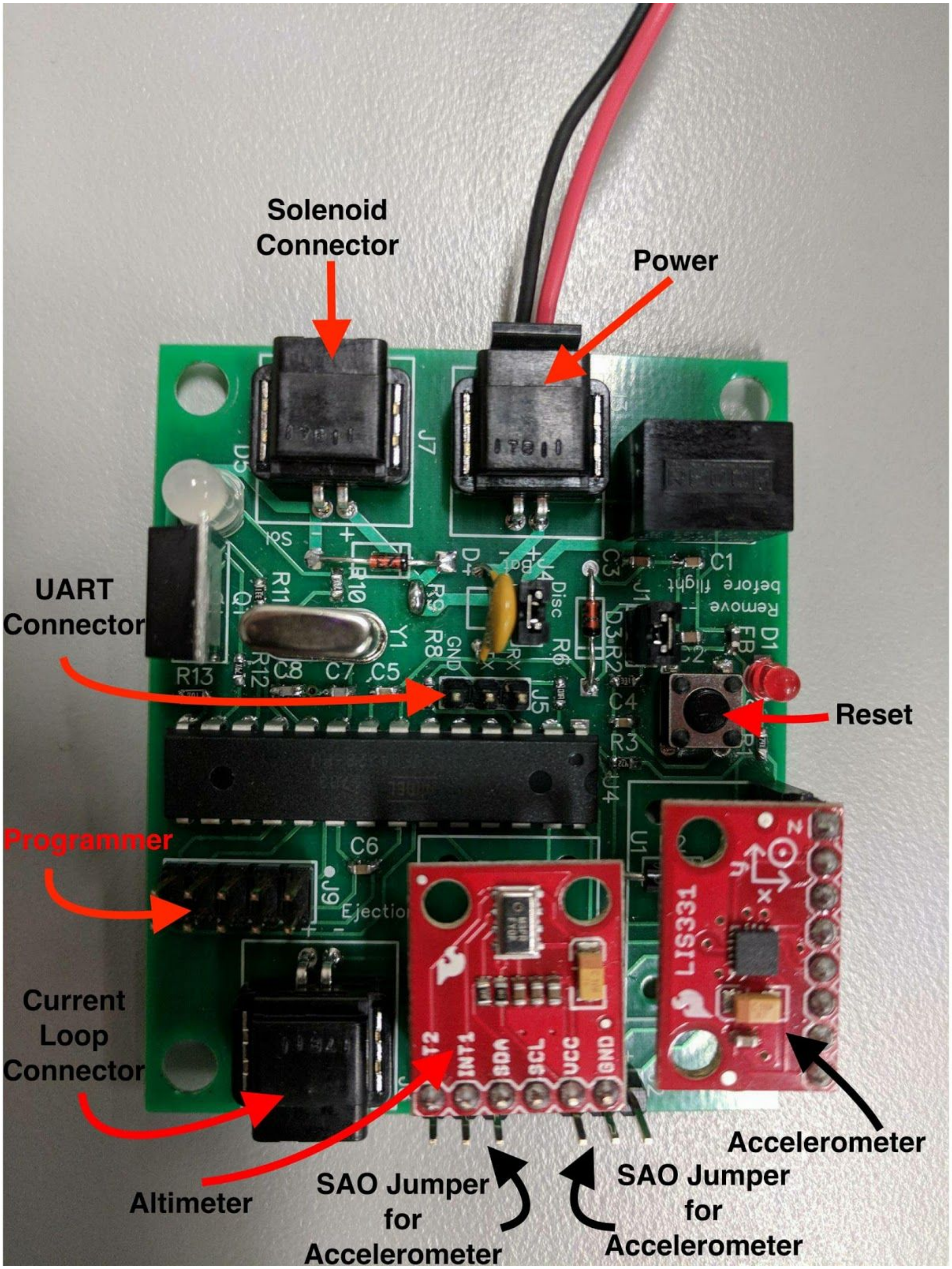
- The UART connector has 3-header pins but the jumper cables have 4. This is because we do not use the red power pin. The other three cables are ground (black), receiver (green), and transmitter (white), which connect to the ground, receiver, and transmitter pins respectively. From the diagram, the top 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

D.8 Post-Flight Inspection Notes

Write down any notes from the post-flight inspection here. Digital notes are also fine, and take as many pictures as you can as well.

Appendix E Matlab Code for Kinetic Energy Calculations

```
global rho;
rho = 0.0765;
global g;
g = 32.174; % ft/s^2
global ftlbf_to_lbmft2persec2;
ftlbf_to_lbmft2persec2 = 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 ftlbf_to_lbmft2persec2
vmax = ((2 * KEmax * ftlbf_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 ftlbf_to_lbmft2persec2
e = ((.5 * m_lbm) * (v_ft .^ 2)) / ftlbf_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: upper half %f lbm | lower half %f lbm\n', upper_w, lower_w)
fprintf('WEIGHT: cords and parachutes %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 lbf\n',
   v_fts_to_ke_ft_lbf(t_velocity, upper_w))
fprintf('The final KE for the lower half is %f ft lbf\n',
   v_fts_to_ke_ft_lbf(t_velocity, lower_w))

end
```

E.1 Matlab Code for Black Powder Calculations

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

```
function [Powder_quantity] = Black_Powder(N,F,L,K)
% This function calculates the amount of black powder necessary to
    deploy
% our parachutes. N is the number of shear pins, F is the force
   required to
% break one shear pin, L is the internal length between bulkheads,
    and K is
% the factor the amount of blackpowder will be scaled by to be
   sure all
% parachutes will deploy. Powder_quantity is the amount of black
   powder
% necessary in grams.
```

```
Powder_quantity = (5.161*10^(-4))*N*F*L*K; % where 5.161*10^(-4)
    is a
% constant derived from the ideal gas law.
```