Piedmont Student Launch Team

2018 NASA Student Launch

Flight Readiness Review

Piedmont Virginia Community College

501 College Drive, Charlottesville, Virginia 22902

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Table of Contents

List of Figures

List of Tables

Glossary of Terms

ABS - Acrylonitrile Butadiene Styrene

ACS - Altitude Control System

AGL - Above Ground Level

APCP - Ammonium Perchlorate Composite Propellant

APCP - Ammonium Perchlorate Composite Propellant

Cd - Coefficient of Drag

CG - Center of Gravity

CHEC - Community Homeschool Enrichment Center

CP - Center of Pressure

DOF - Degrees Of Freedom

FAA	-	Federal Aviation Administration
FMEA	-	Failure Modes and Effects Analysis
FSEE	-	Family Space Exploration Event
GPS	-	Global Positioning System
I/O	-	Input / Output
IMU	-	Inertial Measurement Unit
IR	-	Infrared
IRC	-	International Rescue Committee
IRC	-	International Rescue Committee
JIM	-	Joining Intermediary Member
LiDAR	-	Light Detection And Ranging
NAR	-	National Rocketry Association
NOVAAR	-	Northern Virginia Association of Rocketry
PSLT	-	Piedmont Student Launch Team
PVCC	-	Piedmont Virginia Community College
STEM	-	Science, Technology, Engineering, and Mathematics
TRA	-	Tripoli Rocketry Association
VAST	-	Valley AeroSpace Team

1 Summary

1.1 Team

The Piedmont Student Launch Team (PSLT), representing Piedmont Virginia Community College (PVCC), is working with David Oxford, NAR number 101883, as the mentor for high-power rocketry. David Oxford has level 2 high-power certifications with the NAR and TRA.

PVCC mailing address: 501 College Drive, Charlottesville, VA 22902

1.2 Launch Vehicle

Statistics	Value
Diameter (in.)	6
Length (in.)	105.5
Mass without motor (lbs)	42.7
Mass with motor (lbs)	52.7
Motor	Aerotech L1420
Rail button size	1515
Rail exit velocity (ft/s)	66.7
Static Stability margin	3.2
Parachute diameter (ft)	16
Recovery harness length (ft)	40
Primary ejection charge size (g)	8
Altitude control system gas	Nitrogen
Cd	0.616
Apogee (ft)	3,912

1.3 Payload

PSLT has chosen the deployable rover challenge. To complete this challenge, PSLT has designed a rover which will be housed within the nosecone of the rocket. Once the rocket has landed, the nosecone will be ejected with the rover. Then, it will open, releasing the rover. The rover utilizes six infinity wheels to allow it to maneuver over rugged terrain. It has a solar panel mounted to a backplate which can be folded out by the rover when it has moved the necessary distance. This panel can also be used as a mechanism to flip the rover should it become inverted.

2 Changes Since CDR

2.1 Launch Vehicle

- The altitude control system will now only be directed forward, this change was made to comply with regulations that only allow the primary motor to cause forward acceleration
- The primary ejection charge size has been raised to 8 g, and the back-up ejection charges have been raised to 10 g. This change was made to ensure that the vehicle separates reliably
- The parachute has been increased to a 16 ft diameter to reduce the kinetic energy at landing

2.2 Payload

- The wheels for the rover no longer attach directly to the motor shafts, instead wheel hubs will be attached to the wheels and the motor shaft will be held by the wheel hub

2.3 Project

- A mass simulator was flown on the full-scale in place of the payload
- The purpose of the ACS has changed from being to reach the target altitude to being to act as a proof-of-concept of this type of system, to potentially be developed further by future teams

3 Vehicle Criteria

3.1 Design and Construction of Vehicle

3.1.1 Design Changes Since CDR

- The ACS has been changed to only fire in one direction to accommodate additional requirements
- The parts of the ACS downstream of the regulator have been replaced with equivalent components with maximum working pressures above 1,800 psi, the burst pressure of the lowest pressure burst disk on the regulator

3.1.2 Launch Vehicle Construction

3.1.2.1 Payload Bay

The construction of the payload bay started by cutting one, 12 in. piece of 6 in. diameter fiberglass tube and one 14 in. piece of 6 in. fiberglass coupler. The coupler was epoxied into the airframe piece by applying epoxy to the end of the coupler and sliding the larger tube over it. After the epoxy cured, three, 0.75 in. diameter holes were drilled into the middle of the payload bay for the keyed switches used for the recovery system and the rover.

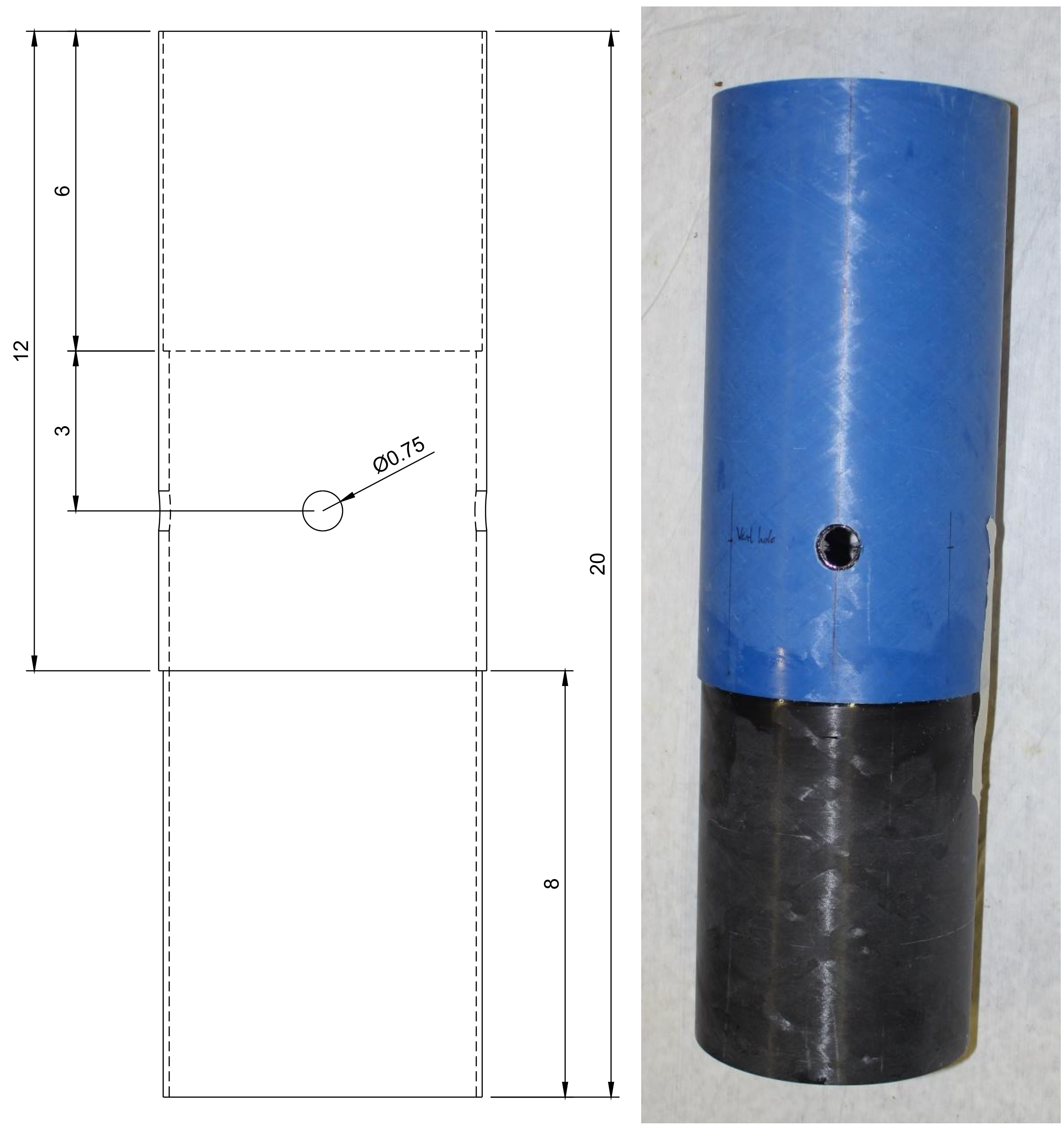

Figure 3.1 – Payload Bay

The rear bulkhead for the payload bay was made by first epoxying together two fiberglass bulkheads of different diameters. Appropriate holes for threaded rods, U-bolts, and mounting ejection cups and terminals were then drilled through the pair of bulkheads using a 3D printed jig for alignment. The U-bolts and ejection cups were both bolted and epoxied into place and the ejection terminals were epoxied into place.

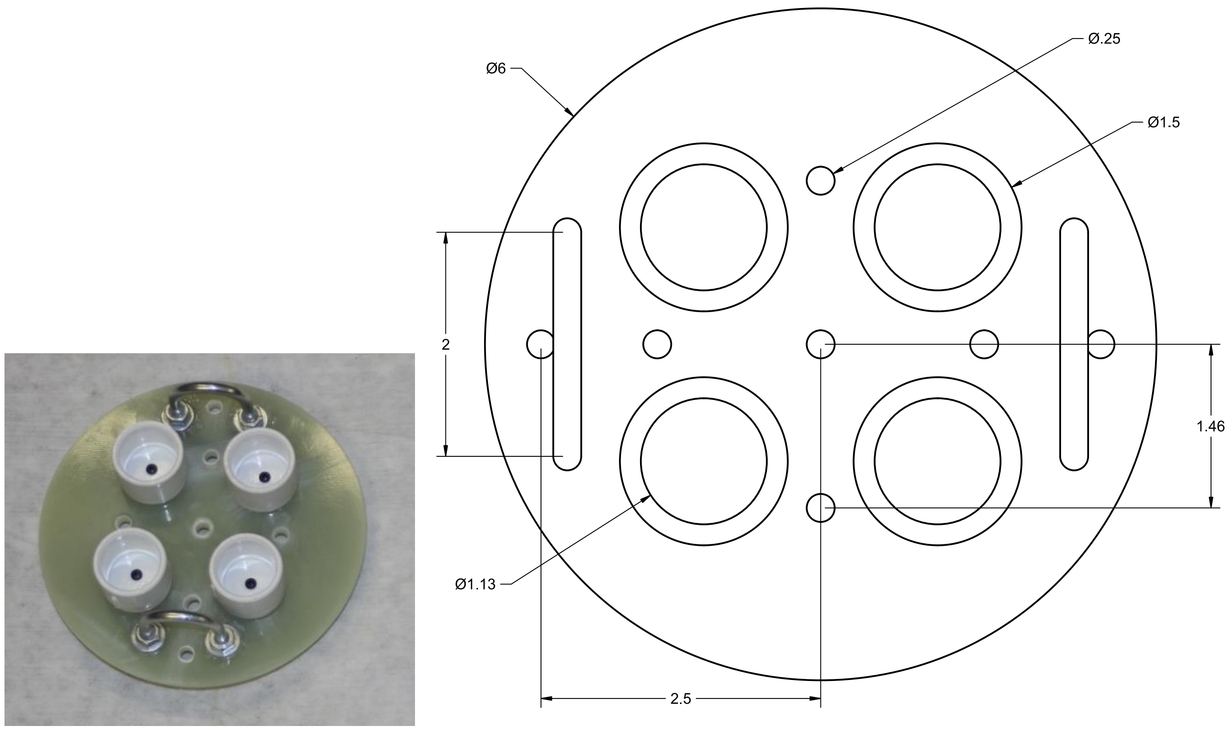

Figure 3.2 – Rear Payload Bay Bulkhead

3.1.2.2 Parachute Tube

The parachute tube was cut to 36 in. and had the appropriate holes drilled in it for removable rivets and shear pins.

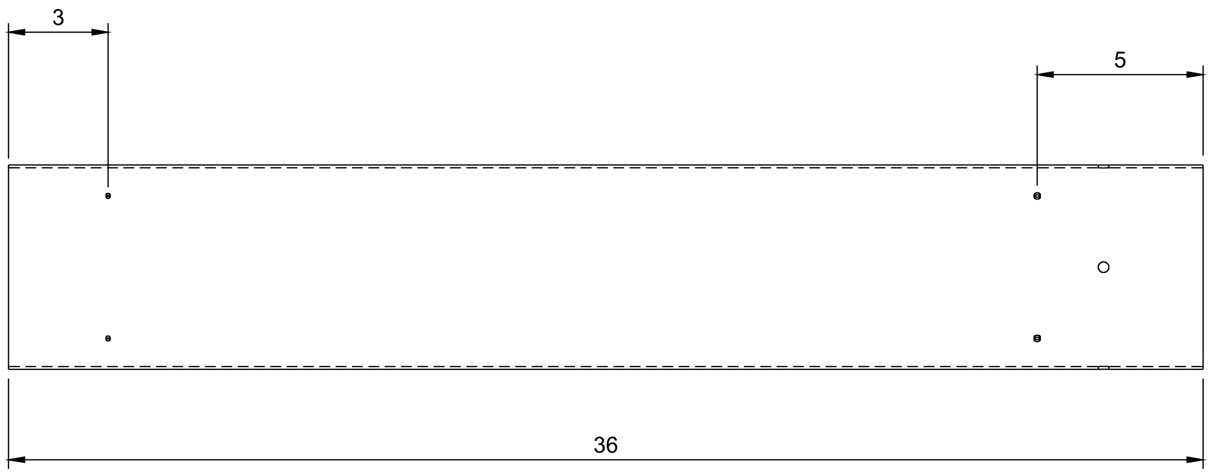

Figure 3.3 – Parachute Tube

3.1.2.3 Joining Intermediary Member (JIM)

A 2 in. section of airframe was cut and epoxied onto the middle of a 14 in. fiberglass coupler to create JIM.

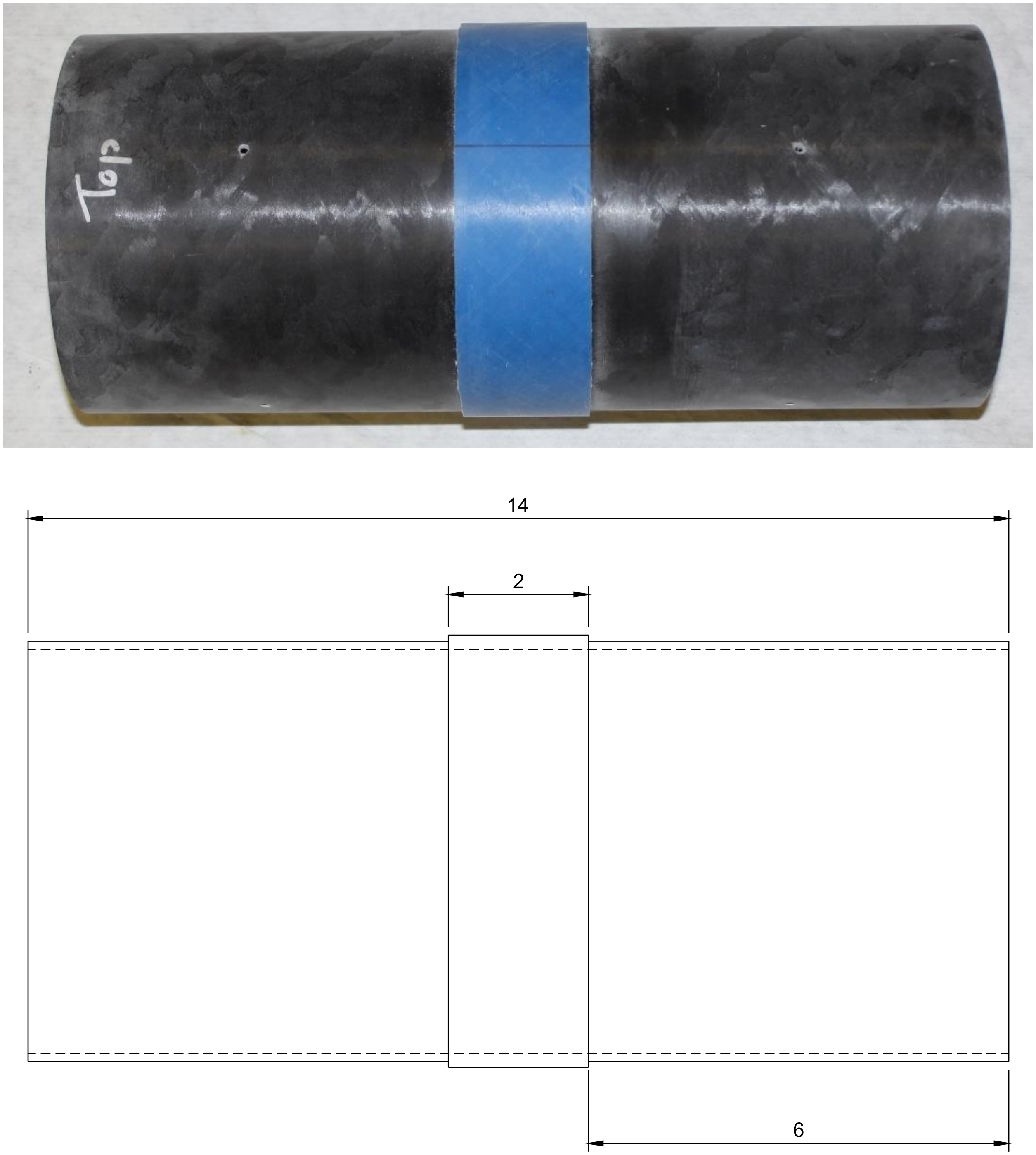

Figure 3.4 – JIM

The forward bulkhead on the booster section was made in the same way as the rear bulkhead on the payload bay, except with an additional hole for threaded rods and without the holes for the ejection cups and terminals

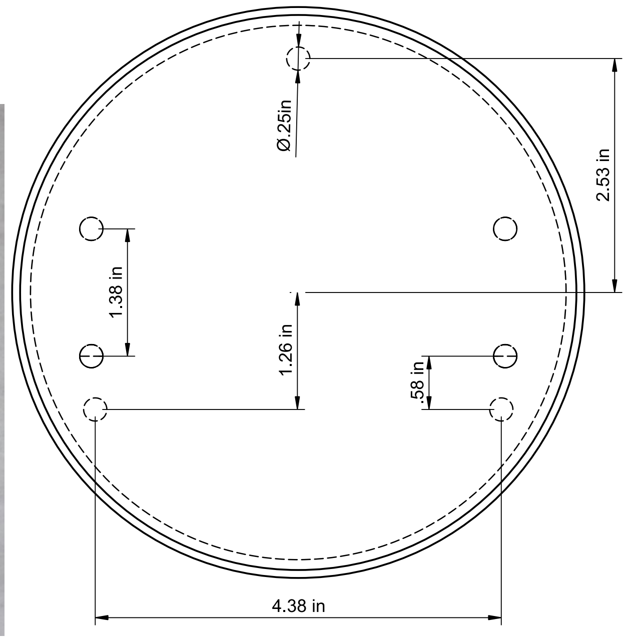

Figure 3.5 – Forward Booster Section Bulkhead

3.1.2.4 Booster Section

3.1.2.4.1 Booster Tube

The booster section was cut to 36 in. and four slots were cut at the bottom for the fins. Holes were also drilled for the thrusters for the ACS.

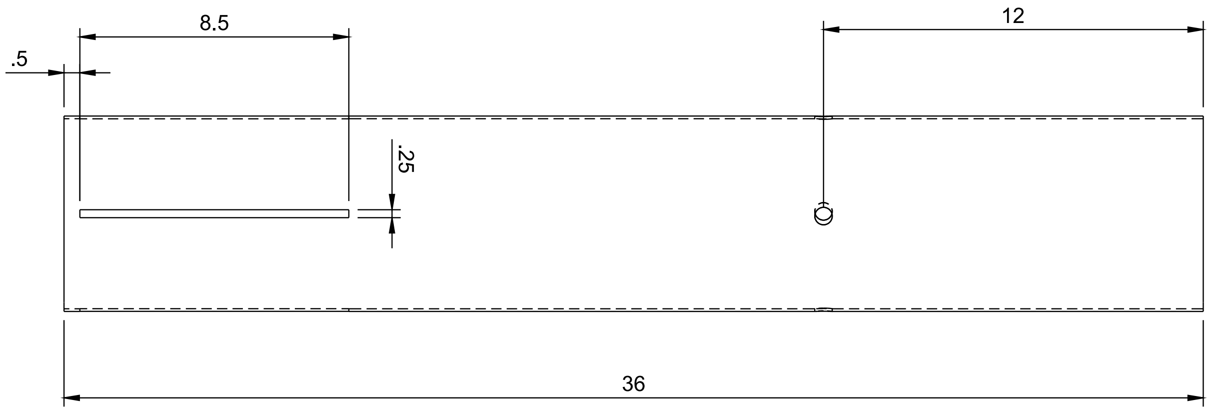

Figure 3.6 – Booster Section Tube

3.1.2.4.2 Motor Tube and Retention

Three holes were drilled into two centering rings. The holes on the forward centering ring had segments of threaded rod put through them, and the holes on the rear centering ring were used to allow access to the inside of the fin can for foaming. The threaded rods going through the forward bulkhead were secured using nuts, washers, and epoxy.

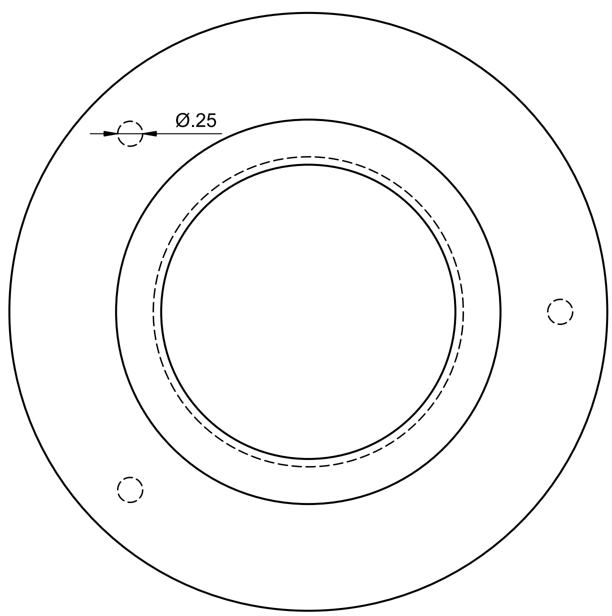

Figure 3.7 – Forward Centering Ring

The forward centering ring was epoxied flush with the fore end of the motor tube, and that assembly was installed into the booster tube.

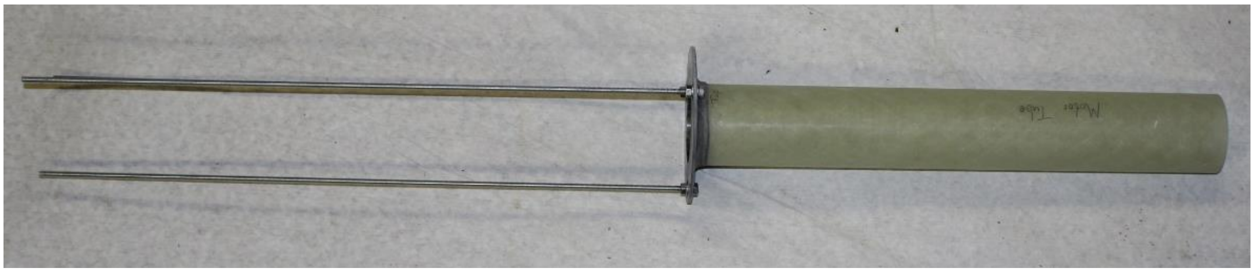

Figure 3.8 – Motor Tube with Centering and Connecting Rods Installed

3.1.2.4.3 Fins

The fins were made from two 0.125 in. fins each, laminated together to thicken them to reduce fin flutter. They were mounted through-the-wall, being epoxied onto the motor tube. The connection of the fins was reinforced with an epoxy clay fillet around the base of each fin and the fin can being filled with an expanding foam.

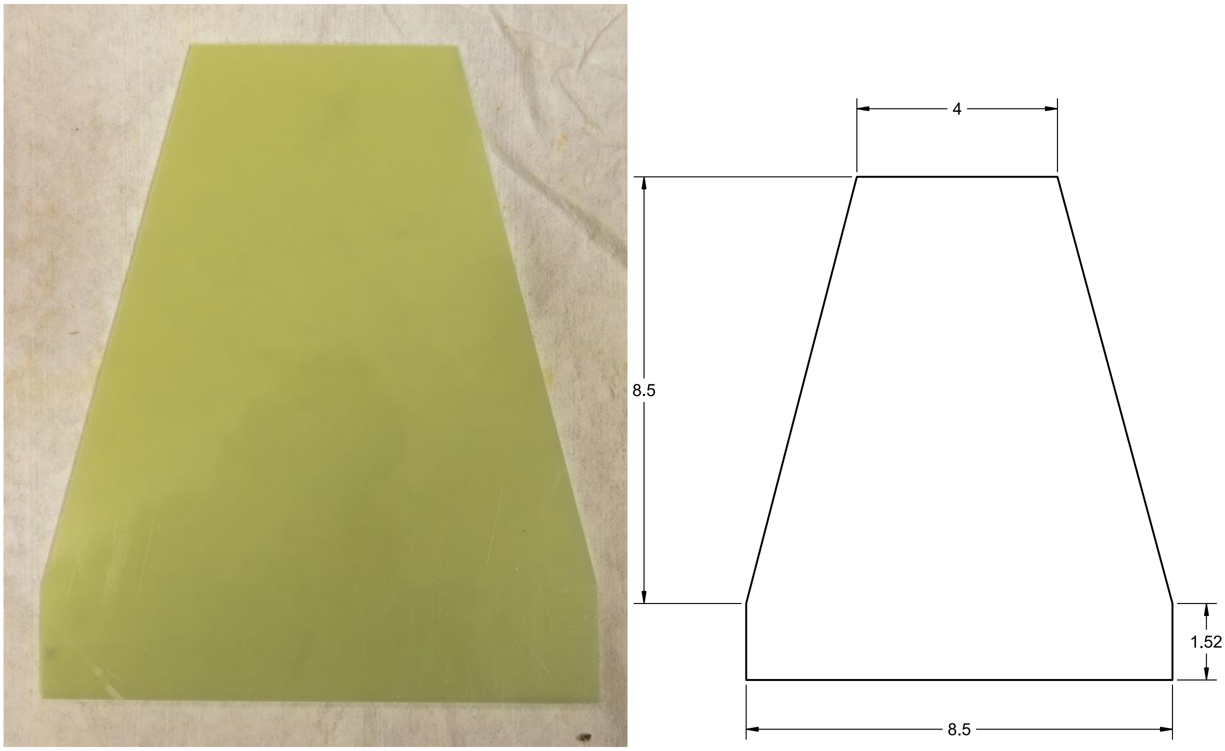

Figure 3.9 – Fin

3.1.2.4.4 Booster Section Final Assembly

Once the fins were attached and the fin can was foamed, the rear centering ring was epoxied in place and a 75 mm AeroPack motor retainer was attached using a high-heat epoxy. Holes for rail buttons were then drilled and they were screwed in with the screws epoxied in place.

3.1.3 Altitude Control System

3.1.3.1 Altitude Control System Hardware

The tee junctions and pipe couplers that comprise the ACS manifold were screwed together using Teflon tape to help seal the connections. All of the threaded connections on the ACS were sealed with Teflon tape. The solenoid valve was attached to the manifold using a pipe coupler, and the four sections of brake line that make up the rest of the feed system were flared at both end with a pair of fittings put on them, and one fitting on each was attached to the manifold. The solenoid was then bolted onto the mounting bracket and it was secured to the threaded rods in the booster section with nuts and washers.

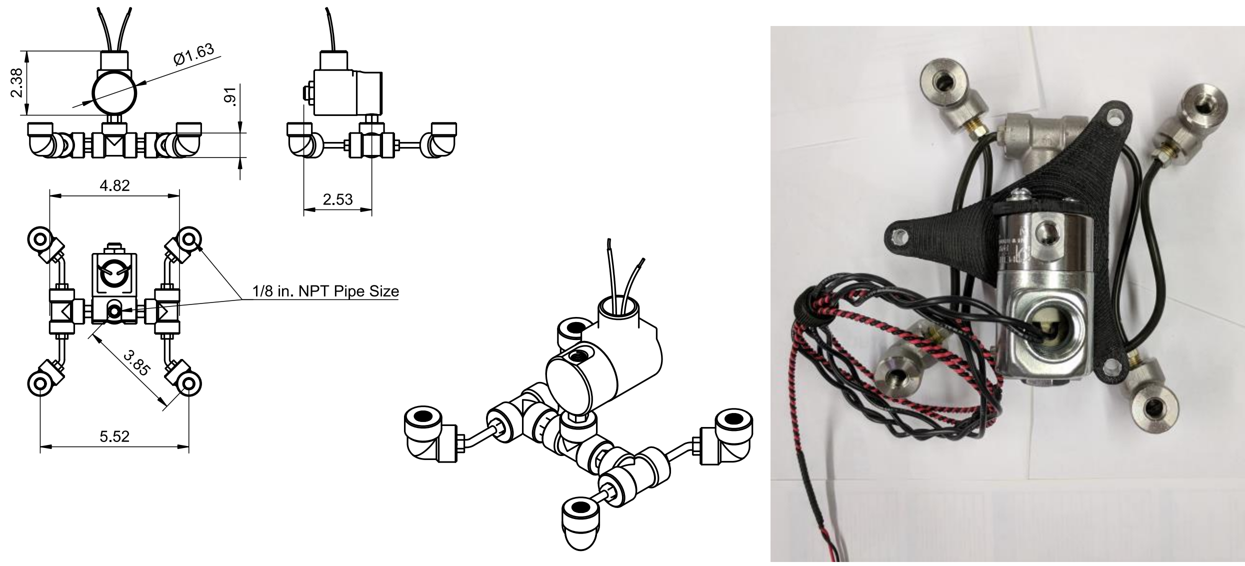

Figure 3.10 – Thruster Assembly

The open end of each of the sections of brake line was then maneuvered to the holes in the airframe for the thrusters to come out of. The thrusters were then attached, and all of the connections using the flared fittings were packed with epoxy clay to prevent leaks.

Once the entire system was installed, the lower portion of the booster section was filled with foam to help secure everything.

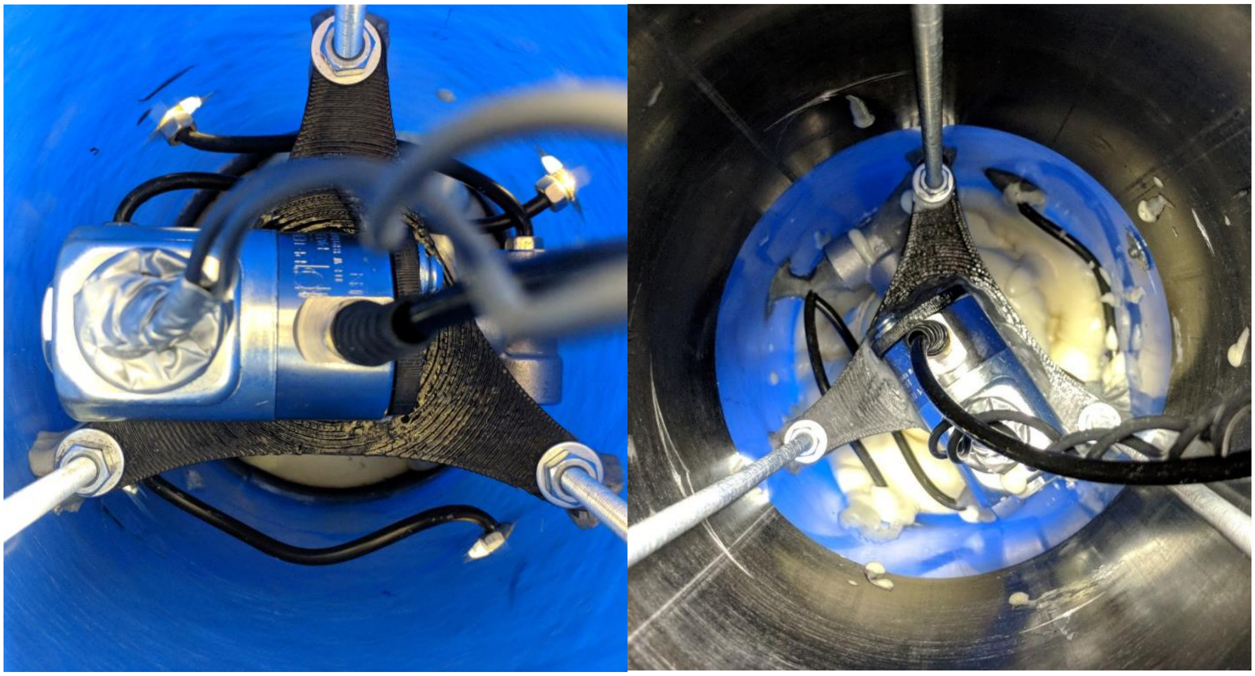

Figure 3.11 – ACS Solenoid Assembly Installed Pre-Foaming (right) & Post-Foaming (left)

Figure 3.12 – View of Thrusters on Outside of Rocket

3.1.3.2 Altitude Control System Electronics

The ACS is controlled by a microcontroller and a relay, both mounted to an electronics sled located in the top of the booster section. The electronics sled was laser cut from a piece of plywood, and holes were then drilled for mounting posts for all of the electronics. Slots were also made in the sled on the laser cutter for the straps used to secure the battery that powers the microcontroller. The two A23 batteries that power the solenoid valve are secured in battery holders which are screwed to the sled.

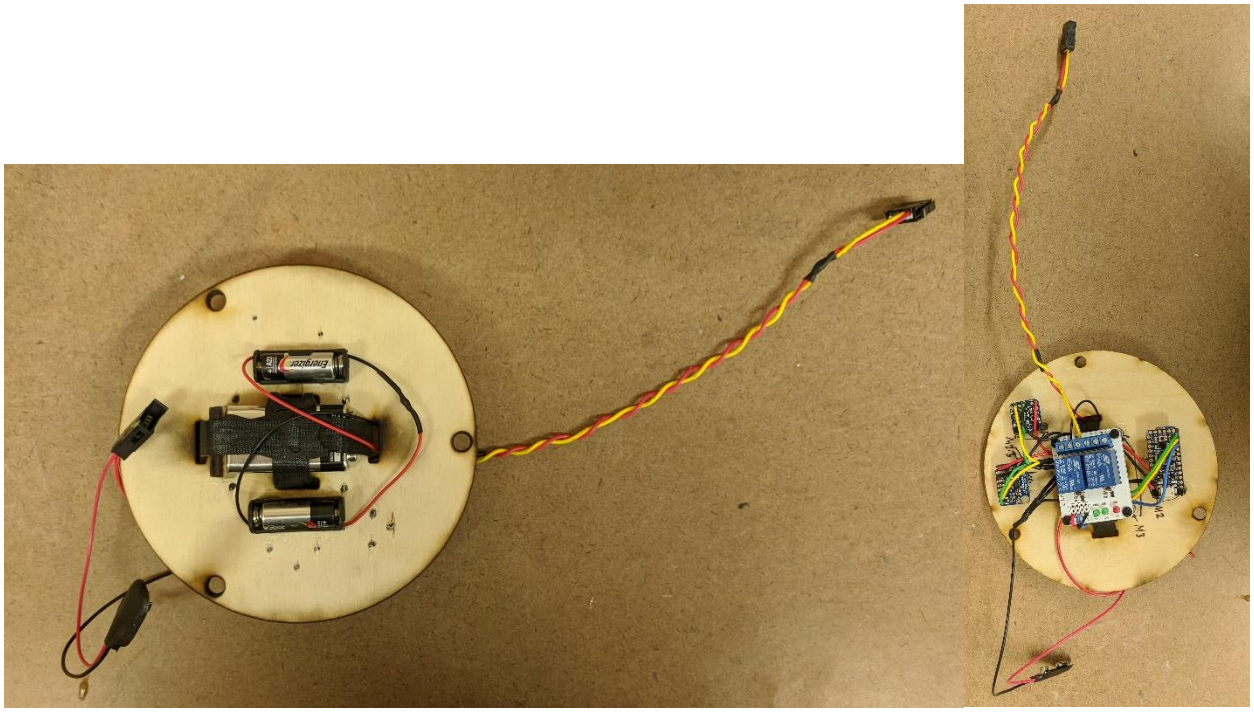

Figure 3.13 - ACS Electronics Top of Sled (left) Bottom of Sled (right)

3.2 Recovery Subsystem

3.2.1 Changes to Recovery System Since CDR

- The amount of black powder used in the main ejection charge has been increased to 8 g
- The amount of black powder used in the three backup ejection charges has been increased to 10 g
- The parachute size has been increase to 16 ft
- RRC3s will be used as both the primary and secondary altimeters

3.2.2 Recovery System Hardware

The 40 ft, 1/2 in. Kevlar recovery harness is attached to the airframe at either end by two U-bolts. Each U-bolt is connected to a quick link, and both quick links at each end are connected to a single swivel, which is in turn tied to the end of the recovery harness with a slip knot.

Figure 3.14 – Recovery Harness with Swivel and Quick Links

The parachute is connected two thirds of the way from the payload bay end of the recovery harness to help prevent the upper and lower sections of the rocket from colliding during descent.

Figure 3.15 – Parachute Connection Point on Recovery Harness

3.2.3 Recovery System Electronics

A pair of RRC3s will be used as the primary and secondary altimeters. It was decided that, to help reduce costs, an Altus Metrum EasyMega would not be flown, as the additional features that it has over an RRC3 are not necessary.

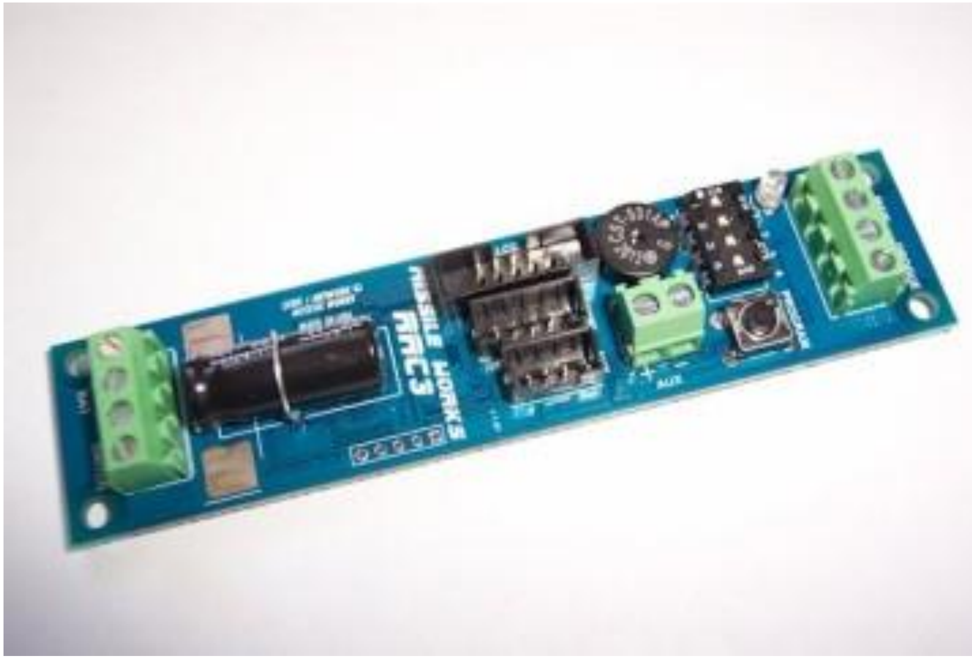

Figure 3.16 – RRC3 Altimeter

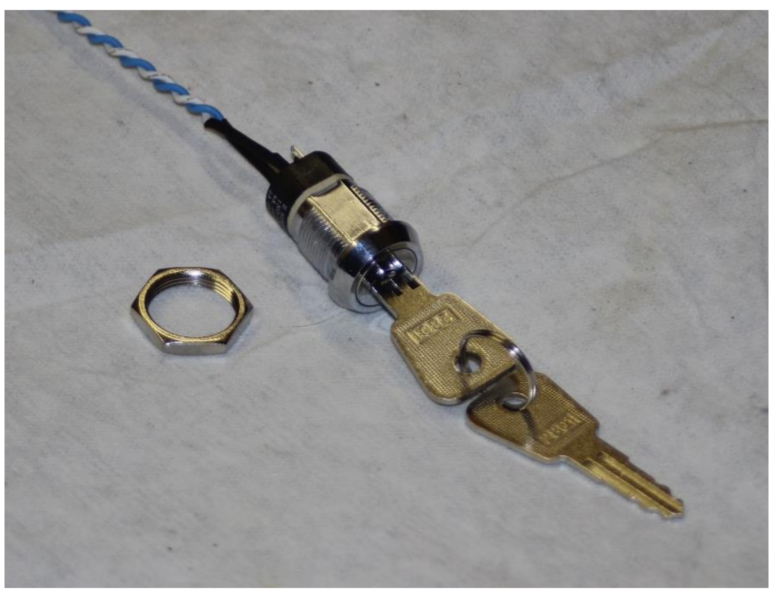

Figure 3.17 – Ejection System Switch

Both of the altimeters and their batteries are mounted on a laser cut plywood sled that is secured to a pair of threaded rods in the payload bay. The altimeters and batteries are mounted to opposite sides of the sled so that, if a battery should somehow break loose, it does not damage either altimeter.

The ends of the avionics bay are shielded from RF interference with a layer of aluminum tape.

The deployment of the parachute after separation is controlled by a pair of Jolly Logic Chute Releases, connected together in series, such that if one does not open, the other can still release the parachute. Both are set to deploy at 700 ft to allow adequate time for the parachute to fully unfurl.

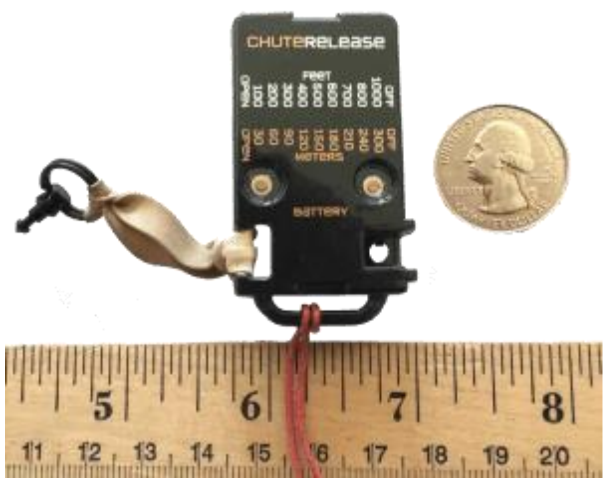

Figure 3.18 – Jolly Logic Chute Release

The following diagram Figure 3.19 shows the layout of the avionics electronics.

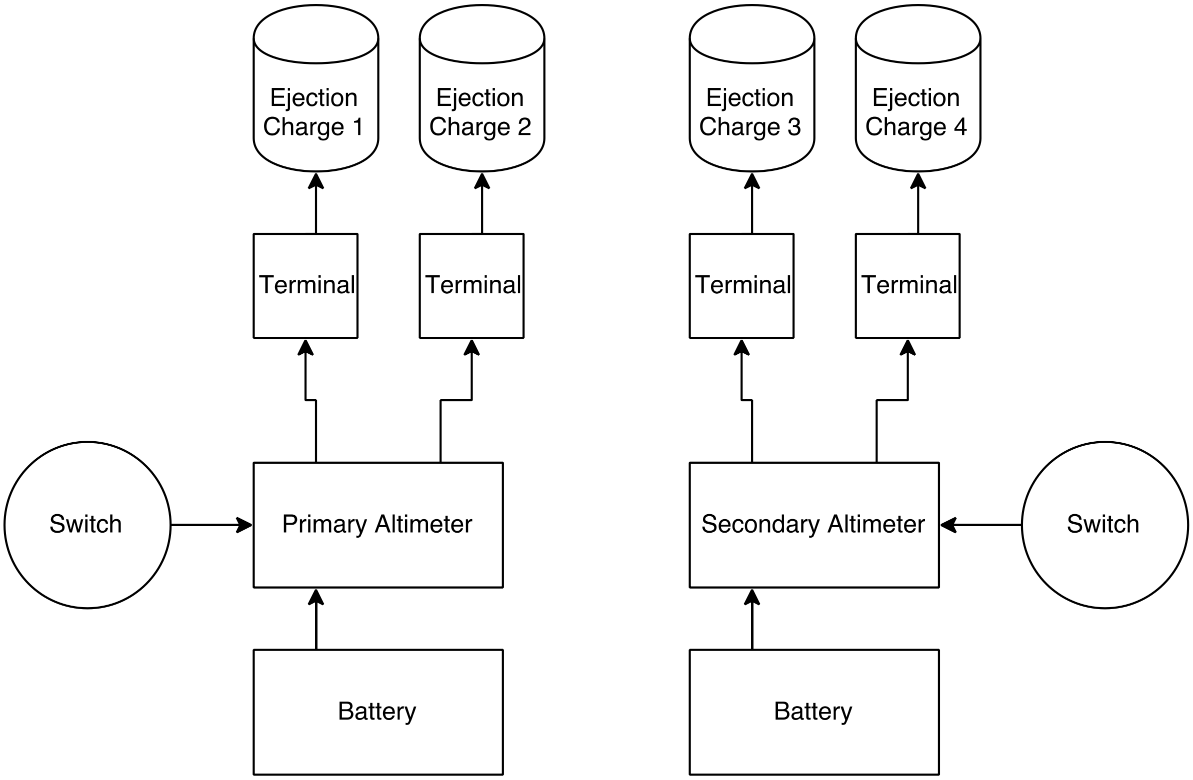

Figure 3.19 – Recovery System Electronics Layout

3.3 Mission Performance Predictions

3.3.1 Flight Simulations

3.3.1.1 Simulation Conditions

Condition	Value
Average Wind Speeds (MPH)	10
Temperature (°F)	59
Altitude above Sea Level (ASL) (ft)	820
Launch Rail Length (in.)	144

Table 3.1 - Expected Launch Day Conditions

3.3.1.2 Simulation Results

3.3.1.2.1 RockSim

Event	Time (s)
Ignition	0
Launch Rail Clearance	0.4
Motor Burnout	3.3
Apogee / Separation	16.2
Backup Ejection Charge 1	17.2
Backup Ejection Charge 2	18.2
Backup Ejection Charge 3	25.3
Parachute Opens	42.9
Landing	72.7

Table 3.2 - RockSim Event Sequence

Parameter	Value
Apogee (ft)	3,955
Max. Velocity (ft/s)	532
Velocity at Rail Exit (ft/s)	65.7
Landing Velocity (ft/s)	15.2

Table 3.3 - RockSim Simulation Results

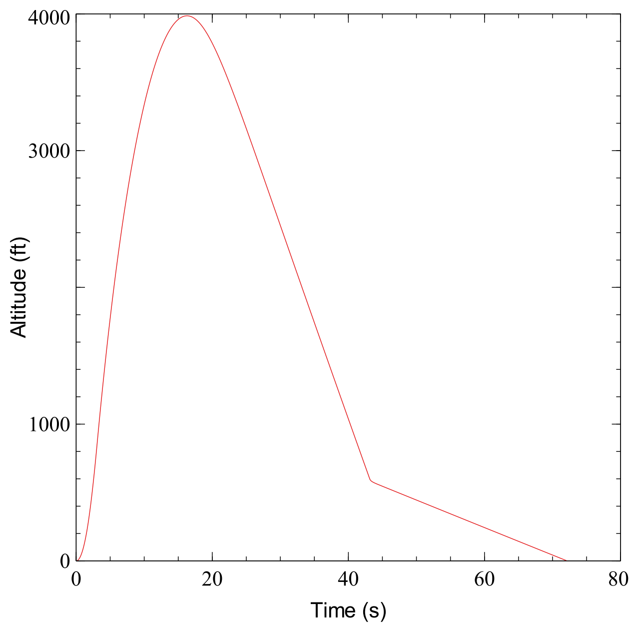

Figure 3.20 - RockSim Altitude

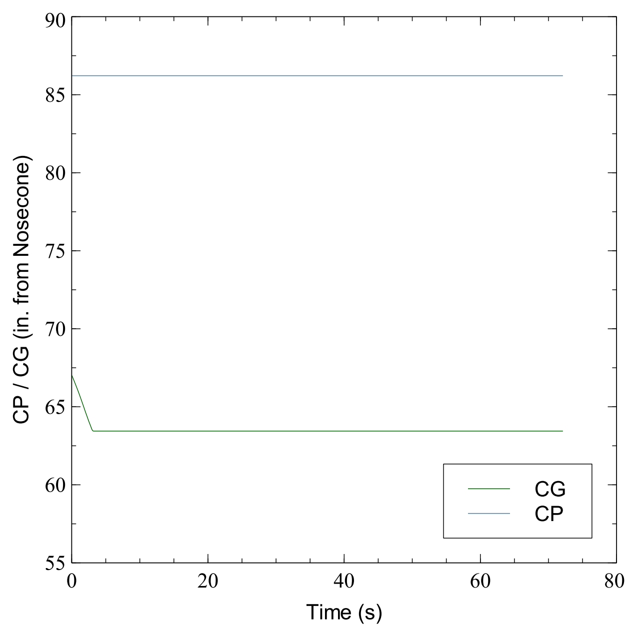

Figure 3.21 - RockSim CP / CG

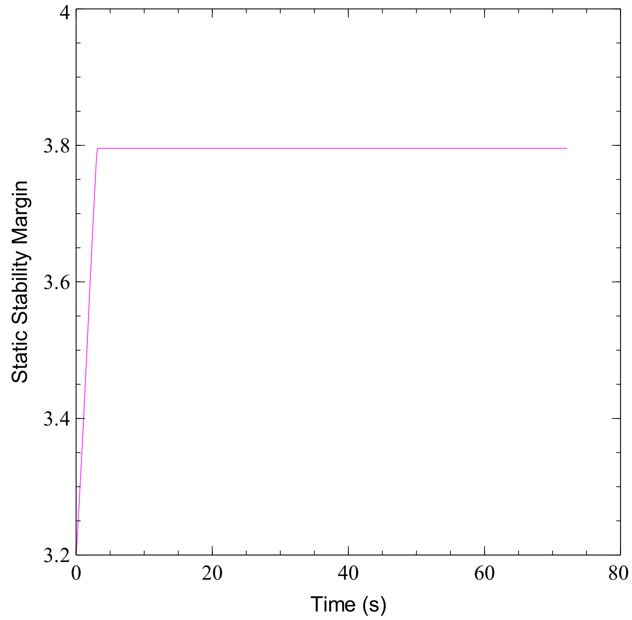

Figure 3.22 - RockSim Stability Margin

Section	Kinetic Energy at Landing (ft-lbf)
Upper Section (Parachute Tube, Payload Tube, Nose Cone)	73.1
Lower Section (Booster Section, JIM)	68.1

Table 3.4 - RockSim Kinetic Energy

Wind Speed (MPH)	Drift (ft)
0	0
5	220
10	250
15	650
20	860

Table 3.5 - RockSim Drift Predictions

3.3.1.2.2 OpenRocket

Event	Time (s)
Ignition	0
Launch Rail Clearance	0.4
Motor Burnout	3.3
Apogee / Separation	16.1

Event	Time (s)
Backup Ejection Charge 1	17.1
Backup Ejection Charge 2	18.1
Backup Ejection Charge 3	25.4
Parachute Opens	43.3
Landing	82.3

Table 3.6 - OpenRocket Event Sequence

Parameter	Value
Apogee (ft)	3,868
Max. Velocity (ft/s)	529
Velocity at Rail Exit (ft/s)	66.7
Landing Velocity (ft/s)	15.5

Table 3.7 - OpenRocket Simulation Results

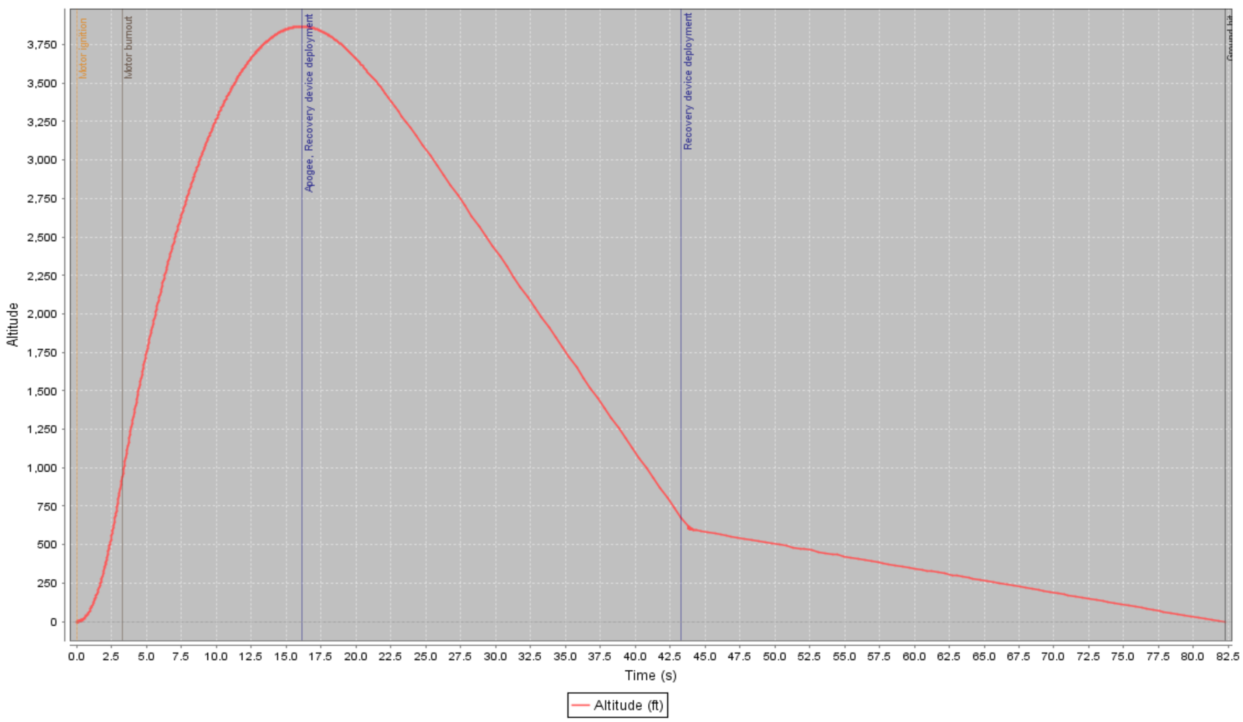

Figure 3.23 - OpenRocket Altitude

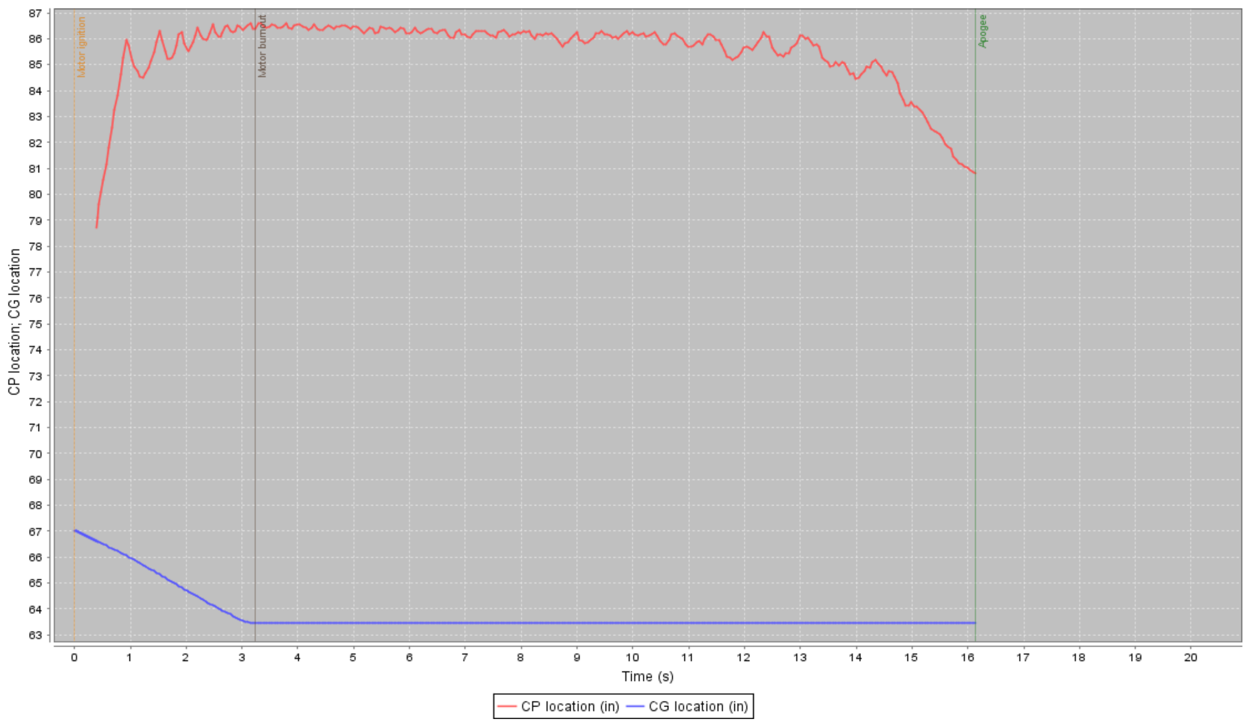

Figure 3.24 - OpenRocket CP / CG

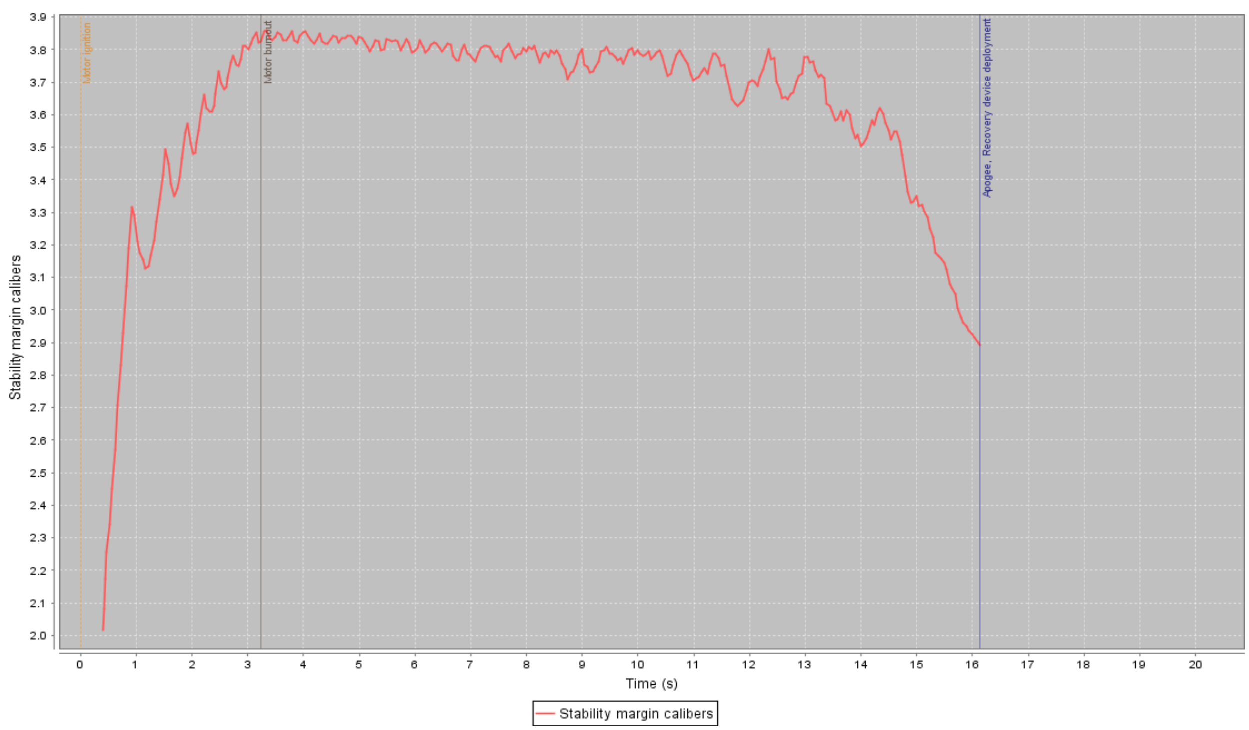

Figure 3.25 - OpenRocket Stability Margin

Section	Kinetic Energy at Landing (ft-lbf)
Upper Section (Parachute Tube, Payload Tube, Nose Cone)	73.6
Lower Section (Booster Section, JIM)	70.3

Table 3.8 - OpenRocket Kinetic Energy

Wind Speed (MPH)	Drift (ft)
0	6
5	92
10	114
15	115
20	26

Table 3.9 - OpenRocket Drift Predictions

3.3.1.2.3 Manual Calculations

Wind Speed (MPH)	Drift (ft)
0	0
5	252
10	505
15	757
20	1,009

Table 3.10 - Manual Calculation Drift Predictions

Section	Kinetic Energy at Landing (ft-lbf)
Upper Section (Parachute Tube, Payload Tube, Nose Cone)	36.3
Lower Section (Booster Section, JIM)	48.0

Table 3.11 - Manual Calculation Kinetic Energy

3.3.1.3 Comparison of Simulation Methods

Now that the model is finalized with the actual mass, CG, and Cd, both RockSim and OpenRocket simulations provide very similar results.

3.4 Full-Scale Flight

3.4.1 Flight Results

The full-scale test flight was performed on 4 March 2018, and it was fully successful. The rocket came stably off of the launch rail and continued to be stable throughout the entire flight. Separation occurred smoothly at apogee as expected, and all three backup charges were observed to have fired at the appropriate intervals. The parachute deployed at around the expected altitude, and the entire rocket came down safely, causing no damage to the rocket or anything else.

One notable difference between the full-scale test flight and launch day is that, due to relatively high winds on the day of the test flight, the full-scale motor was not flown. As a result, the altitude reached was much lower than what is expected on launch day; although, it was very close to the expected altitude. Additionally, because the full-scale motor was not flown, the ACS was not active during the flight. As a result, the ACS will not be active during the flight on launch day; though, it will still be loaded, as the mass is important to the performance of the rocket. The motor flown was a K1200.

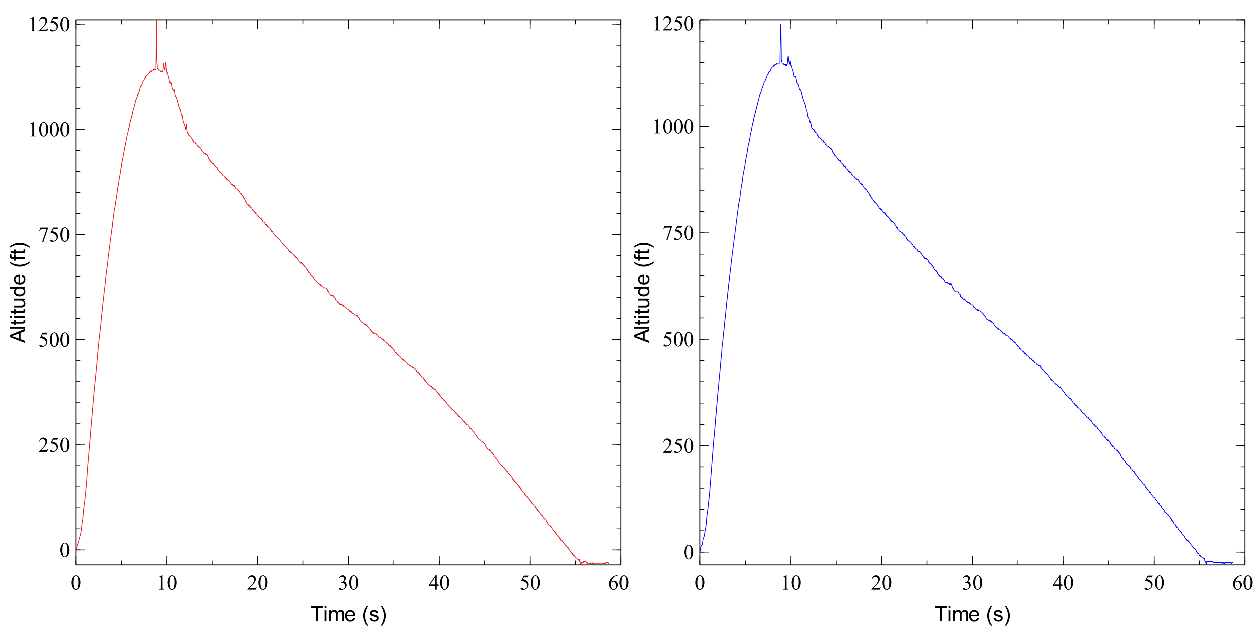

Figure 3.26 - Full-Scale Test Flight Altitudes from Primary (left) and Secondary (right)

Result	Value

Result	Value
Apogee (ft)	1137
Maximum Velocity (ft/s)	255
Time to Apogee (s)	8.8
Descent Time (s)	49.8

Table 3.12 - Full-Scale Test Flight Results

The below graph, Figure 3.26, shows data from the primary altimeter when each of the four ejection charges fired.

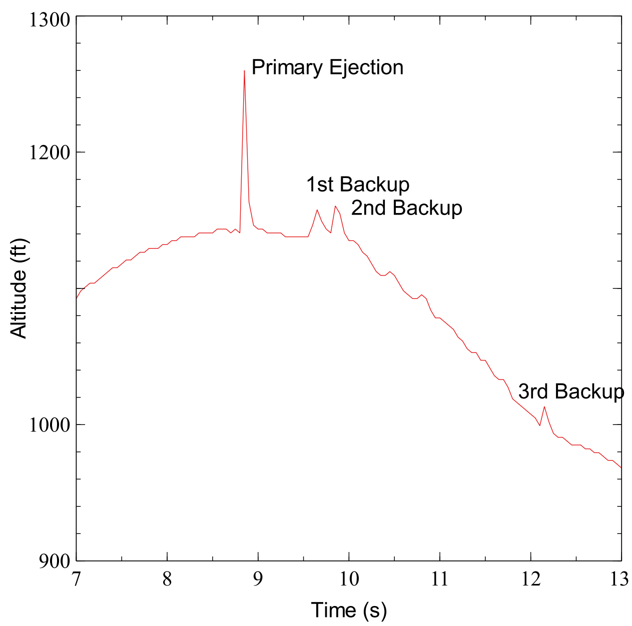

Figure 3.27 - Full-Scale Test Flight Ejection Charges Firing

3.4.2 Launch Day Conditions

Condition	Value
Wind Speed (MPH)	10-15
Temperature (°F)	50
ASL (ft)	600

Table 3.13 - Full-Scale Test Flight Launch Conditions

The conditions experienced at the launch of the full-scale rocket should match moderately closely to what will occur on launch day. The winds were higher than ideal, but still low enough to be able to fly safely.

3.4.3 Comparison of Actual and Predicted Results

The results of the actual flight were very close to the results of the pre-flight simulations, close enough for the variation in wind to account for the difference.

Result	Actual Value	Simulated Value	Error
Apogee (ft)	1137	1184	4%
Maximum Velocity (ft/s)	255	262	3%
Time to Apogee (s)	8.8	9.2	4%
Descent Time (s)	49.8	43.2	15%

Table 3.14 - Comparison of Actual and Predicted Results

3.4.4 Post Flight Simulation

Based on the results of the test flight, the Cd calculated at CDR of 0.62 is still accurate. Any variation from that can be accounted for with wind on the day of the test flight. Because of that, a post flight simulation would be identical to the simulations done for section 3.3 Mission Performance Predictions.

3.4.5 Comparison of Full-Scale and Subscale Flights

After the failure that occurred during the first subscale flight, the primary concern for the full-scale was that it would not separate properly; however, the changes made to the design since that flight seem to have eliminated the issue that occurred then.

4 Payload Criteria

4.1 Deployment

The final deployment design consists of the rover being enclosed a 3D printed, solid-walled nose cone. The rest of the cavity will be filled with fire retardant blow-in insulation. Once the rocket has landed, the rover will be ejected out of the nosecone with an ejection charge. This change was made because the seam in the previous nose cone design was too large and deemed unsafe for flight. In addition, the previous nose cone design failed to pass strength tests (see section 7.1 Testing). The nose cone still is 18 in. in length, with a 6 in. base diameter, however the shoulder was shortened to 4 in. and the number of shear pins was increased to 8.

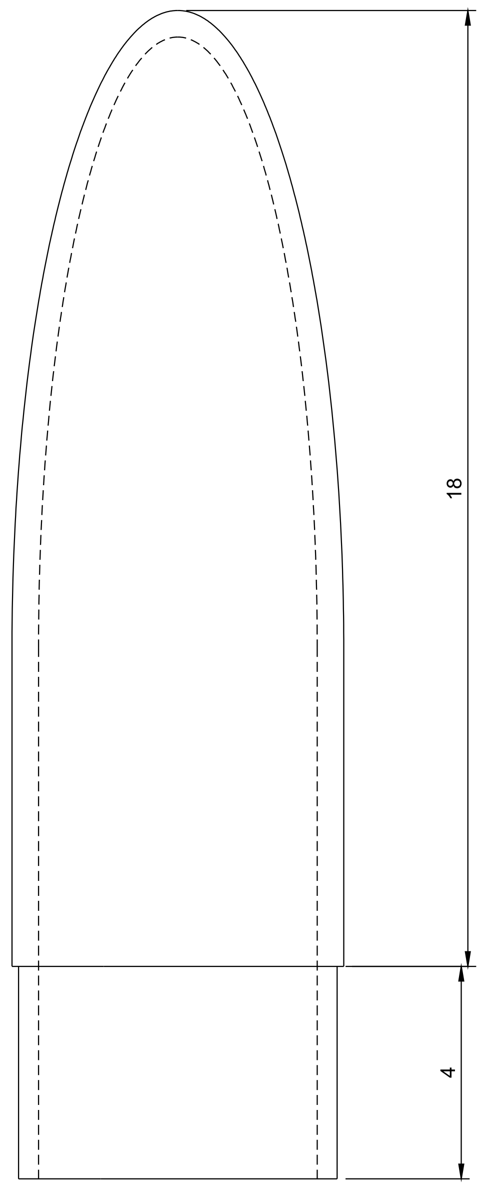

Figure 4.1 – 3D Printed Nose Cone

4.2 Structure

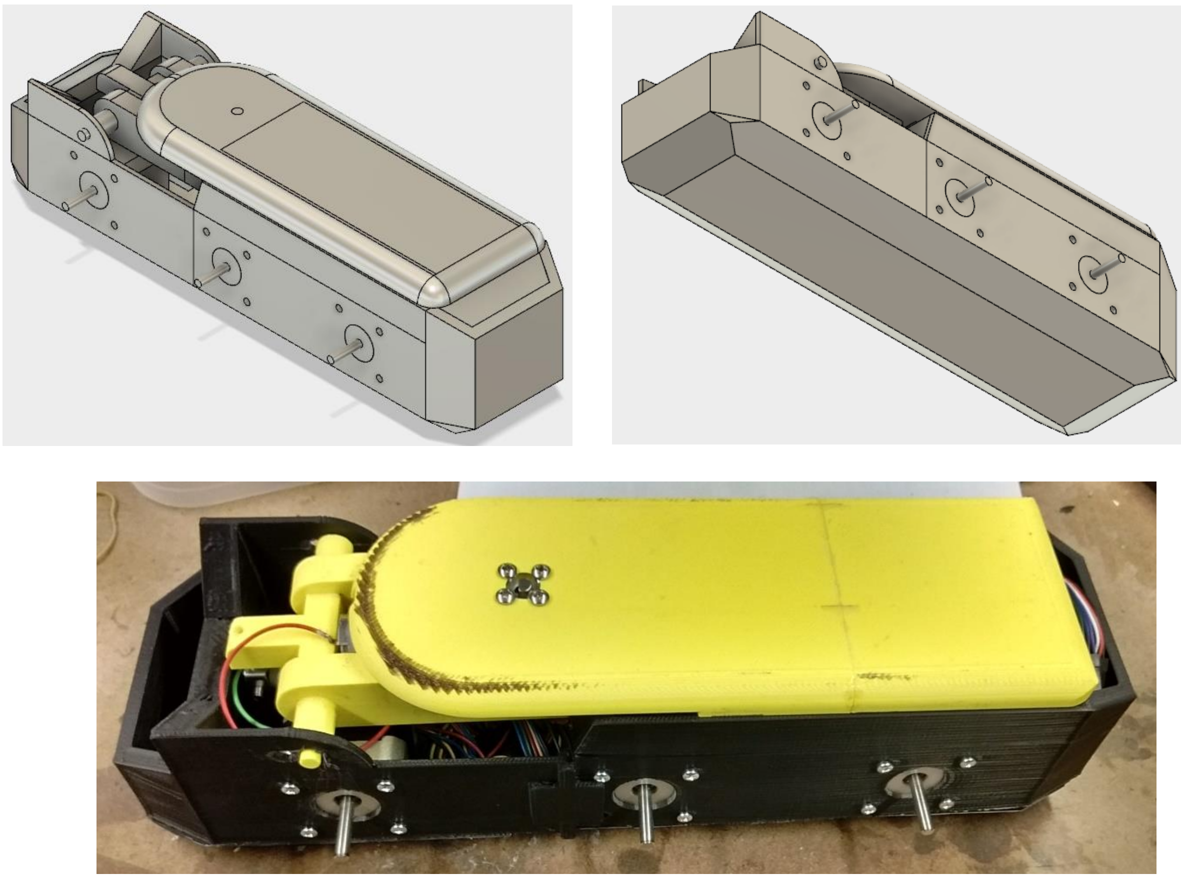

Figure 4.2 - Rover Body

For the time being, the rover body is built out of 3D printed ABS. This is due to limitation in the availability of the milling equipment needed to make the final aluminum parts. Once all of the parts were printed, they were simply bolted or snapped together to form the rover body. The motors and electronics were then all bolted or screwed on, as appropriate.

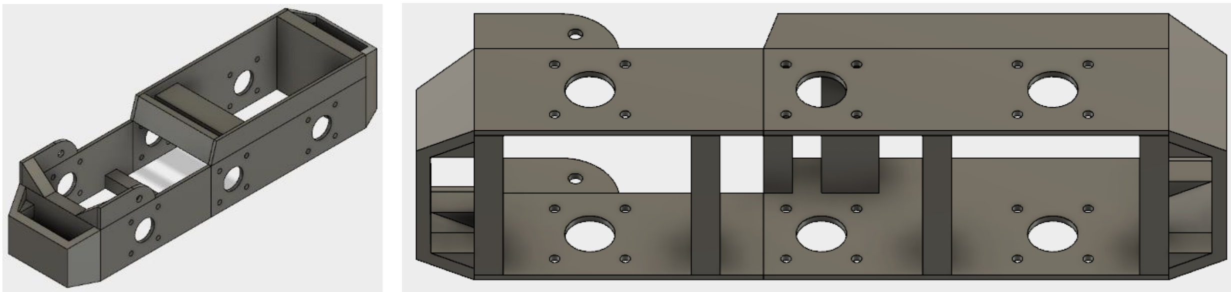

Figure 4.3 - Rover Body Frame

4.3 Electronics

4.3.1 Changes Since CDR

CDR	FRR	Reason for Change
Linear Actuator Control Board (LAC)	Arduino	The LAC has been removed, as it was not necessary. Instead, the linear actuator will be controlled directly by the Arduino
5 V Regulator for Righting Mechanism Motor	12 V for Righting Mechanism Motor	After testing it was determined that the motor could run on 12 V, and so the voltage regulator is not necessary

Table 4.1 - Payload Electronics Changes Since CDR

4.3.2 Construction Methods

4.3.2.1 Circuit Boards

The Arduino Uno, IMU, barometer, GPS module, XBee, video transmitter, and motor drivers are mounted to the 3D printed ABS body panels of the rover using nylon standoffs secured with epoxy and nylon screws. The Arduino and XBee have jumper wires connected to their header pins. All other circuit boards have wires soldered on.

4.3.2.2 Infrared (IR) Sensor and Camera

The IR sensor and camera are mounted to the aluminum front panel of the rover frame, behind a protective cover (which has holes in it to allow them to see out).

4.3.3 Electrical Schematics

Note: the Arduino Uno is shown in every image to show how it connects to everything; however, there is only one in the rover.

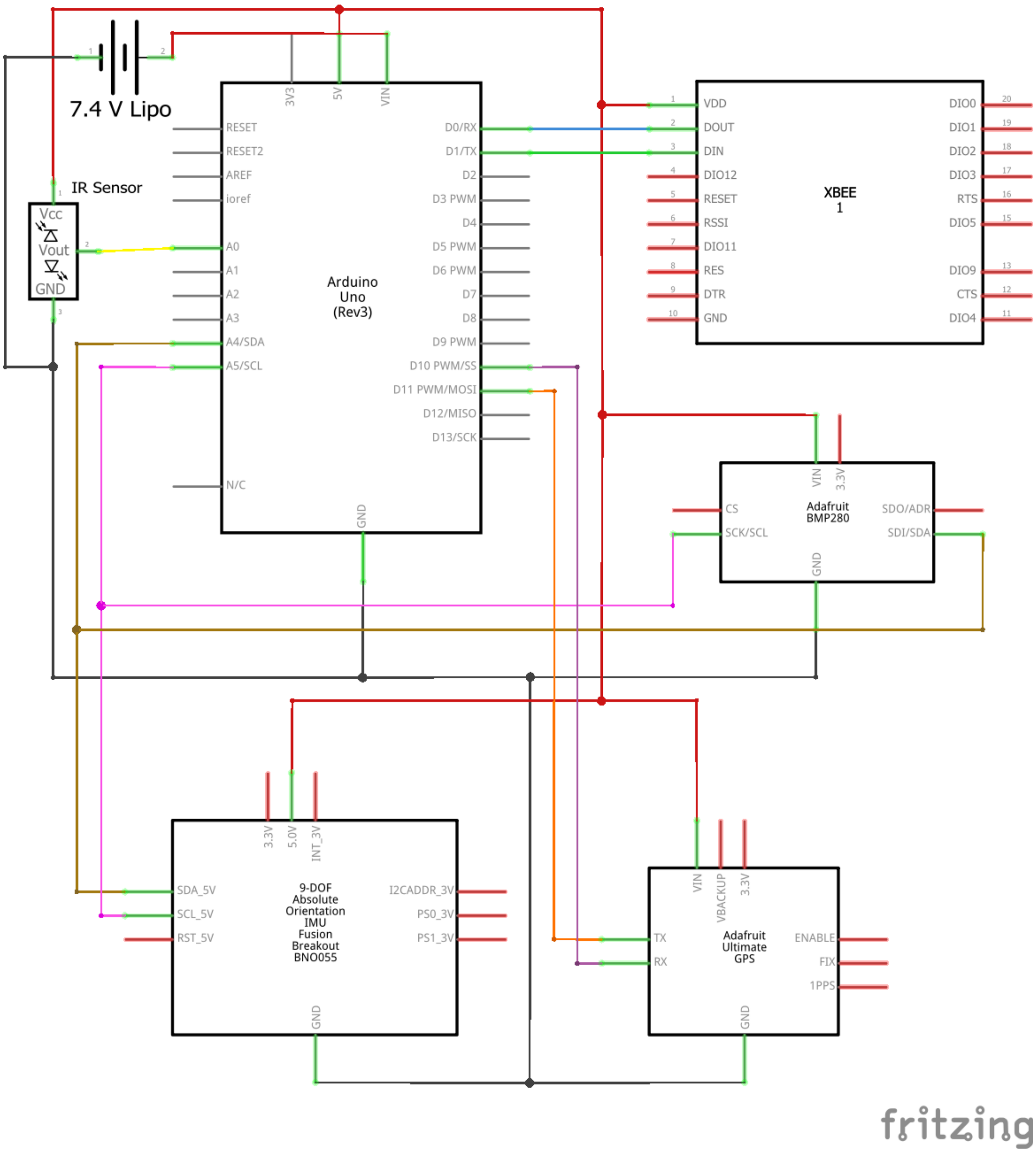

Figure 4.4 – Sensors and XBee Schematic

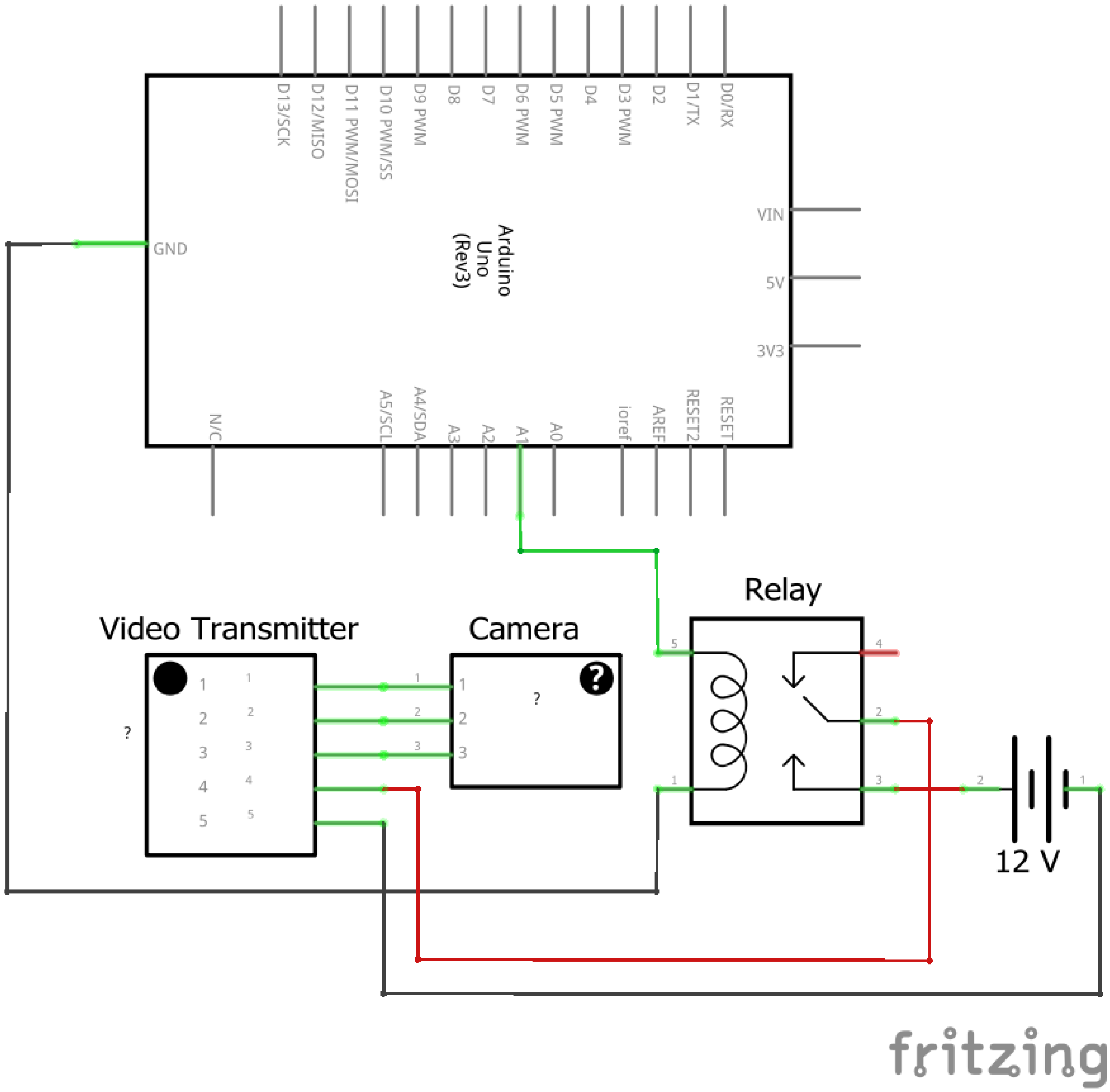

Figure 4.5 – Camera System Schematic

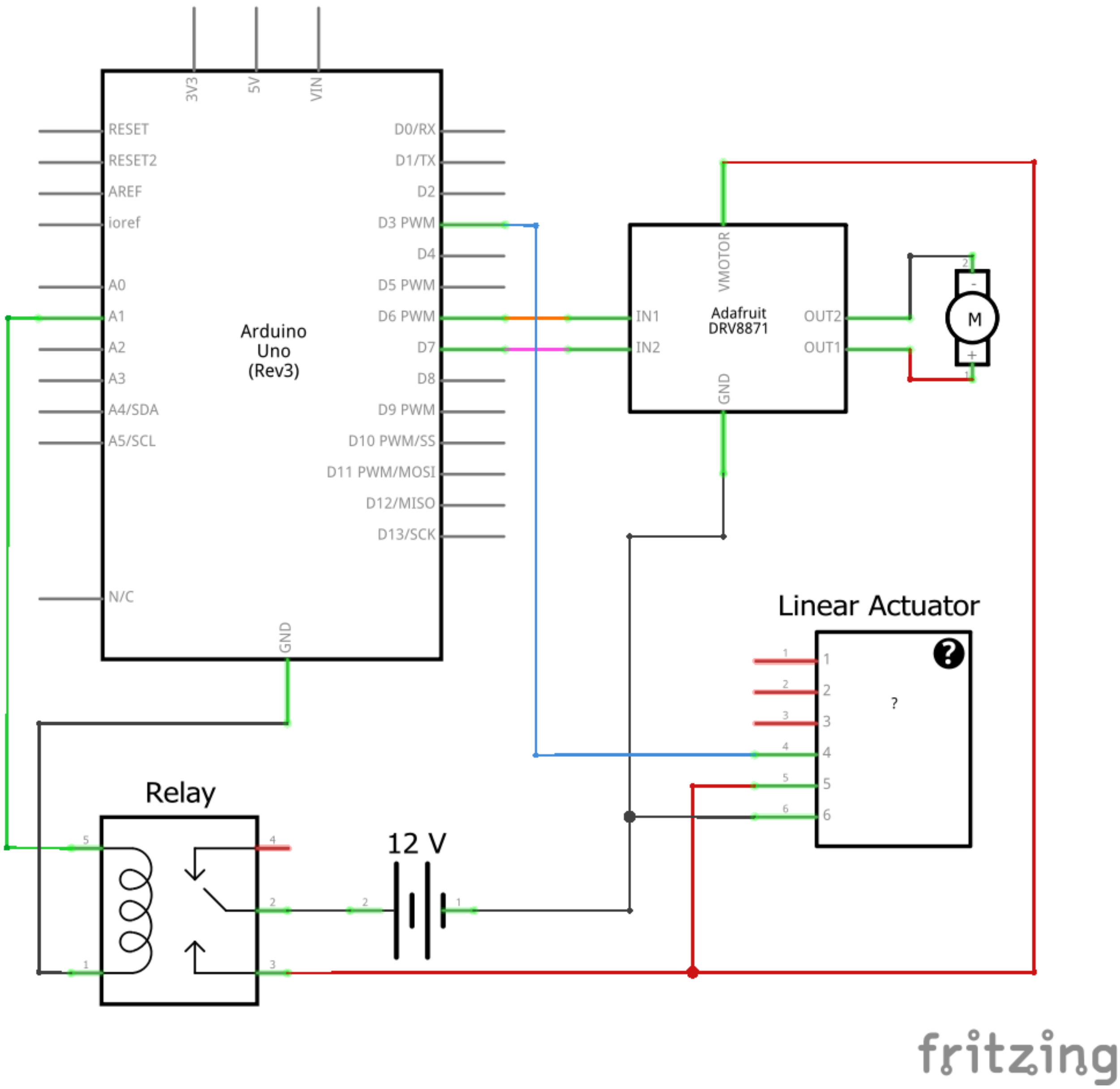

Figure 4.6 – Righting Mechanism Schematic

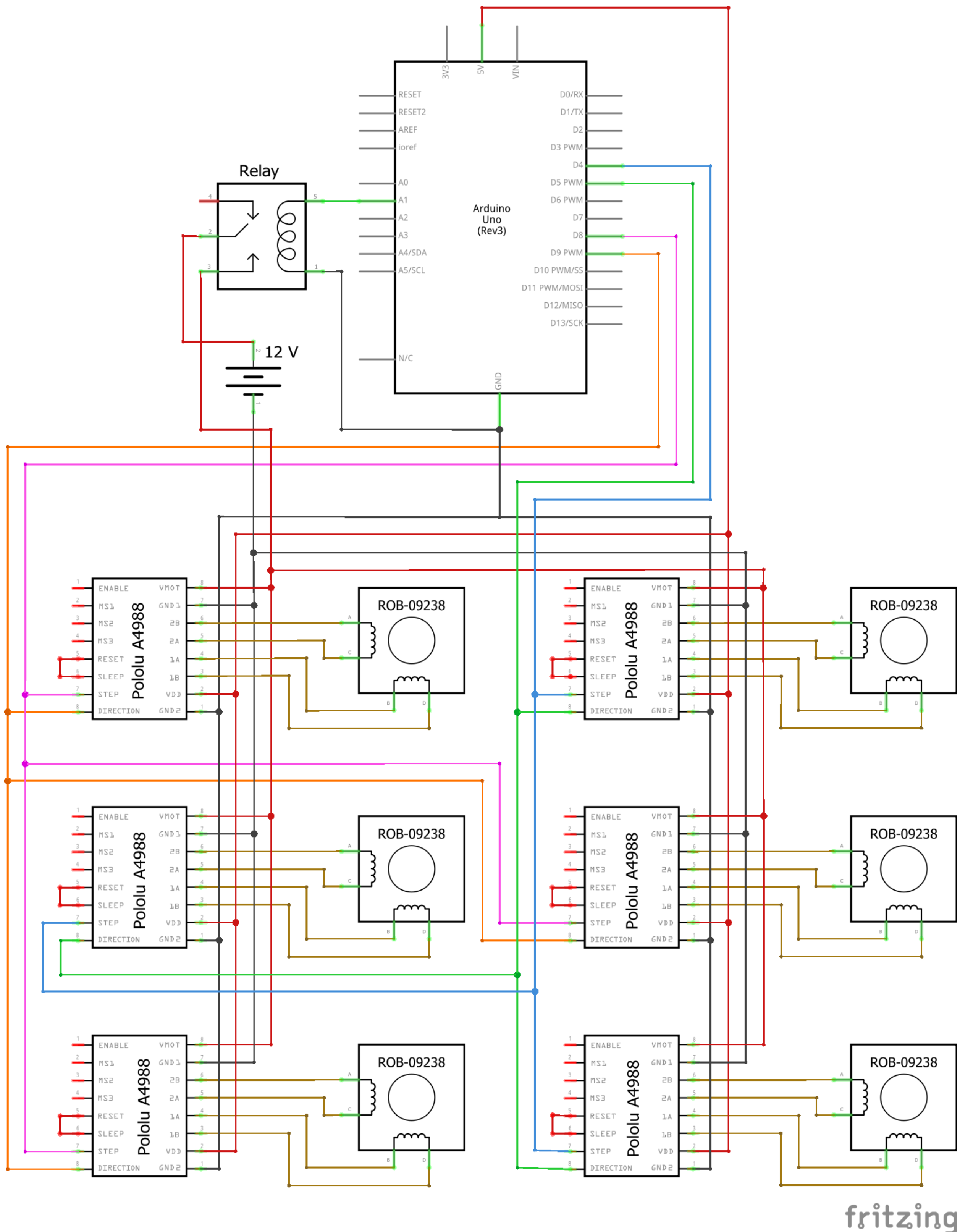

Figure 4.7 – Wheel Motor Schematic

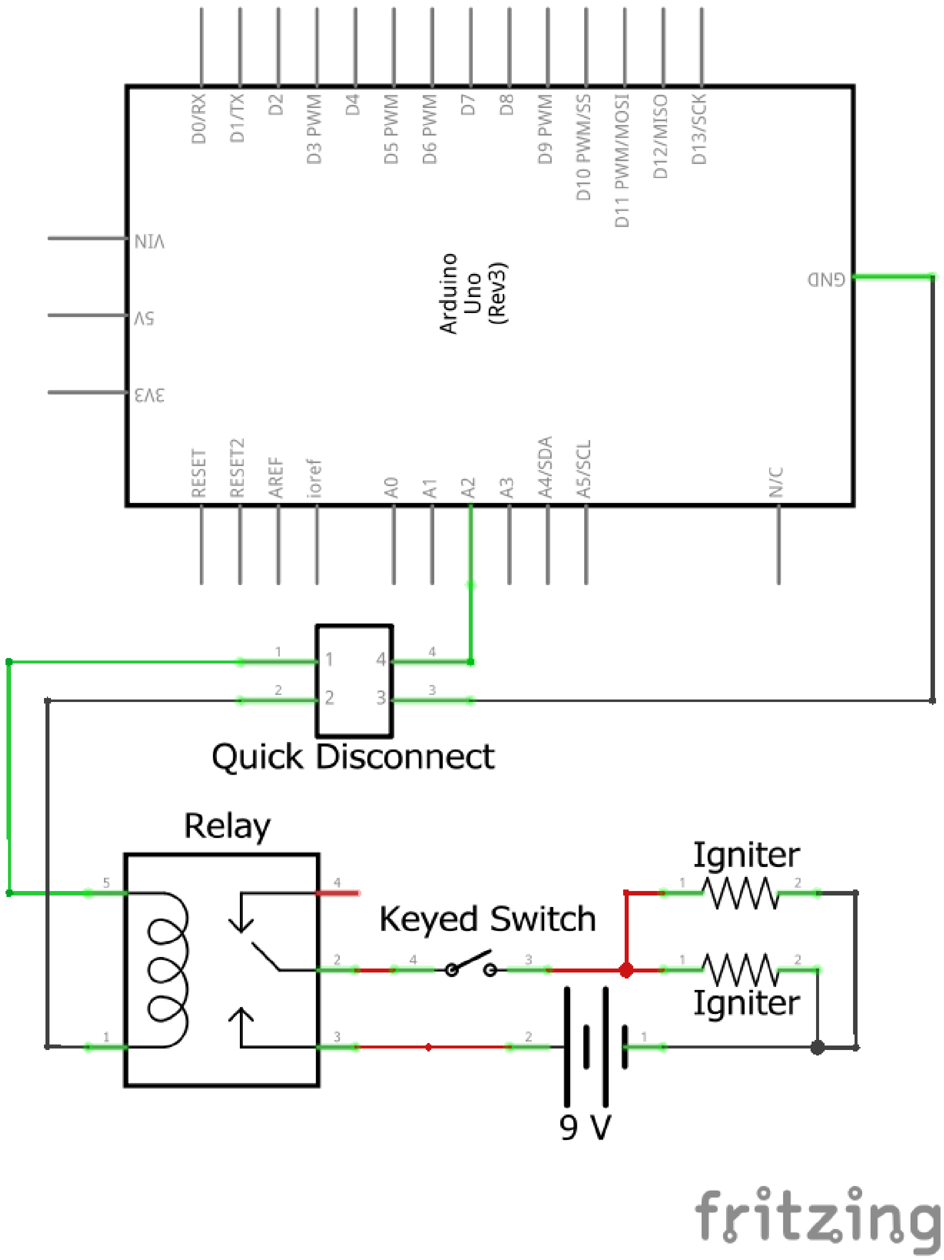

Figure 4.8 – Rover Deployment Schematic

4.4 Mobility

The rover is equipped with six infinity-shaped wheels, each powered by a stepper motor. The infinity shape of the wheels was chosen so that, when stowed in the nosecone, the wheels could be put parallel to the rover body to conserve space, while also allowing a generous amount of ground clearance once out of the payload tube and free from the nosecone. Due to the unique shape of the wheels, a lot of care must be taken to keep them in time, this is why stepper motors are being used. The stepper motors will allow each wheel to be controlled precisely to optimize performance and ensure that the they remain synchronized.

The wheels are made from 1/4 in. aluminum and are 7 in. long by 1.9 in. at their widest.

Figure 4.9 – Infinity Wheel Model

4.5 Righting Mechanism & Solar Panel

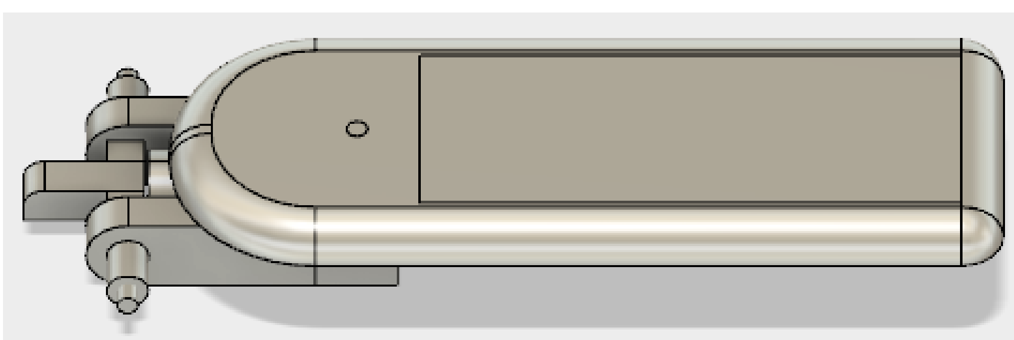

Figure 4.10 - Righting Mechanism with Solar Panel Bracket Model (above) and 3D Printed (below)

The top section of the rover is composed of the righting mechanism and the solar panel bracket, which acts as the arm for the righting mechanism. Orientation will be determined by sensors on the rover. The righting mechanism consists of a mounting bracket and a commercially-available electric motor that is mated to a torque conversion box. The motor has a speed of 1/2 RPM, is powered by 12 VDC, and is held in place by an aluminum strip that will be bolted to aluminum bracket. The bracket is composed of two 1/2 in. thick arms and two 1/4 in. diameter pins that are mounted in two corresponding holes in the sides of the rover body. This bracket is currently 3D printed, but in the future, will be machined from a solid block of aluminum to ensure strength and rigidity. The bracket also has a mounting point in its center for a linear actuator, which will deploy and retract the righting mechanism as needed. This linear actuator has a 50 mm stroke and it is capable of applying a max force of 45 N. If the rover lands on its back, the righting mechanism will deploy, raising the solar panel bracket, and ideally flip the rover onto its front. If the rover lands on its side, the righting mechanism will deploy and then swing the solar panel bracket to the appropriate side to push the rover back onto its front. Then it will swing the solar panel bracket upright, lower the righting mechanism, and complete its travel. The solar panel bracket is attached to the righting mechanism with a commercially-available mounting hub. This hub is screwed into a circular slot on the solar panel bracket, and its set screw is tightened onto the shaft of the righting mechanism motor to keep it attached. Once the rover has completed its travel, it will deploy the righting mechanism to expose the solar panels to the sky, and its mission will be complete.

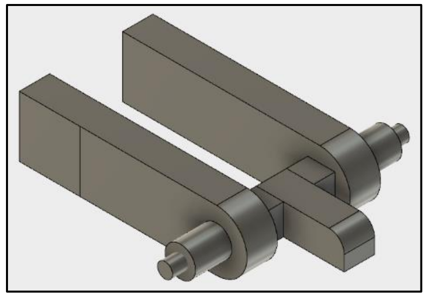

Figure 4.11 – Righting Mechanism Model

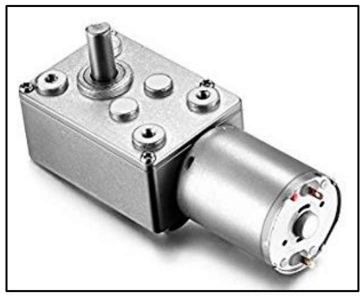

Figure 4.12 – Righting Mechanism Motor

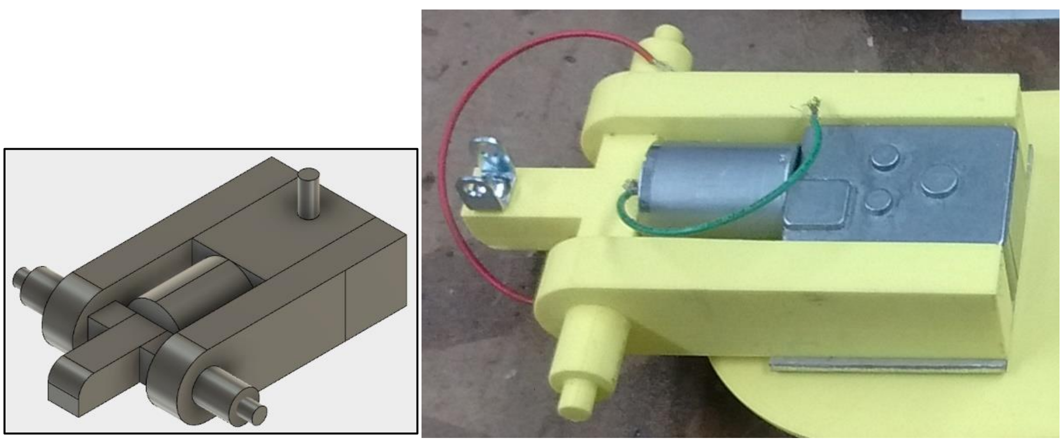

Figure 4.13 – Righting Mechanism with Motor Model (left) and Assembled (right)

Figure 4.14 – Righting Mechanism Installed on Rover

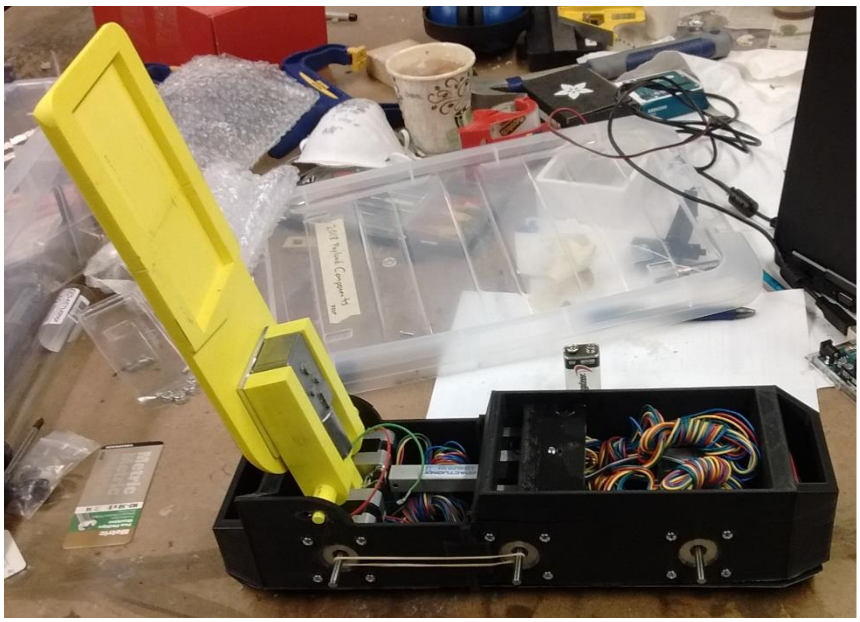

Figure 4.15 – Righting Mechanism Deployed

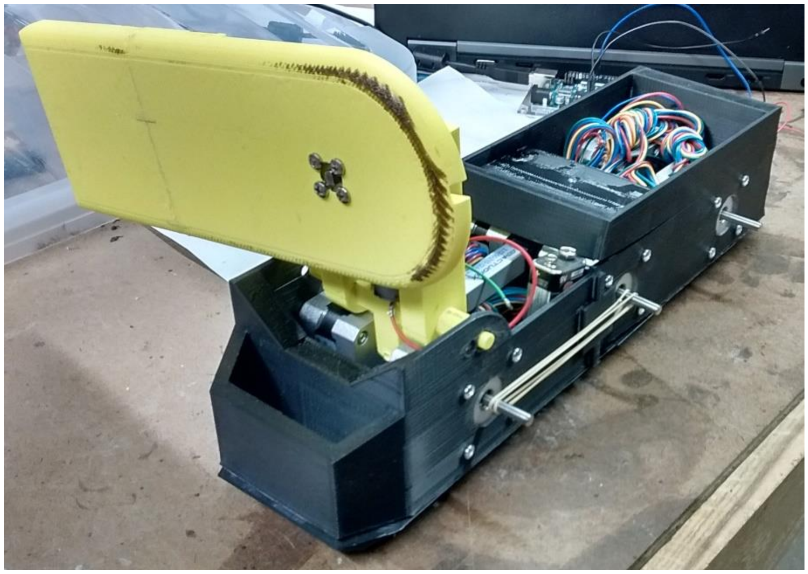

Figure 4.16 – Righting Mechanism Deployed Laterally

5. Safety

5.1 Changes since CDR

– All mitigation verifications have been updated

5.2 Safety and the Environment

Risk Matrix and Definitions

Probability	Severity			
	1 Catastrophic	2 Critical	3 Marginal	4 Negligible
A – Frequent	1A	2A	3A	4A
B – Probable	1B	2B	3B	4B
C – Occasional	1C	2C	3C	4C
D – Remote	1D	2D	3D	4D
E – Improbable	1E	2E	3E	4E

Severity – Probability			
High Risk Unacceptable	Medium Risk Undesirable	Low Risk Acceptable	Minimal Risk Desirable

Tabel 5.1 - Severity-Probability Matrix

Definitions of Severity and Probability

Severity

Catastrophic (1): Loss of life or a permanent disabling injury. Loss of facility, systems or associated hardware. Irreversible severe environmental damage that violates law and regulation.
Critical (2): Severe injury or occupational related illness. Major damage to facilities, systems, or equipment. Reversible environmental damage causing a violation of law or regulation.
Marginal (3): Minor injury or occupational related illness. Minor damage to facilities, systems, or equipment. Mitigatable environmental damage without violation of law or regulation where restoration activities can be accomplished.
Negligible (4): First aid injury or occupational related illness. Minimal damage to facility, systems, or equipment. Minimal environmental damage not violating law or regulation.

Probability

Frequent (A): Occurring or done on many occasions, in many cases, or in quick succession. Hazards that happen this often are treated as they will happen and require mitigating first before anyone may be allowed to perform a task involving a frequent hazard.
Probable (B): Likely to happen. Hazards happening this often should still be expected and must be mitigated first before anyone may be allowed to perform a task involving a probable hazard.

Occasional (C): Occurring, appearing, or done infrequently and irregularly. Occasional hazards will still be mitigated after more probable hazards are reduced first, and occasional hazards will still be taken just as serious as any hazard.
Remote (D): Expected to occur at some point, but not very often. Hazards happening this often will still be mitigated after more probable hazards are reduced first and will still be treated as serious as any hazard.
Improbable (E): Very unlikely to occur. Hazards happening this often will be mitigated after other more probable hazards are reduced first but will be treated as serious as any hazard.

Combined Risk Definitions
High risk / unacceptable: Exceptionally dangerous and will not be allowed to happen under any circumstances.
Medium risk / undesirable: Harmful and objectionable. Will only be allowed if it is necessary. Will require further mitigation to decrease risk.
Low risk / acceptable: Will be allowed but can still be mitigated further to decrease harm.
Minimal risk / Ideal: Will be allowed and has been mitigated to present the least amount of harm.

5.2.1 Personnel Hazards

5.2.1.1 Hazards to Personnel at Launch Sites

Cause(s)	Mitigation(s)	Pre-Mitigation	Verification	Post-Mitigation
		Hazard Effect(s)		
	Ballistic / high speed return of the team's rocket			
	Minor to severe injury to personnel. Possible death. Minor to severe damage to property. Destruction of the launch vehicle. Destruction of the payload. Failure of the mission			
Ejection charges not powerful enough to separate the rocket at apogee	• Ejection charges will be tested multiple times before each flight to ensure energetic separation. • There will be a total of 4 ejection charges that can separate the rocket	1C	Team members will follow all procedures for packing ejection charges as per the pre-launch checklist under "Ejection Charges", and team members will also follow all procedures for testing the ejection charges as per PSLT launch vehicle testing procedures	1E
Altimeter does not have sufficient charge to fire ignitor	• Each altimeter will be connected to a different battery. • The batteries will be replaced each flight with new ones	1C	Team members will follow all procedures regarding setting the altimeter during the pre-launch checklist under "Ejection Charges"	1E
Parachute is	• The recovery system	1C	Team members will follow all	1E

Hazard				
Effect(s)				
Cause(s)	Mitigation(s)	Pre-Mitigation	Verification	Post-Mitigation
not ejected from the rocket when ejection charge fires	will be designed as a "cannon," such that the gas from the ejection charges firing pushes the parachute out of the rocket. • There will be 4 ejection charges, so if one fails to push the parachute out of the rocket, there will be backups		procedures for packing and inspecting the charges in the pre-launch checklist under "Ejection Charges"	
Parachute is melted together by the ejection charge and does not open	A parachute protector will be placed on the recovery harness between the parachute and the ejection charges	2B	Team members will follow all procedures for packing the parachute in the pre-launch checklist under "Final Rocket Assembly" including ensuring the blast protector is properly placed over parachute	2E
Chute release does not have sufficient power and does not open	There will be 2 chute releases used, connected in series, so that if one fails, the other can still release the parachute. Both chute releases will be charged before each flight	2C	Team members will follow all procedures for packing the parachute in the pre-launch checklist under "Final Rocket Assembly" including ensuring the Jolly Logic chute release is on and in good working order	2E
Black powder does not ignite because it is wet	Black powder will be stored in sealed containers. Liquids will be kept away from black powder when it is being worked with	1D	Team members will follow all instructions as set forth by the manufacturer of the black powder including storage and handling procedures	1E
Ejection charge ignitor is bad	• All ignitors will be inspected prior to use. • There will be a total of 4 ejection charges that can separate the rocket, each of which will have a different	1D	Team members will follow all procedures for packing and inspecting the charges in the pre-launch checklist under "Ejection Charges" including inspection of the ignitor leads	1E

Cause(s)	Mitigation(s)	Pre-Mitigation	Verification	Post-Mitigation
	ignitor			
Ejection charge ignitor is not properly connected to bridge	• All electrical connections in the recovery system will be inspected before each flight. • There will be a total of 4 ejection charges that can separate the rocket, each of which will be connected to a different bridge. The altimeters will beep out their continuity status	1D	Team members will follow all procedures for packing and inspecting the charges in the pre-launch checklist under "Ejection Charges" including inspection of the ignitor leads	1E
Bridge is not properly connected to altimeter	• All electrical connections will be inspected before each flight. • There will be a total of 4 ejection charges that can separate the rocket, each of which will be connected to a different bridge. The altimeters will beep out their continuity status	1D	Team members will follow all procedures for packing and inspecting the charges in the pre-launch checklist under "Ejection Charges" including inspection of the altimeter and ignitor leads	1E
Chute release is jammed and does not open	• There will be 2 chute releases used, connected in series, so that if one fails, the other can still release the parachute. • Both chute releases will be tested before each flight to ensure proper operation	2D	Team members will follow all procedures for packing the parachute in the pre-launch checklist under "Final Rocket Assembly" including ensuring the Jolly Logic chute realease is on and in good working order, and also that it is tested before launching	2E
	Ballistic / high speed return of other rockets			
	Minor to severe injury to personnel. Possible death. Minor to severe damage to property			
Some failure	Personnel will be alert at	1C	Team members will be	3C

Cause(s)	Mitigation(s)	Pre-Mitigation	Verification	Post-Mitigation
Hazard				
Effect(s)				
of the rocket	a launch. When a rocket is being launched, personnel will stop what they are doing and watch the rocket until it is safe		briefed by the safety officer before all launch events including NAR safety code part 5 "Launch Safety"	
Motor comes free				
Minor to severe injury to personnel. Damage to the rocket. Minor to severe damage to property				
The motor mount is not properly secured inside the airframe	• Stress tests will be performed on the motor mount to ensure it is able to withstand flight forces. • The motor mount will be inspected before each launch	2C	Launch vehicle motor mount testing procedures state that stress will be applied to the motor mount to ensure it can handle stress. Team members will follow all procedures under the "Motor Preparation" section of the pre-launch checklist including inspection of the motor mount before launch	2E
The motor retainer cap is not properly secured around the motor tube	• Stress tests will be performed on the motor retainer to ensure it is able to withstand flight forces. • The motor retainer will be inspected before each launch	2C	Launch vehicle motor mount testing procedures state that stress will be applied to the motor mount cap to ensure it can handle stress. Team members will follow all procedures under the "Motor Preparation" section of the pre-launch checklist including inspection of the motor retainer cap before launch	2E
The motor casing fails	The motor casing will be inspected before each launch	3C	Team members will follow all procedures under the "Motor Preparation" section of the pre-launch checklist including inspection of the motor casing before launch	3D

Table 5.2 – Assessment of Launch Site Hazards

5.2.1.2 Hazards to Personnel in Facilities

Hazard				
Effect(s)				
Cause(s)	Mitigation(s)	Pre-Mitigation	Verification	Post-Mitigation
Burns				
Minor to severe injury to personnel. Minor to severe damage to property				
Pressurized gas tank combusts	Gas tank will be stored away from heat sources and personnel will not work with gas tank near any heat sources	1C	Team members will follow all PSLT safety rules including following all manufacturer's instructions for storing and handling the gas tank	1E
Accidental motor ignition during motor preparation	Motors will be prepared away from all nonessential personnel. The person preparing the motor will ground themselves before handling motor components. Motors will be prepared away from heat sources. Motors will be prepared away from ignition sources. The ignitor will not be inserted into the motor until the rocket is on the launch pad. All other NAR guidelines will be followed regarding motor handling	1C	Team members will follow all pre-launch procedures under "Motor Preparation" and team members will also follow the NAR safety code including: Section 2 "Motors", Section 3 "Ignition System", and Section 6 "Launcher"	2E
Accidental motor ignition in storage	Motors will be stored away from heat sources. Motors will be stored away from ignition sources. Motors will be stored in sealed containers	1C	Team members will follow all manufacturer's MSDS instructions for the safe handling and storage of rocket motors	2E
Accidental motor ignition during launch pad	All nonessential personnel will vacate the area before the ignitor is inserted into the motor. Ensure	1C	Team members will follow all pre-launch procedures under "Launch Rail Setup" and "Ignitor Installation"	2E

Hazard				
Effect(s)				
Cause(s)	Mitigation(s)	Pre-Mitigation	Verification	Post-Mitigation
preparation	power is disabled to the launch control system before connecting to the ignition leads. Discharge control system clips before connecting them to the ignitor leads			
Accidental black powder ignition during rocket preparation	All nonessential personnel will vacate the area before black powder charges are prepared. The person preparing the black powder charge will ground themselves before handling the black powder. Black powder charges will be prepared away from heat sources. Black powder charges will be prepared away from ignition sources	1C	Team members will follow all pre-launch checklist procedures under “Launch Rail Setup” and “Ignitor Installation”. Team members will also follow all manufacturer’s MSDS instructions for the safe handling of black powder	2E
Accidental black powder ignition during launch pad preparation	All black powder charge ignition systems will require a switch to be armed before they will be able to ignite, and those switches will not be armed until the rocket is on the launch pad. All nonessential personnel will clear the area before black powder charges are armed	1C	Team members will follow all pre-launch checklist procedures under “Launch Rail Setup” and “Ignitor Installation”. Team members will also follow all manufacturer’s MSDS instructions for the safe handling of black powder	3E
Aerosolized spray paint ignites	Painting with spray paint will be done outside. Painting with spray paint will be done away from ignition sources	2D	Team members will be briefed on and follow all safety procedures before entering the shop to build, and team members will follow all manufacturer's MSDS instructions for the handling	3E

Cause(s)	Mitigation(s)	Pre-Mitigation	Verification	Post-Mitigation
Hazard				
Effect(s)				
			and storing of aerosol spray paints	
Accidental black powder ignition in storage	Black powder will be stored away from heat sources. Black powder will be stored away from ignition sources. Black powder will be stored in sealed containers	1D	Team members will be briefed on and follow all safety procedures before entering the shop to build, and team members will follow all manufacturer's MSDS instructions for the handling and storing of black powder	2E
Acetone / acetone fumes ignite	Acetone will be used away from ignition sources. Acetone will be stored in sealed containers. Acetone will not be left open longer than necessary	2D	Team members will be briefed on and follow all safety procedures before entering the shop to build, and team members will follow all manufacturer's MSDS instructions for the handling and storing of acetone	2E
Denatured alcohol / denatured alcohol fumes ignite	Denatured alcohol will be used away from ignition sources. Denatured alcohol will be stored in sealed containers. Denatured alcohol will not be left open longer than necessary	2D	Team members will be briefed on and follow all safety procedures before entering the shop to build, and team members will follow all manufacturer's MSDS instructions for the handling and storing of denatured alcohol	2E
Battery ignites	Battery leads will not be crossed. Electrical systems will be analyzed for the appropriate voltage before any batteries are connected	2D	Team members will be briefed on and follow all safety procedures before entering the shop to build, and team members will follow all manufacturer's instructions for the handling and storing of batteries	2E
Accidental ignitor ignition	Ignitors will be kept away from sources of electrical buildup. Personnel handling ignitors will ground themselves first	3D	Team members will follow all pre-launch procedures including sections "Motor Preparation" and "Ignitor Installation"	3E
	Respiratory illness			

Hazard				
Effect(s)				
Cause(s)	Mitigation(s)	Pre-Mitigation	Verification	Post-Mitigation
Long-term health issues				
Inhaling fiberglass dust	All personnel in the vicinity will wear dust masks when fiberglass is being worked with. All dust will be cleaned up after working with fiberglass, and at least 10 minutes will be given for any remaining dust to settle before personnel remove their masks	2B	Team members will be briefed on and follow all safety procedures before entering the shop to build, and team members will follow all manufacturer's MSDS instructions for the handling and storing of fiberglass	2E
Inhaling acetone fumes	Personnel will take care when working with acetone. Personnel will not place their heads directly over open acetone	3C	Team members will be briefed on and follow all safety procedures before entering the shop to build, and team members will follow all manufacturer's MSDS instructions for the handling and storing of acetone	3E
Inhaling denatured alcohol fumes	Personnel will take care when working with Denatured alcohol. Personnel will not place their heads directly over open denatured alcohol	3C	Team members will be briefed on and follow all safety procedures before entering the shop to build, and team members will follow all manufacturer's MSDS instructions for the handling and storing of denatured alcohol	3E
Inhaling aerosolized spray paint	Personnel will wear at least dust masks, preferably respirators while using spray paint	3C	Team members will be briefed on and follow all safety procedures before entering the shop to build, and team members will follow all manufacturer's MSDS instructions for the handling and storing of aerosol spray paints	3E

Table 5.3 - Assessment of Risks to Personnel from Materials

5.2.1.3 Testing Hazards

Burns				
Personnel are injured; damage to testing facility / area				
Black powder charge goes off while personnel are near rocket during ground fire test	• All personnel will maintain a safe distance from rocket during ground fire test. • Personnel will wear safety glasses before performing a ground fire test	1C	Team members will be briefed before any testing event to ensure they understand safe testing procedures. Team members will follow all safety rules in the PSLT team handbook, and will follow all manufacturer's MSDS instructions for the safe handling of black powder	1E
Black powder charge goes off while testing altimeter	• Any personnel testing altimeters will first take the avionics away from other personnel. • Personnel will point avionics away from themselves and others when testing.	1C	Team members will be briefed before any testing event to ensure they understand safe testing procedures. Team members will follow all safety rules in the PSLT team handbook, and will follow all manufacturer's MSDS instructions for the safe handling of black powder	1E
Ground fire test causes a facility fire	All ground fire tests will be conducted outside away from buildings and people	1C	Team members will be briefed before any testing event to ensure they understand safe testing procedures. Team members will follow all safety rules in the PSLT team handbook	1E

Table 5.4 - Assessment of the Testing Hazards

Personnel are struck by moving parts				
Personnel are injured				
Improperly secured test articles come loose during testing (e.g. ACS nozzle and hose whipping back).	• Ensure all parts of the system being tested are properly secured before testing. • Personnel will maintain a safe distance during testing	1C	Team members will be briefed before any testing event to ensure they understand safe testing procedures including maintaining a safe distance from the rocket. Team members will follow all safety rules in the PSLT team handbook, and will follow manufacturer's instructions for safe handling of components involved in the ACS system	1E
Fast moving parts of test articles striking personnel (e.g. nosecone separating during ground fire test).	• Personnel will not stand in nosecone's travel path during testing. • Personnel will maintain a safe distance away from any systems being tested	1C	Team members will be briefed before any testing event to ensure they understand safe testing procedures including maintaining a safe distance from rocket. Team members will follow all safety rules in the PSLT team handbook	1E

Table 5.5 - Assessment of Testing Hazards

5.2.2 Failure Modes

System				
Hazard				
Effect(s)				
Cause(s)	Mitigation(s)	Pre-Mitigation	Verification	Post-Mitigation

Recovery System				
Parachute fails to deploy, or slow the rocket down				
Injury to personnel and the rocket becomes damaged				
Bulkheads aren't sealed tight, and force from the ejection charge blows through into rocket	• On frigid days when the bulkheads can shrink, keep them insulated.	1C	Team members will follow all pre-launch preparations including section "Launch Vehicle Exterior Inspection"	1E
Ejection charges are packed improperly	• Ejection charges will be packed according to the pre-launch procedural checklist. • Careful inspection of the ejection charges to ensure they are packed properly which will then be verified by the Safety Officer before launch	1C	Team members will follow all procedures for packing and inspecting the charges in the pre-launch checklist under "Ejection Charges"	1E
Dead batteries causing electronics in recovery system to not work	• Only use fresh batteries and batteries that can last long enough to keep electronics powered in case there is a launch delay • Batteries will be carefully inspected and verified by the Safety Officer to ensure they are working before launch	1C	Team members will follow all procedures for inserting and inspecting all batteries in the pre-launch checklist under "Avionics"	1E
Altimeter isn't turned on, or programmed incorrectly	Before launching all components of the rocket will be inspected by the team via the pre-launch checklist, and the range safety officer will inspect the rocket for flight readiness	1C	Team members will follow all procedures for activating and inspecting the altimeters in the pre-launch checklist under "Avionics"	1E
Jolly Logic Altimeter is	• Ensure that the Jolly Logic is fully charged before packing for	1C	Team members will follow all procedures	1E

not charged sufficiently and turns off	launch day. • Have a backup charging device available to charge up Jolly Logic • Careful inspection of the Jolly Logic during pre-launch preparations and verified by the Safety Officer to ensure Jolly Logic is functioning		for activating and inspecting the Jolly Logics in the pre-launch checklist under "Final Rocket Assembly"	
Jolly Logic altimeter is programmed to have parachute deploy too late during descent	• Calculate the correct altitude to deploy parachute so the parachute has enough time to fully deploy and slow down rocket • Careful inspection of the Jolly Logic during the pre-launch preparations to ensure the correct altitude is programmed before flight. This will be verified by the Safety Officer before flight	1C	Team members will follow all procedures for setting correct altitude for Jolly Logics in the pre-launch checklist under "Final Rocket Assembly"	1E
Avionics bay comes loose during flight	• All components of the avionics bay, including bulk heads, U-bolts, washers, wiring, batteries, and the batteries will be securely installed into airframe, • Careful inspection of the avionics bay during pre-launch preparations. This will be verified by the Safety Officer before launch	1C	Team members will follow all procedures in the pre-launch checklist under "Avionics"	1E
Parachute tears during descent	• Analysis to choose a parachute of the correct size and material that is durable enough to withstand forces during flight. • The Parachute will be inspected during pre-launch preparations and verified by the Safety Officer before flight	1D	Team members will follow all procedures in the pre-launch checklist under "Avionics"	1E
Parachute chords become tangled or tear during flight	• The chords of the parachute will be carefully inspected during pre-launch preparations and verified by the Safety Officer to ensure they are not torn or frayed	1D	Team members will follow all pre-launch procedures for packing and inspection of the parachute under sections "Recovery	1E

	• The parachute chords will be packed in a safe manner, carefully inspected and verified by the Safety Officer to ensure they do not tangle up during flight.		System Preparation" and "Final Rocket Assembly"	
Rubber band wrapping Jolly Logic around parachute snaps during flight	Careful inspection of the Jolly Logic during pre-launch preparations to ensure the rubber band has no tears, or that the rubber band is wrapped too tight around the parachute. This will also be verified by the Safety Officer before launch	1D	Team members will follow all pre-launch procedures for packing and inspection of the parachute under sections "Recovery System Preparation" and "Final Rocket Assembly"	1E
Jolly Logic securing pin is not locked in place and comes undone during flight	• Make sure the parachute is wrapped tight enough so that the locking pin can lock into place. • Careful inspection during pre-launch preparations to ensure that the locking pin is secure and cannot come undone. This will be verified by the Safety Officer before launch	1D	Team members will follow all pre-launch procedures for securing and inspection of the Jolly Logics under "Final Rocket Assembly"	1E
Recovery harness breaks	• The recovery harness used will be made of material strong enough to withstand the forces experienced during flight. • The recovery harness will be tested before being used, it will be installed according to the recovery system prep checklist and verified by the Safety Officer before flight	1D	Push/pull test procedures state that force will be placed on the quick links, and all other joints / fittings per the testing procedures to ensure quick links are strong enough to hold. Team members will follow all pre-launch procedures for packing and inspection of the parachute and recovery harness under "Final Rocket Assembly"	1E
Quick links are not secured to recovery harness	Careful inspection of the quick links during pre-launch preparations to ensure the quick links are secured and will not come undone during flight. This will be verified by the	1D	Team members will follow all pre-launch procedures for attachment and inspection of the quick	1E

	Safety Officer before flight		links under "Final Rocket Assembly"	

Table 5.6 - Recovery System Failure Modes and Effects Analysis

Airframe				
Parts separate from vehicle during flight				
Injury to personnel and the rocket becomes damaged				
Fins break off from airframe	• During construction an adequate amount of epoxy that is of a proper mixture will be applied to all contact points of the fins and airframe. • Fins will be inspected before any flights by the team, the Safety Officer, and the Range Safety Officer to ensure they are secure.	1D	Team members will follow all pre-launch procedures for inspection of the rocket's fins under the section "Launch Vehicle Exterior Inspection"	1E
Airframe fractures during flight	• The airframe will be constructed of durable materials. • Stress tests will be performed on airframe to ensure that it can withstand flight forces. • Airframe will be carefully inspected and then verified by the safety officer and the range safety officer before launch.	1D	Push / pull test procedures state that pressure will be place on the airframe to ensure it will withstand forces. Team members will follow all pre-launch procedures for inspection of the airframe under section "Launch Vehicle Exterior Inspection"	1E
Nosecone separates during flight	• During construction the nosecone will be properly attached to airframe and tested before flying. • During launch preparations the nosecone will be inspected by the safety officer and range safety officer before flight to ensure flight readiness	1D	Team members will follow all pre-launch procedures for attachment and inspection of the nosecone under sections "Payload Preparation" and "Launch Vehicle Exterior Inspection"	1E

Fins are asymmetrically attached to airframe	• During construction a fin jig will be used to ensure that the fins are attached symmetrically to the rest of the airframe. • The fins will be inspected and then verified by the Safety Officer before launch	1D	Team members will follow all pre-launch procedures for inspection of the rocket's fins under section "Launch Vehicle Exterior Inspection"	1E
Heat warping the airframe disturbing laminar flow	• During storage, transportation, and preparation the airframe will be kept out of direct sunlight or any other heat sources to prevent heat warping • The airframe will be inspected during pre-launch preparation and then verified by the Safety Officer to ensure there is no warping of the airframe	1D	Team members will follow all pre-launch procedures for inspection of the airframe under section "Launch Vehicle Exterior Inspection"	1E

Table 5.7 - Airframe Failure Modes and Effects Analysis

	Altitude Control System (ACS)			
	Rocket flies out of control			
	Personnel are injured, and the rocket is damaged			
Pressurized gas tank comes loose during flight	• Proper design of the gas tank mountings to ensure the security of the gas tank. • Perform stress tests on the gas tank mountings to ensure they can withstand force of flight. • The gas tank mountings will be carefully inspected during pre-launch preparations and then verified by the Safety Officer before launch	1D	ACS mobile test procedures state that the ACS will engage while the airframe is suspended to ensure the air tank will function properly. Team members will follow all pre-launch preparation procedures for inserting and inspection of the ACS under section "Altitude Control System". Team members will also follow all manufacturer's instructions for the handling of	1E

			components of the ACS	
Gas thrusters on launch vehicle are pointing in the wrong direction when expelling gas during flight	• Calculate where the nozzles should be pointing on the airframe. • Perform adequate testing before flying • Careful inspection of the nozzles during pre-launch preparations to ensure their facings haven't been changed. This will then be verified by the Safety Officer before launch	1D	ACS exhaust test procedures will test to make sure the nozzles are pointed in the right direction and can hold under pressure. Team members will follow all pre-launch preparation procedures for inserting and inspection of the ACS under section "Altitude Control System". Team members will also follow all manufacturer's instructions for the handling of components of the ACS	1E
Obstruction in altitude control system leading to uneven gas distribution	• Careful inspection of the hoses and nozzles during construction to ensure no obstructions are in them. • Test the hoses and nozzles before flying to ensure there are not blockages. • Careful inspection during pre-launch preparations to ensure there are no blockages. This will then be verified by the Safety Officer before launch	1D	ACS exhaust velocity tests will reveal any blockages in the hoses. Team members will follow all pre-launch preparation procedures for inserting and inspection of the ACS under section "Altitude Control System". Team members will also follow all manufacturer's instructions for the handling of components of the ACS	1E
Pressurized gas tank leaking inside airframe causing altimeter to deploy	• Analyzing available gas tanks to ensure one of durable and reliable materials is chosen. • Careful testing and inspection of the gas tank during pre-launch preparations to ensure there are no leaks in the gas	1D	Team members will follow all pre-launch preparation procedures for inserting and inspection of the ACS under section "Altitude	1E

parachute too early	tank.		Control System" Team members will also follow all manufacturer's instructions for the handling of components of the ACS	
Pressurized gas tank becoming extremely cold during use, freezing airframe making it brittle	• The area surrounding the pressurized gas tank will be insulated to prevent the airframe from freezing. • The gas tank area will be carefully inspected during pre-launch preparations and then verified by the Safety Officer to ensure it is properly insulated	1D	Team members will follow all pre-launch preparation procedures for inserting and inspection of the ACS under section "Altitude Control System" Team members will also follow all manufacturer's instructions for the handling of components of the ACS	1E

Table 5.8 - Altitude Control System Failure Modes and Effects Analysis

	Altitude Control System			
	Rocket fails to slow down or speed up			
	Target altitude not reached			
Gas thrusters fire too early or too late	• Sufficient testing of the altitude control system before using in the rocket. • Careful inspection of the system's electronics during pre-launch preparations to ensure it is functioning as intended	2C	ACS Sensor detection tests will show any discrepancy in where the control system is predicting apogee, and where actual apogee is. Team members will follow all pre-launch procedures for inserting and inspection of the ACS under "Altitude Control System"	2E
Gas leaks out before thrusters are	• Sufficient testing of the altitude control system before using in the rocket.	2D	Team members will follow all pre-launch procedures for	2E

supposed to engage	• Careful inspection of the hoses, nozzles, and other components to ensure there are no leaks		inserting and inspection of the ACS under "Altitude Control System"	
Increased drag from nozzles protruding too far from airframe	• Calculate maximum appropriate distance that nozzles can protrude and ensure during building of the rocket that nozzle cannot protrude further than allowed. • Careful inspection of the rocket during pre-launch preparations to make sure nozzles are not protruding further than allowed.	2D	Team members will follow all pre-launch procedures for inserting and inspection of the ACS under "Altitude Control System"	2E
Rocket sits out in the sun for a prolonged period. Gas pressure builds up in tank causing tank to rupture or leak	• Insulate the interior of the airframe with expanding spray foam. • Keep the rocket in a shaded area and away from heat sources • Do not fill gas tank to capacity. Leave room available in the tank in case gas expands	2D	ACS testing procedures state that the tank will only be filled to 2100 psi to prevent excessive pressure buildup. Team members will also follow all pre-launch procedures for inspection of the ACS under section "Altitude Control System"	2E

Table 5.9 - Altitude Control System Failure Modes and Effects Analysis

	Payload			
	Rover is unable to leave launch vehicle or travel full distance for objective			
	Mission failure			
Ejection charge isn't powerful enough to eject rover sled	• Have redundant ejection charges that are more powerful than the primary charge as backups. • Perform ground fire tests to ensure the charge is powerful enough to eject rover sled • Careful inspection of the charges during pre-launch preparations to make sure the correct amount of black powder was put in ejection cup. This will also be verified	2C	Nosecone ground fire test procedures state a ground fire test will be performed to ensure payload separation. Team members will follow all pre-launch procedures for packing the payload charges and inspection of the rover setup before flight	2E

	by the Safety Officer before launch			
Payload hits a rock / obstruction and gets damaged	• Design the payload to be made of durable enough materials to endure contact with any rocks and / or obstructions on the ground • Run simulations of the payload contacting rocks / obstructions to ensure it can handle	2C	Rover mobility test procedures state the rover will be driven 50ft on several types of terrain to ensure stability.	2E
Payload gets stuck in ground	• A rounded nosecone will be used to help mitigate the probability of the payload becoming stuck in the ground • Test flights to make sure the rounded nosecone does not get stuck in the ground	2C	Nosecone impact test procedures state a ground fire test with debris in its path will be conducted to ensure the nosecone will separate after contact with obstructions	2E
Rover trigger does not work	• Have redundant triggers and charges in place as backups in case the primary trigger fails. • Perform adequate testing of the triggers before flying to make sure they are working as intended. • The rover's triggers will be inspected during pre-launch preparations and verified by the safety officer before launch	2C	Rover deployment test procedures state the payload will be triggered several times under varying circumstances to test triggers. Team members will follow all pre-launch procedures for checking the triggers under section "Payload"	2E
Nosecone does not split at all, or enough to allow rover to leave	• Tests on the nosecone separation will be performed before flying to ensure the nosecone splits as intended. • During pre-launch preparations the nosecone will be carefully inspected, and then verified by the Safety Officer before launch to ensure it is functioning as intended.	2C	Nosecone ground fire test procedures state the nosecone charges will engage to ensure proper separation. Team members will follow all pre-launch procedures for inspecting the nosecone under section "Payload"	2E
Payload gets stuck in tree	• The payload design and materials used in its construction will be durable enough to withstand a fall. • The rover will also be tested to	2D	Rover impact test procedures call for the rover to be safely dropped several times to ensure rover	2E

	simulate falls to ensure it is durable		durability	
Batteries for payload electronics are dead	• Use only fresh batteries with a charge long enough to power rover electronics in case there is a flight delay. • Test batteries before flying to make sure they can last long enough to account for a flight delay • Careful inspection of the batteries during pre-launch preparations which will also be verified by the Safety Officer before launch	2D	Rover battery test procedures state that batteries will be inserted, and the rover turned on for at least 3 hours to ensure battery performance. Team members will follow all pre-launch procedures for inspection the rover batteries under section "Payload"	2E
Rover gets stuck in the parachute or debris on the ground	• Design the rover to have orientation sensors to help it avoid obstructions • Adequate testing. Run simulations before flying to make sure the rover can avoid getting stuck in the parachute or other entanglements. • Careful inspection of the rover's orientation sensors to ensure they are functioning as intended. This will then be verified by the Safety Officer	2D	Rover deployment test procedures state the payload charges will engage under varying circumstances to ensure the rover can clear the rocket. Team members will follow all pre-launch procedures for inspecting the rover under section "Payload"	2E

Table 5.10 - Payload System Failure Modes and Effects and Analysis

Payload Ejection Charges				
Charge doesn't fire or isn't powerful enough				
Mission failure				
Ejection charge isn't powerful enough to eject rover sled	• Have redundant ejection charges that are more powerful than the primary charge as backups. • Perform ground fire tests to ensure the charge is powerful enough to eject rover sled • Careful inspection of the charges during pre-launch preparations to make sure the	2C	Nosecone ground fire test procedures state a ground fire test will be performed to ensure payload separation. Team members will follow all pre-launch procedures for packing the payload charges and inspection of the rover setup before	2E

	correct amount of black powder was put in ejection cup. This will also be verified by the Safety Officer before launch		flight. Team members will follow all pre-launch procedures for inspecting the ejection charges under section "Payload"	
Commands to fire ejection charge isn't received	• The team will use equipment strong enough to broadcast a signal to fire ejection charges. The purchase of any new equipment will need to be factored into the team's budget. • Adequate testing of signal transmission to the rover with nearby interference to ensure the signal is strong enough to reach the rover • Careful inspection of the signal transmission equipment during pre-launch preparations to make sure equipment is working as intended. This will then be verified by the Safety Officer	2C	Rover data transmission test procedures state that signals will be sent to the rover over increasing distances to prove transmission stability. Team members will follow all pre-launch procedures for inspecting the transmission equipment under section "Payload"	2E
Arming switch not armed	Arming switch will be carefully inspected during pre-flight preparation and verified by the safety officer to ensure the arming switch is on and in good working order before flight.	2C	Team members will follow all pre-launch procedures for inspecting the arming switch under "Payload'	2E
Damp powder charge fails to ignite	• Black powder will be stored in dry, sealed containers. • The cups will be checked to make sure they are dry before any black powder is placed in them, and they will be carefully inspected by the safety officer before flight	2D	Team members will follow all manufacturer MSDS instructions for storage and handling of black powder. Team members will follow all pre-launch procedures for packing and inspection charges under section "Payload"	2E
Wires are disconnected	• During construction wires will be securely attached to all devices. • All wires and electronics will be	2D	Team members will follow all pre-launch procedures for testing the rover's wiring	2E

	carefully inspected and pull-tested during pre-launch preparations, and will be verified by the safety officer to ensure they are secured before flight		under section "Payload'	
Ignitors are bad	• Ignitors will be tested several times before launching to make sure they function as intended. • All ignitors will be carefully inspected during pre-launch preparations and then verified by the Safety Officer	2D	Nosecone ground fire tests state the ignitors will be connected to the leads and tested to ensure they work. Team members will follow all pre-launch procedures for inspecting the ignitors under section "Payload"	2E

Table 5.11 - Payload System Failure Modes and Effects and Analysis

	Payload			
	Rover is unable to leave launch vehicle or travel full distance for objective			
	Mission failure			
Ejection charge isn't powerful enough to eject rover sled	• Have redundant ejection charges that are more powerful than the primary charge as backups. • Perform ground fire tests to ensure the charge is powerful enough to eject rover sled • Careful inspection of the charges during pre-launch preparations to make sure the correct amount of black powder was put in ejection cup. This will also be verified by the Safety Officer before launch	2C	Nosecone ground fire tests will energetically separate the rover sled and determine if the charge is sufficient. All team members will follow pre-launch procedures for inspecting the rover sled charges under section "Payload"	2E
Payload hits a rock / obstruction and gets damaged	• Design the payload to be made of durable enough materials to endure contact with any rocks and / or obstructions on the ground. • Run simulations of the payload contacting rocks / obstructions to ensure it can handle	2C	Rover mobility testing states that the rover will be driven at least 50 feet on varying terrain types to ensure rover can handle terrain	2E
Payload gets	• A rounded nosecone will be	2C	Nosecone impact tests	2E

stuck in ground	used to help mitigate the probability of the payload becoming stuck in the ground • Test flights to make sure the rounded nosecone does not get stuck in the ground		state that the nosecone will be fired with debris in its path to ensure nose doesn't get stuck	
Rover trigger does not work	• Have redundant triggers and charges in place as backups in case the primary trigger fails. • Perform adequate testing of the triggers before flying to make sure they are working as intended. • The rover's triggers will be inspected during pre-launch preparations and verified by the safety officer before launch	2C	Rover deployment testing states that the trigger will be engaged several times which will prove if the trigger works. Team members will follow all pre-launch procedures for inspecting the rover triggers under section "Payload"	2E
Nosecone does not split at all, or enough to allow rover to leave	• Tests on the nosecone separation will be performed before flying to ensure the nosecone splits as intended. • During pre-launch preparations the nosecone will be carefully inspected, and then verified by the Safety Officer before launch to ensure it is functioning as intended	2C	Nosecone ground fire tests state that the nosecone will be fired and will determine if the rover is able to leave the nosecone	2E
Payload gets stuck in tree	• The payload design and materials used in its construction will be durable enough to withstand a fall. • The rover will also be tested to simulate falls to ensure it is durable	2D	Rover impact testing states the rover will be safely dropped from an elevated position to determine if rover can endure a great fall	2E
Batteries for payload electronics are dead	• Use only fresh batteries with a charge long enough to power rover electronics in case there is a flight delay. • Test batteries before flying to make sure they can last long enough to account for a flight delay • Careful inspection of the batteries during pre-launch preparations which will also be verified by the Safety Officer before launch	2D	Rover battery testing states that fresh batteries will be inserted, and the rover will be turned on for at least 3 hours to ensure battery life. Team members will follow all pre-launch procedures for inspecting the rover batteries under section "Payload"	2E

Rover gets stuck in the parachute or debris on the ground	• Design the rover to have orientation sensors to help it avoid obstructions • Adequate testing. Run simulations before flying to make sure the rover can avoid getting stuck in the parachute or other entanglements. • Careful inspection of the rover's orientation sensors to ensure they are functioning as intended. This will then be verified by the Safety Officer	2D	Rover mobility tests state the rover will be driven at least 50 feet to ensure rover can negotiate around obstacles safely. Team members will follow all pre-launch procedures for inspecting the rover under section "Payload"	2E

Table 5.12 - Payload System Failure Modes and Effects and Analysis

Payload Electronics				
Rover is unable to function as intended				
Mission failure				
Solar panel does not deploy	• Use a design that has proven to work in the past. • Perform multiple tests to ensure that the solar panel will deploy as intended • During pre-launch preparations thoroughly inspect the solar panel deployment to ensure everything is working as intended. This will then be verified by the Safety Officer before launch	2C	Rover solar panel deployment testing states the solar panel will be deployed multiple times to ensure its functionality. Team members will follow all pre-launch procedures for inspecting the rover's solar panel under section "Payload"	2E
Motor failure for solar panel	• The solar panel / righting mechanism will be controlled by two high-torque, low speed motors. The right mechanism will be actuated by a linear actuator and the solar panel bracket will be actuated by a high-torque motor with a speed of 0.5 revolutions per second. • Run multiple tests before launching to ensure the motor works as intended. • Carefully inspect the solar panel motor before launch to	2C	Rover solar panel deployment testing states the solar panel will be deployed multiple times to ensure its functionality. Team members will follow all pre-launch procedures for inspecting the rover's solar panel under section "Payload"	2E

	ensure it is working as intended. This will be verified by the Safety Officer before launch			
Water leaks in causing a short	• Connections will be waterproofed during construction. Any connections or components that cannot be waterproofed will be elevated to help prevent getting wet. • Test the rover to ensure the connections are safe from moisture • Carefully inspect the connections during pre-launch preparations to make sure the connections are dry and safe from moisture	2C	Rover mobility tests state the rover will be driven around at least 50 feet and will show if any moisture is able to get inside. Team members will follow all procedures for inspecting the rover for any structural compromises under section "Payload"	2E
Sensors fail	• Sensors will be mounted and wired securely. If possible, they will be mounted on shock-absorbable material • Multiple tests will be conducted to ensure the sensors are working as intended • Careful inspection of the sensors during pre-launch preparations to ensure they are working as intended	2C	Rover sensor testing will subject the sensors to multiple sensing scenarios to ensure the sensors are performing as intended. Team members will follow all procedures for inspecting the rover's sensors under section "Payload"	2E
Incorrect Wiring	• During construction the wiring will be inspected and attached securely. • Adequate testing of the wires to make sure the function and are not loose • Careful inspection of all wiring including pull-testing of the wires during pre-launch preparations and then verified by the Safety Officer2	2C	Team members will follow all procedures for inspecting the rover's wiring under section "Payload"	2E
Incorrect design for motor controller	• Gather data from numerous sources during design and choose a design that has proven to work and is reliable • Multiple tests will be conducted to ensure the design	2C	Rover mobility test procedures will test the functionality of the motor controller	2E

	is working			
Battery overloads / explodes	Circuit analysis will be performed and tested to ensure the battery functions safely and as intended	2C	Rover battery test procedures state the battery will be used for at least 3 hours, and will test the functionality of the battery	2E
Electronics overheat	Circuit analysis will be performed and tested to ensure the all electronics function safely and as intended	2C	Rover battery test procedures state the battery will be used for at least 3 hours, and will test the functionality of the battery	2E
Bad connections	Careful inspection of all the connections during pre-launch preparations to ensure connections are good. This will then be verified by the Safety Officer before flight	2C	Rover battery test procedures state the battery will be used for at least 3 hours to test battery's functionality. Team members will follow all pre-launch procedures for inspecting the connections under section "Payload"	2E
Broken electronics	• Design to have electronics located away from places that may hit the ground or other hazards. • Mount electronics on shock absorbing materials • Test the design to ensure the location of the electronics is free from danger.	2C	Rover impact tests procedures state the rover will be safely dropped to test the durability of the rover.	2E

Table 5.13 - Payload Electronics System Failure Modes and Effects and Analysis

Payload Communications				
Communications Failure				
Rover failing to deploy properly or getting damaged				
The rover's communications are down due to interference	• Have radio equipment with a signal strong signal to reach the rover and give it commands. Any new	2C	Rover transmission test procedures state the rover will send and receive data over	2E

from another team's equipment	equipment purchased will increase the team's spending, and will need to be factored in when planning the budget • Test the radio equipment by simulating other radio interference to make sure it is strong enough. • Carefully inspect all radio equipment before launch to make sure it is functioning as intended		increasing distances to test signal transfer reliability. Team members will follow all pre-launch procedures for inspecting the rover's communication equipment under section "Payload"	
The rover misinterprets commands	• Accurately analyze the rover's sensor inputs during construction. Design the rover to be durable enough to withstand potential damage it may encounter if it misinterprets commands. • Conduct adequate testing before launching. • Carefully inspect the sensor inputs during pre-launch preparations to ensure they are working as intended	2C	Rover transmission test procedures state the rover will send and receive data over increasing distances to test signal transfer reliability. Team members will follow all pre-launch procedures for inspecting the rover's communication equipment under section "Payload"	

Table 5.14 - Payload Communication System Failure Modes and Effects and Analysis

	Rover's Wheels			
	Damage to the wheels, and / or failure to operate			
	Rover is unable to move			
Rover wheel bearing comes loose or breaks	• Design to have durable components in the wheel system. • Run multiple tests on the rover to ensure the wheels work as intended. • Careful inspection of the wheel during the payload pre-launch checklist.	2C	Rover mobility testing procedures state the rover will drive a minimum of 50 feet which will test the wheels reliability. Team members will follow all procedures for inspecting the rover's wheels under section "Payload"	2E
Wheel gets damaged during	• Design the wheels to be made of durable materials able to	2C	Rover mobility testing procedures state the	2E

deployment or while traversing terrain	withstand contact with obstacles. • Design the wheels to return to their stowage positions before the right mechanism actuates. • Test the wheels several times to ensure they will work reliably. • Careful inspection of the wheels during pre-launch preparations to ensure they are not damaged.		rover will be driven 50 ft over a variety of terrain to ensure it can handle the ground. Rover impact testing procedures state that the rover will be safely dropped several times to prove the rover's durability. Team members will follow all pre-launch procedures for inspecting the rover under section "Payload"	
No power to the wheels	• Have a reliable power system in place that can keep the wheels powered even in case of a launch delay. • Have components powering the wheels on shock absorbing materials. Have all connections soldered securely. • Run multiple tests on wheels to ensure they function as intended. • Carefully inspect all components of the wheel system during pre-launch preparations	2C	Rover mobility test procedures state the rover will drive a minimum of 50 feet to ensure the wheels are powered. Team members will follow all pre-launch procedures for inspecting the rover's wheels under section "Payload"	2E
Wheel gets stuck or entangled in debris	• Program wheels to be able to turn in reverse to free itself from entanglement. • Test the rover multiple times in simulations to ensure the rover can back away from an obstacle. • Careful inspection of the rover's wheels during pre-launch preparations to ensure the wheels are in good working order.	2C	Rover mobility testing procedures state the rover will be driven 50 ft over a variety of terrain to ensure it can handle the ground. Team members will follow all pre-launch procedures for inspecting the rover under section "Payload"	2E

Table 5.15 - Rover Wheel Failure Modes and Effects and Analysis

Motor				
Motor fails to ignite or has defect				
Injury to personnel and damage to rocket				
Motor mount separates from airframe during launch	• During construction an adequate amount of epoxy of a proper mixture will be applied to secure the motor mount to the airframe. • Perform stress tests on the motor mount to ensure the mount is secured to the airframe • During pre-launch preparations the motor mount will be carefully inspected and then verified by the Safety Officer before launch	1C	Motor Mount testing states that stress will be applied to the motor mount to ensure its durability. Team members will follow all pre-launch preparation procedures including inspection of the motor mount under section "Launch Vehicle Exterior Inspection"	1E
Ignitors burn too early	• Research which ignitors are the most reliable and cost efficient. • Test several ignitors to ensure they are reliable. • Follow all launch pad prep procedures including making sure there is no continuity to pad when loading up rocket.	1C	Ejection Ground Fire tests will also test the ignitors to make sure they work. Team members will follow all pre-launch preparation procedures for inserting and inspecting ignitors under section "Ignitor installation"	1E
Motor heat causes fire inside the rocket	• The motor section of the rocket will be completely sealed away from the rest of the rocket by secure bulkheads able to resist heat from the motor. The motor will also have a plugged forward closure to prevent motor injection into the rocket. • Before launch the entire motor section will be carefully inspected and then verified by the safety officer to ensure it is in good condition	2C	Team members will follow all pre-launch prep procedures for inserting and inspecting the motor in sections "Motor Prep" and "Ignitor Installation"	3E

Motor has manufacturer defect	• Follow all manufacturer instructions for storing, transporting and handling the motor. • Test multiple motors of the same make and power to make sure motor works as intended. • Careful inspection of the motor fuel grains and other components during pre-launch preparations to ensure there are no problems with the motor	3C	Team members will follow all manufacturer's MSDS instructions for handling and storing motors. Team members will also follow all procedures for prepping and inspecting the motor under section "Motor Preparation"	3E
No continuity to launch pad	• Follow all pre-launch checklist items including plugging the power into the launch pad when finished prepping rocket on pad. WARNING: If there is no continuity, follow all instructions from the Range Safety Officer first before attempting to troubleshoot continuity at the launch pad.	2C	Team members will follow all NAR safety codes including those pertaining to launch pad setup under parts "Ignition System", "Misfires" and "Launcher". Team members will also follow all pre-launch procedures in sections "Launch Rail Setup" and "Reinspection Procedures"	2E
Motor under propels, or over propels the rocket.	• Run simulations to determine what altitude the motor will propel the rocket to. • Perform multiple launches to ensure motor will propel rocket to desired altitude. • Careful inspection of the motor during pre-launch preparations.	3C	Team members will follow all manufacturer's MSDS instructions for storing and handling the motors. Team members will also follow all pre-launch procedures for installing and inspection of the motor under section "Motor Preparation"	3E

Table 5.16 - Motor System Failure Modes and Effects and Analysis

5.2.3 Environmental Hazards

Hazard				
Effect(s)				
Cause(s)	Mitigation(s)	Pre-Mitigation	Verification	Post-Mitigation
Environmental Impact on Rocket				
Damage to or Loss of the Rocket				
Extreme cold temperatures causing parts to shrink, bulkheads no longer sealing off areas.	• Keep rocket insulated with a blanket. • Use a heating device such as a cordless hair dryer or heat gun to keep parts from getting cold. • Carefully inspect bulkheads and other parts of rocket to make sure all seals are still intact.	1C	Team members will follow all pre-launch procedures for inspecting the airframe under section "Launch Vehicle Exterior Inspection"	1E
Cloudy or rainy conditions causing the rocket to be unable to tracked in the sky after launch	As per FAA regulations for high powered rocketry (14 CFR 101 subpart C, §§ 101.25), a high-powered rocket may not be flown into a cloud or at an altitude where the horizontal visibility is less than five miles. If it is cloudy or raining, then the team will reschedule a launch when the weather is clear.	1D	Team members will follow all FAA regulations for launching in safe weather as set forth by CFR 101 subpart C, §§ 101.25	1E
Direct sunlight / hot temperatures causing electronics to overheat	The rocket will be assembled and stored in shaded area	2D	Team members will follow all pre-launch procedures for inspection of the airframe under section "Launch Vehicle Exterior Inspection"	2E
High humidity causing airframe to swell, or electronics to become wet	The rocket will be inspected by the Safety Officer via the pre-flight checklist and then by the Range Safety Officer for flight readiness.	2D	The safety officer as well as all other team members will follow all pre-launch procedures for inspection of the airframe under section "Launch Vehicle Exterior Inspection"	2E
Windy conditions	• The team will not launch into high winds and will	2D	Team members will follow all safety codes	2E

Hazard				
Effect(s)				
Cause(s)	Mitigation(s)	Pre-Mitigation	Verification	Post-Mitigation
causing the rocket to fly off the intended course and drift further away while landing	wait for better conditions. • The team will check simulations and flights for stability. Minimize time under main parachute to ensure minimal drift while maintaining safe landing speed.		for launching in safe weather as set forth by NAR safety code item #9 “Launch Site”	
High winds causing prep-area tent to blow over	The prep-area tent will be anchored to the ground with metal stakes.	2D	Prep area setup procedures state the tent will be anchored to the ground with metal spikes	2E

Table 5.17 - Assessment of the Impact of the Environment on the Rocket

Hazard				
Effect(s)				
Cause(s)	Mitigation(s)	Pre-Mitigation	Verification	Post-Mitigation
Rocket Impact on the Environment				
Damage to the Environment				
Rocket causing a grass fire during launch or when landing	The location where the team launches at will be free of any dry grass that may catch on fire as per NAR High Powered Rocket Safety Code part 7 "Launcher". Fire extinguishers will be on hand in case any fires do start	2D	Team members will follow all NAR safety codes including part 7 “Launcher”	1E
Rocket crashing or parts breaking off of the rocket during flight, potentially introducing hazardous materials to	• Ground fire test will be conducted to ensure that the recovery system works to avoid crashes. Rocket fins will be securely attached to airframe and tested to ensure they can withstand force. • In case of crash the	2D	Team members will follow all pre-launch procedures for checking that parts attached to the rocket (fins, nosecone, motor mount, etc.) are secured under section "Launch Vehicle Exterior Inspection"	2E

Hazard				
Effect(s)				
Cause(s)	Mitigation(s)	Pre-Mitigation	Verification	Post-Mitigation
the local ecosystem	team will clear the area of debris as much as possible			
Wildlife wandering near launch site potentially harming them	• The range will first be declared clear by the range Safety Officer before any launch occurs. • If any animals get near the launch site, the launch will be postponed, and no one should attempt to move the animal	2D	Team members will be briefed on launch site safety rules regarding wildlife encounters before every launch, and all team members will follow NAR safety code part 5 "Launch Safety"	2E
Liquid coming into contact with APCP motor and then getting into the ground, potentially contaminating ground water	APCP motors will be stored in a dry container away from liquids, and will be kept dry when inserting into rocket and prepping for launch	2D	Team members will follow all manufacturer's MSDS instructions regarding the handling and storing of rocket motors	2E

Table 5.18 - Assessment of the Impact of the Rocket on the Environment

Hazard				
Effect(s)				
Cause(s)	Mitigation(s)	Pre-Mitigation	Verification	Post-Mitigation
Environmental Impact on Rover				
Damage to the rover				
Muddy ground, stones, or corn cobbs preventing rover from moving	• Design the rover's wheels to be able to traverse difficult ground. • Test drive the rover on difficult terrain to prove design works • Carefully inspect rover before launch to	2C	Rover mobility testing procedures state the rover will be driven 50 ft over a variety of terrain to ensure it can handle the ground. Team members will follow all pre-launch	2E

Hazard				
Effect(s)				
Cause(s)	Mitigation(s)	Pre-Mitigation	Verification	Post-Mitigation
	ensure the wheels are working		procedures for inspecting the rover under section "Payload"	
Water from a pond, creek, etc. damaging internal electronics	• Seal the internal electronics behind watertight barriers. • Carefully inspect the rover during pre-launch preparations	2C	Team members will follow all pre-launch procedures for inspecting the rover under section "Payload"	2E
Rover falling from an elevated position	• Build the rover from durable materials. • Test the rover by simulating falls to prove the rover's construction is durable. • Carefully inspect the rover during pre-launch preparations to ensure rover is not damaged	2C	Rover impact testing procedures state that the rover will be safely dropped several times to prove the rover's durability. Team members will follow all pre-launch procedures for inspecting the rover under section "Payload"	2E

Table 5.19 - Assessment of the Impact of the Environment on the Rover

Hazard				
Effect(s)				
Cause(s)	Mitigation(s)	Pre-Mitigation	Verification	Post-Mitigation
Rover's Impact on the Environment				
Damage to the Environment				
Emissions from the rover polluting the air	The Rover will be designed to be completely battery powered	2C	Rover design specifications state that the rover will be battery operated	2E
Electrical fire in the rover spreading to the grass or other	• Test the rover's electronics to ensure the batteries and / or other electronic parts don't overload or catch fire. • Careful inspection of the	2D	Rover battery testing procedures state the rover will be turned on for a minimum 3 hours to test battery. Team members will	2E

Hazard				
Effect(s)				
Cause(s)	Mitigation(s)	Pre-Mitigation	Verification	Post-Mitigation
vegetation	rover's electronics before flight to ensure electronics are in good working order.		follow all pre-launch procedures for inspecting the rover's batteries under section "Payload"	
Parts of the rover breaking off, getting into the soil or water	• Design the rover to be durable. • Test drive the rover to make sure no parts break off. • Careful inspection of the rover during pre-launch procedures • All team member will carefully inspect the rocket landing zone and the path of the rover. All debris will be cleaned up.	2D	Rover mobility testing procedures state the rover will be driven 50 ft over a variety of terrain to ensure it can handle the ground. Team members will follow all pre-launch procedures for inspecting the rover under section "Payload"	3E

Table 5.20 - Assessment of the Impact of the Rover on the Environment

6 Launch Operations Procedures

6.1 Launch Vehicle Exterior Inspection

Must be observed and checked off by either the Safety Officer, or the Deputy Safety Officer.

- ☐ Carefully place the rocket down on the preparation table with the fins over the edge of the table so that there is no pressure put on fins. WARNING: Pressure placed on the fins can cause the fins to warp, and become loose or break off from the airframe.
- ☐ Examine the rocket, making sure the airframe has not warped. WARNING: Warping of the airframe will result in the rocket not passing flight readiness inspection, and the rocket will not fly. If a rocket does fly with warping of the airframe, it can result in the rocket flying off course and crashing.
- ☐ Examine the rocket, making sure there are no cracks or holes in the airframe. WARNING: If there are any cracks or holes in the airframe, the rocket will not pass flight readiness inspection and will not fly. Holes or cracks in the airframe can cause the rocket to fly off course and crash, and the force of flight can cause damage to the internal components of the rocket.
- ☐ Examine the nosecone, making sure there are no cracks or holes in the nosecone. WARNING: If there are any cracks or holes in the nosecone, the rocket will not pass flight readiness inspection and will not fly. If there are any cracks or holes in the nosecone during flight, the force of flight can cause the nosecone to break off and result in the rocket crashing.
- ☐ Examine both rail buttons, making sure they can rotate freely, and that they are mounted securely to the airframe. WARNING: If the rail buttons are not secured, they can separate during rail exit which can cause the rocket to fly off course.
- ☐ Examine the fins, making sure they are on securely, and that there are no cracks or holes in the fins. WARNING: Loose fins will result in the rocket not passing flight readiness inspection and will not fly. If the fins are loose during a flight they could separate from the airframe causing the rocket to fly off course and crash.
- ☐ Examine the fillets that bond the fins to the airframe making sure there are no cracks. WARNING: If the fillets do not seal the fins to the airframe the rocket will not pass flight readiness inspection and the rocket will not fly. If the fillets were compromised during flight the fins could separate from the airframe causing the rocket to fly off course and crash.

☐ Examine the motor mount to make sure it is secured. WARNING: If the motor mount is not secured during flight the motor could eject causing injuries and damage to the rocket.

I have observed and verified that all the above procedures were followed.

Signature____ Print Name______________________________ Date__________________

6.2 Altitude Control System (ACS)

Must be observed and checked off by either the Safety Officer, or the Deputy Safety Officer.

PUT ON SAFETY GLASSES BEFORE WORKING WITH THE ACS. WARNING: Failure to put on safety glasses could lead to injuries if any pressurized gases or objects were to fly into a team member's eyes while working on the ACS.

☐ Check to ensure that the 9-volt (1) and A23 (2) batteries have been replaced before every use. WARNING: If the batteries die before or during flight, the ACS will fail.

☐ Check the tank's connection to the tubing structure (already secured in the rocket tube by foam) to ensure that it is secure. WARNING: If the connections aren't secured they could come loose during flight and get damaged.

☐ Check to ensure the insulation is not damaged. WARNING: Damaged insulation could lead to dangerous temperature fluctuations in the tank.

☐ Test the system by opening the thrusters temporarily (using the electronics to simultaneously test the electronics). The system only needs to be opened enough to allow air through to ensure that air can successfully flow through the system at an appropriate pressure. While air is flowing, carefully listen for any leaks. WARNING: Failure to test the gas flow before launch could result in unfixed gas leaks inside the airframe causing damage to electronics.

  WARNING: When listening for leaks keep your head clear of the nozzles and other points where high-speed gas may exit!

☐ Ensure all electronics are on and functioning. WARNING: If the electronics aren't functioning the ACS will fail during flight.

☐ Remove and refill the tank to the appropriate pressure and again have two separate people check that the pressurization of the vessel is not above 2,100 psi. WARNING: If the tank is over pressurized and the rocket sits out in the sun for too long, the gases can expand and potentially vent or rupture the gas tank.

- ☐ Record that the tank was pressurized.
- ☐ Securely reattach the tank (being sure to open the flow of propellant) and electronics, checking that all parts are securely attached as this will be the final time the system is checked before flight. WARNING: Failure to securely attach the components could result in parts coming loose during flight and getting damaged.

I have observed and verified that all the above procedures were followed.

Signature______________________________ Print Name______________________ Date_____________

6.3 Recovery System Preparation

6.3.1 Parachute

Must be observed and checked off by either the Safety Officer, or the Deputy Safety Officer.

- ☐ Pull parachute out and inspect it for any holes or tears in the fabric. WARNING: Failure to follow this step could lead to the parachute ripping during descent if it has any holes and / or tears in it.
- ☐ Inspect the parachute cords for any tears or fraying. WARNING: Failure to follow this step could result in the chords breaking during descent if there are any tears in them.
- ☐ Lay the parachute on the prep table. Gather the support lines in both hands at the bottom of the canopy and the bottom of the shroud lines. Remove any twists in the lines. Stretch the lines out so they are taut.
- ☐ Arrange the canopy so it lays flat on the table. Neatly tuck in the nylon fabric from the multiple parachute panels (the material between the support lines) in towards the center line of the canopy.
- ☐ Fold the parachute in thirds by folding the top corners in towards the center of the parachute.
- ☐ Using one hand to hold the parachute down, fold the parachute into thirds lengthwise.
- ☐ Flip the parachute over and roll it up into a cylinder.

I have observed and verified that all the above procedures were followed.

Signature______________________________ Print Name______________________ Date_____________

6.3.2 Avionics

Must be observed and checked off by either the Safety Officer or the Deputy Safety Officer.

- ☐ Separate the payload tube completely, removing both bulkheads and the avionics sled, and unclipping both switch connectors.
- ☐ Pull test all wires on the altimeters (primary: 2 drogue, 2 main, 2 switch, 2 battery; secondary: 2 drogue, 2 main, 2 switch, 2 battery).
- ☐ Put two fresh 3.7 V Lipo batteries on the battery shelves. WARNING: Failure to use fresh batteries can result in insufficient current to the igniters and failure of the recovery system!
- ☐ Strap in each battery with two Velcro straps each.
- ☐ Ensure that batteries are secure. WARNING: Failure to properly secure the batteries can lead to them coming loose in flight and coming off of their connectors or damaging the altimeters!
- ☐ Insert fore bulkhead into payload tube.
- ☐ Make sure the avionics are turned off before plugging switches in. WARNING: Failure to follow this step could result in black powder charges igniting, and can result in injury.
- ☐ Connect the altimeter switch connector.
- ☐ Plug batteries into both altimeters.
- ☐ Plug LCD screen into primary altimeter.
- ☐ Turn on primary altimeter.
- ☐ Make sure primary altimeter is configured correctly (ARM ALT: 10; MAIN ALT: 10; DEPLOY MODE: 1).
- ☐ Turn off primary altimeter.
- ☐ Unplug LCD screen.
- ☐ Plug LCD screen into secondary altimeter.
- ☐ Turn on secondary altimeter.
- ☐ Make sure secondary altimeter is configured correctly (ARM ALT: 10; MAIN ALT: 30; DROGUE DELAY: 2; DEPLOY MODE: 2).
- ☐ Turn off secondary altimeter.
- ☐ Unplug LCD screen.
- ☐ Place the avionics sled onto the threaded rods.
- ☐ Secure the avionics sled on the threaded rods with nuts and washers. WARNING: Failure to secure the sled can result in damage to the avionics during flight!

☐ Connect the primary altimeter to its ejection cups. WARNING: Failure to connect will result in the ejection charges failing.

☐ Connect the secondary altimeter to its ejection cups. WARNING: Failure to connect will result in the ejection charges failing.

☐ Insert aft bulkhead into payload tube and onto threaded rods, securing with nuts and washers.

☐ Turn on the primary altimeter and wait for 1 long beep followed by 3 short beeps, repeated. If this fails, go to section 6.10.1 to troubleshoot

☐ Turn off the primary altimeter.

☐ Turn on the secondary altimeter and wait for 1 long beep followed by 3 short beeps, repeated. If this fails, go to section 6.10.1 to troubleshoot

☐ Turn off the secondary altimeter.

I have observed and verified that all the above procedures were followed.

Signature____ Print Name______________________________ Date__________________

6.3.3 Ejection Charges

Can be done only by the mentor. Must be observed and checked off by either the Safety Officer or the Deputy Safety Officer.

PUT ON SAFETY GLASSES BEFORE WORKING WITH THE EJECTION CHARGES. WARNING: Failure to put on safety glasses could lead to injuries when working with black powder.

GROUND YOURSELF BEFORE WORKING WITH THE EJECTION CHARGES. WARNING: Failure to ground yourself could lead to accidental ignition of black powder.

☐ Shorten the ignitor leads.

☐ Make sure all igniter leads are folded twice.

☐ Connect igniter leads to the P1 terminal block.

☐ Insert igniter tip into bottom of P1 ejection cup.

☐ Pour in pre-measured black powder (7+1 g).

☐ Insert wadding.

- ☐ Secure with 3 strips of masking tape. WARNING: Failure to secure the charge with tape could result in black powder falling out of the ejection cup.
- ☐ Connect igniter leads to the P2 terminal block.
- ☐ Insert igniter tip into bottom of P2 ejection cup.
- ☐ Pour in pre-measured black powder (7+3 g).
- ☐ Insert wadding.
- ☐ Secure with 3 strips of masking tape. WARNING: Failure to secure the charge with tape could result in black powder falling out of the ejection cup.
- ☐ Connect igniter leads to the S1 terminal block.
- ☐ Insert igniter tip into bottom of S1 ejection cup.
- ☐ Pour in pre-measured black powder (7+3 g).
- ☐ Insert wadding.
- ☐ Secure with 3 strips of masking tape. WARNING: Failure to secure the charge with tape could result in black powder falling out of the ejection cup.
- ☐ Connect igniter leads to S2 terminal block.
- ☐ Insert igniter tip into bottom of S2 ejection cup.
- ☐ Pour in pre-measured black powder (7+3 g).
- ☐ Insert wadding.
- ☐ Secure with 3 strips of masking tape. WARNING: Failure to secure the charge with tape could result in black powder falling out of the ejection cup.
- ☐ Take payload tube outside from preparation area and away from other people. WARNING: Failure to take altimeter away from a populated location can result in multiple serious injuries if the charges ignite.
- ☐ Making sure ejection cups are pointed away from people, turn on secondary altimeter (rightmost switch) and wait for 1 long beep, then 3 short beeps repeated.
- ☐ Turn off secondary altimeter.
- ☐ Making sure ejection cups are pointed away from people, turn on primary altimeter (center switch) and wait for 1 long beep, then 3 short beeps repeated. WARNING: Failure to keep charges pointed away from people can result in injury if black powder ignites.
- ☐ Turn off primary altimeter.
- ☐ WARNING: Double check all ejection charge loading steps! Failure to properly load the ejection charges can result in failure of the recovery system to be deployed.

I have observed and verified that all the above procedures were followed.

Signature____ Print Name______________________________ Date__________________

6.4 Payload Preparation

Must be observed and checked off by either the Safety Officer or the Deputy Safety Officer.

PUT ON SAFETY GLASSES BEFORE WORKING WITH THE EJECTION CHARGE. WARNING: Failure to put on safety glasses could lead to injuries when working with black powder.

GROUND YOURSELF BEFORE WORKING WITH THE EJECTION CHARGE. WARNING: Failure to ground yourself could lead to accidental ignition of black powder.

☐ Inspect nosecone for defects and damage.

☐ Inspect rover for defects and damage.

☐ Check all wire connections.

☐ Ensure all batteries are fresh / charged.

☐ Connect power to Arduino.

☐ Make sure all body panels are attached and secured.

☐ Wait for an established signal between ground station and rover.

☐ Place rover in the left side of the nosecone. The axles of the front and back drive motors should be placed into the standoffs.

☐ Close the right side of the nosecone towards the left side.

☐ Ensure that the nosecone is closed off and the solenoid is locked. WARNING: If the solenoid is not locked the nosecone could open in flight, leading to debris and an unpredictable trajectory.

☐ Attach two igniters to the terminal block.

☐ Insert both igniter tips into the bottom of the ejection cup.

☐ Pour the pre-measured black powder (1 g) into the cup.

☐ Insert wadding.

☐ Secure with 3 pieces of masking tape.

☐ Attach switch leads to the nosecone.

☐ Insert the nosecone into the payload tube.

☐ Secure with 4 shear pins. WARNING: Failure to secure the nosecone could lead to drag separation and a ballistic return of the nosecone.

I have observed and verified that all the above procedures were followed.

Signature____ Print Name______________________________ Date__________________

6.5 Final Rocket Assembly

Must be observed and checked off by either the Safety Officer or the Deputy Safety Officer.

☐ Attach nosecone to the payload tube, and secure it with 8 shear pins. WARNING: Failure to secure nosecone can lead to nosecone separation during flight.

☐ Attach parachute to recovery harness, and ensure the quick links are on tight and secured. WARNING: Failure to secure quick links can result in the parachute separating from the rocket.

☐ Attach parachute blast protector to the upper end of the recovery harness by running the recovery harness through the blast protector's pre-cut hole.

☐ Attach the lower end of the recovery harness to the 2 U-bolts on the JIM with quick links and ensure the quick links are on tight. WARNING: If the quick links are not on tight the recovery harness may separate from the rocket during flight.

☐ Take both Jolly Logics from their container boxes and inspect them to make sure they are powered and not damaged. WARNING: If the Jolly Logics are not fully charged before flight they may stop working during flight.

☐ Tie both Jolly Logics to the parachute chords with Kevlar twine.

☐ Attach the locking pin of the first Jolly Logic into the pin hole of the second Jolly Logic. WARNING: Failure to ensure the locking pin is secured could result in the pin coming loose during flight.

☐ Attach the locking pin of the second Jolly Logic into the pin hole of the first Jolly Logic. WARNING: Failure to ensure the locking pin is secured could result in the pin coming loose during flight.

☐ Inspect the rubber band that will hold both Jolly Logics in place. WARNING: If the rubber band has any holes or tears in it, the rubber band may snap during flight.

☐ Take both Jolly Logics and wrap the rubber band around the parachute cylinder locking both Jolly Logics into place.

☐ Turn on both Jolly Logics and program them both for 700 feet. WARNING: Programming the Jolly Logics to release at too low of an altitude could result in the parachute not having enough time to deploy before hitting the ground.

☐ Remove any rubber bands that were holding the parachute in its cylinder pack. WARNING: Failure to remove these rubber bands could result in the parachute not opening!

- ☐ Place the parachute blast protector around the parachute and slide parachute and recovery harness into parachute tube from the aft end. Make sure the blast protector is all the way around the parachute, and ensure no part of the parachute is exposed. WARNING: Failure to completely protect the parachute with the protector could result in the parachute melting from ejection charge heat.
- ☐ Insert the z-folded recovery harness into the parachute tube, aft of the parachute.
- ☐ Slide the parachute tube onto the JIM and secure with 4 shear pins.
- ☐ Check that the blast protector is fully covering the parachute. WARNING: Failure the protect the parachute could lead to it being damaged or not deploying!
- ☐ Insert a layer of ejection wading above the parachute.
- ☐ Attach upper end of recovery harness to both fore-end (payload tube) U-bolts, and secure with quick links. WARNING: Failure to secure quick links can result in the parachute separating from the rocket.
- ☐ Slide the parachute tube onto the payload tube and secure with 8 rivets.

I have observed and verified that all the above procedures were followed.

Signature_______________________________________ Print Name____________________________ Date_________________

6.6 Motor Preparation

Can be done only by the mentor. Must be observed and checked off by either the Safety Officer or the Deputy Safety Officer.

PUT ON SAFETY GLASSES BEFORE WORKING WITH THE MOTOR. WARNING: Failure to put on safety glasses could lead to injuries when working with the motor.

GROUND YOURSELF BEFORE WORKING WITH THE MOTOR. WARNING: Failure to ground yourself could lead to accidental ignition of the motor.

- ☐ Assemble motor according to manufacturer's instructions, making sure to check all components for damage. WARNING: Failure to follow the manufacturer's instructions could lead to the motor malfunctioning.

- ☐ Measure igniter against motor. WARNING: Do not insert igniter into motor!
- ☐ Install motor in motor mount and secure with retaining ring. WARNING: Failure to secure motor into the motor mount with retainer ring will lead to motor ejection during flight.
- ☐ Tape igniter to fin for transport to pad. WARNING: Failure to tape igniter to fins can result in losing the igniter during transport.

I have observed and verified that all the above procedures were followed.

Signature__________________________ Print Name__________________________ Date______________

6.7 Launch Rail Setup

Must be observed and checked off by either the Safety Officer or the Deputy Safety Officer.

- ☐ Completely fill out the flight card.
- ☐ Take rocket to the Launch Control Officer for inspection. WARNING: The Launch Control Officer's ruling on the rocket's flight readiness in FINAL, and it will be respected by team members.
- ☐ Take the rocket to the launch pad.
- ☐ Disconnect ignition system power. WARNING: Leaving the ignition system powered could result in the rocket launching while there are still people at the launcher!
- ☐ Unlock launch rail pin.
- ☐ Lower launch rail.
- ☐ Carefully slide rocket onto launch rail. WARNING: If the rocket is not kept straight the rail buttons might break!
- ☐ Raise launch rail to a vertical position.
- ☐ Secure launch rail in vertical position by locking launch rail pin.
- ☐ If possible, spray down launch area with water. WARNING: Launching on dry grass could start a fire.
- ☐ Clear launch area of unnecessary personnel. WARNING: Having unnecessary personnel near the launch area could result in more injuries if the rocket launches unexpectedly.

I have observed and verified that all the above procedures were followed.

Signature__________________________ Print Name__________________________ Date______________

6.8 Igniter Installation

Can be done only by the mentor. Must be observed and checked off by either the Safety Officer or the Deputy Safety Officer. This section will be modified as needed to reflect the launch process of the NAR personnel in Huntsville.

- ☐ Turn on primary altimeter and wait for 1 long beep followed by 3 short beeps, repeated. If this fails, go to section 6.10.1 to troubleshoot
- ☐ Turn on the secondary altimeter and wait for 1 long beep followed by 3 short beeps, repeated. If this fails, go to section 6.10.1 to troubleshoot
- ☐ Arm the payload ejection charge.
- ☐ Insert igniter into motor and secure with plug. WARNING: Failure to insert igniter will result in motor not firing.
- ☐ Ensure ignition system leads are not powered (touch them together and look for sparks). WARNING: Attaching live leads to the igniter could lead to unexpected motor ignition!
- ☐ Connect ignition system leads to igniters.
- ☐ Wrap excess igniter wires around the ignition leads. WARNING: Failure to wrap the wires around the leads may result in the leads falling off the wires, and the motor not firing.
- ☐ Clear launch area. WARNING: Failure to clear the launch area could result in injuries if personnel are too close to the launch pad.
- ☐ Inform RSO that the rocket is ready for launch
- ☐ Make sure a team member remains near the Launch Control Officer in case the launch needs to be delayed.
- ☐ All team members will wait until after the rocket has launched, descended to the ground, and given the all-clear from the Launch Control Officer to move to recover the rocket.

I have observed and verified that all the above procedures were followed.

Signature____ Print Name______________________________ Date__________________

6.9 Reinspection Procedures

After the rocket has been deemed ready to fly no one other than members of the team or necessary NAR personnel should be allowed to handle or make alterations to the rocket for any reason. If this happens, a re-inspection of the rocket will commence with the following procedures:

- ☐ The Launch Control Officer will be notified that the launch needs to be delayed.
- ☐ After the Launch Control Officer has cut the power to the launch pad the team members will wait at least sixty seconds, and after they received the go ahead from the Launch Control Officer to be able to approach the launch pad. WARNING: Failure to adhere to the instructions of the Launch Control Officer can result in the team not being able to launch. If a member approaches the launch pad before the go ahead from the Launch Control Officer, the rocket may launch prematurely leading to personnel getting seriously injured.
- ☐ Only the team mentor may now approach the launch pad to disengage the rocket's motor igniter. WARNING: Too many personnel at the launch pad could result in multiple injuries if the rocket launches prematurely.
- ☐ Carefully disconnect the ignition system power. WARNING: Leaving the power connected may result in premature ignition of the rocket with personnel at the launch pad.
- ☐ Carefully unwrap the ignition system wires from around the launch pad clamps.
- ☐ Remove the launch pad clamps from the igniter and set the clamps down in the appropriate location.
- ☐ Carefully remove the igniter from the motor. WARNING: If the igniter is left in the motor it may ignite.
- ☐ Tape the igniter to a fin.
- ☐ Personnel needed for the remainder of the Launch Pad Removal procedures may now approach the launch pad
- ☐ Disarm the recovery system (primary and secondary altimeters), the payload ejection charge, and the ACS. WARNING: Failure to complete this step could result in the recovery system deploying while on the launch pad.
- ☐ Carefully lower the launch rail to its horizontal position.
- ☐ Slowly slide the rocket off the launch rail. WARNING: Failure to use care when removing the rocket could result in the launch rail buttons on the rocket becoming damaged or breaking off.
- ☐ Hand the rocket off to a team member to hold on to while launch pad disassembly procedures finish.
- ☐ Return the launch rail to its vertical position.
- ☐ Team members will now return the rocket to the team prep area.

☐ Repeat all steps for launch preparation to ensure that the rocket and all components are functioning as intended.

I have observed and verified that all the above procedures were followed.

Signature____ Print Name______________________________ Date__________________

6.10 Troubleshooting

6.10.1 Altimeters

Troubleshooting with loaded charges must be overseen by the Safety Officer or Deputy Safety Officer.

WARNING: Always wear safety glasses when troubleshooting with loaded charges. Always be aware of where the charges are pointed.

If altimeter does not beep:

- ☐ Turn altimeter off
- ☐ Open avionics bay
- ☐ Check battery connectors
- ☐ Check altimeter for damage

If altimeter produces wrong sound:

- ☐ Turn altimeter off
- ☐ Check connection of igniters to terminals

If problem persists:

- ☐ Open avionics bay
- ☐ Check quick connector
- ☐ Check terminals on altimeter

6.10.2 Ignition

If motor fails to ignite:

- ☐ Wait 60 seconds and for clearance from the RSO before approaching
- ☐ Check firing system power
- ☐ Check firing system lead connection

If neither of those are the issue:

- ☐ Replace the igniter
- ☐ If replacing igniter, follow procedures for installing igniter

I have observed and verified that all the above procedures were followed.

Signature_______________________________________ Print Name____________________________ Date_________________

6.10.3 Rover Deployment Failure

If rover fails to deploy:

- ☐ Verify that there is a radio connection, moving to get line-of-sight if necessary.
- ☐ Resend deployment signal.
- ☐ If the rover still doesn't deploy, wait 60 seconds and for clearance from the RSO before approaching.
- ☐ Carefully approach rocket, watching for potential fires or explosions.
- ☐ Disarm the payload ejection charge and proceed with the post-flight procedures.

I have observed and verified that all the above procedures were followed.

Signature_______________________________________ Print Name____________________________ Date_________________

6.10.4 Unfired Ejection Charge(s)

If one or more ejection charges is unfired after landing:

- ☐ Put on safety glasses. WARNING: Failure to wear safety glasses could lead to severe injury in the event that an ejection charge ignites!
- ☐ Keeping clear of the path of the ejection charge, turn off both altimeters. WARNING: Failure to keep clear could lead to severe injury in the event that an ejection charge ignites!

- ☐ Remove igniter leads from terminal blocks, keeping your hands out of the path of the ejection charge. WARNING: Failure to keep clear could lead to severe injury in the event that an ejection charge ignites!
- ☐ Return the payload tube to the prep area.
- ☐ Dispose of the unused black powder and wadding.

I have observed and verified that all the above procedures were followed.

Signature____ Print Name______________________________ Date__________________

6.11 Post-flight Inspection

6.11.1 Successful Flight

These procedures will be modified as needed to reflect competition requirements in Huntsville.

- ☐ Wait for the all-clear from NAR / NASA personnel.
- ☐ Verify radio connection to the payload.
- ☐ Send deployment signal. If the rover does not deploy, go to section 6.10.3 to troubleshoot.
- ☐ Wait for the rover to finish its mission, watching it if possible to ensure that it doesn't leave debris or start a fire.
- ☐ Send shutdown signal.
- ☐ Check the path from the rocket to the rover for any debris and cleanup as necessary.
- ☐ Retrieve rover.
- ☐ Retrieve nosecone.
- ☐ Take them back to the prep area.
- ☐ Go back out to the rocket.
- ☐ Keep distance from rocket landing site and do not go up to rocket until it has been verified that there is no threat of fire or explosion. WARNING: Failure to follow this step could result in personnel being injured.
- ☐ Make sure all 4 ejection charges have fired. WARNING: Failure to follow this step could result in personnel being injured.
- ☐ Record apogee altitude.
- ☐ Turn off both altimeters.
- ☐ Check fins for damage.
- ☐ Check body for damage.
- ☐ Make sure motor is still secured.
- ☐ Check parachute for damage.
- ☐ Check blast protector for damage.
- ☐ Check lower recovery harness swivel for damage.
- ☐ Check 4 recovery harness quick links for damage.
- ☐ Check 4 recovery harness U-bolts for damage.

- ☐ Check parachute quick link for damage.
- ☐ Check parachute swivel for damage.
- ☐ Check upper recovery harness swivel for damage.
- ☐ Disconnect recovery harness from avionics bay (2 quick links).
- ☐ Make sure quick links are closed.
- ☐ Disconnect recovery harness from payload tube (2 quick links).
- ☐ Make sure quick links are closed.
- ☐ Return rocket (in 2 pieces) to tent / assembly area.
- ☐ Remove motor retainer.
- ☐ Remove and save spent motor.
- ☐ Check motor mount for damage.
- ☐ Reattach motor retainer.
- ☐ Remove both bulkheads from payload tube, unclipping connectors.
- ☐ Remove sled (do not unclip switch connector).
- ☐ Take pictures of sled from all angles.
- ☐ Turn on primary altimeter.
- ☐ Record data from primary altimeter.
- ☐ Turn off primary altimeter.
- ☐ Turn on secondary altimeter.
- ☐ Record data from secondary altimeter.
- ☐ Turn off secondary altimeter.
- ☐ Unclip switch connector.
- ☐ Insert aft bulkhead with avionics sled into payload tube.
- ☐ Insert forward bulkhead into payload tube and onto threaded rods, securing with nuts.
- ☐ Insert parachute, blast protector, and recovery harness into parachute tube.
- ☐ Close the nosecone and insert it into the payload tube.

6.11.2 Failed Flight

- ☐ Keep distance from rocket crash site and do not go up to the rocket until it has been verified there is no threat of fire or explosion
- ☐ Take pictures of all debris

- [ ] Record the radius of the debris field
- [ ] Collect all debris
- [ ] Make sure no pieces are missing

Proceed with as much of the successful flight checklist as possible

7 Project Plan

7.1 Testing

7.1.1 Launch Vehicle Tests

Test Name	Test Objective(s)	Success?
Ejection ground fire	Ensure that the ejection charges separate the rocket with enough energy to fully break it apart during flight and push out the parachute	Yes
Flight simulation	Ensure that the rocket will fly safely and correctly	Yes
Motor mount test	Ensure that the motor mount will retain the motor while it is burning	Yes
Push / pull test	Test that each mount and junction will withstand a high amount of force	Partial

Table 7.1 - Launch Vehicle Tests

7.1.1.1 Ejection Ground Fire

- Testing Methodology
  - Follow launch procedures to pack the parachute and prepare the ejection charge (prepare only the P1 charge)
  - Connect ejection cup wires to test harnesses
  - Run test harness leads out through vents holes
  - Place rocket outside
  - Connect launcher leads to test harness leads connected to the P1 charge
  - Stand as far back as possible
  - Use launcher to trigger ignition of ejection charge
- Results
  - With an 8 g charge, the rocket separated sufficiently energetically
- Success?
  - Yes

- Lessons Learned
    - Always opt on the side of having too much black powder, rather than not enough
- Difference from Predicted Results
    - The calculated charge size was 7.7 g, so the final result was as expected

7.1.1.2 Flight Simulations (Since CDR)

- Testing Methodology
    - Create or update rocket model in RockSim
    - Enter launch day conditions
    - Run simulation
    - Repeat (creating a new model to avoid compatibility issues) in OpenRocket
- Results
    - The results of the simulations can be seen in section 3.3 Mission Performance Predictions
- Success?
    - Yes
- Lessons Learned
    - Parachute changed to 16 ft
- Difference from Predicted Results
    - Due to increases in the mass of the rocket during construction, its final apogee is lower than desired; however, the simulations still indicate a safe flight

7.1.1.3 Motor Mount Test

- Testing Methodology
    - Separate the booster section from the rest of the rocket
    - Place it upside down on hard level ground
    - Place a board on top of the motor mount
    - Slowly add weights to the board up to 350 lbs
- Results
    - 380 lbs were placed on the motor mount
    - The weights were left in place for 10 seconds

  - There was no damage to the motor mount, centering rings, or any other part of the launch vehicle
- Success?
  - Yes
- Lessons Learned
  - The materials and construction techniques used for the motor mount are sufficient to withstand the force of the motor
- Difference from Predicted Results
  - None, the motor mount held as much weight as was expected

7.1.1.4 Push / Pull Test

- Testing Methodology
  - Apply a substantial amount of force to all load-bearing joints and parts, including: fins, centering rings, bulkheads, threaded rods, ejection cups, U-bolts, swivels, quick links, and the nosecone
- Results
  - All parts other than the nose cone were undamaged
  - The nose cone (which was printed in multiple segments) repeatedly cracked along the joints between segments
- Success?
  - Partial
- Lessons Learned
  - The materials and construction techniques used for all parts other than the nose cone can withstand substantial force
  - Large 3D-printed parts need to be printed such that the joints between segments have as much surface area as possible
  - The experimental nose cone is not flyable
- Difference from Predicted Results
  - The segments of the nose cone were expected to be more firmly connected

7.1.2 Payload Tests

Test Name	Test Objective(s)	Success?
Nosecone impact test	Ensure that the nosecone can survive an impact from landing or ejection	No
Rover solar panel deployment	Ensure that the rover can deploy a foldable solar panel	Yes

Table 7.2 - Payload Tests

7.1.2.1 Nosecone Impact Tests

- Testing Methodology
  - Drop the nosecone and check for damage
- Results
  - When dropped, the nose cone often split at the joints between segments
- Success?
  - No
- Lessons Learned
  - See 7.1.1.4, above
- Difference from Predicted Results
  - See 7.1.1.4, above

7.1.2.2 Rover Solar Panel Deployment Test

- Testing Methodology
  - Turn on the rover
  - Retract the linear actuator to raise the solar panel bracket
- Results
  - The solar panel bracket was able to fully open to about 95°, exposing the full area of the solar panel, and then close again
- Success?
  - Yes

- Lessons Learned
  - The righting mechanism linear actuator is capable of raising and lower the solar panel bracket to expose or cover the solar panel
  - The linear actuator may not be strong enough to perform its secondary objective of righting the rover if it ends up upside down; more testing of the righting mechanism is required
- Difference from Predicted Results
  - The linear actuator did not produce as much force as expected, partly due to the fact that the test was performed with less than the maximum voltage that the linear actuator can handle

7.1.3 Altitude Control System Tests

Test Name	Test Objective(s)	Success?
Exhaust velocity	Determine whether the ACS exhaust velocity is high enough to create a hazard	Yes

Table 7.3 - ACS Tests

7.1.3.1 Exhaust Velocity

- Testing Methodology
  - Pressurize the tank to flight pressure
  - Secure test materials (such as paper and cloth) in front of the forward firing nozzles
  - Fire the forward thrusters
  - Turn off the ACS
  - Inspect the test materials for damage
  - If they are damaged, decide whether to proceed with caution when using the ACS or use a lower pressure
  - If using a lower pressure, update documentation and repeat this test to ensure that the new pressure is safe
- Results

- The exhaust caused no damage to any test materials

- Success?
    - Yes
- Lessons Learned
    - The ACS exhaust does not pose a safety hazard
    - The exhaust velocity is lower than expected, possibly affecting performance
- Difference from Predicted Results
    - The exhaust velocity was much lower than originally calculated; this is largely due to the fact that most of the ACS hardware was replaced with larger diameter parts with higher pressure ratings

7.2 Requirements Compliance

The following sections identify the verification plans for all the requirements set forth in the USLI handbook as well as those defined by the team. The team defined requirements will discuss not only each requirement and associated verification plan, but also the reason that each requirement was imposed and what team goal it pertains to.

7.2.1 NASA Defined Requirements

ID refers to the requirement's ID in the handbook.

ID	Type of Verification	Verification	Location of Verification
1.1	Demonstration	The team's mentor has been made aware of his responsibilities and restrictions	N/A

ID	Type of Verification	Verification	Location of Verification
1.2	Demonstration	The team's project manager is maintaining a project plan that includes milestones, team activities, and other dates and a list of personnel assignments; the Treasurer is maintaining a current budget and funding plan; the Director of Engagement & Outreach is maintaining a plan for the team's engagement and outreach activities, as well as recording progress toward engagement goals; and the Safety Officer is maintaining a list of hazards and mitigations, and is working with the launch vehicle and payload leaders to develop checklists for testing and launch operations	7.2 Requirements Compliance 7.4 Timeline 7.3 Budgeting 7.5 Educational Engagement 5 Safety
1.3	Demonstration	The contact information for all foreign nationals has been submitted	N/A
1.4	Demonstration	A definitive list of team members going to launch week along with their relevant information has been submitted	N/A
1.5	Demonstration	The team's Director of Engagement & Outreach has been tasked with maintaining a count of the number of individuals engaged, coming up and enacting plans to reach more people, and preparing all reports on engagement activities	7.5 Educational Engagement
1.6	Demonstration	The team has created and hosted a website for document hosting and community engagement, maintained by the team's Webmaster	piedmontlaunch.org
1.7	Demonstration	All deliverables to this point have been posted on the team's website and all remaining documents will be posted by the team's Webmaster, both on the home page and on a documents page which includes past documents	piedmontlaunch.org/documents/
1.8	Demonstration	All deliverables will be exported to PDF format prior to submission	N/A
1.9	Demonstration	All reports will include a table of contents with three levels of section headings added during document assembly	Table of Contents
1.10	Demonstration	All reports will have page numbers at the bottom of the pages added during document assembly	Bottom of page
1.11	Demonstration	Tiger Fuel Co., one of PSLT's primary sponsors, has provided the use of their conference room for teleconference reviews, practice presentations, and all document Q&As	N/A
1.12	Demonstration	The launch vehicle is designed to use a 12 ft, 1515 launch rail	1.2 Launch Vehicle

ID	Type of Verification	Verification	Location of Verification
1.13	Demonstration	PSLT's webmaster has implemented these standards and will continue to ensure they are in place on the team's website	piedmontlaunch.org
1.14	Demonstration	The team's mentor has been identified in all reports	1.1 Team
2.1	Analysis, Testing	The launch vehicle's ability to carry the payload to 5,280 ft has been analyzed using RockSim and OpenRocket, and has been tested in the full-scale test flight	3.3 Mission Performance Predictions 3.4 Full-Scale Flight
2.2	Demonstration	The recovery system includes a commercially available, barometric altimeter to be used as the scoring altimeter on launch day	3.2.2 Recovery Electronics
2.3	Demonstration	The recovery system includes two externally accessible switches, one to arm each altimeter	3.2.2 Recovery Electronics
2.4	Demonstration	The recovery system includes two batteries, one for each altimeter	3.2.2 Recovery System Electronics
2.5	Demonstration	The arming switches in the recovery system are keyed to prevent them from being deactivated by flight forces	3.2.2 Recovery System Electronics
2.6	Analysis, Testing	The Director of Testing & Analysis has overseen the development and implementation of testing to ensure the launch vehicle is able to be reflown without any repairs or modifications	3.4 Full-Scale Flight 7.1 Testing
2.7	Demonstration	The launch vehicle is designed to separate into only two independent sections, which will be tethered together	3.2.1 Recovery Hardware
2.8	Demonstration	The launch vehicle design has only a single stage utilizing only one motor	3.3 Mission Performance Predictions
2.9	Demonstration	The launch vehicle is designed such that the separate sections of it can be prepared for flight in parallel, allowing it to be readied within three hours of the FAA waiver opening	3.4 Full-Scale Flight
2.10	Analysis, Testing	Calculations have been performed on all time sensitive systems on the launch vehicle, particularly the recovery system, to ensure that they are able to remain in launch-ready configuration for at least one hour and they have been tested to verify those calculations	3.2.2 Recovery Electronics 7.1 Testing
2.11	Demonstration	The launch vehicle design allows the motor to be directly connected to a standard firing system and requires no other hardware to initiate launch	N/A
2.12	Demonstration	The launch vehicle design requires no external circuitry or special ground support equipment to initiate launch	N/A

ID	Type of Verification	Verification	Location of Verification
2.13	Demonstration	The launch vehicle design uses a commercially available, Ammonium Perchlorate Composite Propellant (APCP) motor	3.3 Mission Performance Predictions
2.14.1	Demonstration	The launch vehicle design uses one pressure vessel. The model purchased has a factor of safety of 6.4 at the pressure it will be operated at	CDR ACS Addendm
2.14.2	Demonstration, Analysis	The launch vehicle design includes a pressure relief valve which is documented as seeing the full pressure of the included pressure vessel and being capable of withstanding the maximum pressure and flow rate of that vessel	CDR ACS Addendum
2.14.3	Demonstration	The Safety Officer will ensure that the full pedigree of the pressure vessel used in the rocket is recorded and brought to the LRR	N/A
2.15	Demonstration	The launch vehicle design uses a motor that has less than 5,120 N-s of impulse	3.3 Mission Performance Predictions
2.16	Analysis	RockSim and OpenRocket simulations have been done on the launch vehicle design to ensure that the static stability margin at rail exit is above 2.0	3.3 Mission Performance Predictions
2.17	Analysis, Testing	RockSim and OpenRocket simulations have been done on the launch vehicle design to ensure that velocity at rail exit is above 52 ft/s. Additionally, the velocity at rail exit was measured during the full-scale test flight	3.3 Mission Performance Predictions 3.4 Full-Scale Flight
2.18	Demonstration	Two subscale models have been flown, including a reflight as requested	CDR 4.2 Subscale Flight Results CDR Subscale Reflight Addendum
2.18.1	Demonstration	Both subscales closely resembled the full-scale rocket with only a few differences	CDR 4.2 Subscale Flight Results CDR Subscale Reflight Addendum
2.18.2	Demonstration	The subscale rockets carried altimeters to report their apogees as well as other flight data	CDR 4.2 Subscale Flight Results CDR Subscale Reflight Addendum
2.19	Demonstration	The full-scale test flight was done in the same condition that it will be flown on launch day, including the ACS being active, with the exception that a mass simulator was used in place of the payload	3.4 Full-Scale Flight

ID	Type of Verification	Verification	Location of Verification
2.19.2	Demonstration	A mass simulator was flown on the full-scale flight, located in the same location as the payload	3.4 Full-Scale Flight
2.19.3	Demonstration	The altitude control system, the only system that affects the energy of the launch vehicle in flight, was fully active during the full-scale test flight	3.4 Full-Scale Flight
2.19.4	Demonstration	The full-scale motor was flown for the test flight	3.4 Full-Scale Flight
2.19.5	Demonstration	There is no ballast used in the full-scale	N/A
2.19.6	Demonstration	None of the components of the launch vehicle will be changed now unless required for safety purposes	N/A
2.19.7	Demonstration	The full-scale flight was performed on March 4th	3.4 Full-Scale Flight 7.4 Timeline
2.20	Demonstration	There are no structural protuberances fore of the burnout CG	3.1 Launch Vehicle Design
2.21 - 2.21.8	Analysis, Demonstration	The design of the launch vehicle does not include forward canards, forward firing motors, motors that expel titanium sponges, hybrid motors, motor clusters, or friction fitting of motors, and there is no ballast. RockSim and OpenRocket simulations have been done to ensure the launch vehicle design does not exceed Mach 1 at any point in flight	3.1 Launch Vehicle Design 3.3 Mission Performance Predictions
3.1	Demonstration	The launch vehicle has both apogee separation and main parachute deployment staged by onboard altimeters	3.2.2 Recovery Electronics
3.2	Demonstration	Ground ejection tests were done prior to both the subscale and full-scale test flights	7.1 Testing
3.3	Analysis, Testing	RockSim and OpenRocket simulations have been done to determine the velocity at landing of the launch vehicle design, which has been used to ensure that the highest kinetic energy of any section is below 75 ft-lbf	3.3 Mission Performance Predictions 3.4 Full-Scale Flight
3.4	Demonstration	The recovery system does not share any electronics with the payload	3.2.2 Recovery Electronics
3.5	Demonstration	All recovery system electronics are powered by commercially available batteries	3.2.2 Recovery Electronics
3.6	Demonstration	The recovery system has not only redundant altimeters, but has redundancy for all components	3.2.2 Recovery Electronics
3.7	Demonstration	The recovery system design does not utilize motor ejection	3.2 Recovery Subsystem
3.8	Demonstration	The recovery system design uses nylon shear pins to secure the parachute compartment	3.2.1 Recovery Hardware
3.9	Analysis, Testing	RockSim and OpenRocket simulations and hand calculations have been done with the launch vehicle design to ensure that the rocket will not drift more than 2,500 ft from the launch pad	3.3 Mission Performance Predictions

ID	Type of Verification	Verification	Location of Verification
3.10	Demonstration	The payload includes a GPS module that will be used to track the position of the rover, and thereby the rocket, during flight	4.3 Electronics
3.11.1	Demonstration	The recovery system electronics are in a separate compartment from any other electronics with the exception of a pair of switch wires for the payload	3.2.2 Recovery Electronics
3.11.2	Demonstration	The recovery system electronics are shielded from the payload, which has the only transmitting device on the rocket	3.2.2 Recovery Electronics
3.11.3	Demonstration	The recovery system electronics are shielded from the solenoid valves used in the ACS and the solenoid used in the payload	3.2.2 Recovery Electronics
3.11.4	Demonstration	The recovery system electronics bay is shielded at both ends, and there are no other electronics in it	3.2.2 Recovery Electronics
4.1	Demonstration	PSLT has selected the deployable rover challenge	1.3 Payload
4.2	Demonstration	No other challenges have been selected	1.3 Payload
4.3	Demonstration	See 4.2 above	N/A
4.5.1	Demonstration	The rover design remains entirely enclosed within the airframe of the launch vehicle until deployment	4.1 Deployment
4.5.2	Demonstration	The rover design includes a transceiver so that deployment can be remotely triggered	4.3 Electronics
4.5.3	Inspection	The rover will use an onboard GPS module to detect its distance from the rocket. Additionally, when the rover is recovered, that distance will be measured	4.3 Electronics 6 Launch Operation Procedures
4.5.4	Inspection	When the rocket is being recovered, the solar panel on the rover will be inspected to ensure that it has opened	6 Launch Operation Procedures
5.1	Demonstration	The Safety Officer has worked with the payload and launch vehicle leaders to develop the launch operations procedures that will be used for all launches and that will be included in the LRR	6 Launch Operation Procedures
5.2	Demonstration	PSLT has designated a Safety Officer	1.1 Team
5.3 - 5.3.4	Demonstration	The Safety Officer has been made aware of his responsibilities and they are included in the team handbook	N/A
5.4	Demonstration	All team members have been made aware of the rules regarding all launches. Additionally, the Safety Officer and Deputy Safety Officer will ensure that all team members abide by those safety rules and will brief team members on all such rules before any event	N/A
5.5	Demonstration	The Safety Officer's responsibilities include understanding and ensuring compliance with all relevant FAA rules and regulations	N/A

Table 7.4 - Verifications for NASA Defined Requirements

7.2.2 Team Defined Requirements

The following tables discuss requirements defined by PSLT beyond those included in the handbook.

7.2.2.1 Launch Vehicle

Requirement	Purpose	Type of Verification	Verification Plan	Location of Verification
The ACS fires between motor burnout and apogee and the effect is recorded	To demonstrate the capability of the altitude control system	Analysis Demonstration Inspection	The capabilities of the altitude control system have been estimated through calculations. This capability was also demonstrated during the full-scale test flight, and the final result will be determined on launch day by an inspection of the altitude reached	CDR ACS Addendum 3.4 Full-Scale Flight
Use a 1515 launch rail	To ensure the launch rail used is able to support the weight of the rocket	Demonstration	The design of the launch vehicle includes 1515 rail buttons for launch support	1.2 Launch Vehicle
Use a 12 ft launch rail	To increase the stability of the rocket off the launch rail	Demonstration	A 12 ft or longer launch rail will be requested at all launches	1.2 Launch Vehicle

Requirement	Purpose	Type of Verification	Verification Plan	Location of Verification
Have a static stability margin under 4	To prevent the rocket from being over-stable and going off-course or losing excessive altitude due to weather cocking	Analysis	The static stability margin is under 4	3.3 Mission Performance Predictions

Table 7.5 - Verifications for Team Defined Launch Vehicle Requirements

7.2.2.2 Payload

Requirement	Purpose	Type of Verification	Verification Plan	Location of Verification
The rover is able to move even if one wheel motor fails	To ensure the rover is robust and able to move the required 5 ft from the rocket	Testing	The rover’s ability to move with any motor disabled is included in the test set for the payload	Not yet verified
The rover is able to traverse different soil types including at a minimum hard packed dirt, loose dirt, and mud	To ensure the rover is versatile and able to move the required 5 ft from the rocket	Testing	The rover’s ability to traverse different soil types is included in the test set for the payload	Not yet verified

Requirement	Purpose	Type of Verification	Verification Plan	Location of Verification
The rover is able to traverse different terrain types including at a minimum furrowed ground, flat ground, and swampy ground	To ensure the rover is versatile and able to move the required 5 ft from the rocket	Testing	The rover's ability to traverse different terrain types is included in the test set for the payload	Not yet verified
The rover is able to be deployed regardless of how the rocket lands	To ensure the rover is versatile and able to be deployed	Testing	The rover's ability to be deployed in suboptimal landing conditions is included in the test set for the payload	Not yet verified
The rover is able to fit within a 6 in. body tube	To prevent the launch vehicle from having so much drag that it cannot reach one mile on an L-class motor	Demonstration	The rover design is capable of fitting within a 6 in. body tube	Not yet verified
The rover and deployment system are able to withstand high forces applied to the front or back	To ensure the rover and deployment system are robust and able to withstand the forces of ejection and any following impacts	Analysis Testing	The payload's ability to withstand the required forces is included in its test set	Not yet verified

Requirement	Purpose	Type of Verification	Verification Plan	Location of Verification
The rover is able to detect and avoid obstacles	To ensure the rover does not become stuck and is able to move the required 5 ft from the rocket	Testing	The rover's ability to avoid obstacles is included in the test set for the payload	Not yet verified
The rover is able to detect when it is 5 ft from the launch vehicle	To ensure that the rover is the required 5 ft from the rocket when the solar panel deploys	Testing	The rover's ability to detect its distance from rocket is included in the test set for the payload	Not yet verified
The rover stores enough power to be able to remain in standby mode on the launch pad for at least two hours	To ensure that the rover is still functional even if there is a long wait on the launch pad after it has been activated	Testing	The rover's ability to remain in standby mode for two hours is included in the test set for the payload	Not yet verified

Table 7.6 - Verifications for Team Defined Payload Requirements

7.2.2.3 Recovery System

Requirement	Purpose	Type of Verification	Verification Plan	Location of Verification
Have a 99.99% or higher confidence that the launch vehicle will recovery safely	To ensure the rocket is able to be safely recovered	Demonstration	A sufficient number of recovery system tests will be performed to ensure a 99.99% or higher confidence of safe recovery	7.1 Testing

Requirement	Purpose	Type of Verification	Verification Plan	Location of Verification
The recovery harness will have redundant attachment points at both ends	To reduce the load on either attachment point to decrease the risk of failure and to prevent unsafe return if one attachment point fails	Demonstration	The recovery system design utilizes two U-bolts at each end of the recovery harness	3.2.1 Recovery Hardware
The recovery system will utilize four, redundant ejection charges	To ensure separation of the rocket to prevent a ballistic return because of the use of only one point of separation	Demonstration	The recovery system design utilizes four, redundant ejection charges	3.2.1 Recovery Hardware
The recovery harness is able to withstand at least twice the amount of force applied to it during main parachute deployment	To ensure an adequate margin of safety	Analysis Testing	The recovery harness has been lengthened significantly such that, even with an energetic separation, it is not subjected to a major load	3.2.1 Recovery Hardware

Requirement	Purpose	Type of Verification	Verification Plan	Location of Verification
Utilize a "cannon" design where the parachute is stored between the ejection charges and the end of the body tube that it exits through	To ensure the parachute is properly deployed by having it pushed out of the parachute tube by the ejection charges rather than relying on the inertia of any section	Demonstration	The recovery system utilizes this type of design	3.2 Recovery Subsystem

Table 7.7 - Verifications for Team Defined Recovery System Requirements

7.2.2.4 Safety

Requirement	Purpose	Type of Verification	Verification Plan	Location of Verification
Establish an accident reporting system in case anyone is injured	To promote the culture of safety within the team	Demonstration	The Safety Officer is working with the Team Leader to develop an accident reporting system	N/A
Ensure all team members are trained to use any equipment that is necessary for their job	To prevent injury to team members	Demonstration	A list will be kept of what equipment each team member is trained to use, which the Safety Officer will have at any time that personnel might need to use that equipment	N/A

Table 7.8 - Verifications for Team Defined Safety Requirements

7.2.2.5 General

Requirement	Purpose	Type of Verification	Verification Plan	Location of Verification
Engage a minimum of 600 participants in hands on STEM related activities	To spread STEM education	Demonstration	PSLT's Director of Engagement & Outreach is responsible for planning all engagement events, keeping track of the number of people engaged at each event, and writing engagement reports	7.5 Educational Engagement
Reach a minimum of 2000 people to inform them of SL and STEM opportunities	To spread STEM education	Demonstration	PSLT's Director of Engagement & Outreach is responsible for planning all engagement events, keeping track of the number of people engaged at each event, and writing engagement reports	7.5 Educational Engagement
Provide the opportunity for team members to become level one or two high-power certified	To allow team members to be able to gain additional experience with high-power rocketry	Demonstration	PSLT's mentor and several team members are level one or two certified, and so are able to certify other team members that are interested	N/A

Table 7.9 - Verifications for Team Defined General Requirements

7.3 Budgeting

7.3.1 Budget

Item	Vendor	Unit Price	Qty	Cost (including tax and shipping)
Airframe Tube	Madcow Rocketry		All	$329.76
5.5 in .x5.5in x.o.125 in. TTW G10 Fins	Giant Leap Rocketry		4	$156.32
J540 R Motor Reload	Sirius Rocketry	$136.44	1	$136.44
Motor Retainer	Aero Pack	$65.68	1	$65.68
Coupler Bulkhead	Madcow Rocketry		2	$14.31
Tube Bulkhead	Mascow Rocketry	$6.73	1	$6.73
Jolly Logic Chute Release	AMW ProX	$114.52	1	$114.52
RRC3 Sport Altimeter	Apogee Components	$73.11	1	$73.11
Altus Metrum Easy Mega Flight Computer	AMW Prox	$312.48	1	$312.48
1/4 ʻʼ Quick Link	Tractor Supply	$	5	$7.64
7ft TAC-1 Parachute	Giant Leap Rocketry	$151.64	1	$151.64
Recovery Harness	Giant Leap Rocketry		6yd	$18.43
U-Bolt 3/8 in.	Tractor Supply		4	$12.17

Item	Vendor	Unit Price	Qty	Cost (including tax and shipping)
Item	**Vendor**	**Unit Price**	**Qty**	**Cost (including tax and shipping)**
6in. Parachute Protector	Apogee Components		1	$9.89
Swivel	Tractor Supply		3	$7.65
GPS	Missileworks	$90.19	1	$90.19
Assorted Hardware	Various	$37.22	ALL	$37.22
Total				$1,454.18

Table 7.10 - Subscale Budget

Item	Vendor	Unit Price	Qty	Cost (including tax and shipping)
Airframe Tube	Madcow Rocketry	$465.22	All	$465.22
8.5 in. x 8.5 in. x0.25 in. TTW G10 Fins	Giant Leap Rocketry		4	$156.32
L1420 R-P Motor Reload	Sirius Rocketry		2	$491.22
Motor Retainer	Aero Pack	$76.87	1	$76.87
Coupler Bulkhead	Madcow Rocketry		2	$19.36

Tube Bulkhead	Madcow Rocketry	$10.96	1	$10.96
90 deg Brake Line Fittings (Thruster Nozzles)	MSC Industrial Supply		8	$17.55
Item	**Vendor**	**Unite Price**	**Qty**	**Cost (including tax and shipping)**
Ninja Aluminum Compressed Air Tank	Amazon	$150.95	1	$150.95
Jolly Logic Chute Release	AMW ProX	$114.52	1	$114.52
RRC3 Sport Altimeter	Apogee Components	$73.11	1	$73.11
Altus Metrum Easy Mega Flight Computer	AMW ProX	$312.44	1	$312.44
¼ ''Quick Link	Tractor Supply		5	$7.64
14ft, standard, low-porosity, 1.1rip-stop Parachute	Rocketman	$167.45	1	$167.45
Recovery Harness	Giant Leap Rocketry		10yd	$47.34
U-Bolt 3/8 in.	Tractor Supply		4	$12.17
Sunward 18 in. Parachute Protector	Apogee Components	$14.43	1	$14.43
Swivel	Tractor Supply		3	$7.65
GPS	Adafruit	$40.22	1	$40.22
Arduino	Arduino		2	$44.51
IMU	Adafruit	$36.77	1	$36.77

Item	Vendor	Unite Price	Qty	Cost (including tax and shipping)
IR sensor	Adafruit	$15.98	1	$15.98
Altimeter	Adafruit	$10.81	1	$10.81
Xbee	Digi-Key	$53.11	1	$53.11
FPV camera	Lumenier	$54.29	1	$54.29
FPV transmitter+antenna	Lumenier	$40.14	1	$40.14
Assorted Parts (jumper wires, resistors, etc.)	Various	$22.86	All	$22.86
50MM Linear Actuator	Robotshop	$90.89	1	$90.89
Electrical Motor	Amazon	$16.99	1	$16.99
Electric Stepper Motor	Sparkfun		8	$119.60
Solar Panel Bracket	Midwest	$24.58	1	$24.58
Righting Mechanism	Midwest	$22.63	1	$22.63
Rover Frame	Midwest	$13.62	1	$13.62
Solar Panel	Amazon	$8.24	1	$8.24
Springs	Amazon	$5.73	1	$5.73
Pack of 12 3/8’’-24 Fittings for 3/16”tube	Amazon	$8.24	1	$8.24
LTW Fitting Glass 3000 Stainless Steel 316 Pipe Hex Nipple Fitting 3/8” Male NPT Air Fuel Water (Pack of 5)	Amazon	$13.49	1	$13.49

Ninja Paintball Microbore Remote	Amazon	$37.95	1	$37.95
Robert Manufacturing R209 Series Bob Brass Adapter, 3/8"NPT Male x1/8" NPT Female	Amazon	$5.73	1	$5.73
Anderson Metals 56110 Brass Pipe Fitting, Hex Bushing, ½"NPT Male Pipe x3/8"NPT Female Pipe	Amazon		5	$22.75
Assorted Hardware	Various	All	All	$37.22
Universal Mounting Hub-5mm Aluminum	SparkFun Electronics	1	1	$7.49

Table 7.11 - Full-Scale Budget

Item	Vendor	Unite Price	Qty	Cost (including tax and shipping)
Solenoid	Amazon	$13.66	2	$27.32
Springs	Amazon	?	1	?
A 4988 Stepper Motor Driver Carrier	Pololu	$4.95	6	$29.7

Item	Vendor	Unite Price	Qty	Cost (including tax and shipping)
Wheel Motors	SparkFun Electronics	$14.95	6	$89.7
RM Motor	Amazon	$15.99	1	$15.99
TX Antenna	SparkFun Electronics	$7.95	1	$7.95
u.Fl to RP-SMA Cable	Getfpv	$4.99	1	$4.99
Relays	Banggood	$2.59	3	$7.77
IR Sensor	Robotshop	$9.95	1	$9.95
RM Motor Driver	Adafruit	$7.50	1	$7.50
RM Linear Actuator	Actuonix	$90	1	$90
FPV RX	Amazon	$17.98	1	$17.98
JST Connector	Adafruit	$0.75	3	$2.25
Arduino Battery	Amazon	$19.99	1	$19.99
Solar Panel	Amazon	$9.13	1	$9.13
Righting Mechanism (Aluminum Flat Bar)	Midwest	$?	1x4x11	$?
Rover Frame	Midwest	?	0.125x3.5x25	

Item	Vendor	Unite Price	Qty	Cost (including tax and shipping)
Solar Panel Bracket	Midwest	?	1/2x4x23	?
AA Holders	Amazon	$7.99	12PCS 2AA	$7.99
Mounting Hubs	Amazon	$13.89	1	$13.89
Mounting Hubs	SparkFun	$7.49	1	$7.49
IR Sensor Cable	Robotshop	$1.95	1	$1.95

Table 7.12 - Payload Budget

The above expenses have already been incurred, and no significant additional development is expected.

The team's current budget balance will be sufficient to cover the launch week attendees' lodging costs with a $40 per diem for meals and other expenses. Team members are required to cover their own travel costs for the seven-hour drive to Huntsville.

7.3.2 Funding Plan

Since CDR, PSLT formed one new sponsorship with local coffee shop, Snowing in Space Coffee. They are making a brew to be named after the team, the proceeds of the sale of which will go to the team.

There is no big change for PLST three primary funding sources: PVCC, Tiger Fuel Company, and individual donors. As mentioned earlier in PDR, PSLT has already received $5,000 from PVCC. PVCC is also willing to make further contributions for the success of the project in other areas. Tiger Fuel Company and OFM are still dedicated to their corporate sponsorships for PSLT. Especially, Tiger Fuel Company which is still willing to pick up any shortages in the team's budget.

7.4 Timeline

Figure 7.1 - Timeline Part 1

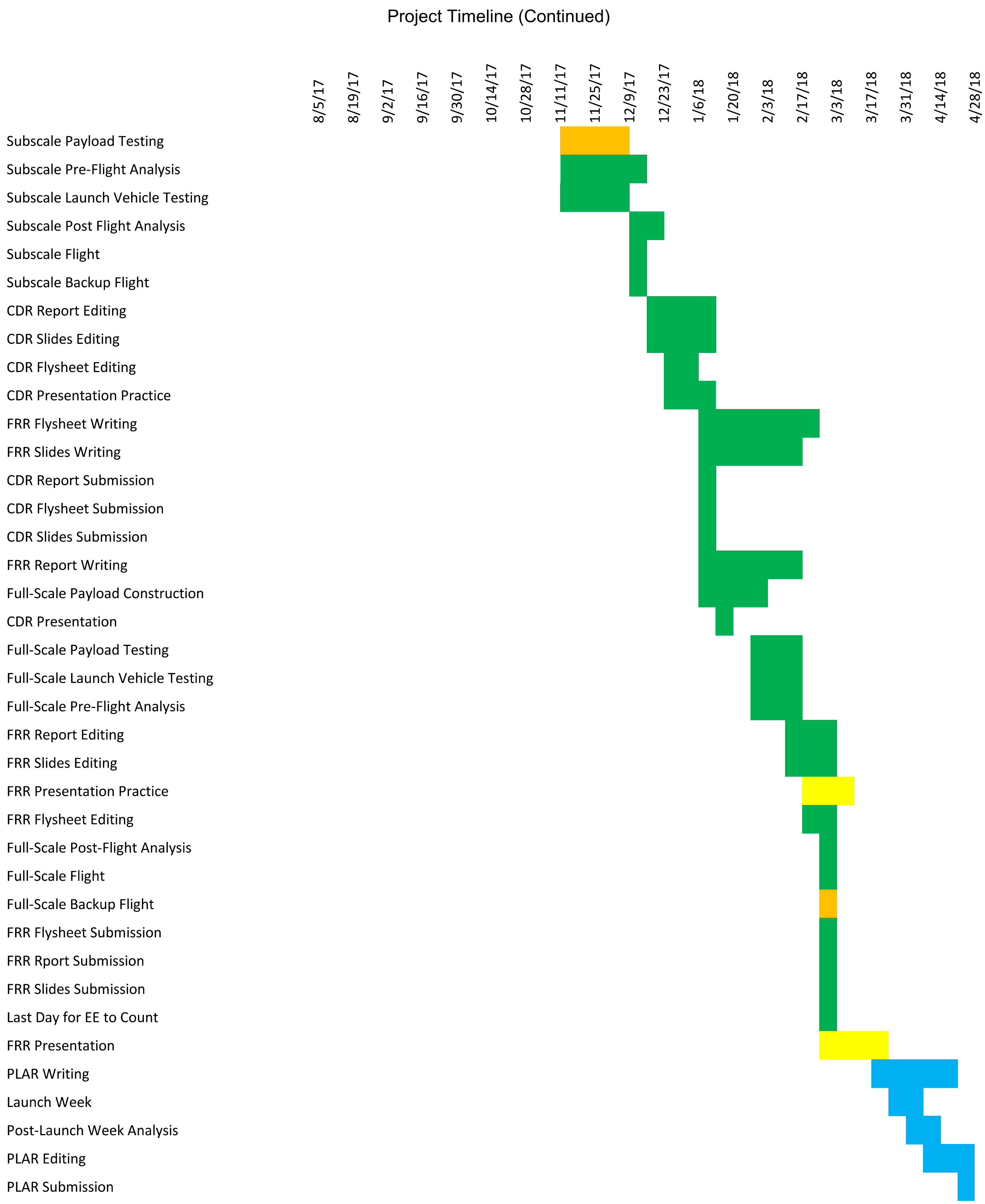

Figure 7.2 - Timeline Part 2

7.5 Educational Engagement

This year the Piedmont Student Launch Team has committed even more time and attention to building sustainable educational partnerships and programs. The team created an educational engagement sub-team this year, unlike last year, and has directly engaged with hundreds of students, educators, parents, and the community at large. The team has taught classes, run educational sessions, hosted events, given talks at schools, and put on demonstrations. PSLT has partnered with local schools, STEM based groups, local businesses, other educational groups, and even formed connections in the offices of local legislators. This year, PSLT has laid the groundwork for years of community engagement and STEM education.

7.5.1 Girls' Geek Day

"Girls' Geek Days are all about sparking elementary school-aged girls' interest in technology and computing by providing a fun, collaborative, hands-on environment to learn new tech skills and helping them connect to other STEM programs in the community." That is the description given on the Girls' Geek Day home page.

Last year the PSLT formed an initial connection to Girls' Geek Day by participating in as many of their sessions as possible. This year PSLT has participated in GGD almost every month and has already been invited back for next year. The activities that PSLT ran over the course of this year varied from demonstrating the flight dynamics of airplanes with paper airplanes, to creating a scale model of the solar system, to launching model rockets.

7.5.2 Community Homeschool Enrichment Center

"The Community Homeschool Enrichment Center (CHEC) supports homeschool families by offering a variety of enrichment courses for children age 5 to 18. Courses were solely enrichment when CHEC formed in 2005, but over time we have started to offer a variety of academic options as well." That is CHEC's official description on their home page. They provide a diverse and creative set of classes to the homeschool community of Charlottesville and the surrounding area.

PSLT's class in CHEC's winter session had 10 students and spanned 8 classes total. They stared with the fundamentals of rocketry. The first half of the class was structured like a science class with a lab. Every class began with a review of the previous week and a safety briefing for the day's activity. Then there was a lecture and class discussion about the concept being covered in that week. After that, the class would end with an activity that demonstrated the concept. The second half of the class was focused on building model rocket kits. The students built their kits in class with the help of the team. On the last day of class, the students all got to launch their rockets at least once, though many of them launched several times.

By the end of the class, many of the students, even several that had been apprehensive about the rockets, were very enthusiastic about rocketry and interested in another class. Unfortunately, though PSLT did offer another class for the spring session, CHEC could not fit that into the only time slot that would have worked. However, PSLT is planning to offer another class in the fall.

7.5.3 Family Space Exploration Event

The FSEE is PSLT's main annual engagement event that the team hosts at PVCC. The goal is to develop it into a well-known, standing event that families come to year-after-year to help increase their kids' exposure to and interest in STEM. This year, there were three main groups of activities.

First, there were multiple STEM related clubs from nearby schools, including PVCC, running educational games and activities for the families. Some of these included the University of Virginia's robotic mining club, they helped kids program Lego Mindstorm robots, the PVCC math club taught kids to play Set as a way to learn pattern recognition and pattern detection algorithms, and BACON, a club from Albemarle Highschool, which demonstrated some of its robots for the kids.

The main activity that the team ran directly was the building and launching of snap-together rockets. Each kid was given a free, snap-together rocket, and team members helped them assemble it, prepare it for flight, and launch it, while also teaching them about how model rockets work. After flying their rockets, the kids were then able to take them home.

Finally, for the older participants, there were two speakers. The first was former astronaut and current director of the University of Virginia's aerospace engineering program, Dr. Kathryn Thornton. Dr. Thornton gave an inspiring speech about the future of space exploration. After that, NRAO research engineer, Dr. Matthew Morgan spoke about the history of the universe and the role that radio astronomy plays in how it is understood.

7.5.4 Partnerships

The Piedmont Student Launch Team has formed many partnerships and connections this year. PSLT has formed a strong partnership with several of their local public schools, including all local elementary schools that participate in GGD. Connections have also been formed with a few middle schools and high schools. The team has been invited to give talks and demonstrations at a couple of different schools this year.

PSLT has also partnered with several local businesses, and the team has organized a few events with these partners. One of PSLT's monetary sponsors, Snowing in Space Coffee, has named a brew after the team and has information on the team and the project in their store.

PSLT has formed a strong, sustainable network of community partnerships this year and will continue to grow that network through volunteering and future events. PSLT will become even more engaged with the local community over the next few years.

7.5.5 Educational Engagement After the Project

PSLT has several engagement activities planned for after the end of the project. The team will be participating in a career fair in March as well as potentially meeting with an astronaut that is coming to Charlottesville. The team will be going to all of the GGDs that they can until GGD takes a break over the summer. This summer, the team will be teaching a week-long course in partnership with PVCC. The college has a summer camp for K-12 students called Kids College, and the student launch team will be teaching one of the sessions.

The Piedmont Student Launch Team will be spending their summer continuing to engage with their community and forming sustainable STEM enthusiasm and programs in Charlottesville and throughout the area.