Tacho Lycos
2018 NASA Student Launch
Flight Readiness Review Report

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Common Abbreviations & Nomenclature

AGL	=	above ground level
APCP	=	ammonium perchlorate composite propellant
ARRD	=	advanced retention and release device
AV	=	avionics
BP	=	black powder
CDR	=	Critical Design Review
CG	=	center of gravity
CP	=	center of pressure
EIT	=	electronics and information technology
FAA	=	Federal Aviation Administration
FMECA	=	failure mode, effects, and criticality analysis
FN	=	foreign national
FRR	=	Flight Readiness Review
HEO	=	Human Exploration and Operations
HPR	=	High Power Rocketry
HPRC	=	High-Powered Rocketry Club
L3CC	=	Level 3 Certification Committee (NAR)
LARD	=	low-altitude recovery device
LCO	=	Launch Control Officer
LRR	=	Launch Readiness Review
LSB	=	Lazy Susan bearing
MAE	=	Mechanical & Aerospace Engineering Department
MSDS	=	Material Safety Data Sheet
MSFC	=	Marshall Space Flight Center
MSL	=	mean sea level
NAR	=	National Association of Rocketry
NCSU	=	North Carolina State University
NFPA	=	National Fire Protection Association
PDR	=	Preliminary Design Review
PLAR	=	Post-Launch Assessment Review
PPE	=	personal protective equipment
RFP	=	Request for Proposal
RSO	=	Range Safety Officer
SL	=	Student Launch
SLS	=	Space Launch System
SME	=	subject matter expert
SOW	=	statement of work
STEM	=	Science, Technology, Engineering, and Mathematics
TAP	=	Technical Advisory Panel (TRA)
TRA	=	Tripoli Rocketry Association

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1. Flight Readiness Review Report Summary

1.1 Team Summary

1.1.1 Name and Contact Information

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1.1.2 Mentor information

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1.2 Launch Vehicle Summary

1.2.1 Size and Mass

The full-scale launch vehicle is 111.5 in. long with a body diameter of 7.5 in. The rocket has a mass of 48.4 lb on the pad, which includes 2.5 lb of nose ballast.

1.2.2 Launch Day Motor

The rocket will use an AeroTech L2200G motor at the competition launch.

1.2.3 Recovery System

The rocket uses an 18.0 in. drogue at apogee, a 5.0 ft parachute at 700 ft AGL, and a 10.0 ft main parachute at 500 ft AGL to slow its descent to an impact speed of 13.3 ft/s.

1.2.4 Launch Rail Size

The rocket vehicle will require an 8 ft, 1515 launch rail for the competition launch.

1.2.5 Milestone Review Flysheet

This document was submitted separately.

1.3 Deployable Rover Payload Summary

The team has chosen to include a deployable rover as the payload for the full-scale launch vehicle. The rover will be stowed in an internal tube that will rotate freely using roller bearings (Lazy Susan bearings) attached at each end of the payload tube. The upper bearing will be attached to a centering ring aft of the main parachute compartment. The lower bearing will be attached to a bulkhead forward of the avionics bay. The payload bay will be sealed during flight by a custom plug in the payload centering ring which will be removed by the force of the main parachute deployment. After landing, the rover will autonomously drive at least 5.0 ft away from the rocket and deploy a set of solar panels to complete the payload mission.

2. Changes Made Since Critical Design Review

2.1 CDR Action Items

The team was instructed to add an additional coupler in the main parachute bay to strengthen the midsection and hatch attachment point, which is described in Section 3.4.4.

2.2 Changes Made to Vehicle Criteria

Table 2-1 lists all changes made to the full-scale launch vehicle since CDR submission. Note that this report uses the terms "launch vehicle" and "rocket" interchangeably.

Table 2-1: List of Changes Made to Full-Scale Launch Vehicle

Description of Change	Reason for Change
Nosecone shaped changed to 3:1 ogive with 7.5 in. diameter base.	CDR design called for 5:1 ogive nosecone which was no longer available for purchase.
Nosecone ballast reduced to 2.5 lb.	After full-scale assembly was complete, only 2.5 lb of nose ballast was needed to achieve a desirable stability margin > 2.0 cal.
Added 2.3 lb of ballast to midsection in the avionics bay. Total ballast is 4.8 lb, exactly 10% of the total full-scale rocket weight.	After full-scale assembly was complete, the rocket was underweight by nearly 4 lb which required adding additional ballast in the midsection reduce CG translation.
Upper and lower midsection body tubes combined into single 48.0 in. long airframe.	The NASA RSO raised concerns regarding this design choice during the CDR presentation and the team decided to remove the split midsection entirely.
A 12.0 in. coupler was added to the main parachute compartment.	The team identified a need for a forward coupler during the CDR presentation. The coupler is fixed inside the main parachute compartment to act as a brace for the forward edge of the midsection access hatch. The coupler also helps create an airtight seal with the hatch for separation.
Fiberglass wrap added to the midsection forward opening.	Damage sustained during the test launch necessitated a major repair to the airframe in the form of a fiberglass wrap. These repairs will be tested at full-scale re-flight.
Fiberglass patches were used to repair damaged avionics bay and hatch areas.	A bulkhead failure during the initial ground ejection tests required the team to patch and repair an area around the avionics bay key switch and two of the hatch screw holes. Following the repairs, the two areas were undamaged during subsequent testing and the full-scale test launch.

Description of Change	Reason for Change
Fin can length reduced by 1.0 in. at the forward end of the body tube.	The forward opening of the fin can suffered major water damage after impact in wet mud following the full-scale test launch. The most damaged length of tube was removed, and the rest of the damaged areas will be repaired using fiberglass wraps and coated with hydrophobic spray for future launches.

2.3 Changes Made to Payload Criteria

Table 2-2 lists all changes made to the deployable rover payload system since CDR submission.

Table 2-2: List of Changes Made to Deployable Rover Payload System

Description of Change	Reason for Change
Material changed on forward bearing carrier to 6061 aluminum.	The change increases the weight of the payload which will decrease the apogee altitude. The metal will also reduce the amount of friction on the ball bearings.
Rover bay receiver switched to Seeedstudio RF Long Distance Receiver/Transmitter Pair.	New electronics package has the capability to transmit up to 2.0 km.
Onboard batteries changed to a combination of AA and C batteries.	Heavier batteries increase the weight of the rocket and decrease the apogee altitude.
Electronic latch rotated to leave the cam facing upwards.	Testing of the rover bay sled indicated that the new orientation was necessary.
Rover platform secured using two L-brackets at the aft lazy susan bearing.	The platform needed a way to be secured so it does not eject from the payload tube.
Reduced the size of upper rover braces in the payload bay tube.	Smaller braces save weight and fabrication time on the 3D printer.
Rover platform is made of birch plywood.	Reduced manufacturing time significantly.

2.4 Changes Made to Project Plan

Table 2-3 lists all changes made to the deployable rover payload system since CDR submission.

Table 2-3: List of Changes Made to Project Plan

Description of Change	Reason for Change
Updated March timeline to add repairs, rebuild, relaunch, clean up, painting, and final checklist assembly.	The full-scale test launch resulted in damage to the midsection and fin can as well as an apogee altitude greater than the 5,600 ft AGL limit. After repairs are complete, the full-scale rocket will be re-flown on March 24, 2018.

3. Launch Vehicle Criteria

3.1 Compliance to Handbook Requirements

Table 3-1, below, contains the launch vehicle requirements listed in the 2018 NASA SL handbook as well as the respective compliance actions, verification methods, status, location within the report, and verification description.

Table 3-1: Full-Scale and Subscale Launch Vehicle Handbook Item Compliance

Handbook Item	Description of Requirement	Compliance	Verification Method	Verification Description	Report Section Location
2.1	The vehicle will deliver the payload to an apogee altitude of 5,280 feet above ground level (AGL).	Based on the current design, an AeroTech L2200G will power the launch vehicle to an ideal apogee altitude of 5,280 ft AGL.	Analysis. The final weight will be calculated, and a motor will be selected to achieve an altitude of 5,280 ft AGL based on these calculations.	Complete. The final weight is predicted to be 48.9 lb and the rocket will use an AeroTech L2200G motor to reach an altitude of 5,280 ft AGL.	Section 5.1
2.2	The vehicle will carry one commercially available, barometric altimeter for recording the official altitude used in determining the altitude award winner. Teams will receive the maximum number of altitude points (5,280) if the official scoring altimeter reads a value of exactly 5,280 feet AGL. The team will lose one point for every foot above or below the required altitude.	A StratoLoggerCF altimeter will be used to record the official altitude.	Test. The StratoLoggerCF that will be used for the competition launch will be tested in a vacuum chamber prior to assembly and launch to ensure correct functionality.	Complete. The StratoLoggerCF was tested in a vacuum chamber prior to assembly and launch, and was shown to perform nominally.	Section 4.4.3.1
2.3	Each altimeter will be armed by a dedicated arming switch that is accessible from the exterior of the rocket airframe when the rocket is in the launch configuration on the launch pad.	Both altimeters will be armed by their own key switch which will be accessible from the exterior of the airframe.	Demonstration. The team will arm the altimeters after assembly on the pad using key switches mounted to the exterior of the rocket. Altimeter activation will be confirmed by the subsequent beeps.	Complete. The two key switches are only accessible from the exterior of the rocket. The location of the key switches ensures that a single team member cannot activate both switches in unison. The launchpad setup checklist contains separate items for arming the key switches. Two separate team members will be responsible for carrying the altimeter keys.	Section 4.4.1
2.4	Each altimeter will have a dedicated power supply.	Each altimeter will be powered by its own 9 V battery tested for conformity.	Demonstration. The team will demonstrate that the two altimeter circuits are entirely independent. The team will use only new batteries for each launch that have been tested prior to assembly.	Complete. The two altimeter circuits are entirely independent of each other and both contain their own 9 V battery. Batteries to be used for launch have been tested, labelled, and resealed for storage until launch.	Section 4.4.7
2.5	Each arming switch will be capable of being locked in the ON position for launch (i.e. cannot be disarmed due to flight forces).	The altimeters will be armed by key switches and will be oriented such that they won't be disarmed by flight forces.	Demonstration. The team will install the key switches such that flight forces cannot change the switch orientation after ignition. The key switches will be wired such that there is no risk of shorting the circuit during flight.	Complete. The heavy-duty key switches can only be turned using keys that will be removed prior to flight. The avionics bay is wired such that key switch wires have no exposed sections to eliminate the risk of shorting the circuit.	Section 4.4.1

Handbook Item	Description of Requirement	Compliance	Verification Method	Verification Description	Report Section Location
2.6	The launch vehicle will be designed to be recoverable and reusable. Reusable is defined as being able to launch again on the same day without repairs or modifications.	The rocket body will be constructed of Blue Tube to increase durability of the rocket. Body tube sections that are at risk for impact damage will be reinforced using fiberglass layers. The recovery parachutes will slow the rate of descent of the rocket to avoid damage upon landing.	Demonstration. The team will demonstrate the reusability of the rocket design after the full-scale test flight. The team will perform a post-flight inspection to ensure that no damage is found on the rocket body, structural components, avionics, and/or payload components.	Incomplete. The team performed a test launch on February 24, 2018 that caused damage to the launch vehicle body tube. The team will perform a re-launch on March 24, 2018 to demonstrate compliance. An FRR Addendum report will be submitted by March 28, 2018.	Section 6.7
2.7	The launch vehicle will have a maximum of four (4) independent sections. An independent section is defined as a section that is either tethered to the main vehicle or is recovered separately from the main vehicle using its own parachute.	The rocket will only have three (3) tethered sections: nosecone, midsection (with payload), and fin can.	Analysis. The rocket design will only require three tethered sections to fly which will be manufactured to the specifications listed in this report.	Complete. The rocket uses only three tethered sections: nosecone, midsection, and fin can. These sections will remain tethered during the entire descent under parachute.	Section 3.4
2.8	The launch vehicle will be limited to a single stage.	The launch vehicle has a single stage.	Analysis. The rocket design will include a single motor.	Complete. The rocket contains a single motor for flight.	Section 1.2.2
2.9	The launch vehicle will be capable of being prepared for flight at the launch site within 3 hours of the time the Federal Aviation Administration flight waiver opens.	The team will practice assembly using detailed checklists prior to launch to ensure that assembly time does not exceed three (3) hours.	Demonstration. The team will demonstrate the capability to prepare the rocket within 3 hours by practicing assembly using detailed checklists prior to launch.	Complete. The team completed dry runs of the rocket assembly in less than 3 hours. The team will continue to practice assembly before each flight to reduce preparation time further.	Section 6.1
2.10	The launch vehicle will be capable of remaining in launch-ready configuration at the pad for a minimum of 1 hour without losing the functionality of any critical on-board components.	Recovery system devices will be activated only once the rocket is on the launch pad to avoid unnecessary battery drain.	Demonstration. The team will incorporate only necessary electronics that do not exceed the available power drawn from batteries.	Complete. The onboard altimeters can remain powered by individual 9 V batteries for several hours after being switched on.	Section 4.4.5
2.11	The launch vehicle will be capable of being launched by a standard 12-volt direct current firing system. The firing system will be provided by the NASA-designated Range Services Provider.	The rocket can be launched using only a standard motor igniter.	Demonstration. The team will launch the rocket using only a standard 12 V DC firing system for the test launch.	Complete. The rocket was launched using only a standard motor igniter and a 12 V DC firing system at the full-scale test launch.	Section 6.1
2.12	The launch vehicle will require no external circuitry or special ground support equipment to initiate launch (other than what is provided by Range Services).	The rocket can be launched using only a standard motor igniter.	Demonstration. The team will demonstrate that the vehicle is capable of launching using only a standard motor igniter without additional equipment.	Complete. The rocket was launched without using any external circuitry or group support equipment at the full-scale test launch.	Section 6.1
2.13	The launch vehicle will use a commercially available solid motor propulsion system using ammonium perchlorate composite propellant (APCP) which is approved and certified by the National Association of Rocketry (NAR), Tripoli Rocketry Association (TRA), and/or the Canadian Association of Rocketry (CAR).	The rocket uses a commercially-produced AeroTech L2200G motor.	Inspection. The team will confirm that the chosen motor is certified by NAR and/or TRA before purchase, and that it uses only APCP as fuel.	Complete. The AeroTech L2200G motor is a APCP-based fuel that has been approved by NAR and Tripoli for high-powered rocketry use. This motor can be purchased from commercial vendors both online or in person.	Section 1.2.2

Handbook Item	Description of Requirement	Compliance	Verification Method	Verification Description	Report Section Location
2.13.1	Final motor choices must be made by the Critical Design Review (CDR).	The team will use an AeroTech L2200G motor.	Demonstration. The final motor choice will be listed in the CDR Report.	Complete. The rocket will use an AeroTech L2200G motor at the competition launch, which was listed in Section 1.2.2 of the CDR Report.	Section 1.2.2
2.13.2	Any motor changes after CDR must be approved by the NASA Range Safety Officer (RSO) and will only be approved if the change is for the sole purpose of increasing the safety margin.	The team does not need to change the selected competition motor.	Demonstration. The team will demonstrate that the AeroTech L2200G motor will allow the rocket to complete all in-flight mission requirements by successfully flying the rocket on a test launch.	Incomplete. The team used an AeroTech L2200G motor for the test launch which caused the underweight rocket to exceed the 5,600 ft AGL altitude limit. The team will re-fly the rocket on an AeroTech L2200G on March 24, 2018 to ensure that the motor will be able to complete all in-flight mission requirements.	Section 1.2.2
2.14	Pressure vessels on the vehicle will be approved by the RSO.	The launch vehicle will not utilize any pressure vessels.	Analysis. The team will not utilize any pressure vessels when designing the rocket.	Complete. The rocket design does not feature any pressure vessels.	Section 3.4
2.14.1	The minimum factor of safety (Burst or Ultimate pressure versus Max Expected Operating Pressure) will be 4:1 with supporting design documentation included in all milestone reviews.	The launch vehicle will not utilize any pressure vessels.	Analysis. The team will not utilize any pressure vessels when designing the rocket.	Complete. The rocket design does not feature any pressure vessels.	Section 3.4
2.14.2	Each pressure vessel will include a pressure relief valve that sees the full pressure of the valve that is capable of withstanding the maximum pressure and flow rate of the tank.	The launch vehicle will not utilize any pressure vessels.	Analysis. The team will not utilize any pressure vessels when designing the rocket.	Complete. The rocket design does not feature any pressure vessels.	Section 3.4
2.14.3	Full pedigree of the tank will be described, including the application for which the tank was designed, and the history of the tank, including the number of pressure cycles put on the tank, by whom, and when.	The launch vehicle will not utilize any pressure vessels.	Analysis. The team will not utilize any pressure vessels when designing the rocket.	Complete. The rocket design does not feature any pressure vessels.	Section 3.4
2.15	The total impulse provided by a College and/or University launch vehicle will not exceed 5,120 Newton-seconds (L-class).	The AeroTech L2200G provides 5,104 N-s of total impulse.	Demonstration. The team will demonstrate that they did not purchase or install a motor exceeding L-class.	Complete. The rocket uses an AeroTech L2200G motor which provides a total impulse of 5,104 N-s, which does not exceed the allowable limits.	Section 5.1.2
2.16	The launch vehicle will have a minimum static stability margin of 2.0 at the point of rail exit. Rail exit is defined at the point where the forward rail button loses contact with the rail.	The rocket has a predicted stability margin of 2.21 cal before ignition, and 2.25 cal at rail exit.	Analysis. The team will utilize OpenRocket, SolidWorks, and hand calculations to determine the location of the CP and CG on the assembled rocket. The stability margin will be calculated as a function of the body tube diameter to ensure that it is greater than 2.0 cal at the time of rail exit.	Incomplete. The rocket has a CP location of 81.1 in. from the nose, and a predicted CG location of 63.8 in. from the nose. For a 7.5 in. diameter body tube, the resulting static margin is predicted to be 2.30 cal at ignition and 2.36 cal at rail exit. The team will confirm these values after assembly is complete for the full-scale re-flight on March 24, 2018.	Section 5.2.2

Handbook Item	Description of Requirement	Compliance	Verification Method	Verification Description	Report Section Location
2.17	The launch vehicle will accelerate to a minimum velocity of 52 fps at rail exit.	The rocket has a predicted rail exit velocity of 77.4 ft/s.	Analysis. The team will use OpenRocket and hand calculations to determine the rail exit velocity of the rocket and ensure that a minimum value of 52 ft/s is achieved.	Complete. OpenRocket predicts an exit rail velocity of 77.4 ft/s which exceeds the minimum 52 ft/s.	Section 5.1.3
2.18	All teams will successfully launch and recover a subscale model of their rocket prior to CDR. Subscales are not required to be high power rockets.	The subscale rocket was successfully launched and recovered on November 18, 2018.	Demonstration. The team will demonstrate a successful launch and recovery of a subscale rocket prior to CDR.	Complete. The team successfully launched and recovered the subscale launch vehicle on November 18, 2018. The subscale flight is described in Section 3.4.3 of the CDR Report.	N/A
2.18.1	The subscale model should resemble and perform as similarly as possible to the full-scale model, however, the full-scale will not be used as the subscale model.	The subscale was designed to function as closely to the full-scale as possible at 52% of the size. The subscale rocket featured a nosecone design different than the full-scale due to manufacturer limitations.	Demonstration. The team will design and fabricate a subscale rocket that closely resembles the full-scale rocket to confirm the design of the full-scale.	Complete. The subscale rocket was designed to be a 52% scale version of the full-scale rocket. The subscale and full-scale rockets feature different nosecone shapes due to manufacturer limitations. The team was able to compare the OpenRocket simulated flight profile to the actual flight profile to measure the accuracy of the OpenRocket simulation for use on with the full-scale rocket.	N/A
2.18.2	The subscale model will carry an altimeter capable of reporting the model's apogee altitude.	The subscale rocket had a StrattoLoggerCF installed at launch to record the apogee altitude.	Demonstration. The team will include an altimeter capable of recording the apogee altitude on the subscale.	Complete. The StratoLoggerCF altimeter installed on the subscale rocket is identical to the altimeter that is installed on the full-scale rocket. The altimeter recorded an apogee of 2,093 ft AGL during the subscale rocket flight.	N/A
2.19	All teams will successfully launch and recover their full-scale rocket prior to FRR in its final flight configuration. The rocket flown at FRR must be the same rocket to be flown on launch day. The purpose of the full-scale demonstration flight is to demonstrate the launch vehicle's stability, structural integrity, recovery systems, and the team's ability to prepare the launch vehicle for flight. A successful flight is defined as a launch in which all hardware is functioning properly (i.e. drogue chute at apogee, main chute at a lower altitude, functioning tracking devices, etc.).	The same rocket will be flown during the full-scale demonstration (competition) flight as the full-scale test flight.	Demonstration. The team will fly the same rocket in the full-scale demonstration flight as in the full-scale test flight.	Incomplete. The full-scale rocket was damaged and exceeded the altitude limit during its test flight on February 24, 2018. The team will repair and rebuild the full-scale rocket to the specifications listed in this report. The team will re-fly the full-scale rocket on March 24, 2018 and submit an FRR Addendum with analysis of the re-flight by March 28, 2018.	Section 6.8

Handbook Item	Description of Requirement	Compliance	Verification Method	Verification Description	Report Section Location
2.19.1	The vehicle and recovery system will have functioned as designed.	The flight and recovery system results will be analyzed thoroughly to determine whether the rocket functioned as designed.	Analysis. Flight simulations, hand calculations, and material modelling will be compared to the flight results.	Incomplete. The full-scale test launch had a successful deployment of the drogue parachute at apogee and the main parachute at 500 ft AGL, but there is no evidence that the LARD was able to inflate after its release at 700 ft AGL. The team will increase the release altitude of the LARD to 800 ft AGL for the full-scale re-flight to ensure its inflation.	Section 6.3
2.19.2	The payload does not have to be flown during the full-scale test flight.	The payload bay is fixed to the midsection, and will be flown during all test flights. The electronics and rover mass was simulated during the first test launch of the full-scale rocket. The full-scale re-flight will feature the fully constructed payload and deployable rover. These components will be tested before, during, and after launch to ensure nominal operation.	Demonstration. The team intends to fly the full rover payload on the full-scale re-flight launch.	Incomplete. Mass simulators were used for the payload and rover components on the full-scale test launch on February 24, 2018. The fully-assembled payload and rover will be included in the full-scale re-flight on March 24, 2018.	Section 6.2
2.19.2.1	If the payload is not flown, mass simulators will be used to simulate the payload mass.	The payload bay is fixed within the midsection and does not require mass simulators. The added weight of rover and payload electronics were simulated during the full-scale test launch by ballast weights mounted in the payload bay.	Demonstration. Mass simulators will be used for the full-scale test launch. The full-scale re-flight will feature the full rover and payload assembly without the need for mass simulators.	Incomplete. The full-scale test launch featured mass simulators for the payload and rover electrical components. The team does not intend to use any mass simulators for the full-scale re-flight on March 24, 2018.	Section 6.2
2.19.2.1.1	The mass simulators will be located in the same approximate location on the rocket as the missing payload mass.	The mass simulators were weighed and fixed to the rover or payload bay to correspond with their modelled location within the payload bay.	Demonstration. Any mass simulators will be secured in the payload section to accurately simulate the final payload CG location.	Incomplete. The mass simulators used during the full-scale test launch on February 24, 2018 were weighed and fixed to the rover body or payload tube in their modelled location. The team does not intend to use any mass simulators for the full-scale re-flight on March 24, 2018.	Section 6.2
2.19.3	If the payload changes the external surfaces of the rocket (such as with camera housings or external probes) or manages the total energy of the vehicle, those systems will be active during the full-scale demonstration flight.	The payload does not change the external surface of the rocket.	Demonstration. The payload will not change the external surface of the rocket.	Complete. The payload does not alter the external surface of the full-scale rocket. The access hatch does not alter the external shape of the body tube, but does feature 8 screws which were all included during the full-scale test flight on February 24, 2018.	Section 3.4

Handbook Item	Description of Requirement	Compliance	Verification Method	Verification Description	Report Section Location
2.19.4	The full-scale motor does not have to be flown during the full-scale test flight. However, it is recommended that the full-scale motor be used to demonstrate full flight readiness and altitude verification. If the full-scale motor is not flown during the full-scale flight, it is desired that the motor simulates, as closely as possible, the predicted maximum velocity and maximum acceleration of the launch day flight.	The team used an AeroTech L2200G motor for the full-scale test flight on February 24, 2018. The team will use another AeroTech L2200G motor for the full-scale re-flight on March 24, 2018.	Demonstration. The team will use an AeroTech L2200G motor for all flights of the full-scale rocket, including the competition launch.	Incomplete. The team used an AeroTech L2200G motor for the test launch on February 24, 2018. The team will use another AeroTech L2200G motor for the full-scale re-flight on March 24, 2018.	Section 6.3
2.19.5	The vehicle must be flown in its fully ballasted configuration during the full-scale test flight. Fully ballasted refers to the same amount of ballast that will be flown during the launch day flight. Additional ballast may not be added without a re-flight of the full-scale launch vehicle.	The full-scale rocket features 4.8 lb of ballast which represents 9.8% of the total mass of the vehicle.	Demonstration. The rocket will be fully ballasted for all ground tests and the full-scale test launch.	Incomplete. The full-scale rocket will include 2.5 lb of nose ballast and 2.3 lb of ballast at the CG, a total of 4.8 lb which represents 10% of the total weight of the rocket. These masses will be included in the rocket assembly for all ground tests and test launches.	Section 3.4.3.1
2.19.6	After successfully completing the full-scale demonstration flight, the launch vehicle or any of its components will not be modified without the concurrence of the NASA Range Safety Officer (RSO).	The team will not modify any components on the full-scale rocket without concurrence of the NASA Range Safety Officer.	Inspection. The team will inspect all components after the full-scale test launch to determine if any modifications will be necessary.	Incomplete. The team will not modify any of the full-scale rocket or payload components after the re-flight is complete. Exterior paint and decals will be added prior to the competition launch with the approval of the NASA RSO.	Section 6.8
2.19.7	Full scale flights must be completed by the start of FRRs (March 6th, 2018). If the Student Launch office determines that a re-flight is necessary, then an extension to March 28th, 2018 will be granted. This extension is only valid for re-flights; not first-time flights.	The full-scale test flight was completed on February 24, 2018. Due to damage and exceeding the altitude limit, the team will conduct a re-flight of the full-scale rocket on March 24, 2018. The backup date for the re-flight is March 25, 2018.	Demonstration. The team will complete the full-scale test launch prior to March 6, 2018. The team will conduct any required re-flights prior to March 28, 2018.	Incomplete. The full-scale test launch was completed on February 24, 2018. The full-scale re-flight will occur on March 24, 2018 with a backup date of March 25, 2018. The team will submit an FRR Addendum by March 28, 2018.	Section 6.1
2.20	Any structural protuberance on the rocket will be located aft of the burnout center of gravity.	The burnout CG is located 60.3 in. from the nose. The forward-most structural protuberance on the rocket are the key switches which are located 61.5 in. from the nose.	Analysis. The rocket design will not include any protuberances located forward of the burnout CG.	Complete. The predicted burnout CG on the full-scale rocket is located 60.3 in. from the nose, which is 1.2 in. forward of the key switches. There are no structural protuberances forward of the key switches.	Section 4.4.1
2.21.1	The launch vehicle will not utilize forward canards.	The launch vehicle has no forward canards.	Analysis. The team will not include forward canards in the rocket design.	Complete. The full-scale rocket does not feature forward canards.	Section 3.4
2.21.2	The launch vehicle will not utilize forward firing motors.	The launch vehicle has no forward firing motors.	Analysis. The team will not include forward firing motors in the rocket design.	Complete. The full-scale rocket does not feature forward firing motors.	Section 3.4

Handbook Item	Description of Requirement	Compliance	Verification Method	Verification Description	Report Section Location
2.21.3	The launch vehicle will not utilize motors that expel titanium sponges.	The AeroTech L2200G motor does not utilize titanium sponges.	Analysis. The team will not use a motor with titanium sponges.	Complete. The full-scale rocket motor, an AeroTech L2200G, does not feature titanium sponges.	Section 3.4
2.21.4	The launch vehicle will not utilize hybrid motors.	The launch vehicle does not utilize hybrid motors.	Analysis. The team will not include a hybrid motor in the rocket design.	Complete. The full-scale rocket does not feature hybrid motors.	Section 3.4
2.21.5	The launch vehicle will not utilize a cluster of motors.	The launch vehicle uses a single AeroTech L2200G motor.	Analysis. The team will not include a cluster of motors in the rocket design.	Complete. The full-scale rocket does not feature a cluster of motors.	Section 3.4
2.21.6	The launch vehicle will not utilize friction fitting for motors.	The launch vehicle motor mount is epoxied to the rocket body tube.	Analysis. The team will not use a friction fit for the motor in the rocket design.	Complete. The full-scale rocket does not feature a friction fitting for motors, and instead utilizes a mounted AeroPack Quick Change Motor Retainer.	Section 3.4.5.4
2.21.7	The launch vehicle will not exceed Mach 1 at any point during flight.	The launch vehicle has a predicted maximum speed of Mach 0.61.	Analysis. The team will utilize simulations to ensure that the rocket speed does not exceed Mach 1.0 during flight.	Complete. The maximum velocity recorded during the full-scale test flight was 751 ft/s, or Mach 0.67.	Section 6.3.2
2.21.8	Vehicle ballast will not exceed 10% of the total weight of the rocket.	The full-scale rocket contains a total of 4.8 lb of ballast, which corresponds to 9.8% of the total weight.	Analysis. The team will not include a total amount of ballast that exceeds 10% the total weight in the rocket design.	Complete. The full-scale rocket contains 4.8 lb of ballast located in the nosecone cavity and avionics bay, which is 10% of the total weight.	Section 3.4.3.1

3.2 Mission Statement

The team is proud to present the full-scale launch vehicle design for the 2018 NASA SL competition in the pages below. This rocket is an original design that includes efforts from team members with backgrounds in, but certainly not limited to, high-powered rocket design, structural analysis, electrical design, and slender-body aerodynamics. It is the goal of the team to always choose the rocket and payload options that require the greatest technical demand to provide a challenge to even the most veteran team members. The rocket will satisfy all the requirements listed in Section 3.1, Section 4.1, and Section 7.1 with an extra focus on maximizing the safety and well-being of all crew and spectators, as well as the environment.

3.2.1 Mission Success Criteria

The success of the full-scale launch vehicle is based on the challenge criteria listed in Section 3.1, Section 4.1, and Section 7.1, as well as the team-derived requirements presented in Section 10.3. The team has defined a successful rocket launch as one where the vehicle apogee is within 100 ft of 5,280 ft AGL (1 mi), the drogue parachute deploys at apogee, the LARD opens by 700 ft AGL, the main parachute deploys at 500 ft AGL, and the entire rocket is reusable immediately after landing. To accomplish these goals, every component of the rocket must work as designed and redundancies should be in place for each component critical to the flight. The team will rely on simulations, physical experiments, and test flights to confirm that the vehicle will be successful with regards to the above criteria for every flight. Additionally, the success of the deployable rover is dependent on the success of the launch vehicle since the rover mission starts once the rocket mission ends.

3.3 Design and Rationale of Full-Scale Launch Vehicle

The team completed the fabrication of the full-scale rocket built to the specifications listed in the CDR Report. The team did address the CDR Action Item listed in Section 2.1 by combining the upper and lower midsection components into a single component with an added coupler to account for a longer access hatch length, which is detailed in Section 3.4.4.8. This rocket was flown on February 24, 2018, but it sustained structural damage during recovery and exceeded the altitude limit of 5,600 ft AGL set by the NASA Student Launch Range Safety Officer. The team will conduct a re-flight on March 24, 2018 and submit an FRR Addendum by March 28, 2018 as specified by Handbook Item 2.19.7 listed in Section 3.1.

Though the airframe is the same between the already-flown and re-flight full-scale rockets, the new design will be described in this report using the future tense since the repairs and final assembly have not been completed as of writing this report. This new design features a shorter length, fiberglass wraps around body tube openings, and additional ballast weight; all necessary to increase the body tube strength while ensuring the rocket does not exceed the altitude limit. Table 2-1 lists all the major design changes that were applied to the new design after the test launch failure. These changes are detailed in this report and will be incorporated into the full-scale rocket during the repair and re-build process. The team will submit the final design, dimensions, and technical specifications of the full-scale rocket in the FRR Addendum by March 28, 2018.

3.3.1 Dimensions and Technical Details

The full-scale launch vehicle was designed using OpenRocket, a free software that is utilized by NAR and TRA rocketeers at all certification levels. The rocket is 111.5 in. long with a constant body diameter of 7.5 in. after the nosecone base. A large body tube diameter was chosen to maximize the volume available within the rocket for the payload with deployable rover. The rocket has three body sections: nosecone, midsection, and fin can. Figure 3-1, below, shows the OpenRocket 3D schematic with body sections labelled respectively.

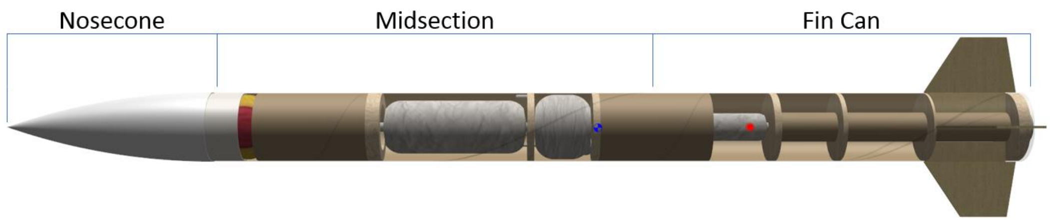

Figure 3-1: OpenRocket Model with Section Labels

The current rocket configuration in OpenRocket has a predicted weight of 48.4 lb when fully assembled, which acts as the maximum allowable weight for the full-scale design. Maximum allowable weights for the payload and avionics bay are described in Section 7.4 and Section 7.5, respectively. For comparison, the detailed SolidWorks model of the current rocket design has a predicted weight of 45.8 lb when fully assembled which includes accurate weights for the payload and avionics bay. Though these values do include weight approximations for the payload, avionics, and motor, they do not include weight values for body paint, epoxy, black powder charges, fiberglass repairs, or fasteners. The weight difference between the two models can be attributed to discrepancies throughout the models including differences in payload weight, material density, and bulkhead holes. Both models will be updated continuously throughout the project timeline to reflect the latest design changes and provide up-to-date values for total mass. The team will also work on applying additional modelling techniques to include as many physical components in the OpenRocket and SolidWorks models as possible. Figure 3-2, below, shows the detailed SolidWorks model which will be compared to the OpenRocket model in Figure 3-1 for component mass confirmation.

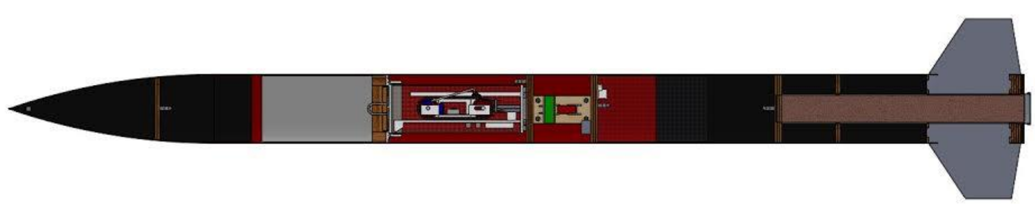

Figure 3-2: Cutaway View of Detailed SolidWorks Model

In its current configuration, the predicted CG location of the rocket is at a point 63.8 in. from the nosecone tip as determined using the mass approximations described above in OpenRocket. The CG location was confirmed using the detailed SolidWorks model to be

64.7 in. from the nosecone tip. Though the predicted total weights of each model differ by nearly 2.6 lb, the CG locations only differ by 0.9 in., which ensures that the stability margin is nearly identical between both models. A minimal difference in CG location between the models is highly favorable and is the result of conscious efforts to balance weights in the payload and avionics bay. The predicted CG location in each model will become more accurate as additional weights, such as body paint, epoxy, and fasteners, are added to the models throughout the design and fabrication process.

3.4 Design and Fabrication of Full-Scale Launch Vehicle

This section includes the digital models, technical specifications, design justifications, and fabrication images for the full-scale launch vehicle, which is shown in Figure 3-3, below.

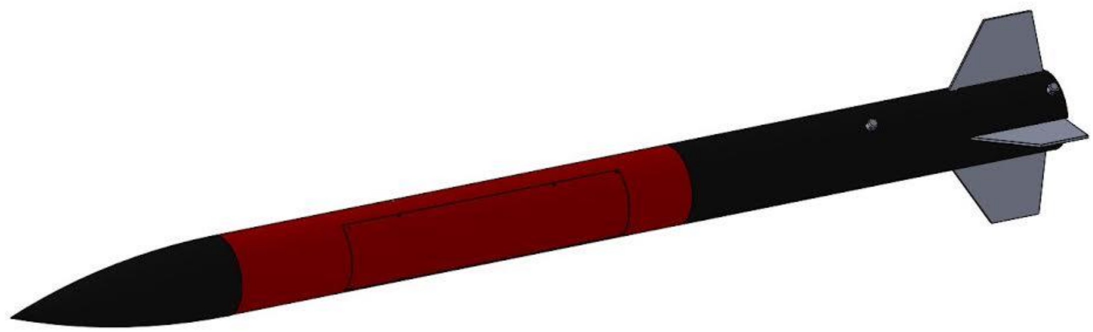

Figure 3-3: Isometric View of the Full-Scale Launch Vehicle

Note that the SolidWorks model shown above is missing key switches installed at the avionics bay and that the rail buttons are actually installed on the opposite side of the rocket from the access hatch.

3.4.1 Body Tube Material Selection

The projected weights of the body tubes and coupler were calculated for the full-scale rocket in order to justify the use of Blue Tube on the rocket. The combined weight of the fiberglass forward airframe body tube, fin can body tube, and coupler was calculated to be approximately 7.83 lb. The combined weight of the Blue Tube forward airframe body tube, fin can body tube, and coupler was calculated to be approximately 4.23 lb. Using Blue Tube body tube components results in a weight savings of approximately 3.5 lb, nearly 10% of the weight of the rocket. Through reducing weight of the rocket, there is also a reduction of loading during flight which provides a higher margin of error for hitting the target altitude of 5,280 ft AGL.

To verify that Blue Tube would be capable of withstanding forces during flight, the compressive strength was analyzed. The principle compressive loads on the airframe are caused by inertia and drag. The peak drag force F_D was calculated using Equation 7 below:

$$F_D = \frac{1}{2}\rho V^2 C_D A \tag{1}$$

where ρ is the air density at sea level, $1.225\frac{kg}{m^3}$; V is the peak velocity of the rocket, $219.56\frac{m}{s}$; C_D is the drag coefficient, 0.451; and A is the frontal area of the rocket, $0.028578\,m^2$. This yields $380.20\,N$. The peak inertial load F_I was calculated using Equation 8 below:

$$F_I = ma \tag{2}$$

where m is the mass of the rocket, $19.090\,kg$, and a is the peak acceleration of the rocket, $142.95\frac{m}{s^2}$. The resulting peak inertial load on the rocket is $2729.1\,N$. The total compressive force F_C on the rocket is given by Equation 9 below:

$$F_C = F_D + F_I = 3109.3\,N = 698.99\,lbf \tag{3}$$

The supplier of Blue Tube, Always Ready Rocketry, has provided axial crush test data for Blue Tube which is shown in Figure 3-4, below.

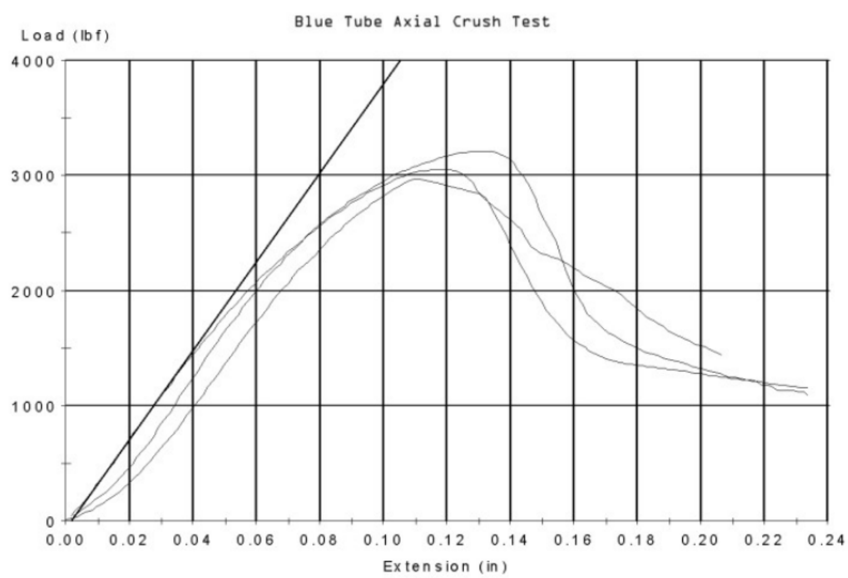

Figure 3-4: Blue Tube Axial Crush Test Data

Over three trials, the buckling load for Blue Tube was approximately 3,000 lb_f. The factor of safety for the Blue Tube airframe on this rocket was calculated to be approximately 4.3, confirming that Blue Tube is suitably strong for this application. This is also a conservative estimate, as the rocket features several bulkheads and centering rings that provide additional support. The team conducted buckling testing on sections of Blue Tube to verify the results received from the supplier. See Section 3.5.1.1 for more details on this testing.

The rocket has a constant body tube diameter of 7.5 in. and is reinforced with several bulkheads and centering rings throughout the vehicle. All components are fixed to the airframe using West Systems 105 epoxy and West Systems 206 Slow Hardener. This epoxy was chosen for its high strength, durability, and working time. The launch vehicle separates at two points: between the nosecone and midsection, and between the midsection and fin can.

3.4.2 Bulkhead Fabrication

All bulkheads were constructed using sheets of 0.25 in. thick aircraft-grade birch plywood. Additional sheets were epoxied together using West Systems 105 epoxy and West Systems 206 Slow Hardener in areas of increased loading such as the motor mount and payload bulkhead. The epoxied bulkheads were under vacuum for 24 hours to allow the epoxy to fully cure. All bulkheads and centering rings were cut from sheets of plywood using a laser cutter. 0.25 in. holes were laser cut into all bulkhead layers that fit a small dowel to prevent misalignment during cure.

The bulkheads and centering rings were positioned upright in the main body tubes at their correct location. The placement of the bulkheads was maintained using tape to stabilize the bulkheads while the epoxy cured.

A drill press was used to create any holes needed through a bulkhead or centering ring. The hole size and placement depended on which components were attached. When installing U-bolts, the fastening nuts were secured using Loctite after installation was complete.

3.4.3 Nosecone Design and Fabrication

The full-scale rocket included a 5:1 ogive nosecone as part of the CDR design, but this size nosecone was unavailable to purchase from any online rocket component retailers. Instead, the team has procured a plastic 3:1 ogive nosecone with a 7.5 in. diameter base which does not alter the design of the rocket other than a slight increase in drag and a shorter overall length. For the case of the full-scale rocket, both changes are considered to be improvements to the design. The nosecone is 22.5 in. long from base to tip. Figure 3-5 below shows the 3:1 plastic nosecone after removing the base.

Figure 3-5: Plastic 3:1 Ogive Nosecone with 7.5 in. Base Diameter

A plastic nosecone also offers a significant cost and weight reduction compared to the original fiberglass design listed in the PDR. Single-mold plastic nosecones are common in high-powered rocketry and are durable enough for multiple launches and recoveries. Since the plastic nosecone does not contain a metal tip, additional nose ballast will be necessary in the form of lead balls epoxied in the nosecone tip cavity.

3.4.3.1 Nosecone Ballast

To add the necessary nose ballast, lead shot balls were acquired and mixed into West Systems 2-part epoxy until they weighed the desired 2.5 lb. The mix was then poured into the nosecone cavity and held level for 24 hours to ensure full curing of the epoxy. The nosecone ballast cannot be removed and is designed to remain fixed in its position for the entire flight.

3.4.3.2 Nosecone Bulkhead

The nosecone features a single bulkhead fixed into the nosecone cavity to be used as a tethering point for the main parachute. The bulkhead consists of three circular sheets of aircraft-grade birch plywood sandwiched together using West Systems 2 part epoxy. The first layer is 0.25 in. thick, and each of the top two layers are 0.125 in. thick for a total thickness of 0.5 in.

The aft face of the bulkhead is fixed 6.0 in. from the base of the nosecone to allow additional volume for stowing the main parachute shock cord. Since the bulkhead is placed inside the nosecone, OpenRocket was used to determine the outer diameter of the bulkhead so that that it corresponded to the inner diameter of the nosecone at its current position. Based on a nosecone wall thickness of 0.08 in., the bulkhead has a diameter 6.9 in. to fit inside the nosecone cavity. Figure 3-6, below, shows the aft face of the nosecone bulkhead with U-bolt installed and the GPS transmitter attached by hook and loop as well as three standoff screws.

Figure 3-6: Nosecone Bulkhead with U-Bolt and GPS Transmitter

3.4.3.3 Nosecone Fabrication

After removing the base of the nosecone, the nose ballast and nosecone bulkheads were installed as described in Section 3.4.3.1 and Section 3.4.3.2, respectively.

The exterior of the nosecone was sanded using 220 grit sandpaper, then successively finer grit sandpapers up to 2000 grit. This process produced a smooth surface finish. The nosecone was then thoroughly cleaned with mineral spirits prior to receiving three coats of Rustoleum Automotive primer. The nosecone was not painted for the test launch.

The nosecone bulkhead consists of 3 layers of 0.25 in. aircraft-grade Baltic birch plywood epoxied together. A U-bolt was installed through the center of the bulkhead as an attachment point for the main parachute shock cord. This allows the nosecone section to remain tethered to the rest of the rocket during recovery rather than falling as a separate, self-contained independent section. The U-bolt shown in Figure 3-7, below, was permanently fixed to the bulkhead during fabrication using Loctite threadlocker to secure the fastening nuts on the opposite side of the bulkhead.

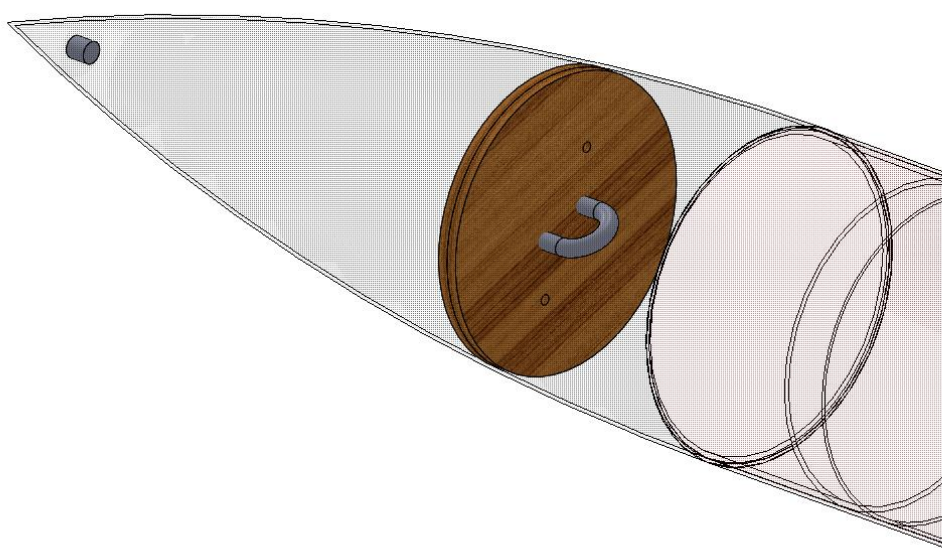

Figure 3-7: Nosecone Model

After fabrication, the nosecone weighed 5.0 lb without any quicklinks or the GPS transmitter installed.

3.4.4 Midsection Design and Fabrication

The rocket midsection contains the payload bay, avionics bay, and part of each parachute compartment. The assembled midsection is 48.0 in. long with a constant body diameter of 7.5 in. to match the base diameter of the nosecone described in Section 3.4.3. Figure 3-8, below, shows the midsection OpenRocket model with labels for each internal component and subassembly.

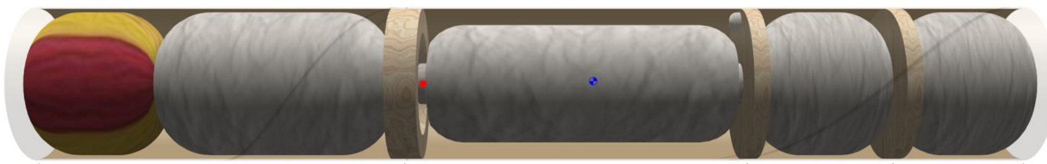

Figure 3-8: Midsection with Component and Subassembly Labels

Note that the model above omits two 12 in. couplers: one installed forward of the payload centering ring in the main parachute compartment and another installed aft of the avionics bulkhead in the drogue parachute compartment. The main parachute coupler is fully enclosed by the main parachute compartment and is used to strengthen the forward attachment point for the access hatch described in Section 3.4.4.8. The drogue coupler length encompasses the entire drogue parachute bay on the midsection, and is epoxied to the fin canto the inner wall of the midsection drogue compartment to leave a 6.0 in. shoulder extending into the fin can. The forward end of the coupler sits flush against the aft face of the avionics bulkhead which was installed exactly 6.0 in. from the base of the midsection.

The main parachute is housed in the forward parachute compartment, and the drogue and LARD parachutes are housed in the aft parachute compartment. The recovery system for the full-scale launch vehicle is described in Section 4. The avionics bay contains the electronics sled with attached altimeters and batteries, which is discussed in Section 4.4.

3.4.4.1 Addressing CDR Action Item

The CDR Action Item listed in Section 2.1 required the team to address the midsection design prior to launching the full-scale rocket. The CDR design contained a cut at the payload centering ring to split the midsection into upper and lower sections to allow for easier access to the payload bay and black powder charges. The NASA Student Launch staff expressed concern for this design as it would severely weaken the midsection and create a failure point at the payload centering ring. To eliminate these concerns, the midsection design has been reverted to its original design listed in the PDR with the addition of a coupler in the main parachute compartment. The midsection is now one single body tube with an access hatch extending along one side of the tube. Though the midsection was damaged during the test launch, it was completely unrelated to the CDR Action Item described above.

3.4.4.2 Payload Bay Design

To determine the desired weight of the payload, the team studied the relationship between payload bay weight, nose ballast weight, overall rocket weight, and the resulting apogees for flights using an AeroTech L2200G motor launching from a vertical 8 ft rail. The results of this study were written in the CDR, and have been updated for the redesign of the full-scale rocket for the re-flight launch. Since the nose ballast weight is now fixed at 2.5 lb, the team studied the relationship between payload weight, midsection ballast, and apogee for flights using an AeroTech L2200G. As the payload and rocket weight were changed, the midsection ballast was updated to ensure a stability margin of greater than 2.0 for the entire flight. As discussed in Section 6.3, the team applied a 4.5% increase in altitude to each of the simulated apogee results to generate a more accurate relationship between payload weight and apogee. Table 3-2, below, shows the OpenRocket flight simulation results for various payload weights when launching on an 8 ft launch rail with no windspeed.

Table 3-2: OpenRocket Flight Simulation Results for Varying Payload Weight

Payload Weight (lb)	Rocket Weight (lb)	Total Ballast (lb)	Simulated Apogee (ft AGL)	Corrected Apogee (ft AGL)
5.0	47.1	4.7	5,431	5,675
5.2	47.3	4.7	5,411	5,654
5.4	47.5	4.7	5,393	5,635
5.6	47.7	4.7	5,371	5,612
5.8	47.9	4.7	5,352	5,592
6.0	48.2	4.8	5,322	5,561
6.2	48.3	4.8	5,303	5,541
6.4	48.6	4.8	5,279	5,516
6.6	48.8	4.8	5,263	5,499
6.8	49.0	4.9	5,231	5,466
7.0	49.3	4.9	5,214	5,448

The results in Table 3-2 show that the payload cannot have a total weight less than 5.8 lb to ensure that the team does not exceed the 5,600 ft AGL altitude limit set by the NASA RSO. The current weight of the payload bay and rover is listed in Section 7.4. The OpenRocket model will be updated once the full-scale rocket is repaired and rebuilt prior to the re-launch scheduled for March 24, 2018.

3.4.4.3 Payload Centering Ring Design

Since the payload will remain fixed within the midsection for the entire flight, it was necessary to add a bulkhead to both ends of the payload bay shown in Figure 3-8. The forward end of the payload is fixed to the rocket body by a 1.5 in. thick centering ring.

The payload centering ring consists of six rings of 0.25 in. aircraft-grade birch plywood sandwiched together using epoxy for a total thickness of 1.5 in. The outer diameter matches the inner diameter of the body tube, approximately 7.34 in., and the inner diameter is 5.0 in. to allow clearance for the rover to deploy after landing.

After using digital calipers to accurately measure and confirm the body tube dimensions, the plywood rings were cut out using a laser cutter. West Systems 2 part epoxy was used to combine the rings, which was allowed to cure for at least 24 hours under a vacuum seal.

The forward face of the payload centering ring acts as the lower end of the main parachute bay. A pair of PVC blast caps were installed on this face using West Systems 2 part epoxy at the base. Since the difference between the inner and outer diameters of the ring is approximately 2.5 in., only blast caps with base diameters of 0.75 in. or less will be used to store the main parachute black powder charges. A wire terminal with two ports was fixed adjacent to each of the blast caps to act as the connection point for the e-match wire being fed into the respective blast cap. The blast cap and terminal pairs were labelled “P” for primary and “S” for secondary. A small hole was drilled at a point between the two blast cap and terminal pairs to allow altimeter wires to be fed around the payload bay and into the main parachute compartment. These wires are color-coded and labelled primary and secondary to ensure proper connection to their respective wire terminal. When assembling the rocket for the launch, this hole was sealed using plumber’s putty to ensure that no ejection gases can escape into the payload bay.

Since the payload centering ring supports the payload bay, upper midsection, and access hatch, the team determined that it would not be suitable to also add an attachment point for the main parachute to the forward face. Instead, the main parachute shock cord is fed through a small, rectangular cutout on the outer edge of the payload ring which is open and accessible by the removable access hatch described in Section 3.4.4.8. The cutout is 0.75 in. wide and 0.25 in. deep which allows ample room for the 0.50 in. shock cord described in Section 4.3.5. When closing the access hatch, the shock cord was held taut in the cutout and then sealed with plumber’s putty to ensure that no ejection gases could escape into the payload bay. Figure 3-9, below, shows the payload centering ring with blast caps and terminals, as it was installed in the rocket body tube.

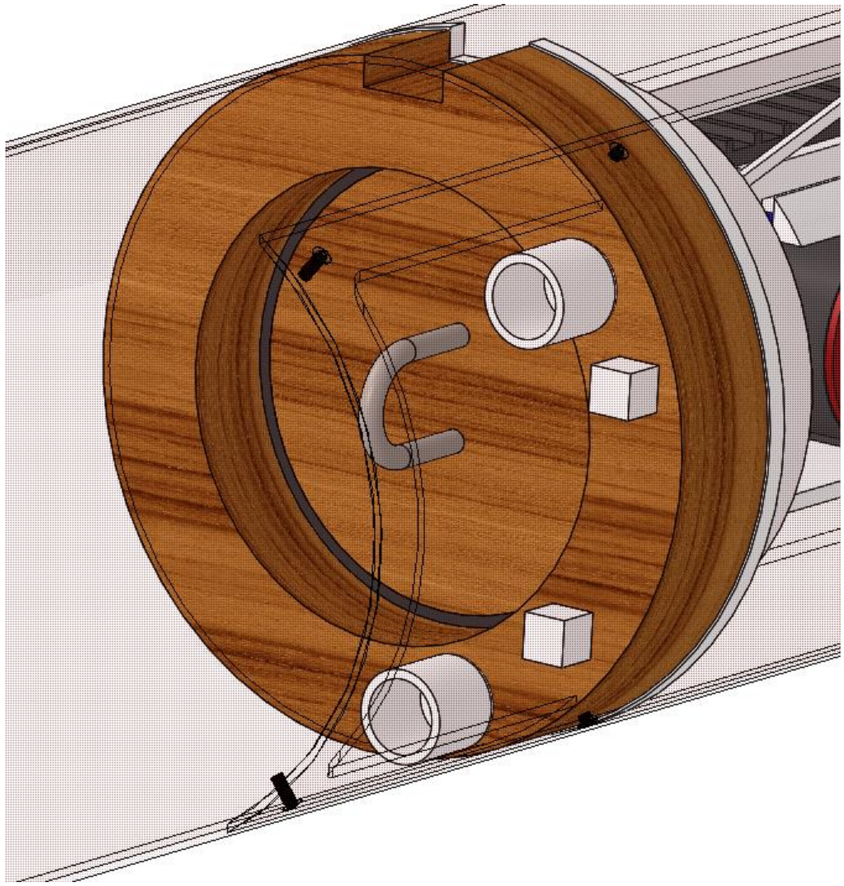

Figure 3-9: Payload Centering Ring Assembly

Note that the figure above does not feature the most recent version of the payload centering ring plug design, which is described in Section 3.4.4.4, below.

3.4.4.4 Payload Centering Ring Plug Design

As shown in Figure 3-9, above, the rover bay was sealed off during flight by a removable plug. The plug consists of three circular sheets of 0.25 in. aircraft-grade birch plywood sandwiched together using epoxy for a total thickness of 0.75 in. After creating the plug body, a weather-resistant rubber seal was glued to the outer edges to ensure an airtight seal. The outer diameter of the plug body with seal is equal to the inner diameter of the payload centering ring. After using digital calipers to accurately measure and confirm the body tube dimensions, the plywood rings were cut out using a laser cutter. West Systems 2 part epoxy was used to combine the rings, which were allowed to cure for at least 24 hours under a vacuum seal. Figure 3-10, below, shows the SolidWorks model of the plug with a rubber seal along the outer edge.

Figure 3-10: Rover Bay Plug

During assembly, the plug was placed over the rover bay opening to the main parachute compartment and pushed into the hole until it was flush against the upper payload bearing. The plug protects the rover from any negative effects due to the rapid gas expansion in the main parachute compartment during each black powder charge explosion. Additionally, the plug acts as the divide between the payload bay and main parachute compartment to ensure that no gases can escape into the payload bay volume which may cause the charges to be ineffective in separating the nosecone and deploying the main parachute.

A U-bolt was installed through the center of the plug body to allow its removal following nosecone separation. A small loop was made in the main parachute shock cord approximately 5.0 ft from the end of the main parachute aft shock cord. A metal, approved carabiner was used to connect the shock cord loop to the plug U-bolt. As the shock cord is pulled out of the compartment, it also pulls the plug out of the payload centering ring to open the rover bay. The plug is designed to be lightweight to reduce any complications with the shock cord and remains tethered to the shock cord during descent.

3.4.4.5 Payload Bay Bulkhead

The payload bulkhead acts as the aft attachment point for the payload tube, and separates the payload and avionics bays. The payload bulkhead consists of three circular sheets of 0.25 in. aircraft-grade birch plywood sandwiched together using epoxy for a total thickness of 0.75 in. After using digital calipers to accurately measure and confirm the body tube dimensions, the plywood sheets were cut out using a laser cutter. West Systems 2 part epoxy was used to combine the sheets, which were allowed to cure for at least 24 hours under a vacuum seal.

The payload bulkhead acts as an attachment point for the main parachute shock cord to ensure that the nosecone and midsection remain tethered during recovery. A U-bolt was installed through the bulkhead on the side of the tube that is accessible by the access hatch. The U-bolt shown in Figure 3-11, below, was permanently fixed to the bulkhead during fabrication with Loctite to secure the fastening nuts on the opposite side of the bulkhead.

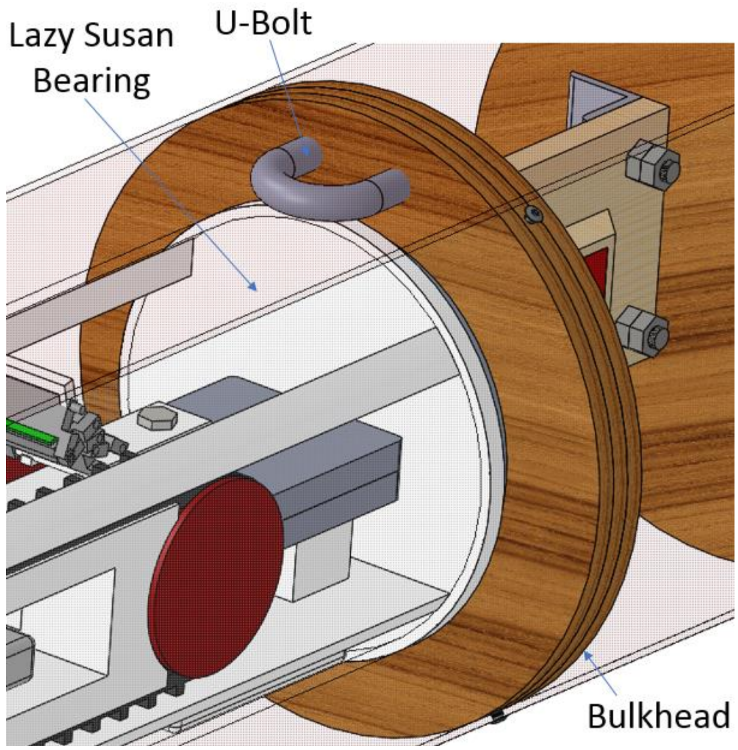

Figure 3-11: Payload Bulkhead

The payload bulkhead contains a single 0.25 in. hole opposite the U-bolt to allow wires from the avionics bay to run up to the main parachute black powder charge terminals.

3.4.4.6 Pressure Sampling Holes

Four 0.25 in. diameter holes were drilled through the body tube walls of the avionics bay to allow the pressure in the bay to remain equalized with the outside air pressure and temperature during flight. To ensure that the holes were spaced equally around the body tube circumference, a square ruler was used to mark the location of each hole. A hand drill was used to drill out each hole which was then sanded to remove any scrap Blue Tube shavings.

3.4.4.7 Avionics Bay Bulkhead

The avionics bay bulkhead separates the avionics bay from the drogue parachute compartment at the aft-most end of the midsection. The avionics bay bulkhead consists of three circular sheets of 0.25 in. aircraft-grade birch plywood sandwiched together using epoxy for a total thickness of 0.75 in. After using digital calipers to accurately measure and confirm the body tube dimensions, the plywood sheets were cut out using a laser cutter. West Systems 2 part epoxy was used to combine the sheets, which were allowed to cure for at least 24 hours under a vacuum seal.

A U-bolt was installed through the center of the avionics bay bulkhead as the forward attachment point for the drogue parachute shock cord. This allows the midsection to remain tethered to the fin can during rocket recovery. The U-bolt was permanently fixed to the bulkhead during fabrication using Loctite to secure the fastening nuts on the opposite side of the bulkhead.

The aft face of the avionics bay bulkhead was installed exactly 6.0 in. from the bottom edge of the midsection to allow enough clearance for the fin can coupler described in Section 3.4.4. This face also acts as the upper end to the drogue parachute bay. A pair of 0.75 in. diameter PVC blast caps were installed on this face using West Systems 2 part epoxy at the base. A wire terminal with two ports was fixed adjacent to each of the blast caps to act as the connection point for the e-match wire being fed into the respective blast cap. The blast cap and terminal pairs were labelled “P” for primary and “S” for secondary. A small hole was drilled at a point between the two blast cap and terminal pairs to allow altimeter wires to be fed around the payload bay and into the main parachute compartment. These wires were color-coded and labelled primary and secondary to ensure proper connection to their respective wire terminal. When assembling the rocket for the launch, this hole was sealed using plumber’s putty to ensure that no ejection gases could escape into the payload bay. Figure 3-12, below, shows the avionics bay bulkhead with PVC blast caps, wire terminals, and U-bolt installed.

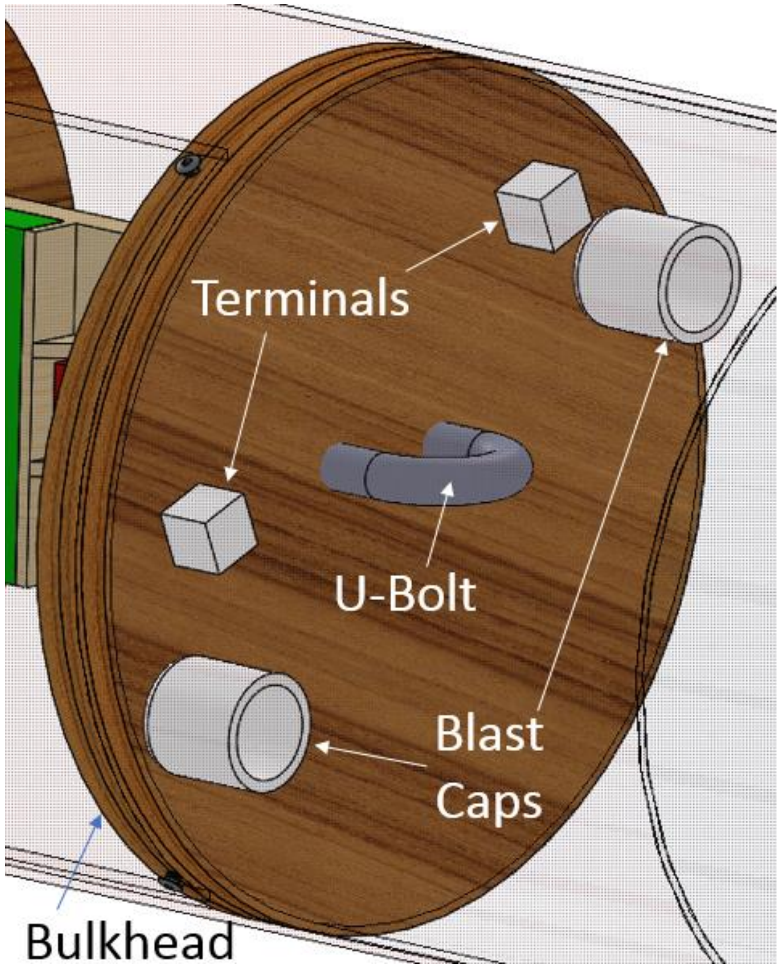

Figure 3-12: Avionics Bay Bulkhead

The payload bulkhead contains a single 0.25 in. hole to allow wires from the avionics bay to run up to the drogue parachute black powder charge terminals.

3.4.4.8 Midsection Access Hatch

The rocket midsection features a removable hatch that allows access to the payload bay and avionics bay during assembly. The hatch was cut from the midsection body tube to ensure that it remains flush and even with the body tube surface when attached for flight. The hatch is 7 in. wide when viewing the rocket as a flat plane; this corresponds to a curvature of 115.5°.

When removed, the hatch opening allows team members to access the U-bolt attached to the payload bulkhead for use when assembling the main parachute shock cord. Team members also have full access to the avionics bay, as well as all altimeter wires leading to the drogue and main parachute compartments. Due to the wide body diameter of the midsection airframe, access to the avionics bay and wires is no longer be limited to only members with small hands, which was a major complication when assembling the subscale rocket.

The hatch is secured to the midsection via a total of eight screws. The two top screws fit into the hatch coupler, four screws fit into the payload bulkheads, and the two bottom screws fit into the avionics bay bulkhead. Figure 3-13, below, shows an exploded view of the hatch and screw placement over the assembled midsection.

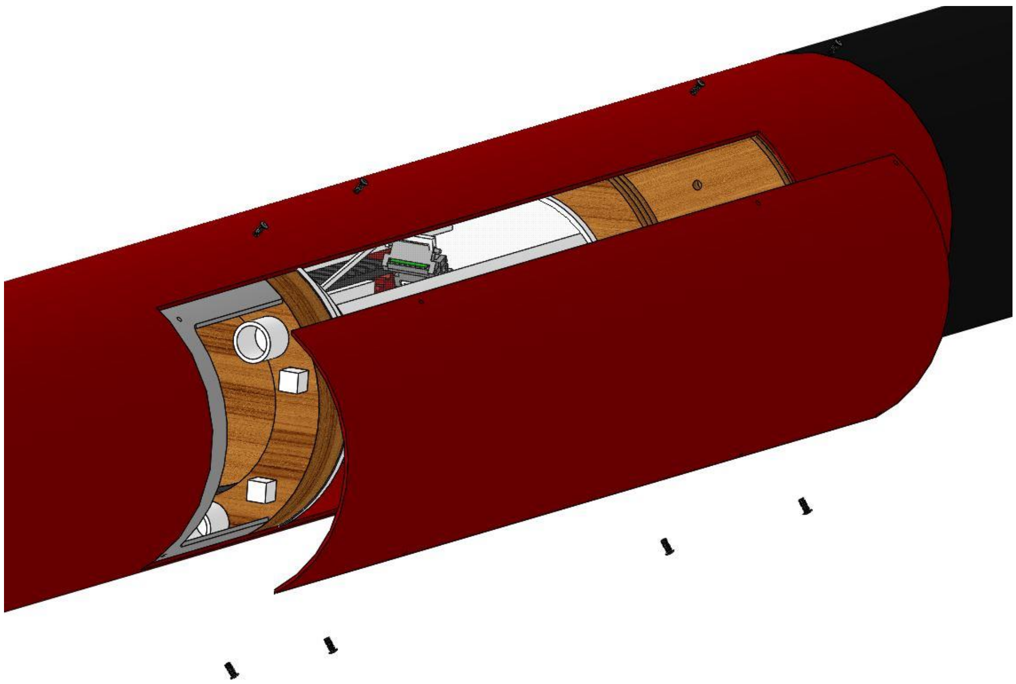

Figure 3-13: Exploded View of Midsection Access Hatch with Screw Placement

The access hatch has a single 0.25 in. hole drilled through the wall to act as a pressure sampling port for the altimeters in the avionics bay. The hatch does not create a seal with the rocket except for the main parachute compartment, where the overlapping coupler and plumber's putty are used to create a seal. After several black powder ejection tests, the hatch has proven itself to be reliable in keeping an airtight seal in the main parachute compartment.

3.4.4.9 Midsection Fabrication

The midsection was cut to a length of 48 in. using a band saw. The access hatch was cut out using a hand Dremel tool and cutting wheel. Marks were made on the midsection 6.25 in. from the aft end and 13 in. from the forward end of the midsection. A paper template was used to mark the hatch boundaries. Figure 3-14 shows the midsection marked for cutting the access hatch.

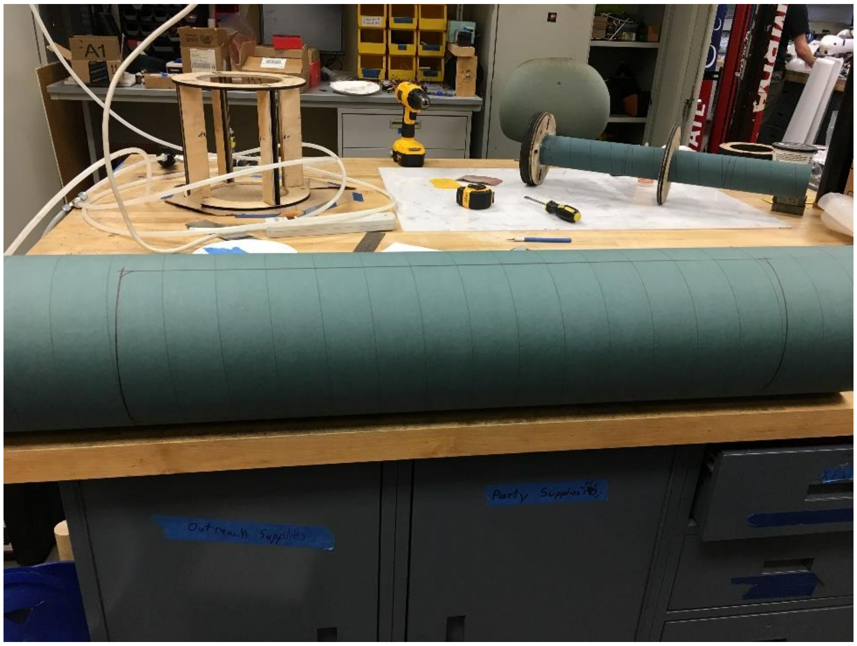

Figure 3-14: Access Hatch Outline

The aft avionics bay bulkhead was installed first. The assembled avionics sled was installed to the aft avionics bay bulkhead to guarantee proper spacing between the avionics bay bulkhead and the aft payload bay bulkhead. A 12 in. coupler was epoxied adjacent to the aft end of avionics bay bulkhead. The avionics bay without the sled can be seen in Figure 3-15 below.

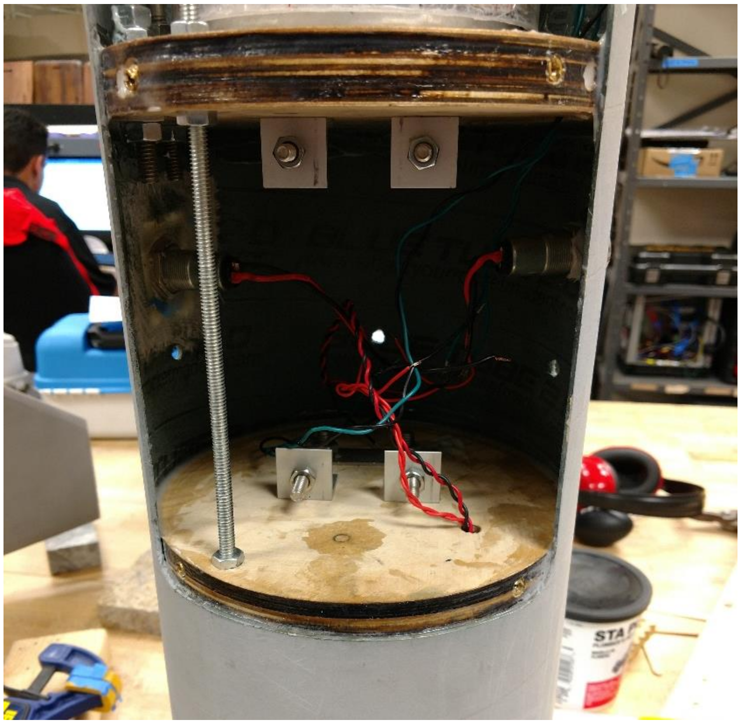

Figure 3-15: Avionics Bay

The entire payload assembly was installed as one unit with the forward payload bay centering ring to ensure the Lazy Susan bearings were properly spaced. The epoxy was allowed 24 hours to cure after each bulkhead installation.

A 12 in. coupler was epoxied inside the midsection directly forward of, and adjacent to, the payload centering ring. A 0.5 in. shoulder was cut from the coupler around the interior boundary of the access hatch. A drill press and 19/64 in. drill bit were used to drill radially into the bulkheads at the access hatch mount locations. For each of the holes, a #6-32 nut insert was threaded and epoxied into the bulkheads. The forward payload centering ring, nut inserts, and access hatch can be seen in Figure 3-16 below.

Figure 3-16: Forward Payload Centering Ring and Hatch Coupler

The hatch was then secured to the midsection using 0.5 in. #6-32 bolts. The bolts and nut inserts can be seen below in Figure 3-17.

Figure 3-17: Nut Insert with #6-32 Bolt

Using a drill press and a step bit, 2 13/16 in. holes were drilled into the body tube at the center of the avionics bay to house the radial switches. The switches were pressed into their respective holes and epoxied into place.

The exterior surface of the Blue Tube had a spiral ridge caused by the filament-wound construction technique. Wood filler was applied to this ridge then sanded smooth using 220 grit sandpaper, then successively finer sandpaper up to 2000 grit. The exterior surface was cleaned thoroughly with mineral spirits prior to receiving 3 coats of Rustoleum Automotive Primer.

3.4.5 Fin Can Design and Fabrication

The fin can on the full-scale launch vehicle is 40.0 in. long and contains the drogue parachute compartment, motor, and mounted fins. As described in Section 4.2, the drogue parachute compartment contains two parachutes: the drogue parachute for deployment at apogee, and the Low-Altitude Recovery Device (LARD) for deployment at 1,000 ft AGL. A 12 in. coupler will encompass the entire length of the inner wall of the drogue parachute compartment, as described in Section 3.4.4.5. The coupler was epoxied such that a 6.0 in. shoulder extends out of the top of the fin can for insertion into the midsection during assembly. The fin can is secured to the midsection during final assembly using multiple shear pins, described in Section 4.3.6. Figure 3-18, below, shows the fin can with all components labelled.

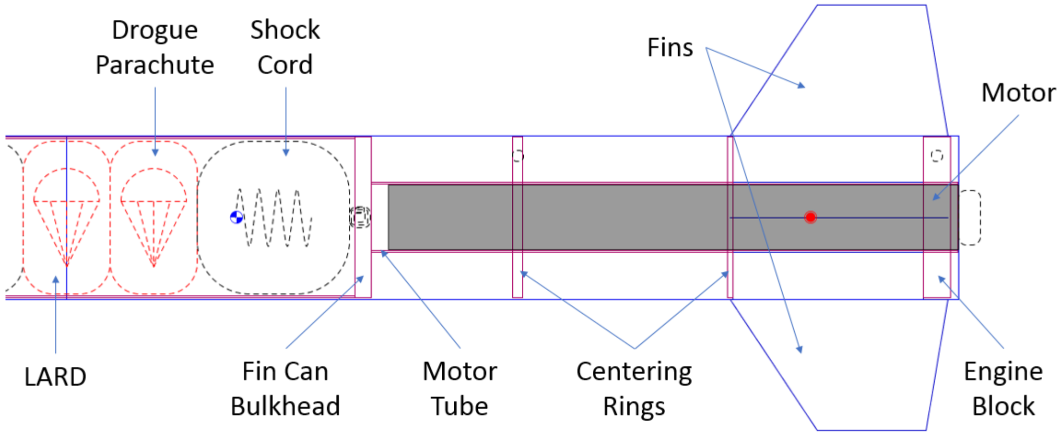

Figure 3-18: Fin Can with Component Labels

As shown in Figure 3-18, above, the fin can has four fins attached through slots cut in the body tube and secured using epoxy fillets at their intersection lines with the body tube.

3.4.5.1 Fin Can Bulkhead Design

The fin can bulkhead separates the drogue parachute compartment and the motor bay, which contains the motor tube, centering rings, and motor. The forward face of the bulkhead was fixed 13.25 in. from the upper end of the fin can to act as the aft end of the drogue parachute compartment. After using digital calipers to accurately measure and confirm the body tube dimensions, the plywood sheets were cut out using a laser cutter. West Systems 2 part epoxy was used to combine the sheets, which were allowed to cure for at least 24 hours under a vacuum seal.

A U-bolt was installed through the center of the bulkhead as the aft attachment point for the drogue parachute shock cord. This allows the fin can to remain tethered to the midsection during rocket recovery. The U-bolt shown in Figure 3-19, below, was permanently fixed to the bulkhead during fabrication using Loctite to secure the fastening nuts on the opposite side of the bulkhead.

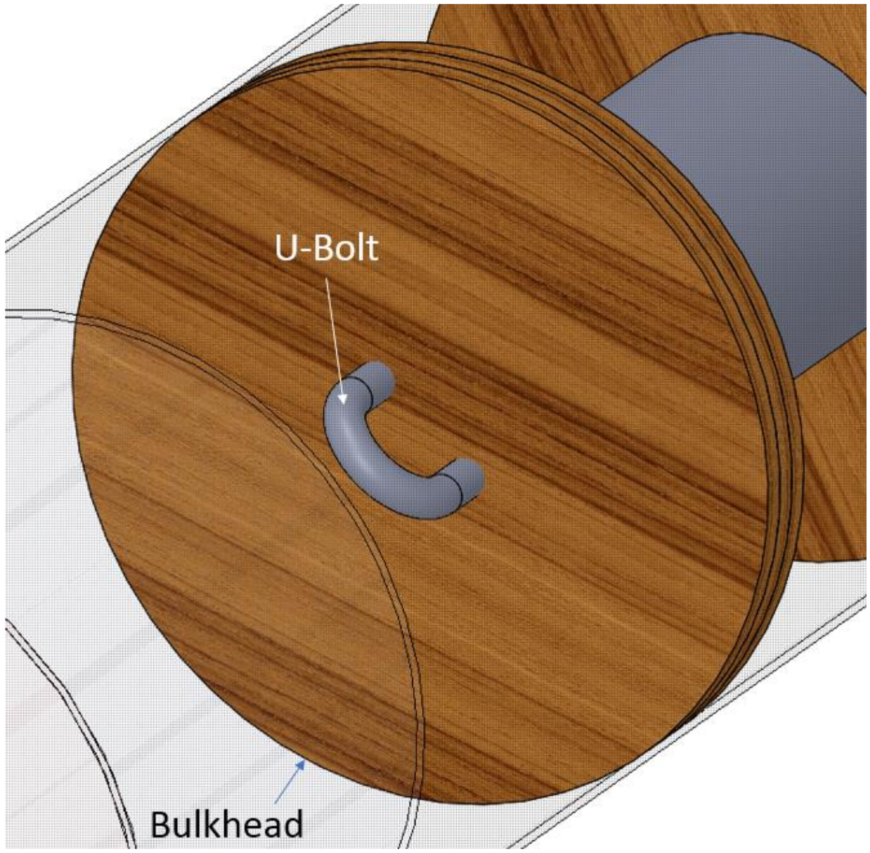

Figure 3-19: Fin Can Bulkhead

3.4.5.2 Centering Ring Design

The motor tube has two attached centering rings to secure the motor from within the fin can. The forward centering ring consists of two rings cut out of 0.25 in. aircraft-grade birch plywood sandwiched together using epoxy for a total thickness of 0.5 in. The aft centering ring consists of a single ring cut out of 0.25 in. aircraft-grade birch plywood. The outer diameter of each ring matches the inner diameter of the fin can body tube described in Section 3.4.1. The inner diameter of each ring matches the outer diameter of the motor tube described in Section 3.4.5.3. After using digital calipers to accurately measure and confirm the body tube dimensions, the plywood rings were cut out using a laser cutter. West Systems 2 part epoxy was used to combine the upper centering rings, which were allowed to cure for at least 24 hours under a vacuum seal. Figure 3-20, below, shows the dimensions for the centering rings with respect to the fin can bulkhead and engine block.

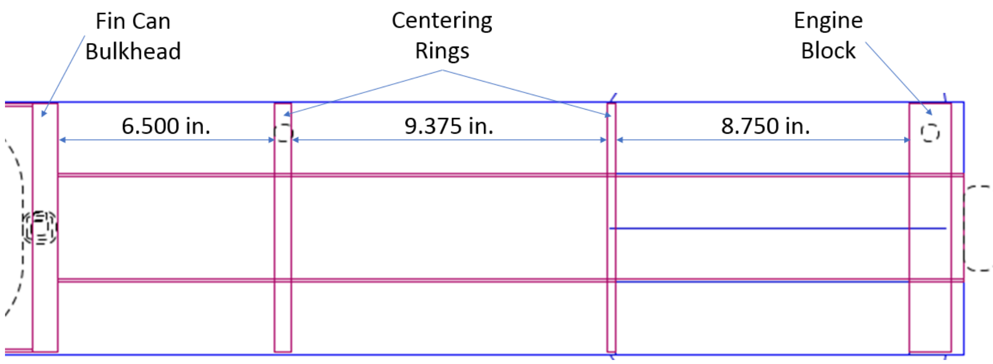

Figure 3-20: Location of Centering Rings Along Motor Tube

The forward centering ring was installed as the uppermost support for the motor tube, since the motor tube itself was not fixed to the fin can bulkhead.

To ensure the proper alignment of the fins during fabrication, the aft centering ring and top layer of the engine block have rectangular cutouts that match notches on the fin tabs in the same location. The fin tab notches fit into the centering ring holes to ensure their proper spacing and orientation along the motor tube. Figure 3-21, below, shows a centering ring layer with rectangular cutouts for the fin tab notches.

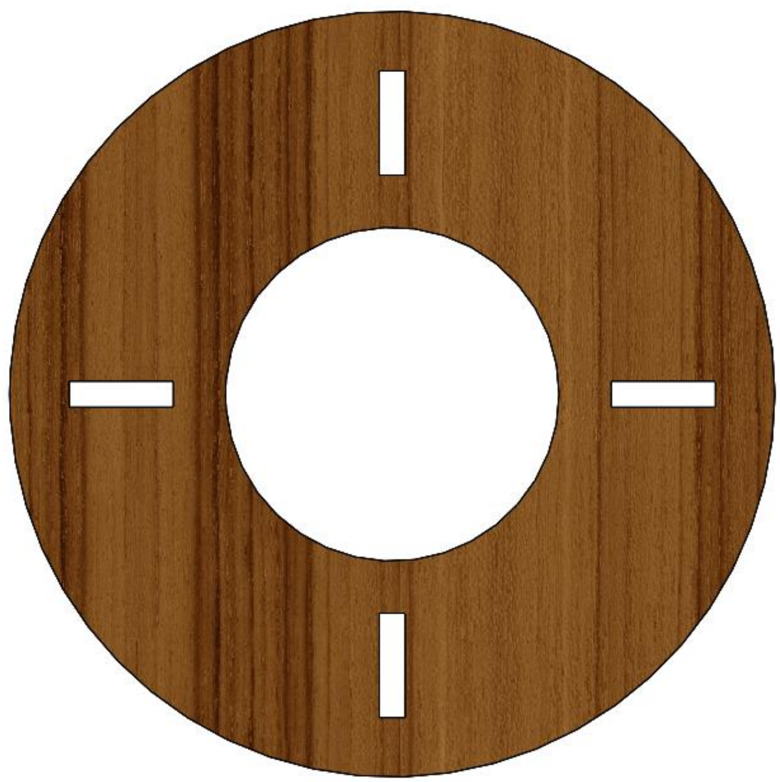

Figure 3-21: Motor Tube Centering Ring with Cutouts for Fin Tab Notches

3.4.5.3 Motor Tube Design

The motor tube is designed to transfer the loading from the rocket motor retainer to the body tube via centering rings and an engine block. The motor retainer was fixed to the aft end of the motor tube, and the inner diameter exactly matches the outer diameter of the motor casing. This allows the motor casing to slide into the tube and be secured using the retainer which acts as the single point of contact between the motor casing and the rest of the rocket. The motor tube is one of the most critical components installed on the rocket, and much caution was used when handling, installing, and securing the motor tube during fabrication.

The motor tube has a length of 27.0 in., which is 0.8 in. longer than the motor casing to ensure that the motor casing fit vertically in the fin can with room to spare. The bottom surface of the motor tube is level with the bottom of the fin can body tube, and extends out from the engine block by 0.375 in.

The motor tube was attached by epoxy to both centering rings, the engine block, and four fin tabs. The designs for the centering rings, engine block, and fins are detailed in Sections 3.4.5.2, 3.4.5.4, and 3.4.5.5, respectively. The entire motor tube and fin assembly were fabricated outside of the body tube and left to cure over 24 hours. Figure 3-22, below, shows each of the epoxy areas along the length of the motor tube, with motor removed for clarity, as green regions.

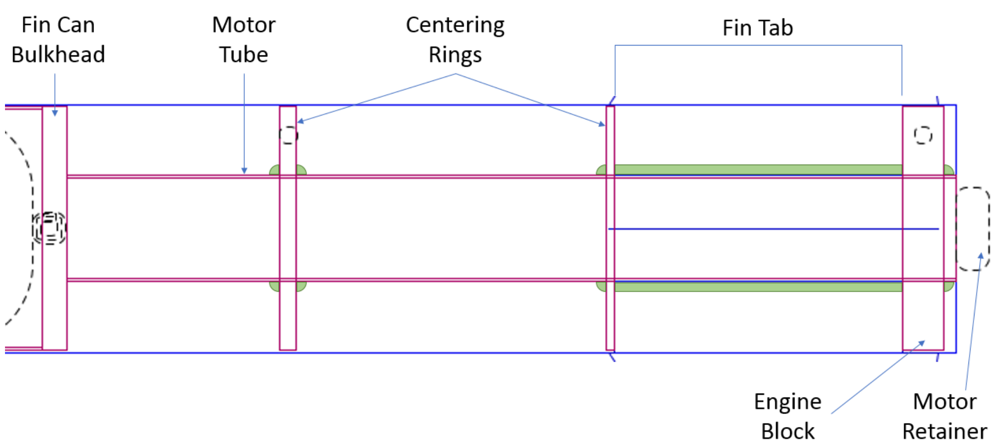

Figure 3-22: Motor Tube with Epoxy Areas Highlighted

3.4.5.4 Engine Block Design

The engine block is designed to withstand the largest expected forces from the motor during flight, and transfers loads directly from the motor retainer to the outer body tube. The engine block consists of five rings cut out of 0.25 in. aircraft-grade birch plywood sandwiched together using epoxy for a total thickness of 1.25 in. The outer diameter of each ring matches the inner diameter of the fin can body tube described in Section 3.4.5. The inner diameter of each ring matches the outer diameter of the motor tube described in Section 3.4.5.3. After using digital calipers to accurately measure and confirm the body tube dimensions, the plywood rings were cut out using a laser cutter. West Systems 2 part epoxy will be used to combine the upper centering rings, which will then be allowed to cure for at least 24 hours under a vacuum seal.

The engine block was the first component epoxied to the motor tube during assembly. The engine block lower face is recessed into the fin can body tube by 0.125 in. to allow the motor tube to extend past the engine block and remain level with the bottom of the fin can. A flanged motor retainer was installed over the motor tube and was fixed to the engine block face by special wood screws. The dimensions of the retainer, including the necessary recess between the engine block and bottom of the fin can, were provided by the manufacturer, AeroPack. Figure 3-23, below, shows the engine block with motor retainer fixed in place after fabrication.

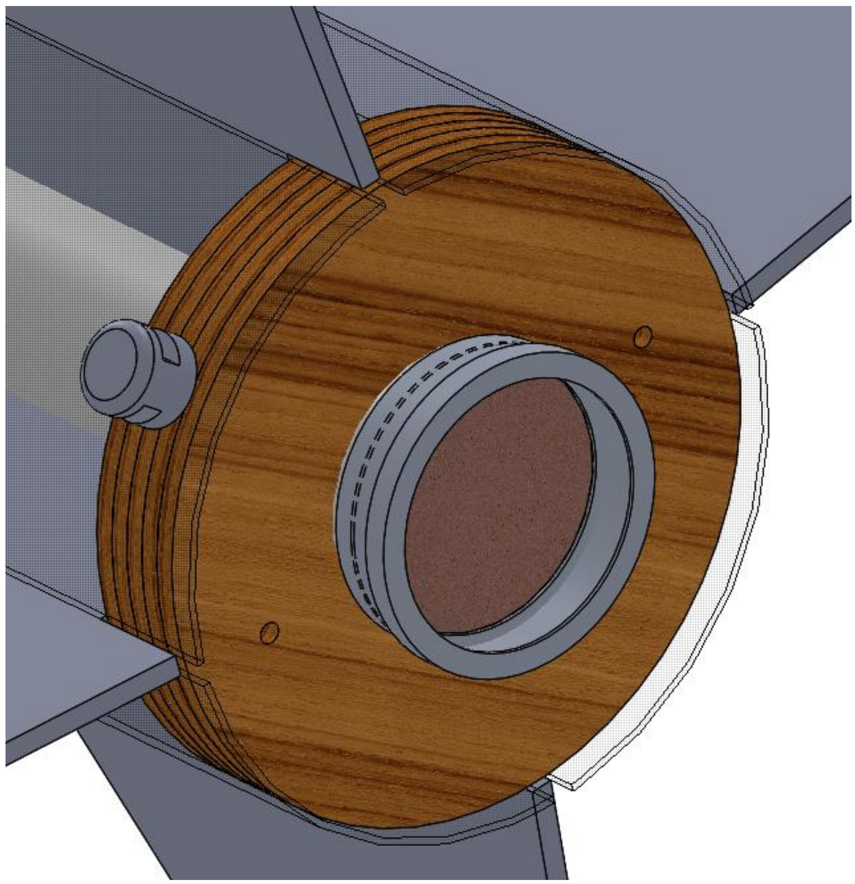

Figure 3-23: Engine Block and Motor Retainer

Once the motor retainer was installed on the engine block, the motor casing was able to slide into the motor tube during assembly. A retainer cap was then screwed on to secure the motor within the motor tube immediately prior to launch.

3.4.5.5 Fin Design and Mounting

The rocket fins are critical to controlling the rocket stability during ascent, but require precise fabrication to limit any errors in manufacturing and installation. The surface area, cross-sectional shape, and location of the fins control the location of the CP along the length of the rocket, which is described in Section 5.2.1. The greatest effect on CP can be observed when the fins are installed at the aft-most end of the rocket, which also increases the stability margin by pushing the CP closer to the tail if the CG remains unchanged. There are numerous sources of conflicting information regarding fin shapes and sizing available in books and online, so the team relied on advice from mentors and results from OpenRocket flight simulations to design the fins.

Alan Whitmore, one of the team mentors identified in Section 1.1.2, offered the following advice to the team when asked about fin sizing:

1. Straight lines are easier to design, cut, and install than curved lines.
2. Any part of a fin that extends beyond the bottom of the body tube will be more likely to break off at impact, thus eliminating rocket reusability.
3. The most durable fins have forward swept trailing edges with the rear of the root chord starting some small distance from the bottom of the body tube.
4. Fins with a span that exceeds the root chord length will be more subject to the negative effects of fin flutter during flight.
5. Fins with a span less than half of the root chord length generally do not perform very well during flight.
6. The most common fin design for high-powered rockets is the clipped delta.

Applying the above advice, the launch vehicle fins are trapezoidal, each with a root chord of 10.0 in., a tip chord of 5.0 in., and a span of 6.0 in. The leading edge of each fin is swept back by 2/3, or 2.0 in. of sweep for every 3.0 in. along the span, to increase high-speed aerodynamic performance. The trailing edge of each fin is swept forward by a slope of 1/6, or 1.0 in. for every 6.0 in. along the span, to increase the impact durability, and thus reusability, of the rocket. The rocket features four identical fins installed at 90° increments around the circumference of the fin can. Figure 3-24, below, shows the dimensions of each fin as well as dimensions for the fin tabs that were used to attach the fins to both the motor tube and fin can body tube.

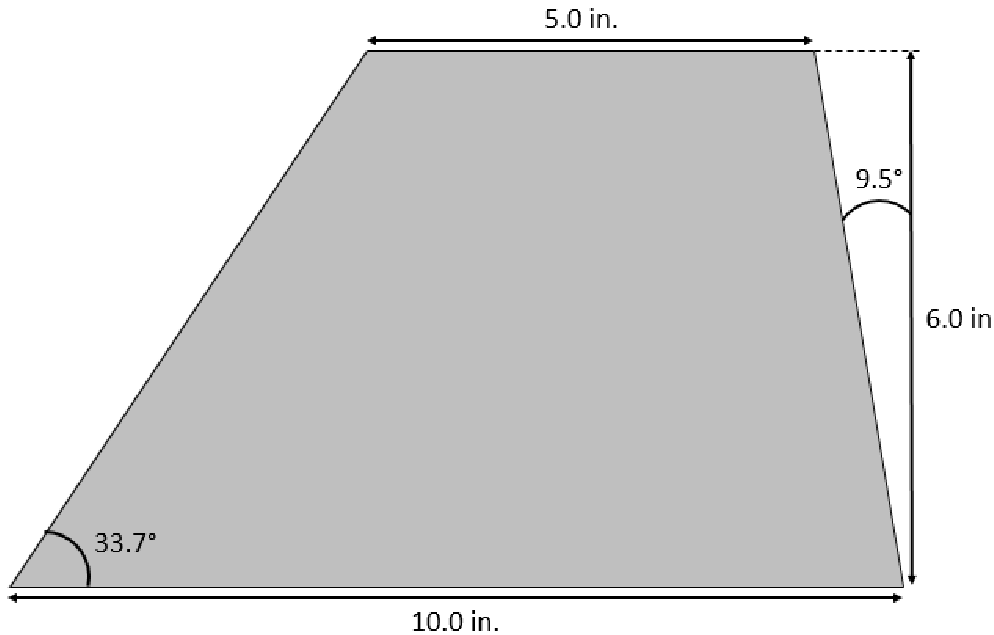

Figure 3-24: Fin Dimensions

Each fin was installed as described in Section 3.4.5.7, with fin tabs being used to better secure each fin to the rocket body tube as well as to aid in transferring the loads from the motor to the body tube. Each tab is 8.75 in. long to match the length between the lower face of the aft centering ring and the upper face of the engine block. The depth of the tabs will equal the length between the outer walls of the motor tube and body tube, approximately 2.25 in. Figure 3-25, below, shows all fin and fin tab dimensions.

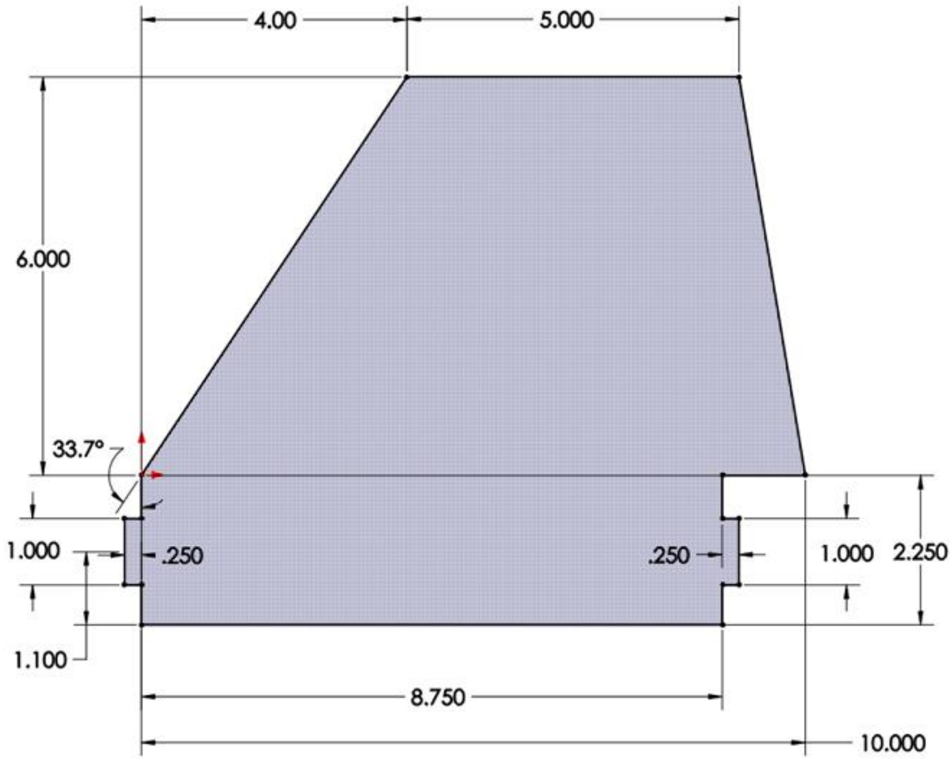

Figure 3-25: Fin Tab Dimensions

Each fin consists of two cutouts of 0.125 in. aircraft-grade birch plywood sandwiched together using epoxy for a total thickness of 0.25 in. Using two sheets reduces flutter during flight, and the simple manufacturing method allows for extra fins to easily be created in the event of failure. After using digital calipers to accurately measure and confirm the body tube and motor tube dimensions, the plywood fins were cut out using a laser cutter. West Systems 2 part epoxy was used to combine two cutouts for each fin, which were allowed to cure for at least 24 hours under a vacuum seal.

3.4.5.6 Launch Rail Buttons

Two rail buttons were installed on the exterior surface of the body tube to secure the full-scale launch vehicle on the vertical rail for launch. It is desirable to place rail buttons close to the tail of the rocket so that the rail can guide the vehicle in the vertical direction for as long as possible. It is also important that the rail buttons be installed at strong points in the rocket body as the entire weight of the rocket will be supported by the buttons while on the rail prior to launch.

The forward rail button was installed at the forward motor tube centering ring, and the aft rail button was installed at the engine block. The rail buttons were installed after allowing 24 hours for all epoxied elements in the motor tube to cure. To install each rail button, a pilot hole was drilled through the body tube and ring. The rail buttons were screwed in through the pilot holes using the manufacturer-recommended screws. The rail buttons were installed on the opposite side of the rocket as the access hatch, described in Section 3.4.4.8, to ensure that the team could access all flight-critical components even while the rocket was resting on the launch rail prior to launch.

3.4.5.7 Fin Fabrication

The fins were constructed out of two sheets of 0.125 in. aircraft-grade birch plywood epoxied together using West Systems 105 epoxy and West Systems 206 Slow Hardener. The outline of the fins was cut from sheets of plywood using a laser cutter. The sheets were epoxied together and held under vacuum for 24 hours to allow the epoxy to fully cure. Figure 3-26 below shows the fins curing under vacuum.

Figure 3-26: Fin Curing Process

To increase aerodynamic performance, the exterior edges of the fins were sanded to a rounded bevel using a belt sander and angle guides.

3.4.5.8 Fin Can Fabrication

The fin can body tube section was cut to a length of 41 in. using a band saw. The fin slots were laser cut by the supplier, Always Ready Rocketry. Small cuts were made from the aft end of the fin slots to the bottom of the tube to allow the body tube to slide on the fin and motor mount assembly. The engine block was epoxied to the motor tube and left to cure for 24 hours. This subassembly can be seen below in Figure 3-27.

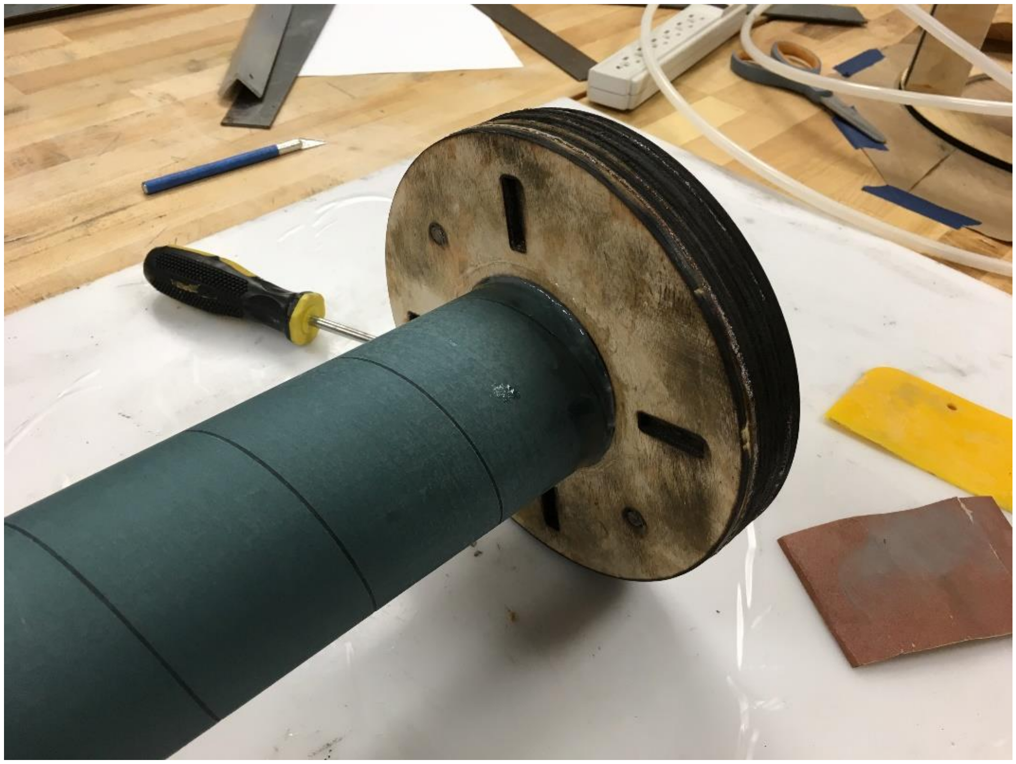

Figure 3-27: Motor Tube and Engine Block

The fins were aligned around the motor tube using the aft centering ring and engine block. Epoxy fillets were added between the fins, motor mount, and centering ring. The fin can body tube slid over this assembly while the epoxy was still wet. An external rig slid over the body tube and fully constrained the fins in place. Fillets were then added to the fins and body tube, and the motor mount and body tube. This whole assembly was left to cure for 24 hours. Figure 3-28 shows the applied fillets to the fins.

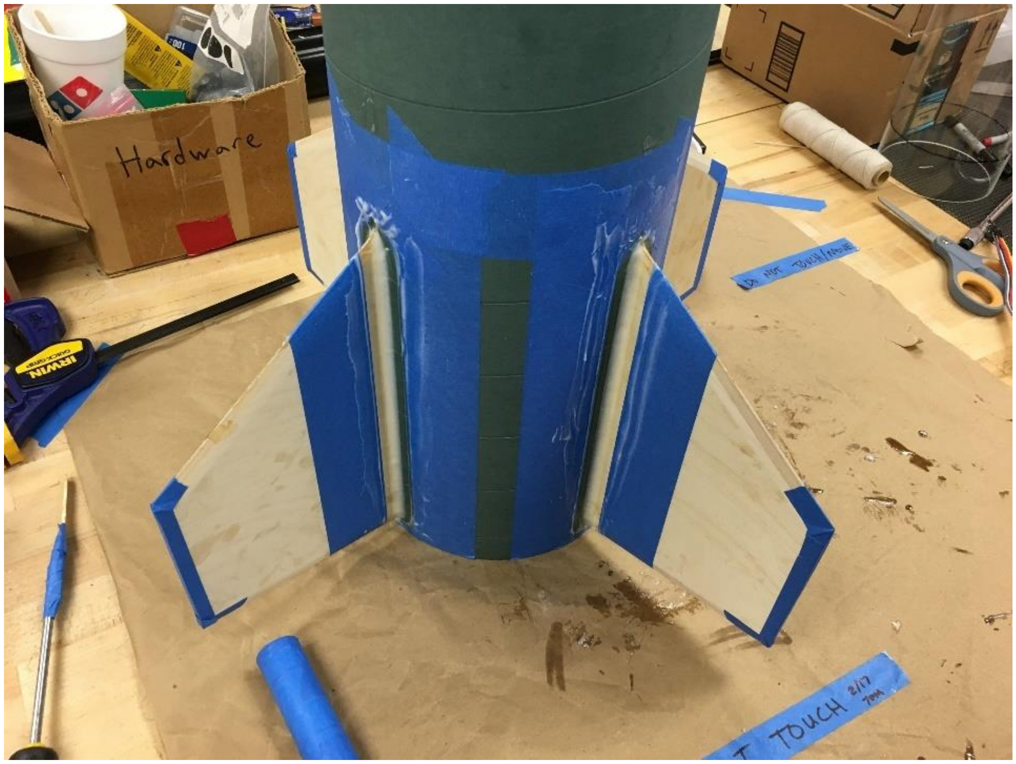

Figure 3-28: Epoxy Fillets on Fins

A drill press and 3/32 drill bit were used to drill radially into the bulkheads at the rail button locations to create pilot holes. 1 in. wood screws were used to secure the rail buttons to the fin can.

3.5 Flight Reliability Confidence

After completing fabrication, analyzing the results of simulated loading, and by recovering the full-scale rocket after its test launch, the team is confident that the full-scale rocket will be ready to launch at the competition.

3.5.1 Launch Vehicle Pre-Fabrication Testing

This section contains analysis of the tests performed by the team to validate the design of the full-scale launch vehicle prior to fabrication and launch

3.5.1.1 Blue Tube Buckling Testing and Analysis

Buckling tests were conducted on sections of 5.5 in. outer diameter Blue Tube. A hydraulic press was used to axially load the Blue Tube until buckling occurred. A Helm load cell coupled with LabView Data Acquisition was used to record vertical load and stroke of the hydraulic press. The load cell used in testing is shown below in Figure 3-29.

Figure 3-29: Helm Load Cell Used during Testing

Figure 3-30 below shows the resultant loading profile from a 5 in. long section of Blue Tube.

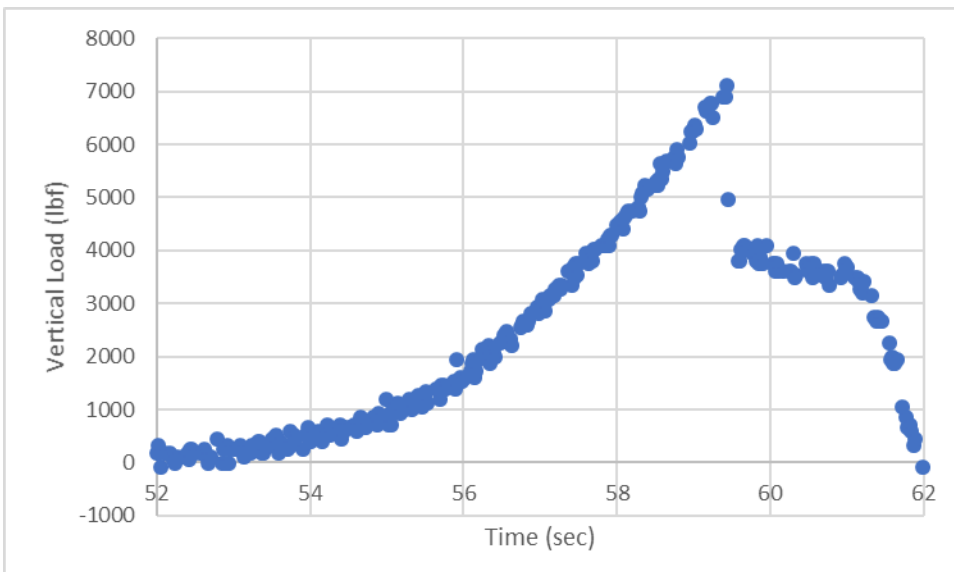

Figure 3-30: Blue Tube Loading Profile

Buckling occurred at a peak force P_{crit} of 6770 lb and total deformation of 0.023 in. The buckled test specimen is shown below in Figure 3-31.

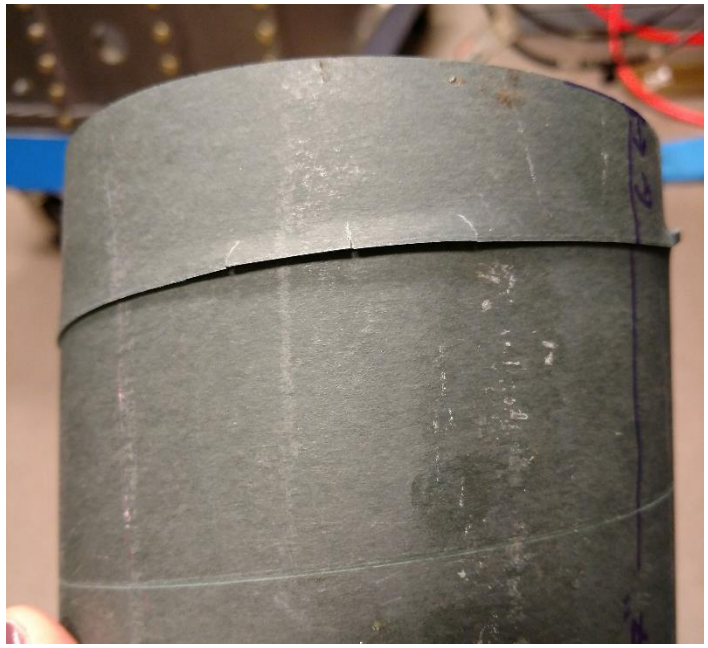

Figure 3-31: Buckled Blue Tube

As expected, the Blue Tube failed along the seam formed by the filament winding construction process. This section of Blue Tube had a wall thickness of 0.07 in. and cross-sectional area of 1.19 square in. The resulting peak stress value was determined to be 5670 psi. This test was replicated in Ansys to ensure accurate material properties for Blue Tube were used in subsequent analyses. The results of this analysis are shown below in Figure 3-32.

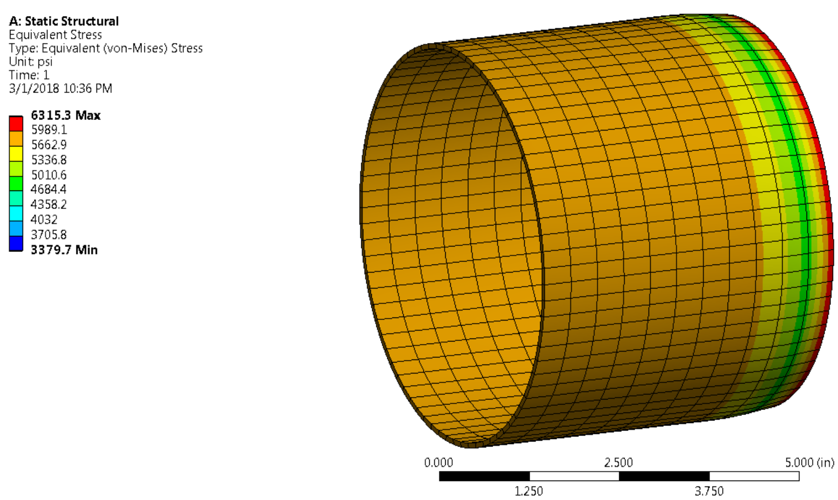

Figure 3-32: Ansys Verification of Blue Tube Buckling

Although the Blue Tube was modeled as an isotropic material, the peak stress and deformation values match very closely to those in the buckling test. The material values used in this analysis were used for all subsequent Blue Tube analyses.

3.5.1.2 Midsection Access Hatch Loading

The midsection with the revised hatch design was tested for safety under a peak compressive load of 699 lb. All bulkheads, couplers, and holes were included in the analysis to be as representative of the actual full-scale launch vehicle as possible. The equivalent stresses experienced on the midsection are shown below in Figure 3-33.

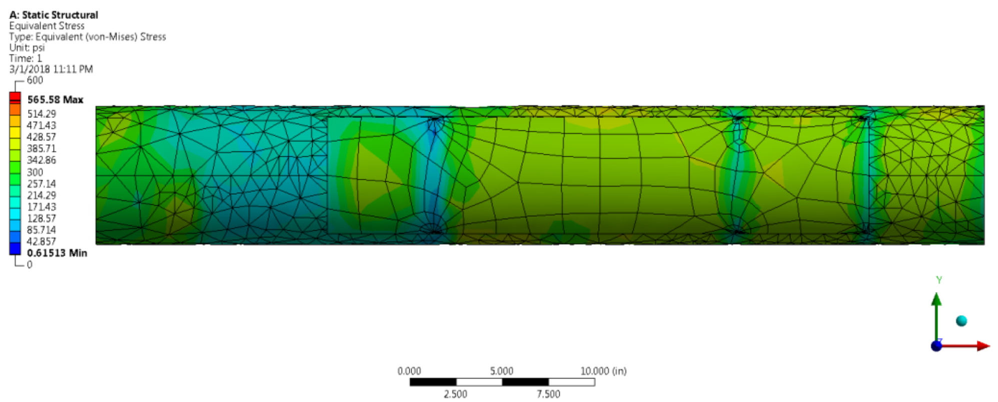

Figure 3-33: Ansys Verification of Midsection Access Hatch during Flight

The peak stress experienced by midsection under this loading is 565 psi. With a critical stress value of 5,670 psi, as determined from the buckling test, the Factor of Safety was determined to be 10.0 for the Blue Tube components in the midsection.

3.5.1.3 Launch Loading on Fin Can

The fin can and motor mount were assessed in Ansys using launch conditions as described in Section 5.1.2. Figure 3-34 below shows the equivalent stress experienced on the Fin Can during launch.

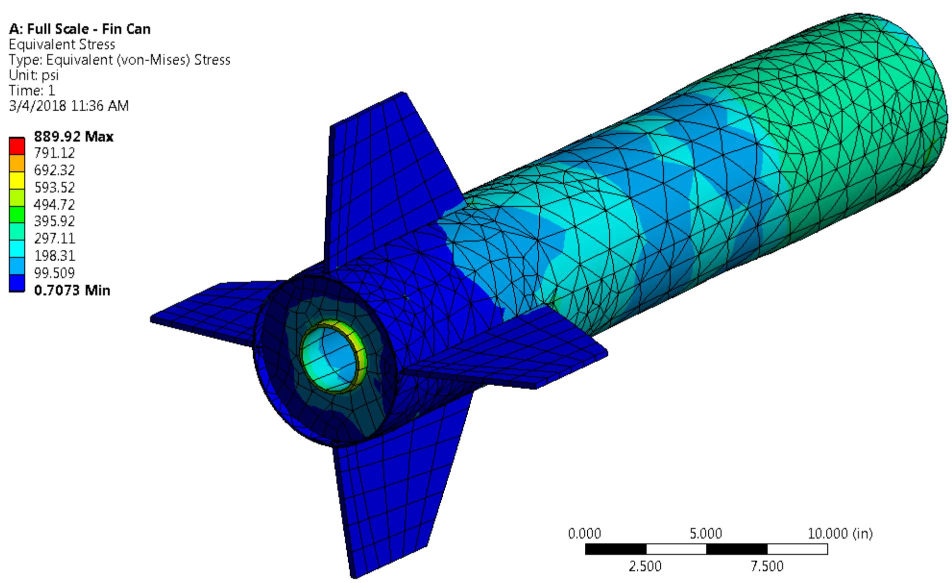

Figure 3-34: Ansys Verification of Fin Can Loading during Launch

A peak stress value of 890 psi is experienced in the motor mount. The ultimate tensile strength of aircraft-grade Baltic birch plywood was assumed to be 4000 psi, which grants a safety factor greater than 4.

3.5.1.4 LARD Deployment Analysis on Fin Can

The fin can bulkhead with U-bolt that attaches to the LARD and drogue parachute shock chord was analyzed for the peak opening force of the LARD. From OpenRocket simulations, it was determined that the peak force during this event was 709 lb. The opening force was analyzed as a point force acting on the fin can bulkhead. Figure below shows the Safety Factor of the fin can during this event.

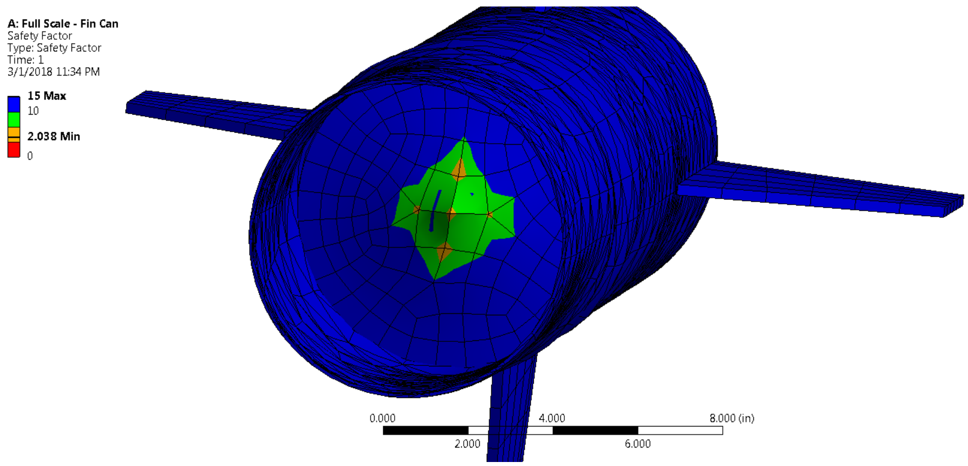

Figure 3-35: Ansys Verification of LARD Deployment on Fin Can Bulkhead

The Factor of Safety of the bulkhead was determined to 2.0 – which is above the mandated 1.5. The LARD opening force was also used to determine compliance of the epoxy bond holding the bulkhead in place. West Systems 105 Epoxy and 206 Slow Hardener were used to bond the bulkhead to the body tube. The ultimate tensile strength of this epoxy is 7320 psi, as provided by the supplier. A minimum Safety Factor of 1.5 mandates that the peak allowable stress experienced by the epoxy is 4880 psi. 0.25 in. epoxy fillets hold the fin can bulkhead in place. With an inner diameter of 7.34 in., the bonding area was determined to be 5.765 square in. Using the peak opening force of 709 lb the peak stress experienced in the bond was determined to be 123 psi., which is well below the maximum allowed stress of 4880 psi.

4. Launch Vehicle Recovery Systems

4.1 Compliance to Handbook Requirements

Table 4-1, below, contains the launch vehicle recovery system requirements listed in the 2018 NASA SL handbook as well as the respective compliance actions, verification methods, and status.

Table 4-1: Full-Scale Launch Vehicle Recovery System Handbook Item Compliance

Handbook Item	Description of Requirement	Compliance	Verification Method	Verification Description	Report Section Location
3.1	The launch vehicle will stage the deployment of its recovery devices, where a drogue parachute is deployed at apogee and a main parachute is deployed at a lower altitude. Tumble or streamer recovery from apogee to main parachute deployment is also permissible, provided that kinetic energy during drogue-stage descent is reasonable, as deemed by the RSO.	The launch vehicle uses a dual deploy recovery system which utilizes a drogue parachute at apogee and a main parachute at 500 ft AGL. An additional parachute, the LARD, deploys at approximately 700 ft AGL to further reduce the descent velocity.	Demonstration. The team will use the dual deploy recovery system at the full-scale test launch. The team will demonstrate successful deployment of all parachutes at their designated altitudes.	Incomplete. The drogue and main parachutes successfully deployed at apogee and 500 ft AGL, respectively. Though the LARD was released at its target altitude, it failed to inflate before main parachute deployment. The team will include the LARD on the re-flight scheduled for March 24, 2018.	Section 6.5
3.2	Each team must perform a successful ground ejection test for both the drogue and main parachutes. This must be done prior to the initial subscale and full-scale launches.	The team used multiple ground ejection tests to determine that both fin can and nosecone separation events require 4.0 g to be successful. The full-scale rocket will contain redundant charges of 4.5 g for each separation event.	Test. The team will conduct ground ejection tests prior to the subscale and full-scale test launches. The charge size and location will not change after testing is complete.	Incomplete. The team performed ground ejection tests prior to the full-scale test launch to determine that both fin can and nosecone separation events require 4.0 g of black powder. The team will perform additional ground ejection tests prior to the full-scale re-flight scheduled for March 24, 2018.	Section 4.3.6
3.3	At landing, each independent sections of the launch vehicle will have a maximum kinetic energy of 75 ft-lb$_f$.	The launch vehicle separates into three independent, tethered sections during descent. The nosecone, midsection, and fin can kinetic energy at impact are to be 21.10 ft-lb, 46.04 ft-lb, and 46.99 ft-lb, respectively.	Analysis. The team will use simulations and hand calculations to confirm that each section of the rocket will impact with less than 75 ft-lb of kinetic energy.	Complete. The hand calculations of kinetic energy at landing show that the nosecone, midsection, and fin can kinetic energy at landing will be 21.10 ft-lb, 46.04 ft-lb, and 46.99 ft-lb, respectively.	Section 5.3.2
3.4	The recovery system electrical circuits will be completely independent of any payload electrical circuits.	The avionics bay is separated by thick bulkheads on either side to ensure that there is no interaction between flight-critical electronics and the onboard payload.	Analysis. The payload and avionics bay will be designed independently of each other and strict electrical schematics will be used to ensure that there is no interaction between components.	Complete. The recovery electronics were designed and installed to be completely independent from other electronics onboard the launch vehicle.	Section 4.4.7
3.5	All recovery electronics will be powered by commercially available batteries.	Only fresh, tested 9 V batteries will be used for each launch.	Demonstration. The team will only use unused, tested 9 V batteries for each launch.	Complete. The team used fresh, tested batteries for the full-scale test launch. The team has a pack of fresh, tested batteries available for all future launches.	Section 4.4.5

3.6	The recovery system will contain redundant, commercially available altimeters. The term "altimeters" includes both simple altimeters and more sophisticated flight computers.	The dual deploy recovery system relies on two commercially-available altimeters for parachute deployment and altitude confirmation. The StrattoLoggerCF is primary and the Entacore is redundant.	Analysis. The team will design the rocket electrical system to utilize two altimeters: one StratoLoggerCF and one Entacore. These altimeters will be completely independent of each other to increase redundancy and reliability. Strict electrical schematics will be used when wiring altimeters.	Complete. Electrical schematics of the as-built electronic recovery system show that the team uses one StratoLoggerCF and one Entacore AIM USB 4.0. Both are independently powered, independently armed, and trigger a drogue and a main ejection.	Section 4.4.3
3.7	Motor ejection is not a permissible form of primary or secondary deployment.	Parachute deployment will only occur as a result of altimeter-controlled black powder charge detonation.	Analysis. The team will not rely on a motor ejection charge to deploy parachutes.	Complete. Electrical schematics of the as-built electronic recovery system show that every separation event is triggered by a commercially bought altimeter.	Section 4.2
3.8	Removable shear pins will be used for both the main parachute compartment and the drogue parachute compartment.	During full-scale rocket assembly, Nylon shear pins are used to assemble the rocket sections together for launch. Ground ejection tests have confirmed that the Nylon pins will shear at each separation event.	Demonstration. The team will use Nylon shear pins to secure parachute compartments for launch. The team will also demonstrate that the shear pins will shear at each separation event.	Complete. Four 4-40 Nylon shears were used to secure the two parachute compartments during ground ejection tests and the full-scale test launch.	Section 4.3.6
3.9	Recovery area will be limited to a 2,500 ft. radius from the launch pads.	Hand calculations show that the rocket will drift a maximum of 2,411.6 ft from the launchpad in steady 20 mph winds.	Analysis. The team will use simulations and hand calculations to confirm that lateral drift is within allowable limits for launch.	Complete. Hand calculations and OpenRocket simulations both show that the full-scale rocket will not drift beyond 2,500 ft.	Section 5.3.1
3.10	An electronic tracking device will be installed in the launch vehicle and will transmit the position of the tethered vehicle or any independent section to a ground receiver.	All rocket sections will remain tethered during descent and recovery. A BigRedBee BRB 900 GPS unit will be housed in the payload bay to allow tracking from a ground receiver.	Demonstration. The team will include a GPS tracker in the rocket to allow for ground tracking after landing. This system will be used for the full-scale test launch.	Complete. The GPS transmitter successfully tracked and transmitted the rocket location during the full-scale test launch.	Section 6.5.1
3.10.1	Any rocket section, or payload component, which lands untethered to the launch vehicle, will also carry an active electronic tracking device.	The nosecone, midsection, and fin can will remain tethered together during the descent. The nosecone contains a GPS transmitter to track its location.	Demonstration. The team will include at least one active electronic tracking device in each untethered section of the rocket.	Complete. The full-scale rocket separated into three independent sections but remained tethered during the descent. The GPS transmitter tracked the entire full-scale test launch.	Section 6.5.1
3.10.2	The electronic tracking device will be fully functional during the official flight on launch day.	The full-scale rocket uses a BigRedBee BRB 900 GPS unit to track its location during flight and recovery.	Test. The team will test the GPS unit prior to launch and will bring backup components to each launch.	Complete. The team successfully tested a BRB900 GPS unit on campus, and successfully used the same device during the full-scale test launch.	Section 4.4.4.2
3.11	The recovery system electronics will not be adversely affected by any other on-board electronic devices during flight (from launch until landing).	The recovery system electronics are stowed in a separate avionics bay from all other onboard electronics. The recovery system is wired independently of other onboard electronics.	Analysis. The recovery system will be designed independently of all other onboard electronics and stowed in a separate compartment in the rocket.	Complete. The recovery system was designed so that the GPS tracker was separated from the altimeters by two different bulkheads. Both the altimeters and the GPS tracker functioned as expected during the test launch.	Section 6.5.1

3.11.1	The recovery system altimeters will be physically located in a separate compartment within the vehicle from any other radio frequency transmitting device and/or magnetic wave producing device.	The recovery system electronics are stowed in the avionics bay which is surrounded by bulkheads on either end.	Analysis. The rocket design will include a separate compartment for the recovery system electronics, labelled "avionics bay."	Complete. All recovery system altimeters are located in the avionics bay, the GPS tracker is located on the nose cone bulkhead, in the same compartment as the main parachute.	Section 4.4.3.3
3.11.2	The recovery system electronics will be shielded from all onboard transmitting devices, to avoid inadvertent excitation of the recovery system electronics.	The flight-critical electronics will be separated from the rest of the payload section by 0.75 in. thick bulkheads on either side of the avionics bay.	Demonstration. The team will confirm that the altimeters are not affected by payload electronics using ground tests and a full-scale launch prior to the competition launch.	Complete. Both the altimeters and the GPS transmitter where operational during the test launch, and both functioned as expected.	Section 4.4.2
3.11.3	The recovery system electronics will be shielded from all onboard devices which may generate magnetic waves (such as generators, solenoid valves, and Tesla coils) to avoid inadvertent excitation of the recovery system.	The rocket payload does not contain any magnetic wave generating devices.	Analysis. The team will not include any magnetic generating devices on the rocket.	Complete. The rocket does not contain any magnetic wave generating devices.	Section 7.4.5
3.11.4	The recovery system electronics will be shielded from any other onboard devices which may adversely affect the proper operation of the recovery system electronics.	The flight-critical electronics will be separated from the rest of the payload section by 0.75 in. thick bulkheads on either side of the avionics bay.	Demonstration. The team will confirm that the altimeters are not affected by payload electronics using ground tests and a full-scale launch prior to the competition launch.	Incomplete. The full-scale test flight did not contain all payload electronics on board. The team will continue testing the payload electronics to ensure there is no interaction with the recovery system electronics.	Section 4.4.2

4.2 Description of Recovery Events

Figure 4-1 below displays an overview of the recovery system for the full-scale rocket. The main components of the system are integrated to contribute to 2 successful separation events, releasing a total of 3 parachutes. The first separation deploys the drogue parachute at apogee as required, while releasing a contained recovery device still restricted using a Jolly Logic Chute Release (the Low Altitude Recovery Device – so named as to not be confused with a drogue or pilot chute). The second separation releases the main parachute.

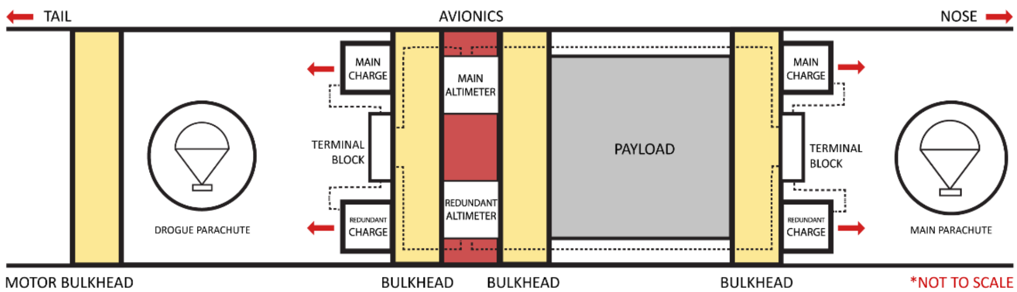

Figure 4-1: Recovery System Diagram

Successful recovery system performance begins in the avionics bay. The avionics bay houses two altimeters: the main altimeter and the redundant altimeter. The redundant altimeter is included for the event that the main altimeter fails.

At an apogee of 5,280 ft AGL, a signal is sent from the main altimeter to the terminal block in the drogue compartment. The terminal block relays the signal through an E-match to a small PVC cap housing enough black powder to complete the first separation, covered by 3M blue painters tape to secure the E-match within the cap. The calculations for the exact black powder charge sizes are in Section 4.3.6, and will be defended with ground ejection tests prior to launch. The transmitted signal will cause the first separation to occur, and the drogue parachute will release. One second later the redundant altimeter will send a signal through the terminal block in the drogue compartment to an E-match inserted into a second, equivalent black-powder charge. This event releases the drogue parachute should there be an interruption or failure in the main system charge.

The addition of the Low Altitude Recovery Device (LARD) is intended to reduce the instantaneous deceleration felt throughout the rocket when the main parachute is deployed. To reduce drift, the drogue parachute size was reduced. Without the LARD, the main would deploy at a descent velocity of approximately 70 ft/s, defended later with OpenRocket simulations. The main deployment would cause the payload to suddenly jolt 180 degrees which may dislodge the delicate rover components in the payload bay. The LARD is a larger parachute to be deployed prior to the main parachute, slowing down the vehicle to a descent of 28.4 ft/s and will allow for the main to deploy and the rover to remain secured in the payload with no significant forces. At this point, the first separation of the recovery system is complete.

The second step of the recovery system is a successful second separation and release of the main parachute. For the full-scale launch vehicle, the second separation occurs at 500 ft AGL.

At 500 ft AGL, the main altimeter sends an electrical signal through the payload bay, to the terminal block in the compartment housing the main parachute. The signal transmits from the terminal block through an E-match connected to a PVC cap filled with an appropriately sized black powder charge, secured with 3M blue painters tape. This charge will pressurize the main cavity and forcefully separate the nosecone from the midsection of the rocket. This event releases the main parachute deployment bag, which allows for more time between the unfurling of the shroud lines and the main parachute opening, thereby decreasing the impulse from the parachute opening. One second later, the redundant altimeter will send a signal through the terminal block to a second E-match connected to a second, identical PVC cap. The black powder calculations and results from ground ejection tests are included in Section 4.3.6.

4.3 Recovery System Hardware

A pre-reefed parachute was chosen for the main parachute. The Fruity Chutes Iris Ultra Compact parachutes employ reefing of the inner diameter shroud lines. Reefing these lines changes the shape of the parachute during descent. In changing the shape of the parachute, the coefficient of drag C_d is increased. The coefficient of drag for the un-reefed, elliptical parachute is 1.5, where the coefficient of drag of a reefed parachute with the same diameter is 2.2.

The focus of the drogue parachute was to find a small parachute to minimize wind drift. For this reason, an elliptical parachute with C_d of 1.5 was chosen.

The LARD will be a Fruity Chutes Iris Ultra Compact 60 in. parachute. The LARD will attach to the same shock cord line as the drogue and release during the drogue separation event, but will be retained by a Jolly Logic Chute Release until the desired deployment altitude.

4.3.1 Drogue Parachute

The drogue parachute is a Fruity Chutes Elliptical 18 in. parachute. The C_D of the parachute is 1.5, and the parachute is attached to a loop in the aft shock cord by a size 1 quick link (explanation in Section 4.3.5), where the quick link attaches to the I-bolt. The size of the drogue is chosen to decrease wind drift. The drogue deploys during the drogue separation at apogee. The drogue parachute is protected within the rocket by a Nomex cloth.

The drogue parachute will introduce drag at apogee during it's deployment; this is the point where vertical velocity is 0 ft/s. At apogee, after all of the motor propellant has burnt on ascent, all of the forces on the rocket are momentarily balanced. Though a large parachute deployed at apogee would promote a soft, safe landing and a recoverable, reusable rocket as listed in requirement 2.18 of the 2018 NASA SLI Handbook, the effect of deploying a large parachute at approximately 5280 ft AGL could result in a landing position outside of the recovery range. Wind drift restrictions are posted in requirement 3.9 of the 2018 NASA SLI Handbook, which limits landing distance from the launch pad to a 2500 ft radius.

For drogue sizing, the C_{d_d} will be 1.5 for an elliptical parachute. The following equation can be used to determine the equilibrium descent velocity for parachutes of specific surface areas:

$$C_{d_d} = \frac{2mg}{V_{ed}^2 S_0 \rho} \quad (4)$$

where m is the mass of the body falling beneath the parachute, which is the empty rocket weight of 38.2 lb or mass of 1.19 slugs, g is the coefficient of gravity 32.174 ft/s^2, V_{ed} is the terminal velocity of the falling mass with the drogue, S_0 is the surface area of the employed drogue, and ρ is the air density, .002377 slugs/ft^3. In order to determine the size of parachute needed, the team focused on minimizing drift, and therefore the team did not set a limiting bound or minimum descent velocity / terminal velocity limit for the weight falling beneath the drogue.

To minimize drift beneath the drogue parachute, a parachute size of 18 in. is selected. This size changed since the CDR, where a 24 in. parachute was going to be utilized, but due to the decrease in drift with the decrease of drogue size, a Fruity Chutes 18 in. elliptical chute was selected. The terminal velocity of the rocket beneath the drogue will be 113 ft/s. The descent velocity beneath the drogue is high, but section 4.3.2 explains the use of a LARD Parachute device as a primary recovery device and how its implementation will benefit the recovery system.

4.3.1.1 Descent Rate

OpenRocket simulations predict the descent rate of the falling rocket beneath the drogue to be 113 ft/s. The descent rate is high, but in order to reduce wind drift the drogue must be reduced.

4.3.2 LARD Parachute

The LARD parachute is a Fruity Chutes Iris Ultra Standard 60 in. parachute with a C_D. The LARD is utilized to reduce the amount of force transferred to the payload during main parachute ejection. The LARD is contained within a 4 in. deployment bag. The deployment bag is attached to the top loop of the LARD parachute with a size 1 quick link. The shroud lines of the LARD are Z-folded within the deployment bag loops. The flap of the deployment bag is folded over the shroud lines. In order to pull the parachute from the deployment bag, a pilot chute is attached to the top of the deployment bag second loop. The pilot chute is folded with its shroud lines inside. The pilot chute is laid on top of the deployment flap and a nomex cloth is wrapped around. The nomex cloth is attached to the same loop as the drogue chute in order to avoid tangling with the pilot shroud lines. Around this entire recovery set up, a Jolly Logic chute release is attached with two rubber bands connecting the key of the chute release. The chute release is turned on before storing within the rocket, and set to release the key at 900 ft AGL in order to allow for the LARD parachute to eject and inflate and effectively complete the objective.

4.3.2.1 Descent Rate

OpenRocket predicts the descent rate beneath the LARD to decrease to 27 ft/s. This is a drastic decrease in descent rate from the drogue descent rate and will prove effective for decreasing wind drift as well as absorbing some of the shock of the main parachute inflation.

4.3.3 Main Parachute

The main parachute is a Fruity Chutes Iris Ultra Standard 120 in. parachute with a C_D of 2.2. The main parachute is contained within a deployment bag with a different arrangement than the LARD parachute; unlike the LARD, there is no pilot parachute. The 7.5 in. deployment bag top loop is attached to the U-bolt in the nosecone, and the deployment bag is not attached to the main parachute in any other way. The parachute is folded and inserted into the deployment bag with the shroud lines z-folded into the outer loops on the deployment bag. The flap of the deployment bag is folded over the shroud lines and inserted into the nosecone. The main parachute I-bolt is attached to a loop in the forward shroud shock cord using a size 2 quick link.

At 500 ft AGL, the main separation will eject the main parachute allowing it to deploy fro the deployment bag. A deployment bag is being used to slow down / delay the deployment of the chute, further reducing the opportunity for wind drift. A similar equation to the drogue calculation will be used:

$$C_{d_m} = \frac{2mg}{V_{em}^2 S_{0_m} \rho} \tag{5}$$

but the terminal velocity of the falling weight beneath the main parachute, V_{em}, will be set as a maximum of 15.38 ft/s the maximum impact velocity for a kinetic energy of 75ft-lbf, calculated in Section 5.3.2. The chosen style of parachute C_{d_m} is 2.2 as shown above. Figure 4-2, below, shows the predicted descent velocities of Iris Ultra Standard parachutes of various diameters.

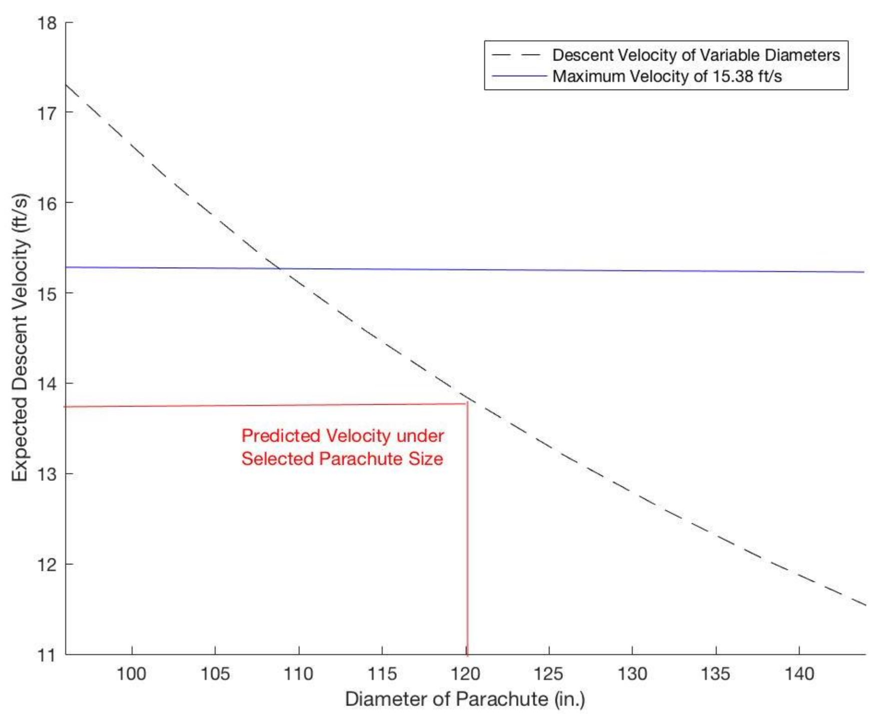

Figure 4-2: Full-scale Main Sizing vs. Descent Velocity Prediction

From Figure 4-2, for the maximum impact velocity of 15.38 ft/s (the maximum descent velocity for the total falling body weight to be within the kinetic energy limit) a parachute diameter of at least 108 in. is required. For a safe landing, and to account for any weight variances in construction, the Iris Ultra Compact 120 in. parachute will be used for the main parachute and will allow for a descent velocity of 13.85 ft/s, which is below the maximum impact velocity of 15.38 ft/s. The descent and impact velocity predicted by OpenRocket simulations is 13.55 ft/s, 0.3 ft/s more than the calculated descent velocity from the Fruity Chutes descent rate calculator. The effective kinetic energy limits for each independent section at landing are discussed in Section 5.3.2. The predicted kinetic energies of each Section at landing are included in the Table 4-2 below.

Table 4-2: Full-Scale Predicted Kinetic Energy Values at Impact

Body Section	Mass (slugs)	Maximum Descent Velocity (ft/s)	Kinetic Energy at Landing (ft-lbf)
Nosecone	0.22	13.85	21.10
Midsection	0.48	13.85	46.04
Fin Can	0.49	13.85	46.99

4.3.3.1 Descent Rate

Open rocket predicts the descent rate beneath the main parachute to decrease to 13.55 ft/s. The main parachute descent rate of 13.55 ft/s is less than the maximum body section descent rate (13.85 ft/s) required for each body section to land within the maximum kinetic energy at landing of 75 ft/s.

4.3.4 Quicklinks

The recovery system contains two sizes of quick links, one standard size attaching the shock cord to all of the bulkhead U-bolts and plug, and parachutes, and one smaller size attaching parachutes to deployment bags, as well as the pilot chute I-bolt for the LARD to the LARD deployment bag. The quick link measurements can be seen in the graphic below.

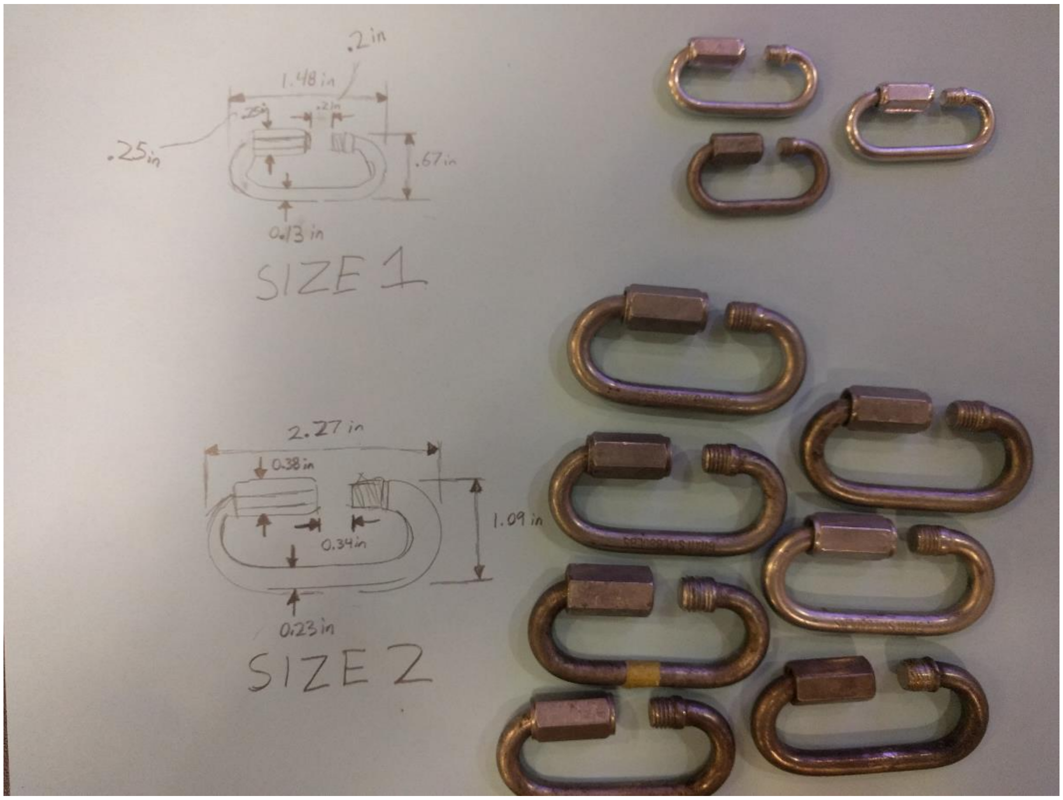

Figure 4-3: Quick Link Layout, Size and Count

There is a total of 10 quick links used within the recovery system. "Size 1" refers to a smaller quick link, "Size 2" refers to the mid-size quick link. Below is a condensed layout of the forward portion of the recovery system between the nosecone and forward midsection with labels to display the location and size of quick links within the system.

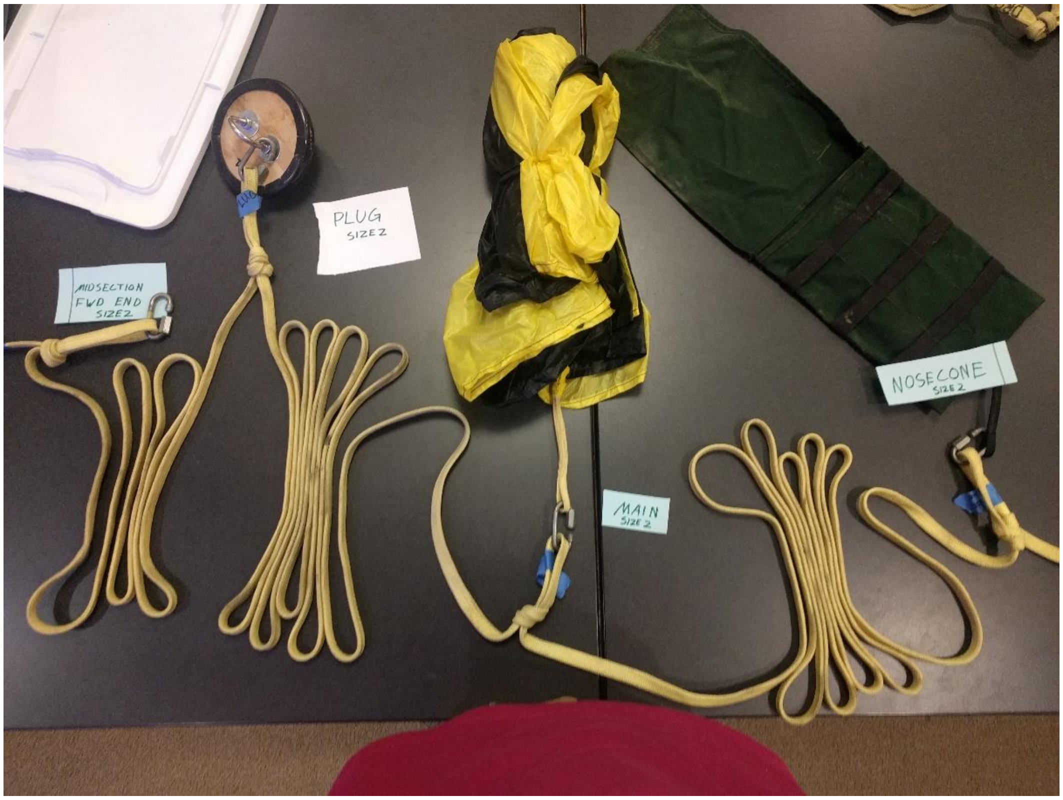

Figure 4-4: Quick Links Within the Forward Recovery System

Below is a condensed layout of the aft portion of the recovery system between the aft midsection bulkhead and fin can midsection with labels to display the location and size of quick links within the system.

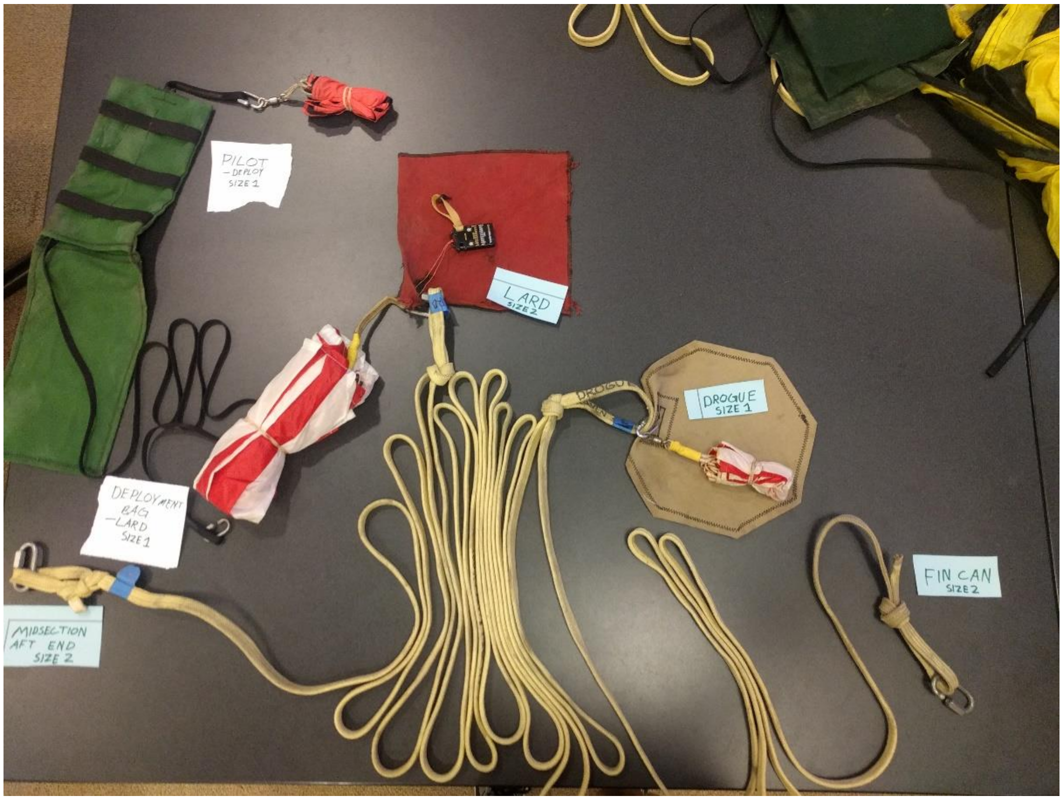

Figure 4-5: Quick Links Within the Aft Recovery System

The strength of the small quick links, size 1, is 200 lb in the long direction. The strength of the mid-size quick links is 500 lb in the long direction, which is the direction that pulls most in our system. The quick links were chosen because they were already available, this fits the team derived goal to utilize available resources and save money on materials.

4.3.5 Shock Cord

For both the forward (main) and aft (drogue) separations, a total of 480 in. of shock cord are used to minimize the opportunity for the separated rocket sections to interfere with one another during flight.

The following graphic shows the layout of the forward shock cord, between the nosecone and the forward end of the midsection.

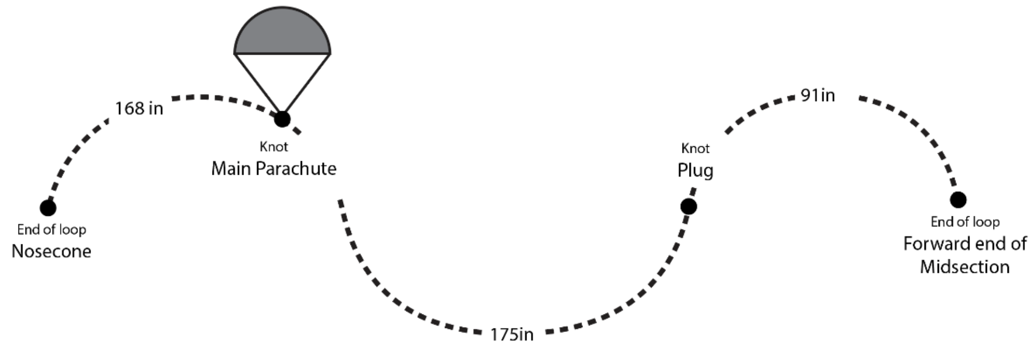

Figure 4-6: Forward Shock Cord Diagram

The forward shock cord contains a loop knot (bowline knot) for the main parachute 168 in. from the nose cone. The shock cord is attached to the nose cone with a quick link (size 2) to the U-bolt in the nose cone bulkhead, on the same quick link the main parachute deployment bag is attached, allowing plenty of room for the main parachute to inflate. The plug which plugs the payload section to protect against black powder exposure is attached to a knot 175 in. from the main parachute, attached via bowline knot and a quick link (size 2). In order to be pulled from the payload safely and not interfere with the rover, the plug is 91 in. from the forward end of the midsection. The shock cord attached to the forward end of the midsection is woven through a slot in the centering ring and lazy-susan bearing, in order to reach through the payload section. Through the open hatch a bowline knot is tied to an untied end, a quick link (size 2) is attached and then attached and closed to the bulkhead U-bolt on the aft payload bulkhead/forward midsection bulkhead.

The aft shock cord is shown in the graphic below.

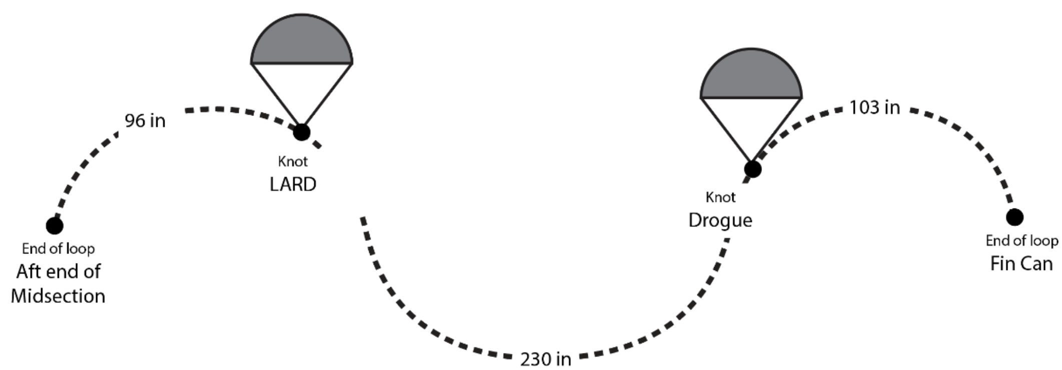

Figure 4-7: Aft Shock Cord Diagram

The aft shock cord contains a loop knot (bowline knot) attached with a quick link (size 2) to the aft end of the midsection bulkhead. The LARD parachute is attached 96 in. from this bulkhead, with a loop and bowline knot and quick link (size 2). The drogue parachute is 230 in. from the LARD, attached with a bowline loop and quick link (size 2). The final loop in the shock cord attaches to the fin can, 103 in. down the shock cord, also attached with a quick link (size 2) to the u-bolt in the fin can.

The shock cord is loaded slightly differently than in the past; the shock cord quicklinks are attached and the system is laid out length wise, and then the shock cord between segments is folded accordion style and loosely rubber banded and placed within the respective sections of the rocket before final assembly/ connection of body sections.

4.3.6 Black Powder Charges

The black powder charge size for both primary charges is a mass of 4 grams. The black powder was resized following ejection testing that did not account for the amount of space taken up by the volumes of shock cord and volumes of parachutes. Though the empty cavity lengths are calculated to require a mass of 6(+) grams, the amount of space taken up by all of the recovery system's devices was nearly half of the volume in both the forward and aft sections.

During the first ejection test for the full-scale test launch, the large charge size ripped both the nosecone bulkhead from the nosecone, and emitted enough force through the payload section to completely remove the forward payload bulkhead from within the rocket, jarring the altimeter switch key switch from the inside and inducing structural damage. The minor setback allowed for redesign and resizing of black powder charges to a primary charge size of 4 g as mentioned above, and a redundant charge size of 4.5g.

The old lengths were 20.25 in. (between nosecone and forward midsection) and 19.00 in. (between the aft midsection and fin can); however, the deployment bag of the main parachute combined with the shock cord in the forward section took up 10 in. so the forward calculation is included below,

$$m_{main} = 0.006 * (L_b - L_r) * (D)^2$$

where L_b is the length between the closed cavity bulkheads and L_r is the length of the space taken up by recovery equipment, assuming the entire diameter of that space/volume is consumed. The calculation is done as follows,

$$m_{main} = 0.006 * (20.25\ in. - 10\ in.) * (7.34\ in.)^2 = 3.3g$$

but to be on the safe side, the charge is planned to be 4 grams for the primary charge. As usual, the redundant charge adds .5 grams, and so the redundant charge is 4.5 g.

The calculation for the aft section is the same, but the amount of space taken up by the recovery equipment L_r is 9 in. for the aft/drogue and LARD section. The calculation is done as follows,

$$m_{main} = 0.006 * (19\ in. - 9\ in.) * (7.34\ in.)^2 = 3.2g$$

and again, to be safe, the primary charge is planned to be 4 grams. The redundant charge is 4.5 g.

The ejection testing for both charges was successfully tested and the test flights with the new charge sizes were also successful, so the competition flight separations will prove successful.

4.4 Recovery System Avionics

The launch vehicle contains a single avionics bay which houses all recovery system electronics except for the Jolly Logic Chute Release which is attached directly to the LARD parachute. The AV bay is 6.25 in long, and contains an AV sled which is placed into the bay through the removable hatch on the body tube. The AV sled holds two 9V batteries and two commercially available barometric altimeters. Each altimeter has a dedicated battery and is armed with a dedicated key switch, the two systems operate on separate circuits and are independently redundant.

4.4.1 Exterior Switches

Two key switches are accessible from the outside of the rocket body. Each key switch was fit through a drilled hole in the rocket airframe, secured with a nut, then epoxied to the interior of the airframe. The two altimeters responsible for drogue and main deployment are each armed with a dedicated key switch, and the switches are accessible from the exterior of the rocket airframe when the rocket is in the launch configuration on the launch pad. The switches are capable of being locked in the ON position for launch. The switches will not be armed until the vehicle is erected on the launch rail to avoid battery drain and premature black powder detonation.

4.4.2 Avionics Sled

The AV sled holds the altimeters and batteries secure in the AV bay, and is placed into the AV bay through the removable hatch during launch day assembly. The fully assembled sled can be seen in Figure 4-8 and Figure 4-9.

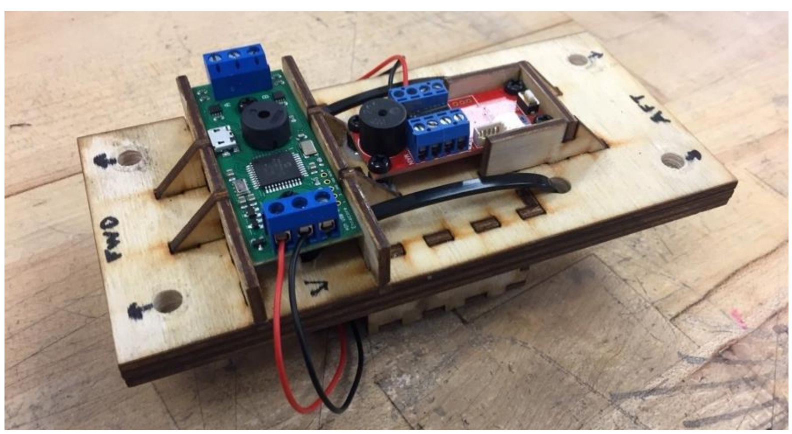

Figure 4-8: Assembled AV Sled Altimeter View

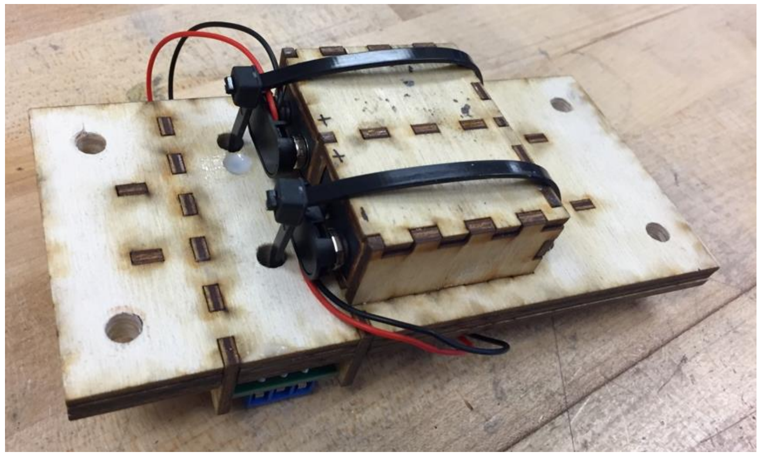

Figure 4-9: Assembled AV Sled Battery View

The sled was designed to enable both altimeters to be viewed face up from the hatch, allowing for easy access to altimeter terminals and a clear view of the wiring. The sled was constructed out of laser cut 0.125 in. thick aircraft birch plywood, using finger joints and epoxy to hold the pieces together. Plywood was chosen because it is readily available, easy and quick to work with, and relatively light. For extra strength, the main platform of the sled was made by sandwiching 3 identical pieces of plywood, giving a total thickness of 0.375 in. The dimensions of the sled are shown in Figure 4-10.

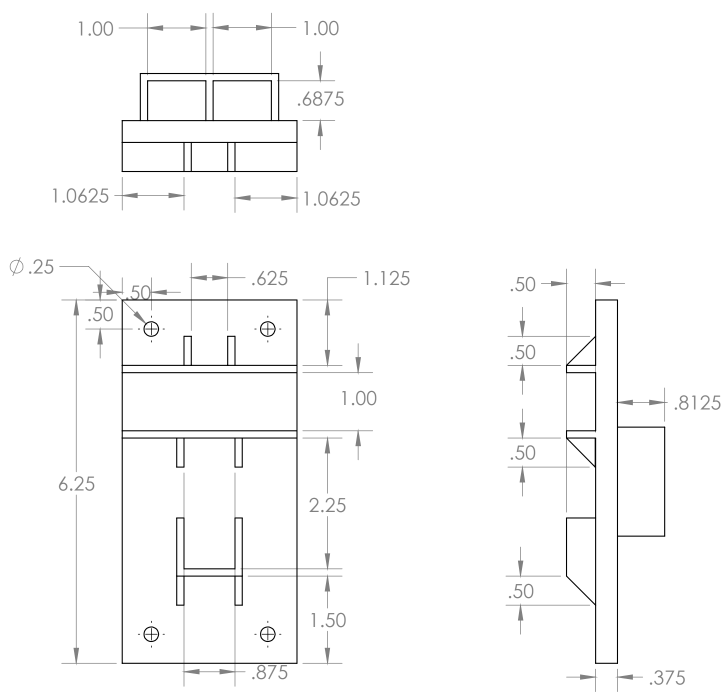

Figure 4-10: AV Sled Dimensions

The side of the sled facing the hatch contains two slots for the altimeters. The slots provide additional support to the altimeters during flight without blocking access to terminals or coming into contact with the electronics. The altimeters are mounted onto the face of the sled using small plastic standoffs to keep electronic components from contacting the sled surface. The standoffs are aligned with designated attachment points on the altimeters, and epoxied to the sled. The side of the sled facing away from the hatch contains two slots to hold two 9 V batteries. To prevent the batteries from falling out of their slot or getting disconnected during flight, each battery and battery cap is tightly zip tied to its enclosure using small holes drilled into the sled. During assembly and prior to a launch, the altimeters and batteries will be secured to the sled before the sled is inserted into the AV Bay.

Inside the AV Bay, four aluminum 1 in. by 1 in. L brackets are permanently screwed to the forward and aft fixed bulkheads, two to each bulkhead. The brackets are oriented so that the outer face faces the hatch. A bolt was placed through each bracket, pointing towards the hatch, and the head of each bolt was permanently glued to the inner face of the L bracket. During assembly, the sled is mounted onto the four bolts, one on each corner, then secured with a nut. This design for mounting the sled was chosen because it uses easily accessible fasteners and is quick and easy to assemble. Figure 4-11 shows the AV sled mounted in the AV bay.

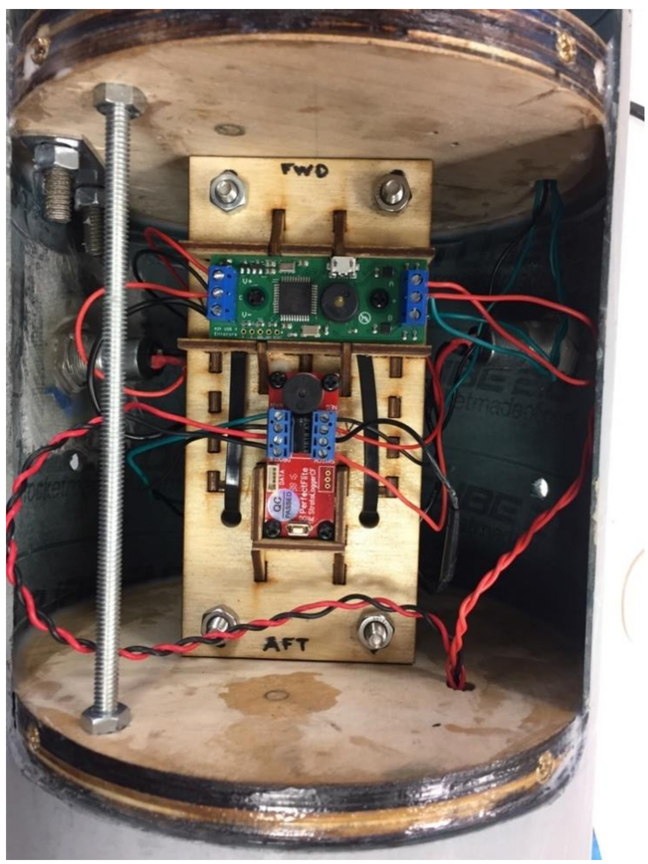

Figure 4-11: Fully Assembled AV Bay

4.4.3 Altimeters

The team is using a StratoLoggerCF and an Entacore AIM USB 4.0 to measure altitude and trigger primary and redundant separation charges. These altimeters were chosen because the team has successfully used these altimeters in the past. Two different brands of altimeters will be used to avoid the possibility of both altimeters failing due to a common manufacturer's defect. The two altimeters are independently redundant systems: each is powered by a dedicated 9 V Duracell battery, armed with a dedicated key switch, and triggers a drogue and main charge.

4.4.3.1 Primary Altimeter

The StratoLoggerCF, shown in Figure 4-12, was chosen as the primary altimeter.

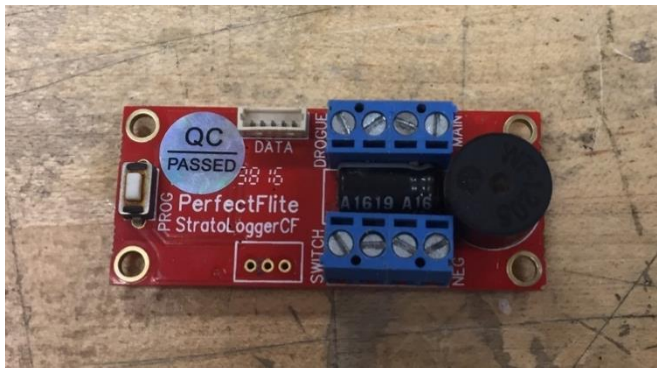

Figure 4-12: Primary Altimeter StratoLoggerCF

The StratoLoggerCF was chosen as the primary altimeter because it can only vary the altitude of main deployment, and cannot add a time delay to main deployment like the Entacore can. The StratoLoggerCF will also function as the competition altimeter, its readout will determine the altitude of apogee. The StratoLoggerCF is programmed to activate drogue deployment at apogee and main deployment at 500 ft. The wiring for the altimeters is color coded: red and black wire will lead from the StratoLoggerCF drogue terminals to a terminal block on the aft face of the AV bulkhead, which will be wired to the drogue primary charge. Green and black wire will lead from the StratoLoggerCF main terminals to a terminal block on the forward face of the Payload centering ring, which will be wired to the main primary charge.

4.4.3.2 Redundant Altimeter

The Entacore AIM USB 4.0, shown in Figure 4-13, was chosen as the redundant altimeter.

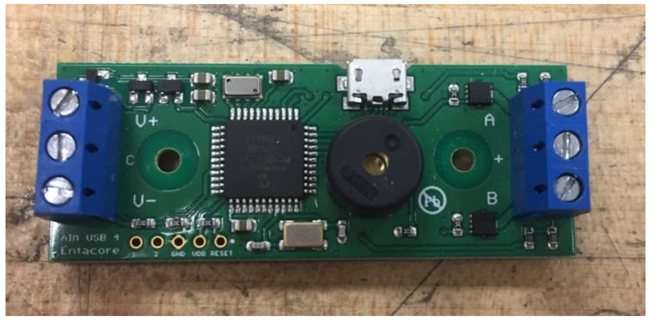

Figure 4-13: Redundant Altimeter Entacore AIM USB 4.0

The Entacore is programmed to activate drogue deployment at one second after apogee and main deployment at one second after 500 ft. The 1 s delay is added to the redundant charges to avoid over pressurizing the tube and damaging bulkheads or the body tube. A delay of 1 s has been used by the team before and has proven to be sufficient. The wiring for the altimeters is color coded: solid red wire will lead from the Entacore “A” terminal to a terminal block on the aft face of the AV bulkhead, which will be wired to the drogue redundant charge. Solid green wire will lead from the Entacore “B” terminal to a terminal block on the forward face of the Payload centering ring, which will be wired to the main secondary charge.

4.4.3.3 Electromagnetic Sensitivity

The only radio transmitter on board the rocket is the BRB 900 GPS tracker. The transmitter is attached to the nose cone bulkhead, it is 3.5 ft away from the altimeters, with two bulkheads, the payload, and the main parachute in between. The material between the transmitter and the altimeters provides adequate shielding from EM waves. This was shown during the test launch, where both the transmitter and the altimeters functioned as expected with no sign of interference.

The payload features one 400 MHz radio receiver which operates a latch. The GPS tracker transmits on a different wave length, so there will be no interference. This was also shown during the test flight, where the latch was unaffected by the transmitter.

4.4.3.4 Altimeter Testing

The StratoLoggerCF and Entacore altimeters were tested to ensure that they trigger at the correct altitudes. Each altimeter was programmed to set off the main parachute black powder charge at 500 ft AGL upon descent. A 9 V battery was chosen and tested using a multimeter to confirm the correct amount of output voltage. One green LED and one resistor was wired in series to the main parachute terminal and yellow LED and resistor was wired in series to the drogue parachute terminal on the altimeter. The resistors were added to prevent the altimeters from blowing out the LEDs. The altimeter was then connected to the battery and the entire circuit was placed inside a mason jar. The lid of the jar had a small opening to allow a plastic air hose to enter the jar. The lid was screwed on tight and putty was placed along all the seams to ensure an airtight seal. Using a vacuum pump, the pressure in the jar was reduced to a near vacuum. Once the vacuum pump is turned off, the yellow light illuminated briefly to indicate the apogee event. The pressure in the jar will be increased slowly and the green light illuminated briefly to indicate the main event. Four altimeters, two of each type, successfully completed the test. Main firing is shown in figure

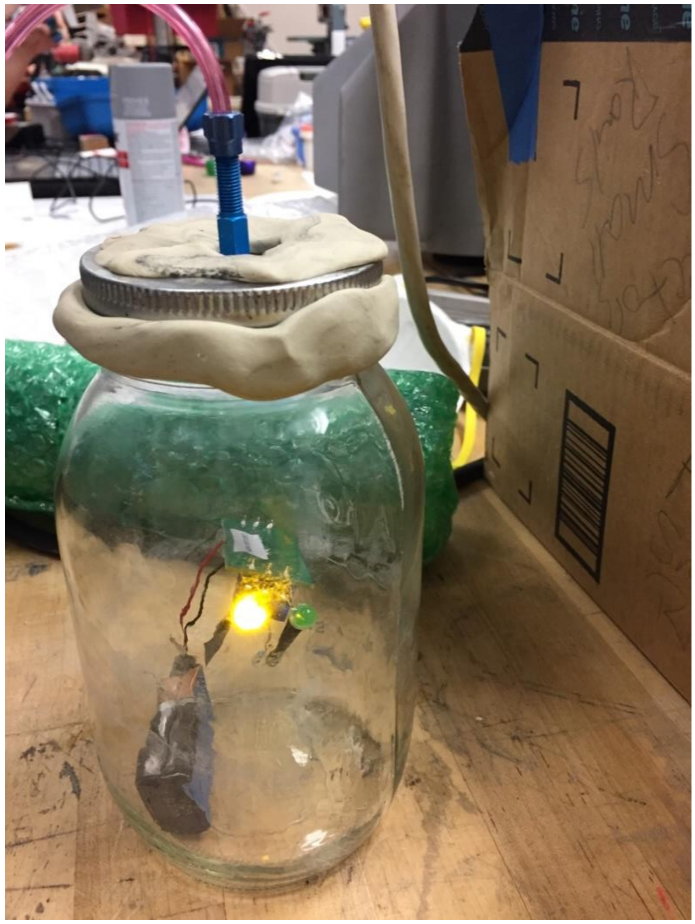

Figure 4-14: Successful Altimeter Test

4.4.4 GPS Transmitter

GPS tracking of the full-scale rocket is done by a BigRedBee BRB900, shown in Figure 4-15, which uses an XBee-PRO 900HP transmitter.

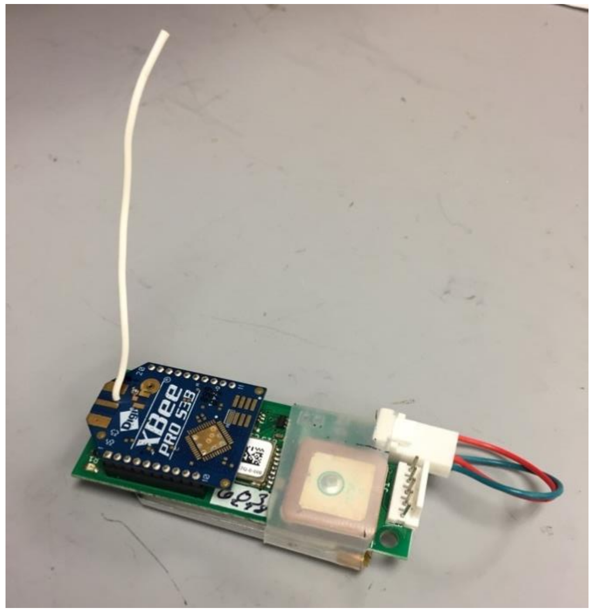

Figure 4-15: GPS Tracker BRB900

A BRB 900 is used because it does not require an amateur radio license, and the team has successfully used them in the past. The BRB 900 is a self-contained system with an internal battery, GPS receiver, and 900 MHz spread spectrum transmitter. An LCD display receives the coordinates of the rocket in real time. The GPS is mounted onto the nosecone bulkhead, behind the parachute, and secured with Velcro and 2 standoff screws. The parachute and deployment bag will protect the transmitter from the ejection charge, and there will be sufficient space to extend the whip antenna along the rocket body.

4.4.4.1 Transmitter Frequency

The transmitter operates on a 900 MHz, spread spectrum wavelength. Since this is a frequency hopping system, it is resistant to narrowband interference. The wattage of the transmitter is 250mw. The range is approximately 6 miles according to the BRB900 documentation. With a fully charged battery, the transmitter can operate for more than 24 hours.

4.4.4.2 GPS Testing

The team had two BRB900 GPS trackers on hand, both of which were tested. Each transmitter was turned on outside with a clear view of the sky to obtain a satellite lock, and the LCD receiver was turned on to connect to the transmitter. One of the transmitters was not able to obtain a satellite lock after several attempts, and was discarded. The remaining transmitter was placed in a backpack, and taken on Wolfline Route 8, a bus route around NC State's campus. Upon completing one loop and returning to the lab, the GPS data was uploaded to a computer and opened in google earth. The GPS test data is shown in Figure 4-16. Some parts of the route are obscured because the altitude of the tracker dipped below what was ground level altitude when the GPS first obtained satellite lock. This is not an issue when viewing rocket launch data. The position data was compared to a map showing the route 8 path, and was found to be accurate.

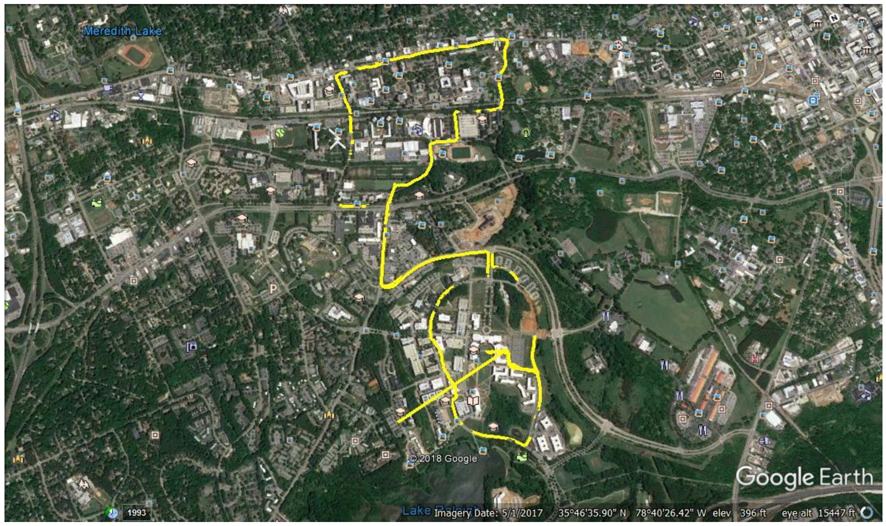

Figure 4-16: GPS Test Data

4.4.5 Batteries

Each altimeter is powered by a dedicated 9 volt Duracell battery. The Duracell brand was chosen for the batteries because the team conducted an experiment in a previous year which found that Duracell brand batteries generally deviated from 9 volts less than other brands. The two batteries fit into slots on the AV sled. To prevent the batteries from falling out of their slot or getting disconnected during flight, each battery and battery cap is tightly zip tied to its enclosure using 0.25 in. holes drilled into the sled. The GPS transmitter is powered by its own rechargeable Lipo battery which can power the transmitter for more than 24 hours on a full charge.

4.4.6 Avionics Bay Components and Weights

Every component in the avionics bay was weighed with a scale and listed in Table 4-3 below:

Table 4-3: Avionics Bay Component Weights

Components	Weight (lb)
1 Plywood Sled	0.22 lb
1 StratoLoggerCF	0.02 lb
1 Entacore AIM USB 3.0	0.03 lb
2 Duracell batteries, 9V	0.20 lb
2 key switches	0.22 lb
2 battery caps	0.01 lb
4 ft of wire	0.07 lb
2 terminal blocks	0.03 lb
4 L brackets	0.08 lb
4 bolts	0.08 lb

Components	Weight (lb)
8 nuts	0.09 lb
4 screws	0.01 lb
1 threaded rod	0.09 lb
Total:	1.15 lb

4.4.7 Electrical Schematic of Avionics

The electrical schematic of avionics is shown in Figure 4-17. The schematic demonstrates that the system is independently redundant. The wires leading to the ejection charge terminal blocks are correctly color coded, and everything is positioned approximately how it would appear if viewed from the hatch, as shown in Figure 4-11.

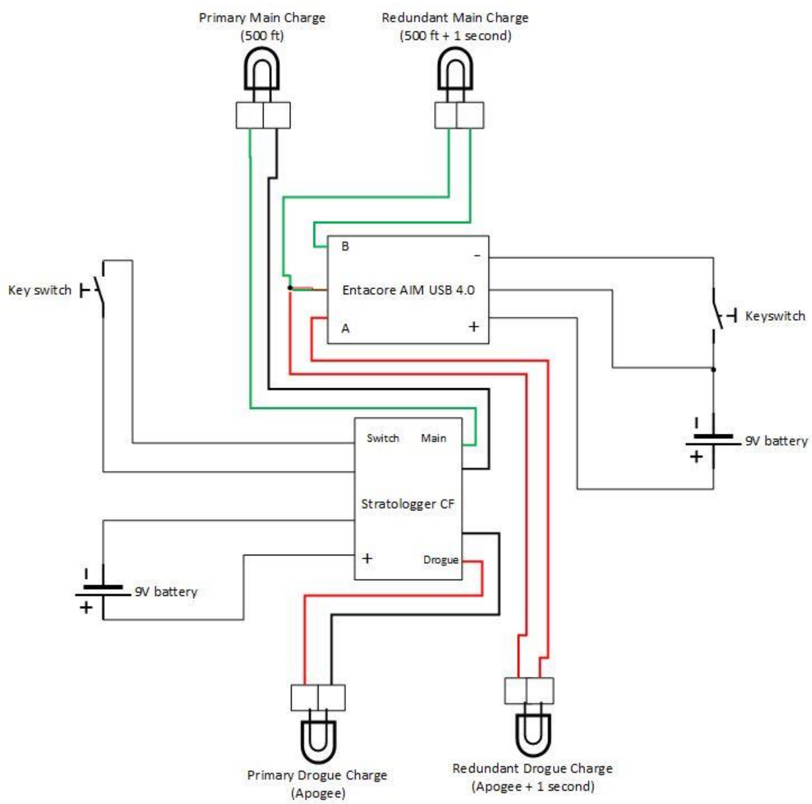

Figure 4-17: Electrical Schematic of Avionics

5. Launch Vehicle Performance Predictions

5.1 Flight Profile Predictions

This section contains analysis of simulated flight profiles of the full-scale launch vehicle from OpenRocket and published simulation information for the selected motor.

5.1.1 Simulated Flight Profiles

The team has relied on flight simulation results to determine the effectiveness of the full-scale launch vehicle design. Figure 5-1, below, shows the results from one of these simulated launches, where the location was set to Huntsville, AL and windspeed was a constant 10 mph, launching from an 8 ft launch rail angled 5° from vertical.

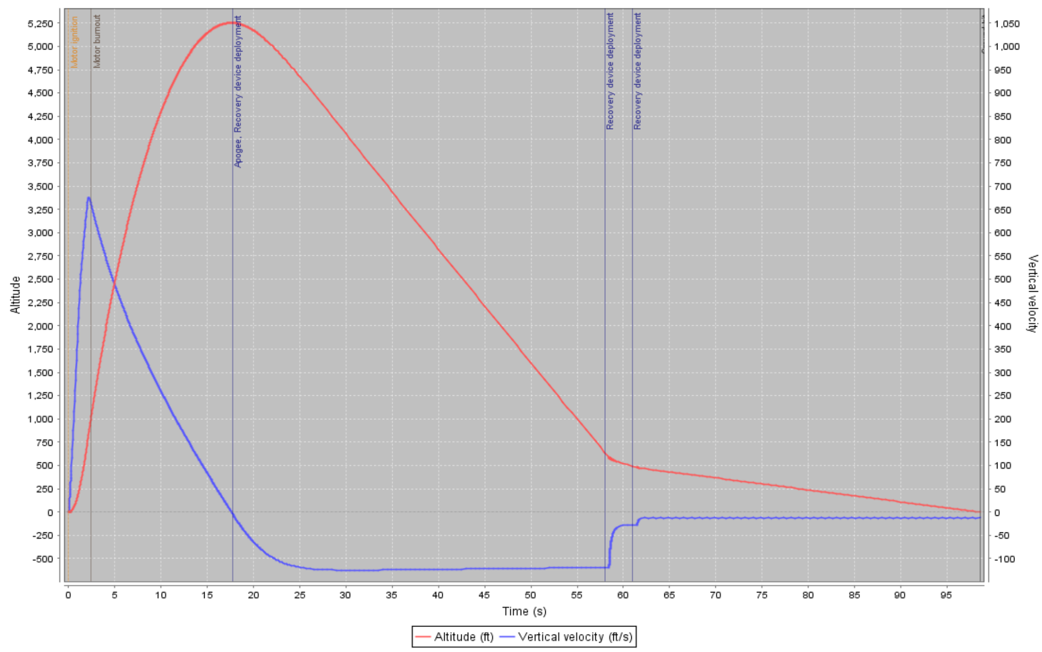

Figure 5-1: OpenRocket Simulation with 10 mph Winds at Huntsville, AL

Figure 5-1, above, shows that the rocket motor will burn out at approximately 2.4 seconds to let the rocket coast for another 15.3 seconds until reaching apogee at 5,253 ft AGL. The entire flight lasts 98.5 seconds and the ground impact velocity is 12.1 ft/s, well below the limit assigned in Section 5.3.2. The team is confident that the numerous flight simulations run using OpenRocket are reasonable to use when iterating the rocket design.

Table 5-1, below, shows the results for various flight simulations using the same environmental parameters described above.

Table 5-1: OpenRocket Simulation Results for Varying Winds

Wind Speed (mph)	Apogee (ft AGL)	Flight Time (s)	Impact Velocity (ft/s)
0	5399	100	12.1
5	5391	101	12.1
10	5253	99	13.7
15	5331	100	13.7
20	5282	100	13.7

The simulation results show that the rocket has a very predictable and steady flight pattern. Regardless of wind speed, the apogee never deviates more than 150 ft, and the impact velocity is never greater than 13.7 ft/s. The team is confident that the rocket will perform as expected, and intends to continue using OpenRocket simulations throughout the remainder of the project to observe the effects that any small change may have on the overall design.

5.1.2 Simulated Motor Thrust Curve

The chosen contender for the full-scale motor is the AeroTech L2200G-P, with the simulated motor thrust curve shown below in Figure 5-2.

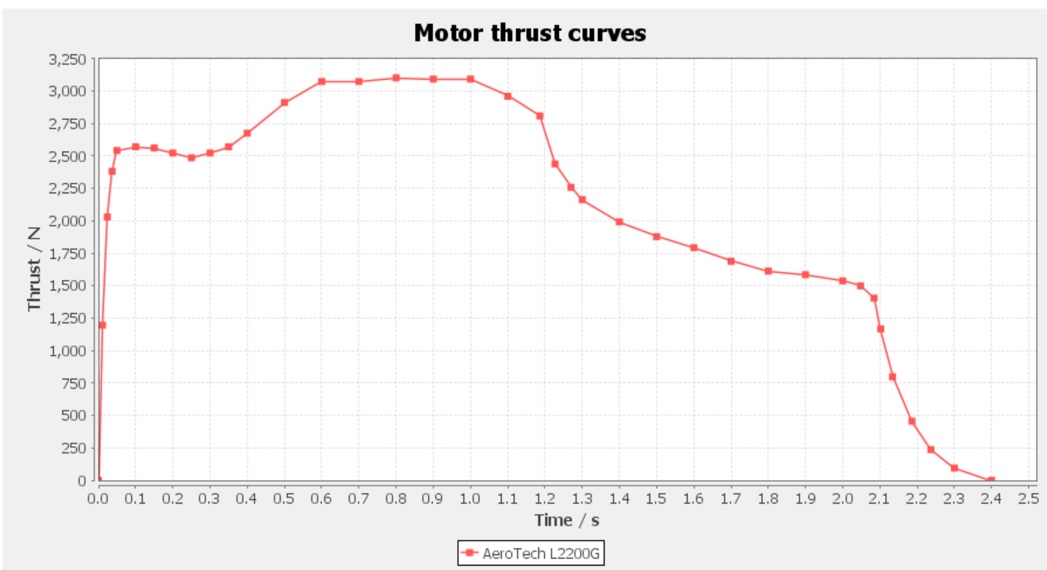

Figure 5-2: AeroTech L2200GP Motor Thrust Curve

From the thrust curve in Figure 5-2, the performance provides the highest max thrust 3100 N and the total impulse of 5,104 N-s in less burn time (2.4 s), stabilizing the rocket quickly during flight.

5.1.2.1 Simulated Motor Thrust-to-Weight Curve

From the thrust-to-weight curve in Figure 5-3 below, the thrust-to-weight ratio can be determined for the selected AeroTech L2200G motor.

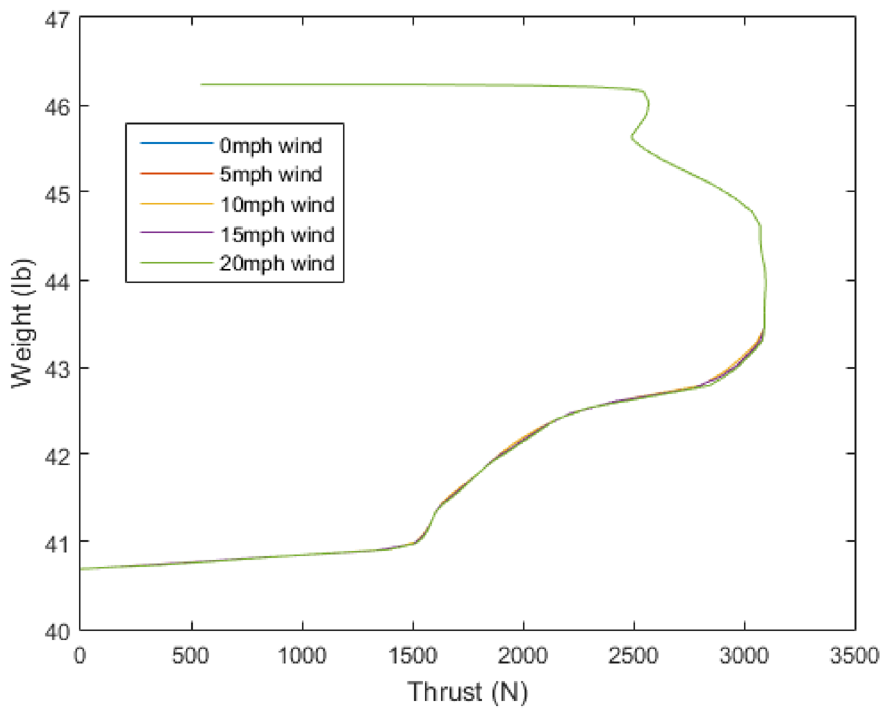

Figure 5-3: AeroTech L2200G Motor Thrust-to-Weight Curve

To calculate the thrust-to-weight ratio Equation 6 is used

$$\frac{T}{W} = \frac{Max\ Thrust}{Max\ Weight} \tag{6}$$

and both values can be taken from OpenRocket simulations and manufacturer data. After converting the maximum rocket weight from pounds to Newtons, the ratio is calculated below as

$$\frac{T}{W} = \frac{3100N}{209.51N} = 14.97 \tag{7}$$

5.1.3 Launch Rail Exit Velocity

The rail exit velocity requirement 2.17 of the 2018 NASA Student Launch Handbook sets a lower limit of 52 ft/s for the exit speed of the rocket from the launch rail. In order to determine the launch speed of the full-scale rocket, the locations of rail buttons and the size of the launch rail were determined.

Equation 9, shown below, is the equation for launch rail exit velocity:

$$V_{exit} = \sqrt{\frac{2L(T - W\sin\theta)}{m}} \quad (8)$$

where L is the distance the top rail button travels before leaving the rail (ft) and is equivalent to:

$$L(in.) = L_{rail}(in.) - d_{rb_{aft}}(in.) \quad (9)$$

which is equivalent to the difference in the length of the rail and the distance between the top most rail button and the aft most point of the rocket. For the full-scale:

$$L = 96\ in. - 19\ in. = 77\ in. = 6.42\ ft$$

and T is the average thrust (lb_f) over the first instant of flight, taken from Open Rocket simulation. The predicted values for both subscale and full-scale motors are provided below:

$$T = 2{,}243\ N = 504.25\ lb_f$$

W and M are the weight and mass of the launch vehicle, listed below**:**

$$W = 48.4\ lb_f$$

$$m = 1.50\ slugs$$

θ is the angle of the launch rail from horizontal, which is typically 85 degrees from horizontal for launch purposes for both full-scale and subscale.

$$\theta = 85°$$

With this information, MATLAB is used to analyze the rail exit velocity, and is plugged in below for clarification. The MATLAB code is included in Appendix A.

$$V_{exit} = \sqrt{\frac{2 * (6.42\ ft) * (504.25\ lbf - (48.4\ lbf)\sin(85°))}{1.50\ slugs}} = 62.48\ ft/s$$

The hand calculations show that the rocket will achieve a vertical speed of 62.48 ft/s at the end of the launch rail, which exceeds the minimum requirement of 52 ft/s listed in the NASA Student Launch handbook.

5.1.3.1 Alternative Calculations

OpenRocket Simulations predict that the rocket will leave the launch rail with a V_{exit} of 74.8 ft/s. This value is greater than the hand calculated value shown above, which is also greater than the minimum requirement of 52 ft/s listed in the NASA Student Launch handbook. The difference between the hand calculations and the OpenRocket prediction can be attributed to accuracy discrepancies between the two methods. The OpenRocket simulation accounts for the real-time velocity of the rocket after ignition, while the hand calculations assume a constant thrust equal to the average thrust of the AeroTech L2200G motor.

5.2 Flight Stability Predictions

This section contains the calculations and analysis for the center of pressure (CP) location and the resulting stability margin for the full-scale launch vehicle.

5.2.1 Center of Pressure

According to the OpenRocket model, the CP location of the rocket in its current configuration is at a point 81.1 in. from the nosecone tip. This value was computed automatically by the software at Mach 0.3, which corresponds to the approximate average Mach number of the rocket from launch to apogee.

The Barrowman's Method, which defines a simple algebraic method for calculating the CP position on a subsonic rocket, was applied to confirm the OpenRocket prediction for CP position. Barrowman's Method allows the rocket to be split into three parts: nosecone, transition, and fins. Since the rocket does not include a transition section, only the nosecone and fin equations were considered. The coefficient for nosecones C_N was defined as a constant equal to 2. The arm length for any ogive nosecone X_N can be defined as:

$$X_N = 0.466L_N \tag{10}$$

where L_N is the length of the nosecone. Using L_N = 22.5 in., X_N was calculated to be 10.5 in. The coefficient for fins C_F can be defined as:

$$C_F = \left(1 + \frac{R}{S+R}\right)\left[\frac{4N\left(\frac{S}{d}\right)^2}{1 + \sqrt{1 + \left(\frac{2L_F}{C_R + C_T}\right)^2}}\right] \tag{11}$$

where R is the radius of the rocket body, S is the fin semi-span length, N is the number of included fins, d is the diameter of the rocket body, L_F is the fin mid-chord line length, C_R is the fin root chord length, and C_T is the fin tip chord length. Using R = 3.75 in., S = 6.0 in., N = 4, d = 7.5 in., L_F = 6.185 in., C_R = 10.0 in., and C_T = 5.0 in., C_F was calculated to be 7.7. The equation for the arm length of the fins X_F can be defined as:

$$X_F = X_B + \frac{X_R}{3}\frac{(C_R + 2C_T)}{(C_R + C_T)} + \frac{1}{6}\left[(C_R + C_T) - \frac{(C_R C_T)}{(C_R + C_T)}\right] \tag{12}$$

where X_B is the distance from nosecone tip to fin root chord leading edge and X_R is the fin sweep length measured parallel to the rocket body. Using X_B = 100.0 in., X_R = 4.0 in., C_R = 10.0 in., and C_T = 5.0 in., X_F was calculated to be 103.7 in.

The equation for CP position of the entire body is a weighted average of the coefficient for each component, and can be defined as:

$$X_{CP} = \frac{C_N X_N + C_F X_F}{C_N + C_F} \tag{13}$$

The CP position was calculated to be 84.52 in. from the nosecone tip, which is 3.4 in. aft of the CP position from OpenRocket. This is a significant difference and equates to an increase of 0.45 cal to the stability margin. However, this disparity can be explained by comparing the complexity of the OpenRocket calculation to the simplicity of the Barrowman's Method. When calculating the CP position, OpenRocket considers effects due to flight speed, nosecone shape, nosecone length, body diameter, body length, fin shape, fin location, fin leading edge shape, and surface roughness due to body paint. Compared to Barrowman's Method, which only considers nosecone shape, nosecone length, fin shape, and fin location, the OpenRocket calculation is much more advanced and can be considered more accurate. Though Barrowman's Method was used to approximately confirm the CP position, the OpenRocket prediction for CP position was used when calculating the rocket stability margin and determining the amount of ballast necessary for stable flight.

The equation for the stability margin of a rocket S_M can be defined as:

$$S_M = \frac{X_{CP} - X_{CG}}{d} \tag{14}$$

Where X_{CP} and X_{CG} are the distances from nosecone tip to the rocket CP and CG, respectively, and d is the rocket outside diameter. Stability margin is measured in calibers, where one caliber is equal to the rocket outside diameter. Using the results from OpenRocket, X_{CP} = 81.1 in. and X_{CG} = 63.8 in., the stability margin was calculated to be 2.3 cal. Since this value is the stability margin of the rocket after full assembly and before launch, it exceeds the handbook requirement (see Table 4-1) that the rocket must have a stability margin of at least 2.0 when exiting the launch rail since the stability margin will only increase during flight. Figure 5-4, below, shows the CG and CP locations on the OpenRocket model.

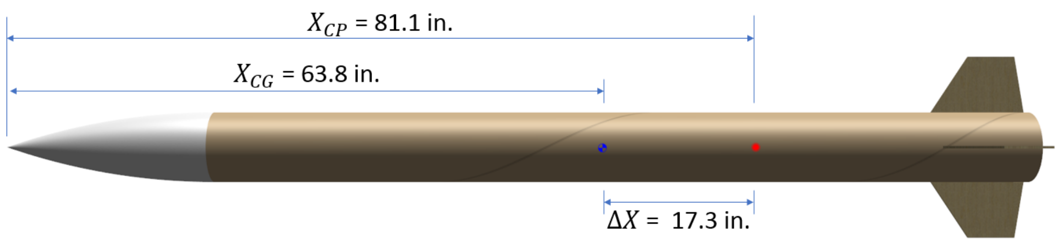

Figure 5-4: OpenRocket Model with CG and CP Locations Shown

Detailed analysis of how the stability margin will change throughout the flight is shown in Section 5.2.2.

5.2.2 Stability Margin

Stability margin is a measure of how sensitive the rocket will be to any perturbation during flight and is a function of the CG and CP locations, as well as the diameter of the rocket body. As the motor burns and ejects mass, the CG will translate forward in the rocket while the CP location remains fixed, thereby increasing the stability margin throughout the entire powered phase of flight. However, a large stability margin is not desired as it may cause the rocket to pitch off-course due to an external perturbation, such as a gust of wind. Once perturbed, the rocket flight will become unpredictable which is not ideal in any scenario. To increase spectator safety and confirm that the rocket will perform as expected, the team investigated how the stability margin changed during flight.

There are three important events in the ascent profile of the rocket where the stability margin is important to consider: ignition, rail exit, and burnout. Using the OpenRocket model and Barrowman's Method results described in Section 5.2.1, the stability margin at ignition is predicted to be 2.3 cal. This value represents the minimum stability margin during the flight, as the CG and CP locations are closest with the motor installed and full of propellant. After 0.23 seconds, the rocket will have cleared the launch rail after burning 0.58 lb of propellant, thus shifting the CG location to a point 63.4 in. from the nose. At rail exit, the full-scale rocket will have a stability margin of 2.36 cal which is greater than the 2.0 cal required by the NASA Student Launch handbook. Finally, motor burnout will occur at 2.4 seconds after ignition which will leave the CG at 59.5 in. from the nose for the remainder of the ascent profile. From motor burnout to apogee, the rocket will have a stability margin of 2.88 cal which is not large enough to make the rocket over-stable. Figure 5-5, below, shows the stability margin as a function of flight time and altitude for the first 5 seconds of the launch.

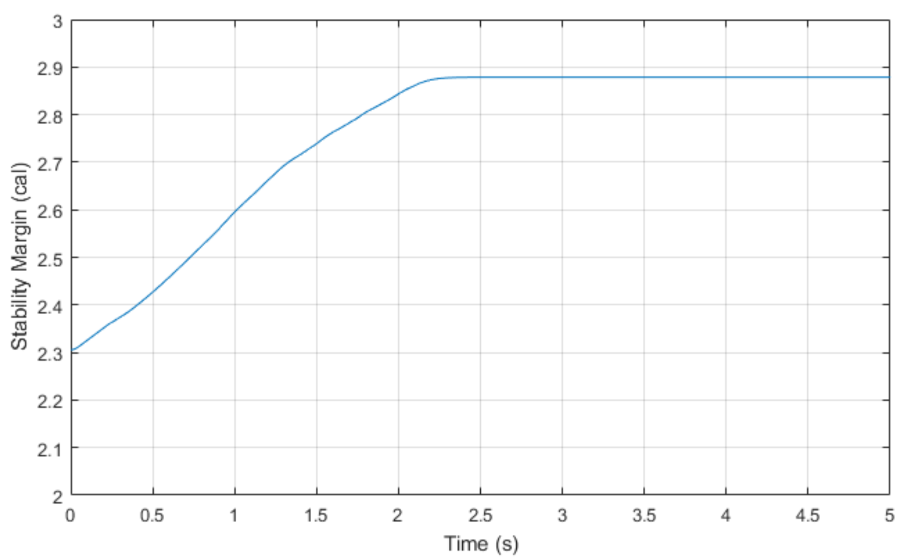

Figure 5-5: Time vs. Stability Margin

After motor burnout, the stability margin will remain constant until apogee since the rocket does not have any drag inducing equipment, such as cameras or airbrakes, and is no longer relevant after fin can separation and drogue deployment.

5.3 Recovery Profile Predictions

This section contains analysis for the recovery flight profile of the full-scale launch vehicle.

5.3.1 Variable Wind Drift

To defend requirement 3.9 of the 2018 NASA Student Launch handbook, which states that recovery distance must remain within a 2,500 ft radius of the launch pad, wind drift calculations are completed to predict performance in various wind conditions. OpenRocket was used to simulate launches with constant windspeeds of 0, 5, 10, 15, and 20 mph, with the launch rail angled 0° from vertical to achieve maximum altitude and flight time. Table 5-2, below, shows the results of the OpenRocket simulations in varying windspeeds:

Table 5-2: OpenRocket Simulation Wind Effect on Altitude and Drift

Windspeed (mph)	Windspeed (ft/s)	Apogee (ft AGL)	Descent Time (s)	Lateral Drift (ft)
0	0.0	5,399	82.1	8.3
5	7.3	5,391	83.1	245.7
10	14.7	5,253	81.0	592.9
15	22.0	5,331	81.8	769.0
20	29.3	5,281	82.3	1,092.2

The OpenRocket simulation results show that the lateral wind drift is expected to stay well below the 2,500 ft maximum set by the NASA Student Launch handbook. Figure 5-6, below, shows a visualization of the predicted wind drift distances over a satellite image of the Bragg Farms property where the competition launch is set to take place.

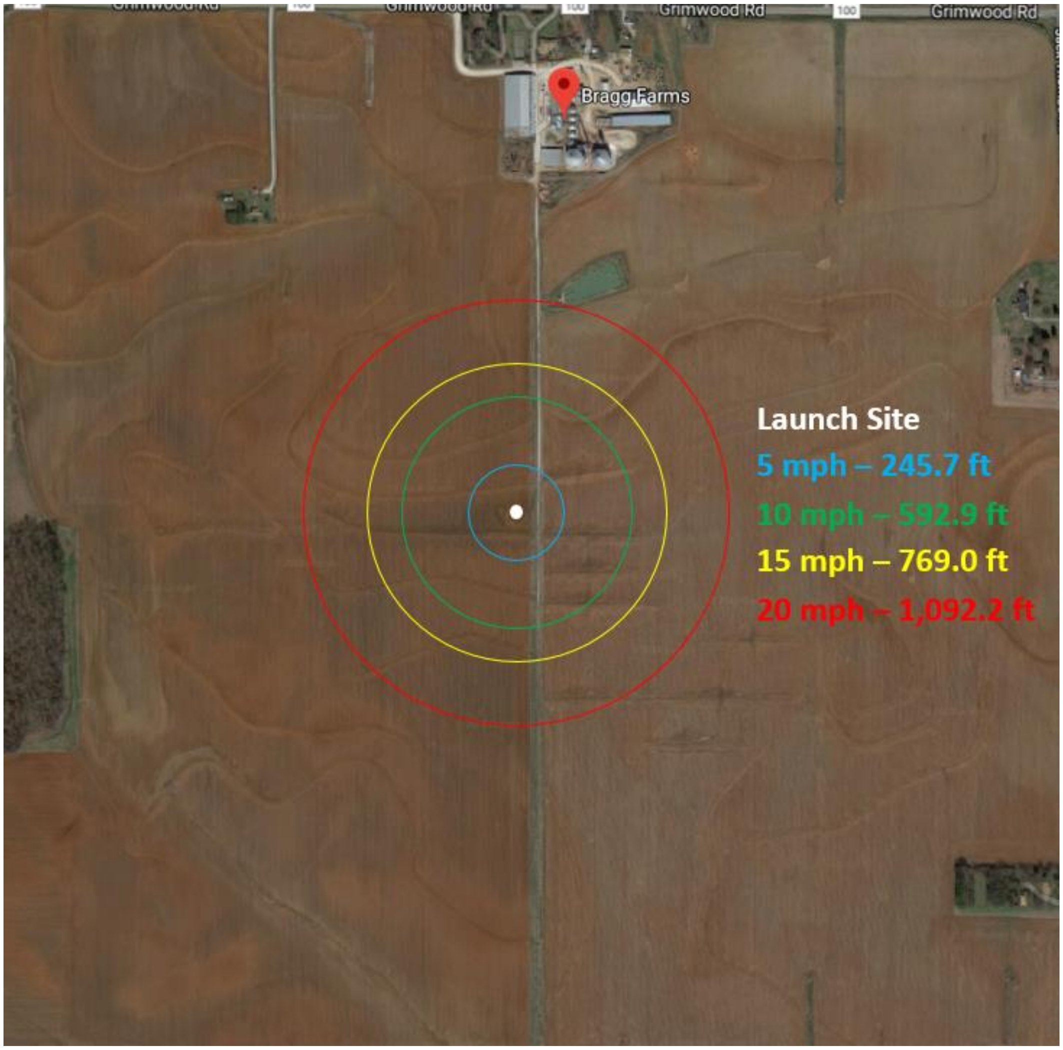

Figure 5-6: Visualization of Wind Drift from OpenRocket Simulations

Following a successful relaunch of the full-scale rocket, the team will compare the actual wind drift distances to the values shown in this section.

5.3.1.1 Alternative Calculations

With the apogee and descent times known for each windspeed from the OpenRocket simulations, the hand calculations were completed for comparison. Wind drift can be defined as:

$$d_{drift}\,(ft) = t_{descent}\,(s) * V_{wind}\,\left({}^{ft}/_{s}\right) \tag{15}$$

where d_{drift} is the lateral distance at landing from the launch pad, $t_{descent}$ is the time the rocket sections take to reach the ground from apogee, and V_{wind} is the wind speed converted to ft/s from mph.

Table 5-3, lists the results for the wind drift hand calculations in varying windspeeds:

Table 5-3: Hand Calculations of Wind Effect on Altitude and Drift

Windspeed (mph)	Windspeed (ft/s)	Apogee (ft AGL)	Descent Time (s)	Lateral Drift (ft)
0	0.0	5,399	82.1	0.0
5	7.3	5,391	83.1	606.6
10	14.7	5,253	81.0	1,190.7
15	22.0	5,331	81.8	1,799.6
20	29.3	5,281	82.3	2,411.4

As shown in the table, the hand calculations result in wind drift values that far exceed the OpenRocket predictions, but are all still below the 2,500 ft limit listed in the NASA Student Launch handbook. The most likely reason for this is that the hand calculations assume a constant wind speed and direction which is often not the case in real application. Figure 5-6, below, shows a visualization of the predicted wind drift distances over a satellite image of the Bragg Farms property where the competition launch is set to take place.

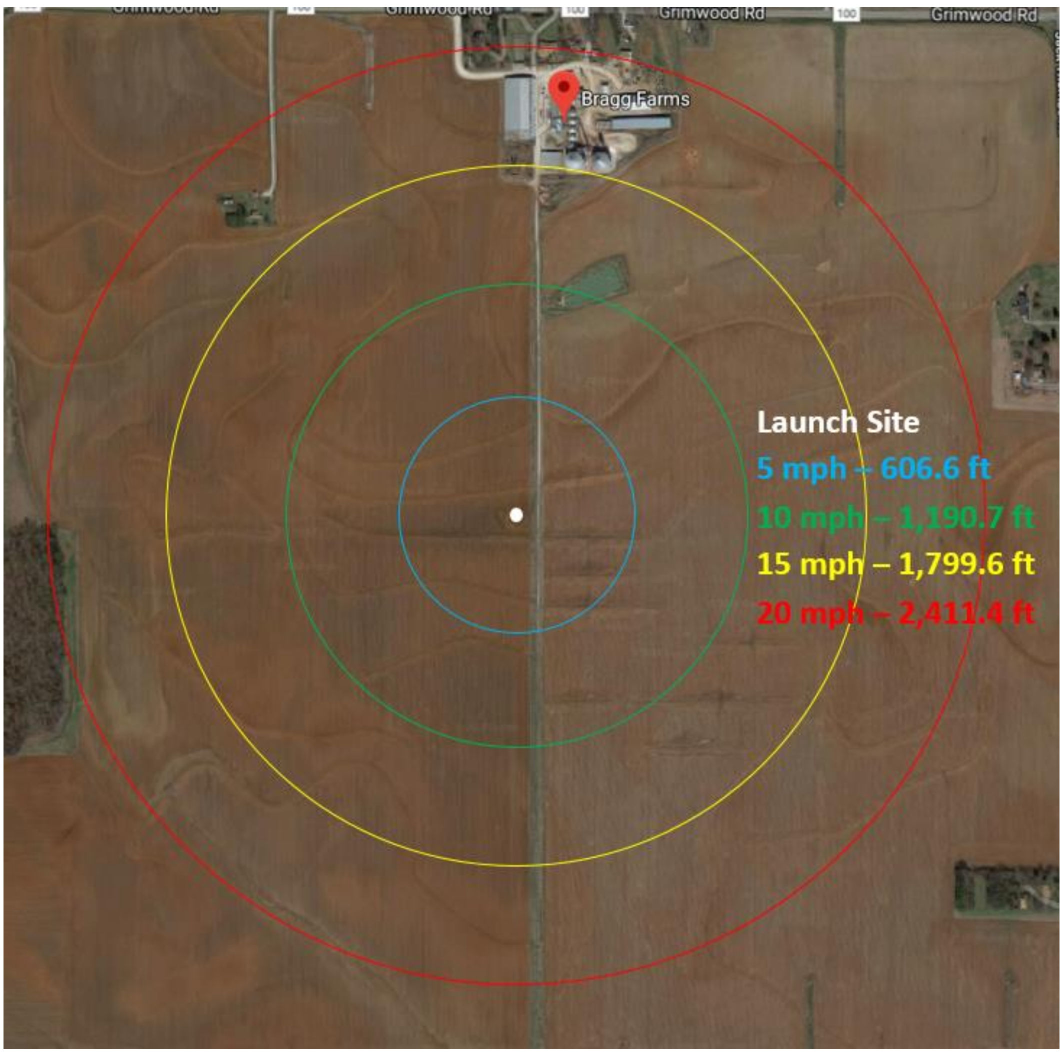

Figure 5-7: Visualization of Wind Drift from Hand Calculations

It is unknown how OpenRocket calculates lateral wind drift, so the team cannot confidently conclude that one method is more accurate than the other. Following a successful relaunch of the full-scale rocket, the team will use the wind drift results to justify the accuracy of either the OpenRocket simulation or hand calculations.

5.3.2 Kinetic Energy at Landing

To determine the kinetic energy of each independent section at landing, it was necessary to determine the maximum impact velocity, the terminal velocity, for each section based their respective empty masses. Limiting the terminal velocities establishes an upper limit for the impact velocity/descent rate of the falling rocket body, and will ensure that the falling rocket body will land with a kinetic energy less than the established maximum requirement.

Using MATLAB for analysis, the maximum impact velocities of each Section of the falling rocket body, with parachutes, can be defined as:

$$KE = \frac{1}{2}mV_i^2 \rightarrow V_i = \sqrt{\frac{2KE}{m}} \quad (16)$$

where KE is kinetic energy, m is the empty mass, and V_i is the impact velocity for the respective section. The empty weight of the rocket is defined as the total weight minus propellant and recovery harnesses, which was calculated to be 37.5 lb or 1.16 slugs. Using the assigned kinetic energy of 75.0 ft-lb_f and the known empty rocket mass of 1.16 slugs, the maximum allowable descent velocity of all section masses combined was calculated as 11.4 ft/s. However, the Student Launch handbook states that each independent section must not exceed 75 ft-lb_f at landing, not the entire rocket.

To study the kinetic energy of each independent section at landing, the team found the empty mass of each section then used Equation 16, above, to determine the maximum allowable descent velocity. Table 5-4, below, contains the empty mass and maximum allowable impact velocity for each independent section of the full-scale launch vehicle.

Table 5-4: Maximum Impact Velocity for each Independent Section

Independent Section	Mass (slugs)	Maximum Impact Velocity (ft/s)
Nosecone	0.15	31.62
Midsection	0.55	16.51
Fin Can	0.42	18.90

As shown in Section 5.1.1, the fastest predicted impact velocity across all of the varying windspeed cases was 13.7 ft/s at 10-20 mph. These results show that the parachutes have been sized properly and verify the recovery system described in Section 4. The design was further verified by the full-scale test launch which recorded an impact velocity of 9 ft/s. It is also important to note that the altimeters are located in the midsection which has the lowest allowable impact velocity. It can be concluded that each independent section will land with less than 75 ft-lb_f of kinetic energy.

6. Launch Vehicle Test Flight

6.1 Launch Day Conditions

The full-scale rocket was launched on February 24, 2018 from a field outside of Bayboro, NC located at 35.172°N, 76.832°W. The field is operated by the local Tripoli prefect and all launches are covered by an FAA waiver to 16,000 ft MSL. All three team mentors listed in Section 1.1.2 were present at the launch to help the team assemble the rocket and prepare for launch. Figure 6-1, below, shows the full-scale rocket after clearing the launch rail.

Figure 6-1: Full-Scale Launch Vehicle Moments After Ignition

The New Bern airport, located approximately 13 mi from the field, reported windspeeds of 9 knots (10.4 mph) from a heading of 250° at the time of launch. Since the launch site is a large, flat field, the localized windspeeds were assumed to be slightly greater. The team observed several rockets drifting far downrange due to faster upper-level winds.

6.2 Onboard Equipment

The rocket was equipped with two altimeters – a StratoLoggerCF as primary and Entacore as redundant – to record altitude and initiate rocket separation. The fin can separation was set to occur at apogee to deploy the drogue parachute. The LARD parachute was wrapped in a deployment bag and bound by a Jolly Logic Chute Release set to open at 700 ft AGL to deploy the LARD from its deployment bag. The nosecone separation was set to occur at 500 ft AGL to deploy the main parachute.

The rocket included mass simulators in the payload bay to mimic the weight and location of the payload electronics, rover electronics, and additional hardware. The electronic latch was installed in the payload to hold the rover structure during launch to prove the reliability of the latching system. The removable plug was included to seal the main parachute compartment and protect the rover bay during flight. Figure 6-2, below, shows the fully assembled payload with mass simulators and the avionics bay prior to installing the access hatch to complete the midsection assembly.

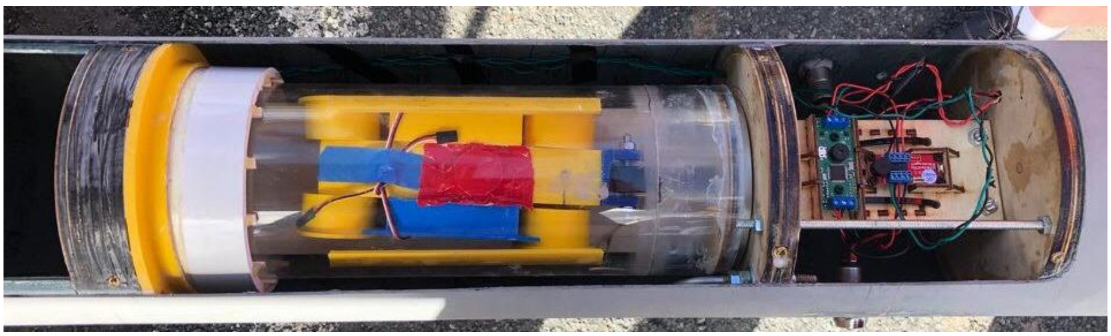

Figure 6-2: Assembled Payload and Avionics Bays Prior to Hatch Installation

The team was ready to launch at approximately 3:30 pm EST after one hour of preparation and three hours of assembly. The team hopes to reduce this time in the future by assembling much of the midsection prior to arriving at the field. Not only will this ensure that the team complete assembly within the allotted time, but it will also help reduce the risk of team members getting sunburnt or dehydrated.

6.3 Flight Profiles

This section contains the predicted data from OpenRocket and the actual flight results from the StratoLoggerCF altimeter for the maiden flight of the full-scale rocket.

6.3.1 Predicted Flight Model

The full-scale OpenRocket model was updated to have the same weight and CG location as the fully-assembled rocket. A flight simulation using OpenRocket was set up using steady 10.4 mph winds with a heading of 250°, as reported by the New Bern Airport weather statement. OpenRocket does not have an option for including gusting winds, and the effects of any wind gusts during flight would be difficult to predict regardless. The 18 in. drogue parachute was set to deploy at apogee, the 5 ft LARD parachute was set to deploy at 700 ft AGL, and the 10 ft main parachute was set to deploy at 500 ft AGL. The simulated rocket was fired from an 8 ft launch rail angled 5° from vertical in the downwind direction. Figure 6-3, below, shows a co-plot of flight time versus rocket altitude and vertical velocity.

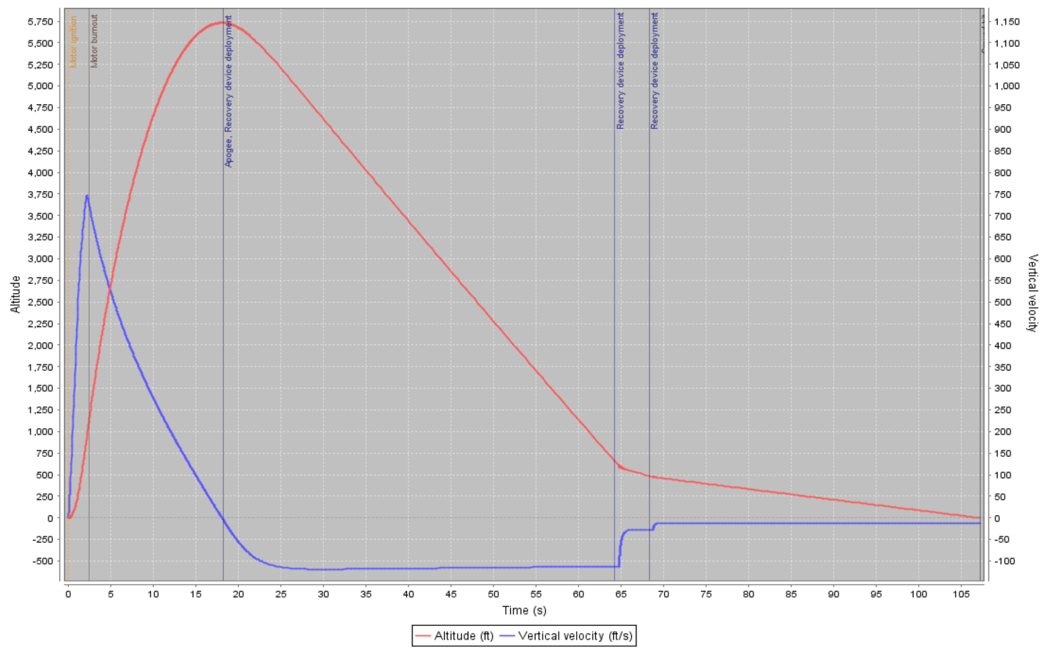

Figure 6-3: OpenRocket Flight Profile of Full-Scale Test Launch

The OpenRocket flight simulation predicted an apogee of 5,732 ft AGL, which is greater than the maximum allowable altitude of 5,600 ft AGL set by the NASA RSO. The maximum vertical velocity was predicted to be 747 ft/s, which is equivalent to Mach 0.67. The impact velocity of the subscale was predicted to be 11.5 ft/s which is both reasonable and within the design limits of the vehicle. The simulation also indicated a total flight time of approximately 108 seconds with drogue, LARD, and main parachute deployment at 18, 64, and 68 seconds, respectively. The predicted wind drift was 663 ft from the launchpad. These predicted values are all within safe levels for flight of the full-scale rocket.

As discussed in Section 6.5, the LARD parachute was deployed from its deployment bag at the correct altitude, but it did not have enough time to inflate before the main parachute deployed, thus tangling the LARD shroud lines in the main shock cord. The OpenRocket simulation was updated to keep the LARD onboard, but never actually deploy the parachute. Figure 6-4, below, shows the updated OpenRocket simulation where the LARD parachute is omitted from the recovery staging.

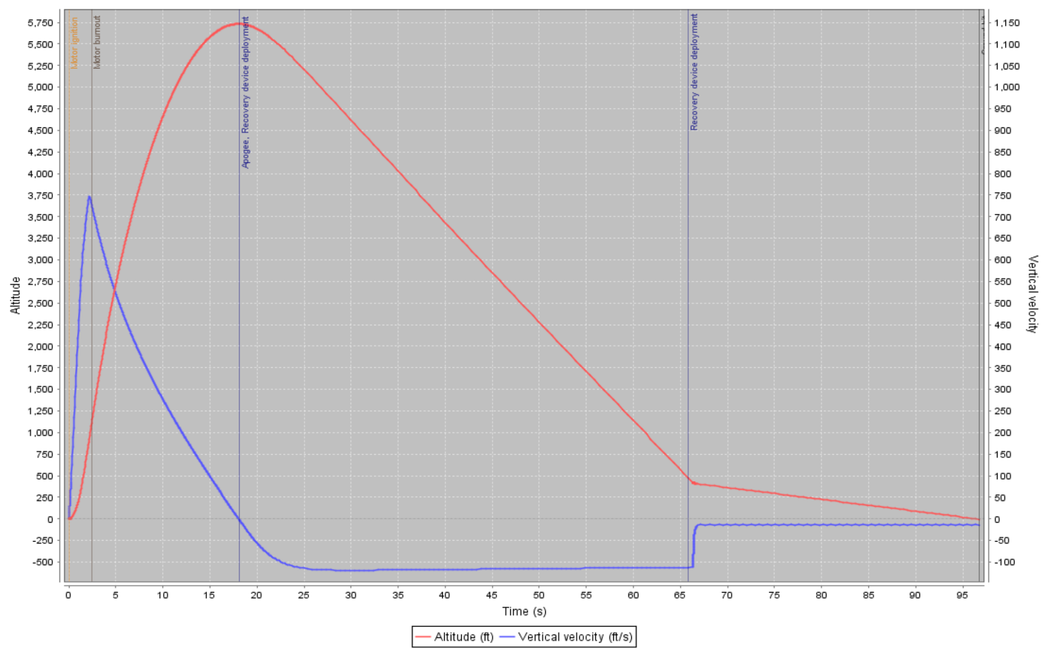

Figure 6-4: OpenRocket Flight Profile of Full-Scale Test Launch without LARD Deployment

The OpenRocket flight simulation predicted an apogee of 5,732 ft AGL, which is greater than the maximum allowable altitude of 5,600 ft AGL set by the NASA RSO. The maximum vertical velocity was predicted to be 747 ft/s, which is equivalent to Mach 0.67. The impact velocity of the subscale was predicted to be 12.9 ft/s which is both reasonable and within the design limits of the vehicle. The simulation also indicated a total flight time of approximately 97.3 seconds with drogue and LARD/main parachute deployment at 18.2 and 65.7 seconds, respectively. The predicted wind drift was 514 ft from the launchpad. These predicted values are all within safe levels for flight of the full-scale rocket.

6.3.2 Actual Flight Model

Flight data was recorded during the full-scale launch by the onboard StratoLoggerCF altimeter. Figure 6-5, below, shows a co-plot of data points taken from the StratoLoggerCF for flight time versus rocket altitude and vertical velocity.

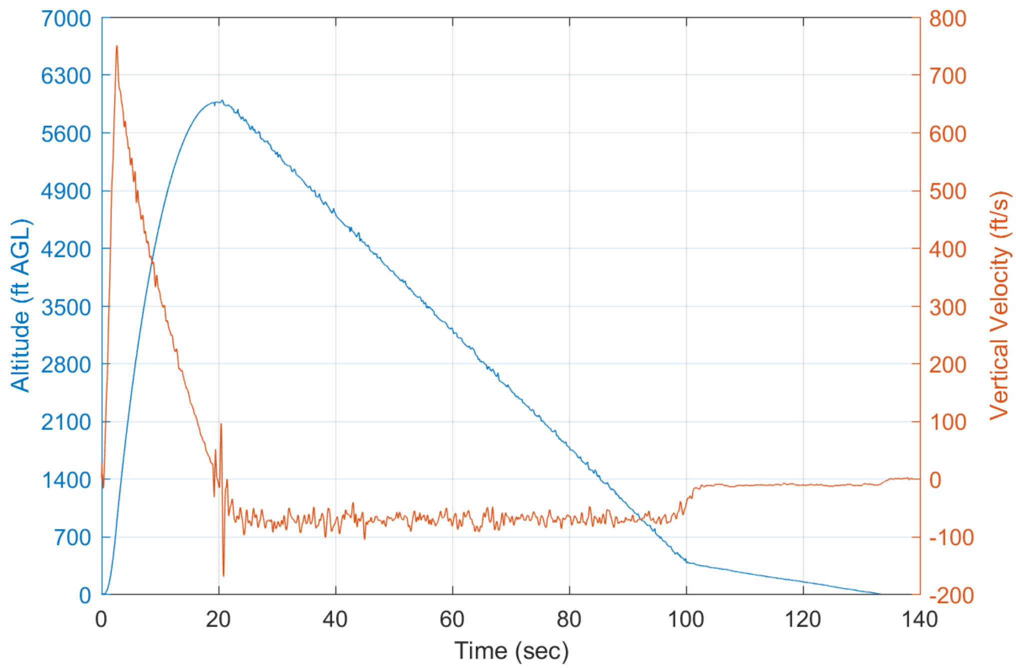

Figure 6-5: Actual Flight Profile of Full-Scale Rocket Test Launch

The StratoLoggerCF data indicated an apogee of 5,984 ft AGL, which is greater than the allowable altitude of 5,600 ft AGL set by the NASA RSO. The maximum vertical velocity was measured to be 751 ft/s, which is equivalent to Mach 0.67. The total flight time was 133.3 seconds with drogue deployment at 20.6 seconds and LARD/main deployment at 98.3 seconds. The rocket drifted a total of 1,783 ft from the launchpad before impacting the ground at 10 ft/s. Table 6-1, below, shows the predicted and actual flight profile results with the error value included as a percentage.

Table 6-1: Comparison of Predicted and Actual Subscale Flight Results

Condition	Predicted Value	Actual Value	Percent Error
Apogee	5,732 ft AGL	5,984 ft AGL	4.4%
Max Velocity	747 ft/s	751 ft/s	0.1%
Impact Velocity	12.9 ft/s	10.0 ft/s	22.5%
Time to Apogee	18.2 s	20.6 s	13.2%
Time to Parachutes	65.7 s	98.3 s	49.6%
Total Flight Time	97.3 s	133.3 s	37.0%

When comparing the OpenRocket simulation and actual flight results, the actual apogee is 4.4% greater than the predicted apogee for the same rocket configuration. This result is consistent with the subscale results which saw an actual apogee 4.2% higher than the predicted apogee. Using these similar results across two different flights, it can be assumed that OpenRocket will always underestimate the apogee altitude by up to 4.4%. Going forward, the team will apply a 4.5% increase in altitude to all OpenRocket simulations to get a more accurate value for predicted apogee for all rockets.

The predicted and actual values for maximum velocity are only different by 4 ft/s, which indicates a high level of accuracy within OpenRocket for predicting flight velocity and acceleration during the motor burn phase. However, OpenRocket has a much higher level of error when predicting the descent velocity and ground impact velocity of the rocket. The predicted impact velocity is 2.9 ft/s greater than the actual velocity, which corresponds to a 22.5% increase. It is likely that OpenRocket cannot compute the exact drag forces created by the tumbling, separated rocket during descent, which would slow the entire rocket even if no parachutes were deployed. These results correspond with the subscale simulation results, so it can be assumed that the OpenRocket values for descent and ground impact velocity will consistently be slightly greater than the actual flight values.

The OpenRocket simulation showed an extreme level of error when calculating the total flight time for the full-scale test launch. As described above, errors in calculating the additional drag from the tumbling, separated rocket likely allowed OpenRocket to underestimate the time to apogee, parachutes, and landing by up to 49.6%. This phenomenon was also observed when analyzing the subscale flight results, except with a much lower percent error of 6.8%. It can be assumed that OpenRocket simulations will underestimate the flight time, but there appears to be no consistent percent error for the results. In the future, it would be beneficial for Student Launch teams to combine the results from many different schools over many years to determine if an accurate percent error can be applied to the OpenRocket results.

Though the OpenRocket flight simulations can contain varying levels of error in the results, the software is still very useful as part of the design process for the full-scale rocket. The OpenRocket model gives a very accurate prediction of the CG and CP locations on the rocket, which are critical to the stability margin calculation. The OpenRocket model predicted a CG location of 66.1 in. from the nose, which was extremely close to the actual location 66.3 in. from the nose. After updating all the component weights in OpenRocket, the model weighed 44.5 lb and the actual rocket weighed 44.3 lb, which is close enough to be considered useful and accurate.

At minimum, the OpenRocket software can be used to provide an accurate model of the rocket with values for weight, CG and CP locations, maximum velocity, and apogee with minor corrections.

6.4 Estimation of Drag Coefficient

The drag coefficient for the full-scale rocket used during the test launch was predicted by OpenRocket to be an average of 0.39 during the ascent phase of the flight. This value is nearly identical to the subscale rocket, which had a predicted C_D of 0.42 during ascent. Both subscale and test launch full-scale rocket were painted smooth prior to launch to reduce surface roughness. It can be assumed that the value for C_D produced by OpenRocket is both reasonable and accurate for use with rocket designs.

The magnitude of total drag acting on the rocket is the result of a combination of factors including paint, finish, fin epoxy fillet radii, nosecone shape, and body diameter. The team used wood filler on the exterior of the Blue Tube airframe to create a smooth surface for painting. After sanding the exterior surface, three coats of primer paint were sprayed and sanded with high grit sandpaper to ensure a smooth, uniform exterior surface. The same painting process was applied to the fins and nosecone which did not require any wood filler prior to paint. The fins feature epoxy fillets with a radius of curvature of 0.5 in. to reduce stress concentration at the intersection of each fin and the body tube. After the epoxy had cured, the joints were sanded to create a smooth transition from fin to body tube and painted using the process described above. The leading and trailing edges of the fins were sanded to a point to better ensure that the airflow will remain laminar along the surface during flight, thus reducing the surface drag towards the tail of the rocket. At the time of launch, the rocket exterior was smooth and uniform all along the body with the only surface perturbations being the small screw heads used to secure the access hatch described in Section 3.4.4.8 and the key switches described in Section 4.4.1.

6.5 Launch Vehicle Recovery

The full-scale rocket contained all of the recovery equipment described in Section 4 of this report, with the Jolly Logic Chute Release set to open at 700 ft AGL. During the post-flight analysis, the team studied photos taken of the descending rocket to determine if the LARD had activated correctly. The team has concluded that the Jolly Logic Chute Release did open correctly, but that the LARD parachute did not have enough time to unfurl the deployment bag, deploy the pilot parachute, and fully inflate before the main parachute deployed, thus tangling the LARD shroudlines in the main parachute shock cord.

Figure 6-6, below, was taken when the rocket was approximately 600 ft AGL and clearly shows the drogue parachute and LARD pilot parachutes inflated.

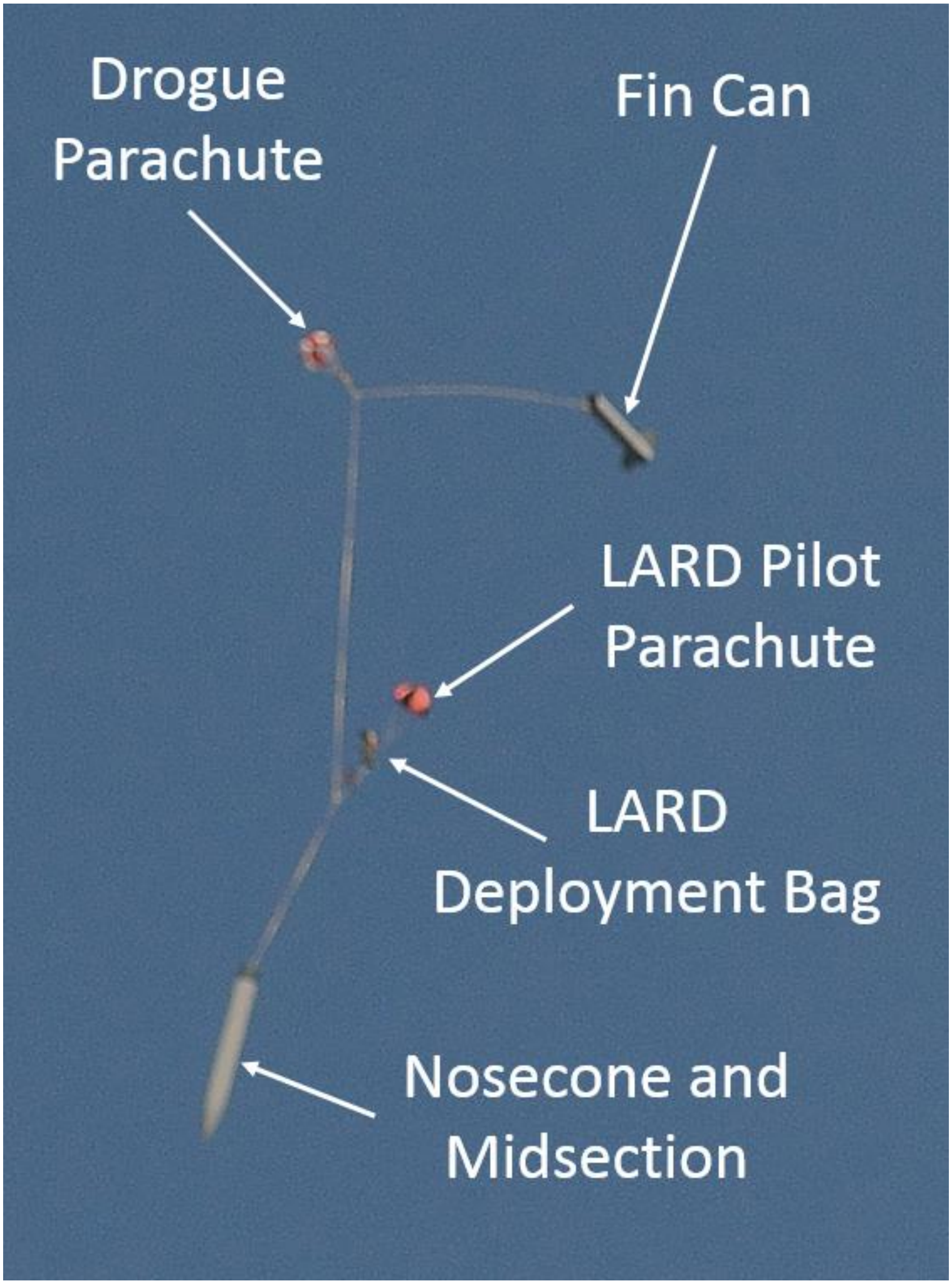

Figure 6-6: Photo Taken Before Main Parachute Deployment

Figure 6-7, below, was taken when the rocket was approximately 400 ft AGL after the main parachute had fully inflated. Note the dark smoke cloud at the top of the image from the nosecone separation event.

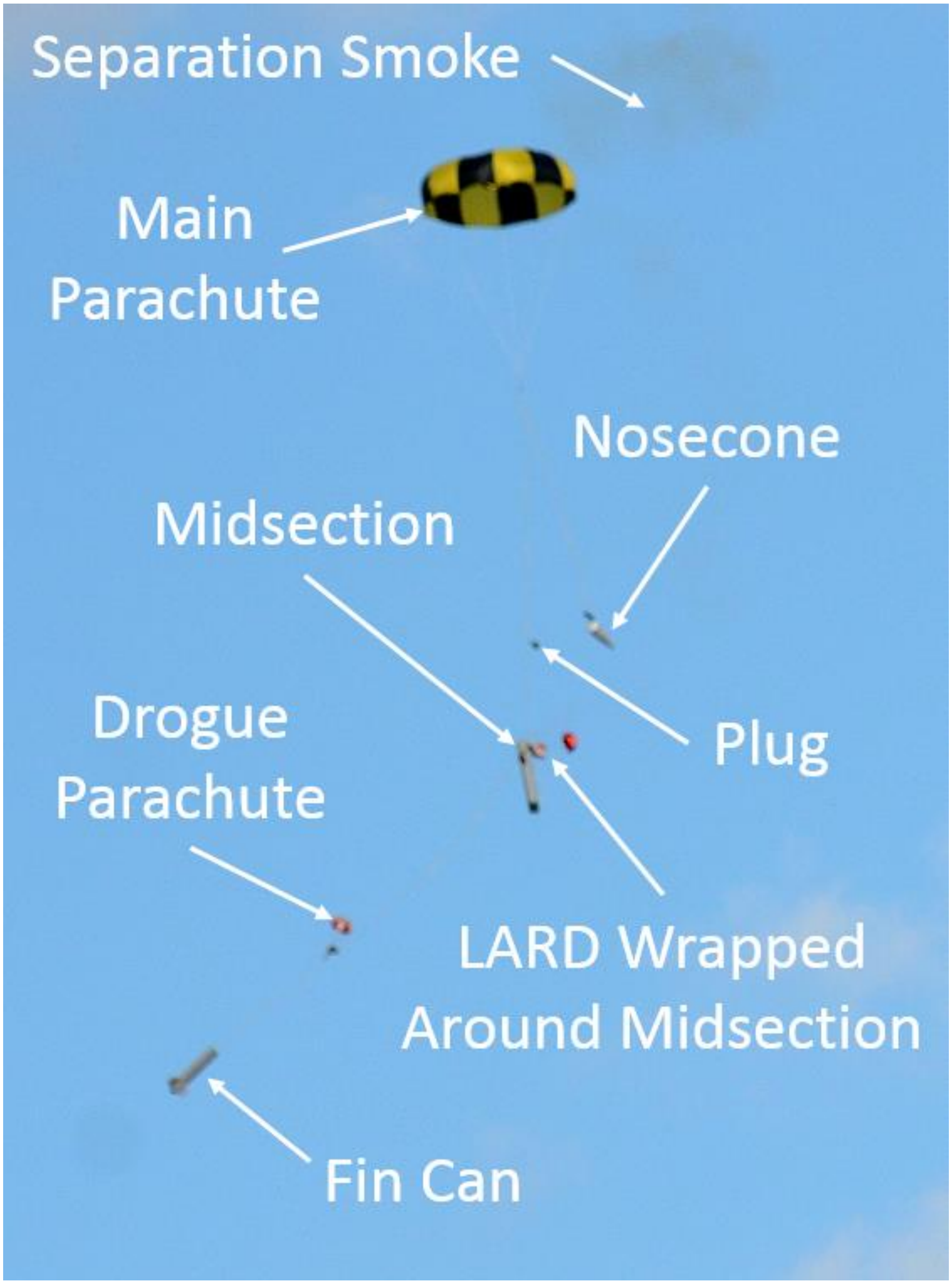

Figure 6-7: Photo Taken After Main Parachute Deployment

The two images above clearly show that the LARD pilot parachute deployed, but that the LARD was never able to fully inflate. To correct this issue prior to the re-flight, the team will conduct drop tests of the LARD assembly to determine the time necessary for the parachute to inflate and normalize. This will allow the team to coordinate the deployment events in order to not damage the rocket body or parachutes, and to ensure the safety of those on the field.

6.5.1 Wind Drift

As described in Section 6.1, the windspeed was approximately 10.4 mph at the time of launch, which is equivalent to 15.3 ft/s. Using the StratoLoggerCF data, the descent time for the test launch was 112.8 s, which is 22.9 s longer than the descent time predicted by OpenRocket. Using the steps shown in Section 5.3.1.1, the lateral wind drift distance was calculated to be 1,720 ft from the launchpad. This value exceeds the wind drift calculations from OpenRocket, but still rests within the 10-15 mph target range for the hand calculations shown in Figure 5-7.

Figure 6-8, below, shows the GPS track for the test launch using the GPS receiver described in Section 4.4.4. Note that the red line in the image intersects the takeoff and touchdown points.

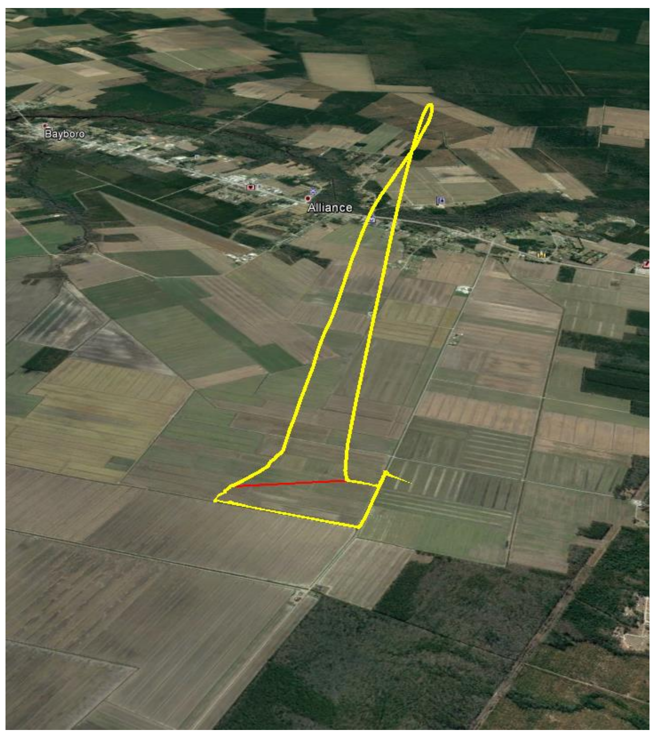

Figure 6-8: GPS Track of the Full-Scale Test Launch

The GPS data shows that the rocket drifted approximately 1,901 ft from the launchpad to the initial impact location. This value is much higher than expected, but does not exceed the 2,500 ft maximum drift distance. These results show that the hand calculations described in Section are more accurate than the wind drift values predicted by OpenRocket, though both underestimated the amount of drift for 10.4 mph winds.

The rocket itself was recovered an additional 150 ft away from the impact location, which indicates that the rocket was dragged by the main parachute the same distance. Unfortunately, it is not possible for the team to stop the parachute from dragging the rocket in high winds. Instead, efforts to repair and reinforce the full-scale airframe are described in Section 6.8.

6.6 Payload Results

Though the payload was not flown on the test launch, it was still important to test whether the electronic latch described in Section 7.4.5.2 could withstand the launch and landing forces without releasing the rover improperly. After recovery, the latch was discovered to be still in the closed position and the rover components were completely undamaged. The test launch confirmed that the payload bay components could withstand a flight on the full-scale rocket.

6.7 Post-Flight Inspection

The rocket was recovered by a pair of team members to simulate conditions at the competition launch where only 2-3 team members can venture downrange to recover the rocket. Figure 6-9, below, shows the two team members recovering the rocket at the field.

Figure 6-9: Recovering the Rocket After Landing

As shown in the image above, the three independent sections of the rocket landed slow enough to not cause damage from impact alone. However, the fin can sustained major water damage after being dragged through the mud and a small creek. The ground scar from the fin can is shown on the left side of the image above and spans over 150 ft.

Upon arrival, the first step for recovery was to control the main parachute and stop it from dragging the rocket any further. One team member tackled the parachute while the other started recovery operations. After photos were taken of each component, the shock cord lines were disassembled and the carried back to the launch area. Figure 6-10, below, shows one of the team members carrying the midsection back to the launch area.

Figure 6-10: Recovering the Midsection

After all components were recovered, the team performed a post-flight inspection on the rocket using the checklist shown in Section 9.9. The team photographed and cleaned each component before disassembling the rocket.

6.7.1 Midsection Body Tube Damage

The midsection parachute cavity sustained structural damage from the main parachute shock cord and water damage from landing in the wet, muddy field. The main parachute shock cord "zippered" the wall of the main parachute cavity during descent, which was likely caused by the LARD not inflated before the main parachute. Figure 6-11, below, shows the midsection main parachute cavity before it was recovered from the field. Note the shock cord "zipper" on the left side of the image.

Figure 6-11: Midsection Zipper and Water Damage

Had the LARD fully inflated, the deceleration of the rocket during main parachute deployment would have been much smaller and damage to the midsection body tube would have been unlikely. Section 6.8.2 describes the repairs made to the midsection body tube in the days following the launch.

6.7.2 Fin Can Body Tube Damage

The fin can parachute cavity sustained major water damage from landing in the muddy, wet field. Figure 6-12, below, shows the fin can before it was recovered from the field, still full of water and mud.

Figure 6-12: Fin Can Filled with Mud

Blue Tube does not resist warping from humidity or water very well, and the body tube material expanded into the cavity. It was no longer possible to fit the midsection coupler into the fin can due to the extensive damage. Section 6.8.3 describes the repairs made to the fin can body tube in the days following the launch.

6.8 Design Alterations

This section contains a description of the repairs and reinforcements made to the full-scale launch vehicle following the test launch. The following design alterations, repairs, and reinforcements will be completed prior to the full-scale re-flight scheduled for March 24, 2018.

6.8.1 LARD Deployment Altitude

After analyzing the photos taken of the full-scale recovery, it will be necessary to alter the Jolly Logic Chute Release separation altitude to allow more time between LARD deployment and main parachute deployment. The team intends to perform drop tests of the LARD assembly to determine the time necessary to allow the LARD parachute to exit the deployment bag and inflate. After inflation, an additional delay will be necessary to ensure that the rocket descent velocity has normalized prior to main parachute deployment.

6.8.2 Midsection Body Tube Repair

The midsection of the full-scale launch vehicle experienced zipper damage from the forward end of the body tube to the forward end of the access hatch coupler – a length of approximately 5 inches. The body tube was manipulated to realign the zippered section along the seam. Epoxy was applied to the interior and exterior surfaces of the body tube around the zipper damage. Using extra sections of body tube, the zippered area was clamped both internally and externally to create a smooth surface finish and force the damaged body tube back to its original shape and diameter. The result of this process is shown below in Figure 6-13 and Figure 6-14

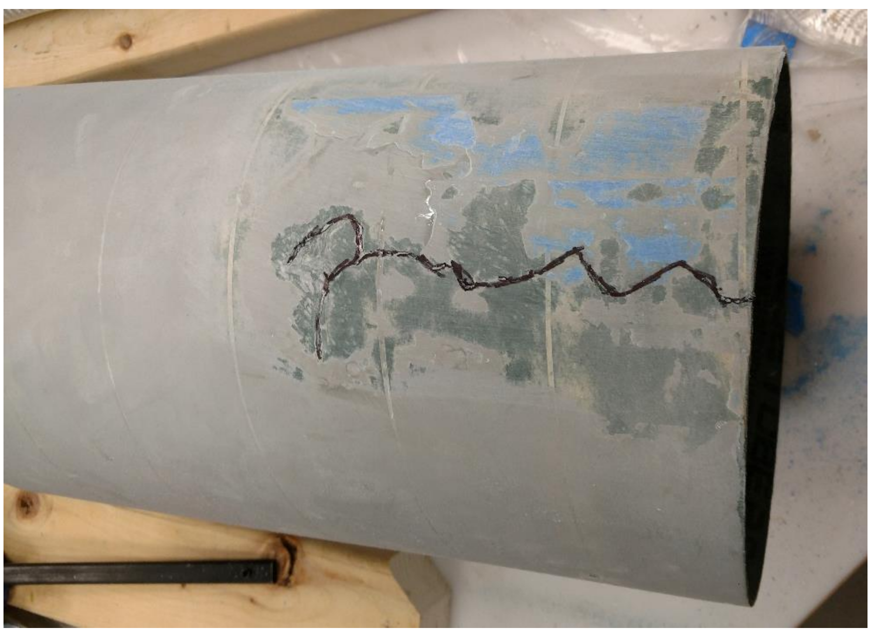

Figure 6-13: Bonded Midsection Zipper

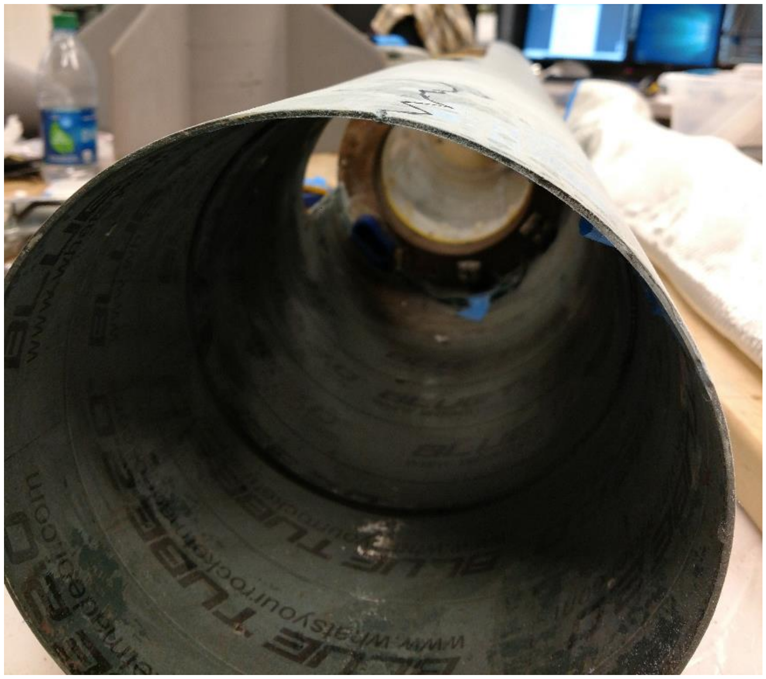

Figure 6-14: Bonded Zipper Interior Profile

Looking at the profile of the bonded zipper damage, it is obvious that the above process produced a smooth, solid seam and the body tube was returned to its original dimensions. Once fully cured, fiberglass was wrapped around the body tube over the damaged area and impregnated with West Systems 105 Epoxy and 206 Slow Hardener to regain the hoop strength of the midsection. The wet layup was clamped radially using extra sections of body tube and left to cure for 24 hours. The fiberglass was trimmed and sanded to produce a smooth surface finish and transition.

6.8.3 Fin Can Body Tube Repair

The forward edge of the fin can received minor water damage upon retrieval of the full-scale launch vehicle. The water damage caused the layers of Blue Tube to delaminate – deforming the body tube. The location of deformation is critical, as the fin can must fit perfectly to the midsection coupler. A process similar to that used to repair the midsection was used to return the fin can to its original dimensions. Clamps and extra sections of body tube constrained the fin can while epoxy cured the body tube. A single layer of fiberglass was wrapped around the fin can in the damaged area to add further water protection, thus increasing the reusability and recoverability of the full-scale launch vehicle.

7. Payload Criteria

7.1 Compliance to Handbook Requirements

Table 7-1, below, contains the deployable rover experimental payload requirements listed in the 2018 NASA Student Launch handbook as well as the respective compliance actions, verification methods, and status.

Table 7-1: Full-Scale Experimental Payload Handbook Item Compliance

Handbook Item	Description of Requirement	Compliance	Verification Method	Verification Description	Report Section Location
4.1	Each team will choose one design experiment option from the following list: target detection, deployable rover, or landing coordinates via triangulation.	The team has chosen option 2: the deployable rover.	Demonstration. The team will construct a rover and will not perform the other experiments.	Complete. The team chose option 2: the deployable rover.	Section 7.2
4.2	Additional experiments (limit of 1) are allowed, and may be flown, but they will not contribute to scoring.	The team has chosen not to perform additional experiments.	Demonstration. The team will construct a rover and will not perform the other experiments.	Complete. The team chose not to perform additional experiments.	Section 7.2
4.3	If the team chooses to fly additional experiments, they will provide the appropriate documentation in all design reports, so experiments may be reviewed for flight safety.	The team has chosen not to perform additional experiments.	Demonstration. The team will construct a rover and will not perform the other experiments.	Complete. The team chose not to perform additional experiments.	Section 7.2
4.5	Deployable rover challenge requirements.	See below.	N/A	N/A	N/A
4.5.1	Teams will design a custom rover that will deploy from the internal structure of the launch vehicle.	The rover is an original design and is stowed within the full-scale launch vehicle payload bay during flight.	Demonstration. The team will design and produce a custom rover that will be stowed within the full-scale rocket during flight to deploy after landing.	Incomplete. A mass simulator resembling the final rover was used on the full-scale test flight, and the final rover will be flown on the re-flight scheduled for March 24, 2018.	Section 7.2
4.5.2	At landing, the team will remotely activate a trigger to deploy the rover from the rocket.	A pair of male-to-female wires connects the latch remote receiver with the rover computer, and a signal is sent across the wires to activate the rover.	Demonstration. The team will use the connection between the receiver and the rover to activate the rover.	Incomplete. No form of deployment was used during the full-scale test flight. The umbilical cord method of deployment will be tested during the full-scale re-flight on March 24, 2018.	Section 7.5.3
4.5.3	After deployment, the rover will autonomously move at least 5 ft. (in any direction) from the launch vehicle.	The motors that are responsible for the rover's motion remain active long enough for the rover to move at least 5 ft.	Demonstration. The two servos will rotate such that the treads are pulled around the housing, causing forward motion.	Complete. Initial testing with the rover design used in the full-scale test flight has shown that the rover can drive under its own power.	Section 7.5.2
4.5.4	Once the rover has reached its final destination, it will deploy a set of foldable solar cell panels.	A sail system is deployed by an arm controlled by a motor on top of the rover.	Demonstration. A servo activated after the rover reaches its final destination will rotate an arm which unfurls the solar panels.	Incomplete. The solar sail has not been fabricated or tested yet. The team will test the solar sail system before the competition launch.	Section 7.5.2.4

7.2 Mission Statement

The payload is a custom designed rover, which is to deploy from the internal structure of the launch vehicle upon remote triggering. During flight, it is housed in the payload tube, which is rotating about a Lazy Susan bearing system. Upon landing, the payload tube self-rights, and the electric latch keeping the rover in the tube is unlocked. At the same time, the rover exits the payload tube is to autonomously drive 5 ft in any direction and deploy foldable solar cell panels upon reaching the final resting point. The solar panels will be deployed using a rotating arm with folded panels attached. As the arm rotates, the panels unfurl. The experiment is considered to be successful when the rover deploys from the launch vehicle, travels the required distance, and deploys the solar cells with minimal damage.

7.2.1 Mission Success Criteria

The experiment is considered to be successful when the rover deploys from the launch vehicle, travels the required distance, and deploys the solar cells with minimal damage.

7.3 Design and Rationale of Payload

This section contains digital models, technical specifications, design justifications, and fabrication images of the deployable rover and payload bay used to house the rover during flight.

7.3.1 Changes to Payload Bay Structure Since CDR

Since the CDR, the forward bearing material has changed and the electronics were upgraded to transmit more reliably over a longer range.

7.3.1.1 Forward Bearing Material Change

During the assembly of the payload, installing the ball bearings into the forward ball bearing track and keeping them in place while attaching the Schedule 40 PVC contacting piece was difficult. To eliminate this trouble, the team took the ball bearings out and used Sta-Lube Super White multipurpose grease. This grease does not have a friction coefficient resulting in the payload to still roll freely during flight. Figure 7-1 is an image of the forward bearing during the full-scale test launch with Sta-Lube grease.

Figure 7-1: Forward Bearing with Sta-Lube Grease for Lubrication

The payload weight was approximately 3 lb underweight during the full-scale test launch. This resulted in the rocket exceeding the desired 5,280 ft apogee critically. To lower the apogee to the desired level, more weight must be installed in the payload. The team is working on changing the forward bearing system from the ABS plastic to 6061 aluminum. This change will increase the weight of the payload by 0.5 lb. The team will use the ball bearings with the new aluminum piece which will also add 0.07 lb.

7.3.1.2 Rover Bay Electronics Long-Range Upgrade

The team changed the transmitter and receiver for the payload latch to meet the requirement of being able to trigger the rover from 2,500 ft away. The triggering system described in the CDR had a maximum range of 60 ft using components that had been donated to the team. To increase the range of the receiver without breaking FCC regulations, the team will use a Seeedstudio 433 MHz RF long distance transmitter/receiver pair. This new transmitter/receiver pair has the capability to reach up to 2 km (6,562 ft), far exceeding the 2,500 ft required maximum distance.

7.3.2 Changes to Rover Since CDR

Since writing the CDR, a few modifications to the structure and operation of the rover have happened. Improvements have been made to the structure of the rover body as well as on board electronics.

7.3.2.1 Body Structure Improvements

After constructing the first rover, it was found that there was little contact area between the body and the track housings, so tabs were added to allow for screws to be used. It was also noted that the rover was too long for the treads to wrap around the wheels, so the rover was shortened. The latch screw mechanism was also improved; instead of being vertical, the latch screw is now in a more secure horizontal position.

7.3.2.2 Rover Electronics

Coding on the MSP430 proved to be unnecessarily complex when Arduino could be used to perform the same functions with considerably less computation. Because of this, the team decided to replace the MSP430 with an Arduino Micro. Since the team cannot approach the vehicle after it lands, the latch system will be activated by a more powerful transmitter/receiver. To ensure that there will be no interference between latch and rover electronics, only one transmitter/receiver will be used. To activate the rover, the latch receiver will send a signal via wire from one of its digital I/O pins to a digital I/O pins on the Arduino Micro.

7.4 Design and Fabrication of Payload Bay

This section contains the technical specifications, design justifications, and fabrication images for the payload bay design that will house the rover during flight. Figure 7-2, below, shows the full assembled payload bay before adding the rover.

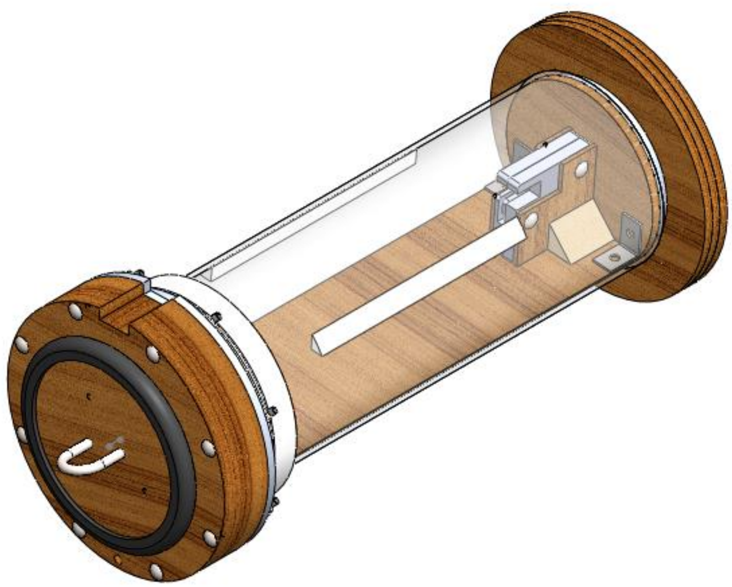

Figure 7-2: Isometric View of Assembled Payload Bay without Rover

Note that the payload centering ring plug and bulkheads are not included in the weight calculations for the payload bay. The forward plug is described in Section 3.4.4.4.

7.4.1 Dimensions and Technical Specifications

The length of the payload bay section is 15.5 in. between opposing interior faces of the bulkheads. The weight of the payload bay structure without rover is 5.94 lb. Table 7-2 shows the components of the payload integration system and their individual weight.

Table 7-2: Payload Bay Component Weights

Component	Weight (lb)
Payload tube	1.22
Rover Platform	0.23
Rover Supports x 2	0.05
Platform Seal	0.09
Payload Latch	0.15
Latch Support	0.04
Forward Bearing Track	0.71
Aft Lazy Susan Bearing	0.45
Payload Tube Bearing Mount	0.11
Forward Centering Ring	0.78
Aft Bulkhead	0.72
PVC Bearing Contact Piece	0.21
Payload Tube Spacers x 12	0.01
AA Battery and Clip x 2	0.55
C Batteries x3	0.47
Platform L-Bracket x2	0.04
Ball Bearings x74	0.07
Latch Support Hardware	0.01
Centering Ring Hardware	0.03
Total	**5.94**

With an empty weight of 5.94 lb, the payload must house a rover weighing at least 1.06 lb to meet the desired total weight of 7.0 lb in the payload bay. Section 7.5.1 contains analysis for the rover weight.

7.4.2 Payload Bay Tube

The payload tube is a 5.25 in OD x 5 in ID acrylic tube that is 14 in. long. This tube is the housing for the rover during the flight. Figure 7-3 is a model of the payload tube supported between the two bulkheads.

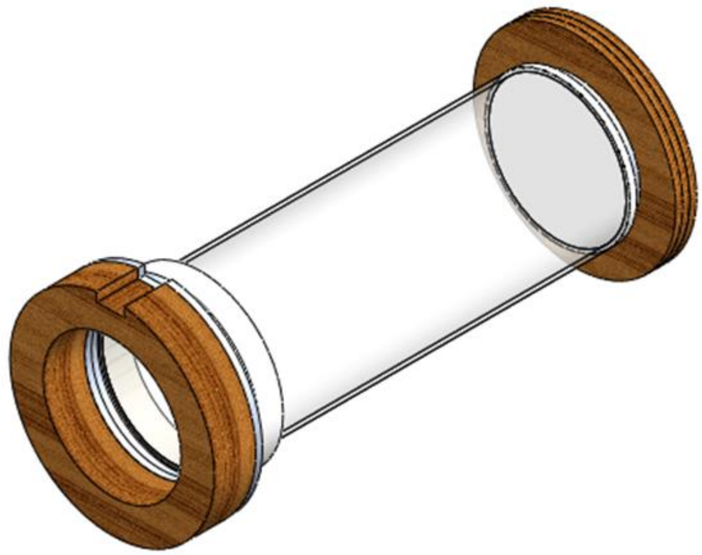

Figure 7-3: Isometric Model of Payload Tube Supported Between Bulkheads

The forward bearing will be attached to the payload centering ring described in Section 3.4.4.3 and the aft bearing will be attached to the forward avionics bulkhead described in Section 3.4.4.5.

7.4.2.1 Rover Bay Access Hole

A hole was drilled into the payload tube using a ½" machine drill bit in order to access the screws in the L-bracket that secures the rover platform to the wooden disk at the aft end of the payload. After drilling the hole, however, it was discovered that the angle needed to get the screws is not adequate for the screwdrivers used to secure the screws.

7.4.3 Payload Bay Bearings

The payload tube will be in between two Lazy Susan bearing systems to promote rolling during the launch vehicle's descent to ensure the payload is orientated in a deployable position after landing. Acrylic was chosen due to its strength and transparency.

7.4.3.1 Forward Bearing

The forward bearing system is an original design. The design is made of 6061 aluminum was constructed in one of NC State's machine manufacturing labs. Changing aluminum will increase the payload weight and will decrease friction between the ball bearings and the piece. The initial design used in the test launch was constructed of ABS plastic. ABS plastic was chosen for this design due to the team's capability of creating it on a 3D printer. To save material but to ensure the print is adequately strong, this design was printed using a 40% infill with a bed temperature of 80 degrees Celsius and a nozzle temperature of 220 degrees Celsius. The aluminum design is similar to the ABS design except the aluminum piece will have one size ball bearing track and PVC track. This design was implemented because it was easier to manufacture. This new design now requires the walls of the PVC to decrease to a size of 5 mm.

This bearing system connects to the payload tube via a 5 in. schedule 40 PVC connector piece. This piece has the dimensions of 6 in. outer diameter, 5.5 in. inner diameter, and a height of 2 in. This piece is designed to be attached to the payload tube with wooden strip spacers in between. These wooden strips were manufactured from a piece of .125 in. birch plywood and attach to the to the payload tube with one end flush with the tube forward edge. Using the bearing track, the appropriate leading edge difference was found by inserting the PVC piece into the ball track with the ball bearings insert in the track. The payload tube is inserted inside the PVC piece and resting on the inner wall of the ball track. During construction, a level was used to make sure the system was leveled when the PVC was attached to the support pieces. Hot glue was used to attach the PVC to the support pieces. This attachment has been deemed secure after multiple ejection tests and a test launch.

The aluminum bearing track will be attached to the payload centering ring by eight .25 in. lag bolts and nuts. These will be mounted radially around the center in 45 degree spacing. Both designs have a 1 in. slot in them for the main parachute shock chord. Opposite of this slot is another .25 in. hole for wires for the electric charges. Figure 7-4 is a model of the aluminum bearing carrier.

Figure 7-4: Model of the Aluminum Bearing Carrier

The aluminum bearing carrier was manufactured and will be included in the full-scale rocket during the re-flight scheduled for March 24, 2018.

7.4.3.2 Aft Lazy Susan Bearing

The aft Lazy Susan Bearing is a VXB 120mm Lazy Susan Bearing Turntable Bearing. This bearing has a 120 mm (4.7 in.) outer diameter and a 60 mm (2.4 in.) inner diameter. It is 10 mm in thickness. This bearing was chosen because the inner ring and outer ring are optimal for attaching the bearing to the tube and since it is a manufactured product, its proper function is a guarantee. The LSB is attached to the tube via a 5 in. birch plywood disk. This disk was laser cut to guarantee precision. It is attached to the interior of the payload tube at the aft end with the edges flush. The LSB is then secured to the disk with screws provided by the manufacturer. Washers are used to prevent the LSB from making contact with the wood, resulting in no friction between the two parts preventing roll. To attach the LSB to the avionic bay bulkhead, holes had to be drilled through the disk in order to expose the screw holes. 1” screws are used to attach the LSB to the bulkhead. Figure 7-5 is a side view of the model of the bearing between the wood tube disk and the avionics bulkhead.

Figure 7-5: Aft Lazy Susan Bearing Installed on Full-Scale Launch Vehicle

After fabrication was complete, the team tested the aft Lazy Susan Bearing to ensure that it was capable of self-righting on its own. A small weight imbalance was created within the payload tube, and the bearing successfully self-righted itself.

7.4.4 Rover Bay Platform

The rover platform is created two .125 in birch plywood pieces epoxied together. These two pieces were fabricated with a laser cutter due to the precision it can cut. The platform is designed to rest 1.25 in below the lateral axis in the payload tube. The width of the platform to fit at this distance below is 4.0 in. and the length of platform is 13.75 in. After the two pieces were epoxied together, they long edges were sanded to match the interior curve of the tube.

At the forward end of the platform, an ABS plastic piece is used to create a protective barrier for the electronics underneath the platform from the elements. This piece was created using a 3D printer for reasons of the printer is capable of producing the complex shape of the piece. The piece is design to fit the curve of the tube below the platform.

This design was tested during the full-scale test launch with Sta-Lube Super White multipurpose grease instead of ball bearings. This was done as an alternative method of producing no friction between the tube and the bearing system.

The payload latch is mounted to the aft end of the platform. A .75 in. by 1.5 in. slot was cut out of the platform to allow the latch sit parallel with the platform. The latch is orientated so that the cam faces upwards and rotates counterclockwise while released. The latch is mounted in between two plywood pieces manually cut that covers all of latch except for the cam. Two holes were drilled in the plywood pieces to allow a #8-32 bolt, washer, and #8-32 nut for each hole to secure the latch. Two .8x.8x1.5 in. triangles were cut from a 2x4 in. board to support the latch and mount. Figure 7-6 is a side view of the model of the platform and the latch brace.

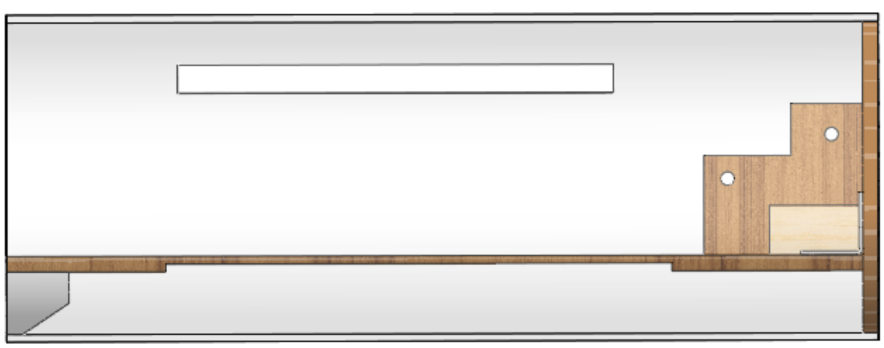

Figure 7-6: Side View of the Platform with Latch Brace

Figure 7-7, below, shows the full payload tube attached to the forward 3D printed carrier bearing and aft lazy susan bearing.

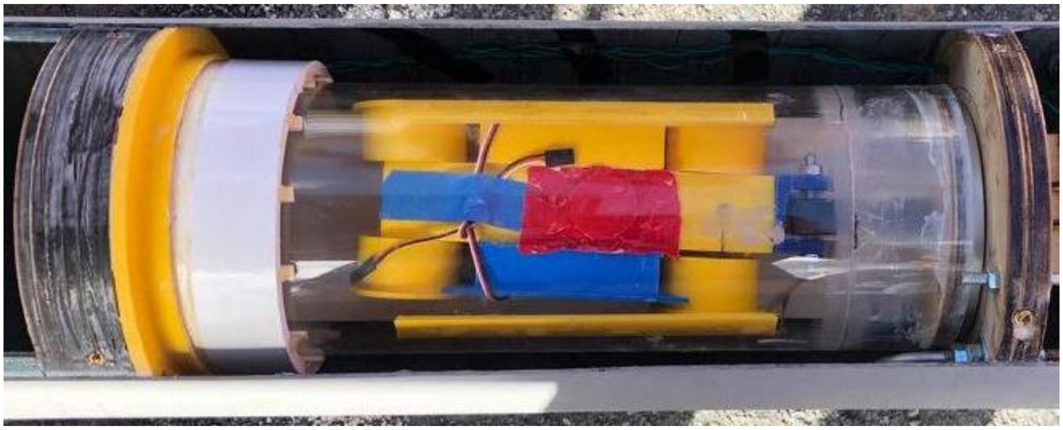

Figure 7-7: Top View of Payload Installed in Full-Scale Launch Vehicle

When fabricating the tube, the team was unable to acquire a 14 in. long acrylic tube in time for assembly, so two tubes were combined to create the desired length. A 12 in. tube and 2 in. tube were combined using Loctite acrylic epoxy which can be seen on the right side of the image above. The acrylic is no longer clear due to the use of sandpaper to ensure a smooth joint.

7.4.5 Rover Bay Electronics

The payload will contain electronics to trigger the latch and release the rover and initiate its deployment.

7.4.5.1 Long-Range Receiver

As stated in Section 7.3.1.2, the team is using a Seeedstudio 433MHz RF Long Distance Transmitter/Receiver Pair to trigger the latch and start the rover. This transmitter/receiver pair has the capability to transmit up to 2 km. This maximum range exceeds the maximum transmitting range given. This transmitter transmits a 433.92MHz frequency over a bandwidth of 1.5MHz and requires 3-9V to operate.

The receiver operates with 5V of power. This receiver has seven connective pins. One pin for power input, one for ground, 4 data pins, and power output pin. The receiver batteries are connected to the power input and output of the receiver. The ground pin is connected to the ground pin in the latch. Although there are 4 pins for data, only two are utilized. One data pin connects to the latch to trigger the unlock mechanism and the other connects to a pin on the rover to trigger the Arduino on the rover. Figure 7-8 is an image of the transmitter and receiver pair provided by Seeedstudio's website.

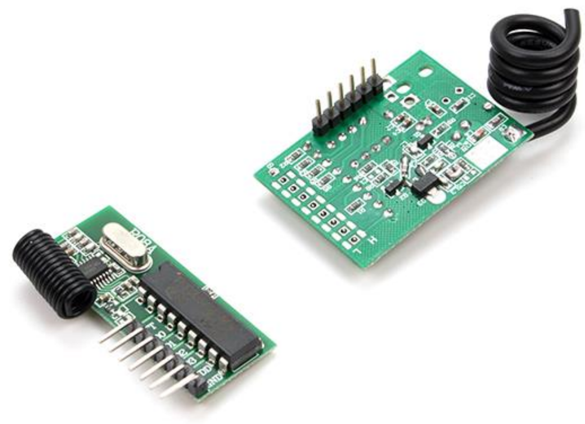

Figure 7-8: Seeedstudio 433 MHz RF Long Distance Transmitter/Receiver Pair

This receiver and transmitter pair will be purchased on March 9, 2018 and will be tested immediately after delivery. To test the transmitting distance, the team will take the Seeedstudio receiver/transmitter pair to a local park. Before going to the park, a distance of 2500 ft will be determined via Google Maps. The receiver will be wired to the three C batteries and the latch will be wired to the two AA battery clips. At the park, one team member will be at one end of the field with the transmitter while the other walks the 2,500 ft with the receiver and rotary latch. At increments of 200 ft the team member with the transmitter will test the transmitting power. If the transmitting distance exceeds 2500 ft, the test will be successful, if the transmitting falls short, the battery power provided will be adjusted and the test will be conducted again.

7.4.5.2 Electronic Release Latch

The rover will be secured in the payload tube by a Southco R4-EM-161 electronic rotary latch. This latch is powered by 12V. The latch has 6 pins: power input, ground, control input, common input, normally open, and normal closed. The power input, ground, control, and common are used. The power input is connected to the battery, the ground is connected to the ground in the receiver, and the control is connected to the data 1 pin on the receiver. Figure 7-9 is an image of the Southco latch provided by the Southco website.

Figure 7-9: Southco R4-EM-161 electronic rotary latch

As mentioned in Section 2.3, the latch is oriented with the cam facing upwards as shown above. This orientation has been found to be the best to release the rover. The rover has a .25 in. rod at its tail end which is held by the cam. This cam has been found strong enough to withstand the forces inflicted by ejection blasts and parachute deployment. is an image of the Southco rotary latch.

7.4.5.3 Battery

Two sets of batteries are used to power the electronics. AA batteries will be used to power the rotary latch. The batteries will be used Waykino 4 X 1.5V AA Battery Case Holder Storage Plastic Box Battery Spring Clip Black Red Wire Leads ON/OFF Switch with Cover to attach to the payload platform. Three C batteries will be used to power the receiver. The batteries will be attached to the underside the platform by BHCW Holder 1 C Cell W/6" Wire Leads. Figure 7-10 is a model of the batteries attached to the platform.

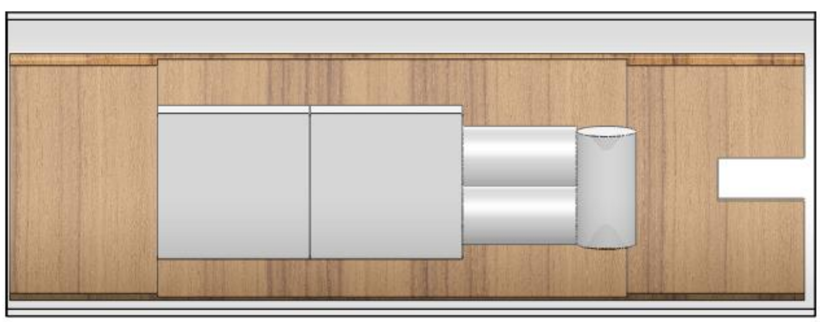

Figure 7-10: Model of the Platform Underside with Batteries Secured

These batteries act also as weight for the payload towards the desired weight of 7 lb. This weight below the platform provides enough offset in weight to promote the self-stabilization of the payload after landing.

7.4.5.4 Electrical Schematic for Rover Bay

Figure 7-11, below, shows an electrical schematic for the payload electronics.

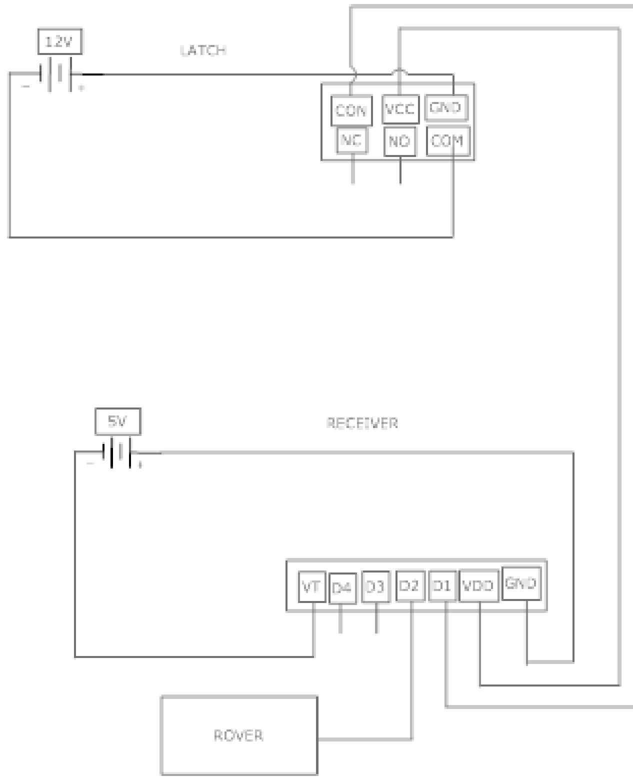

Figure 7-11: Electrical Schematic for Payload Electronics

To reduce the risk of damaging wires during launch or landing, all wire leads will be soldered and heat-wrapped during fabrication. Wires will also be taped to the platform surface to reduce clutter, and any wires that must bend to fit will be given proper bend curvatures to avoid unintentional disassembly.

7.5 Design and Fabrication of Deployable Rover

To meet the requirements outlined in Section 4.5 of the NASA Student Launch handbook, the team chose to design a rover with tracks. This was done to maximize traction, power efficiency, and volume efficiency. When compared to wheels, treaded tracks allow for greater grip when driving over rough terrain and are less susceptible to getting stuck. Tracks also require less power to achieve similar performance to wheels, and the space inside the tracks' housings can be utilized for additional storage. During flight, the rover is kept in place by an electronic rotary latch at the rear of the rover and by slots above the rover. The latch prevents longitudinal motion within the payload tube, and the slots keep the rover from moving laterally. Upon landing, the self-righting payload tube rotates into the correct orientation due to the center of gravity of the entire payload offset from the axis of rotation. A radio signal is sent to the payload to unhook the latch, and an umbilical cord connecting the latch receiver and rover activates the rover. A signal is sent from a digital I/O pin from the receiver to a digital I/O pin on the Arduino which causes the code on the Arduino to run. The rover utilizes two motors controlling the rotation of both front wheels, thus pulling the tracks around their housings to drive the rover forward. The motors remain active long enough for the rover to travel at least 5 ft laterally from the payload landing site and stop in place. To meet the requirement of deployable solar panels, an arm is attached to a servo on top of the rover, and the rotation of the servo turns the arm and unfurls the panels. Figure 7-12, below, shows the current rover model with external components labelled.

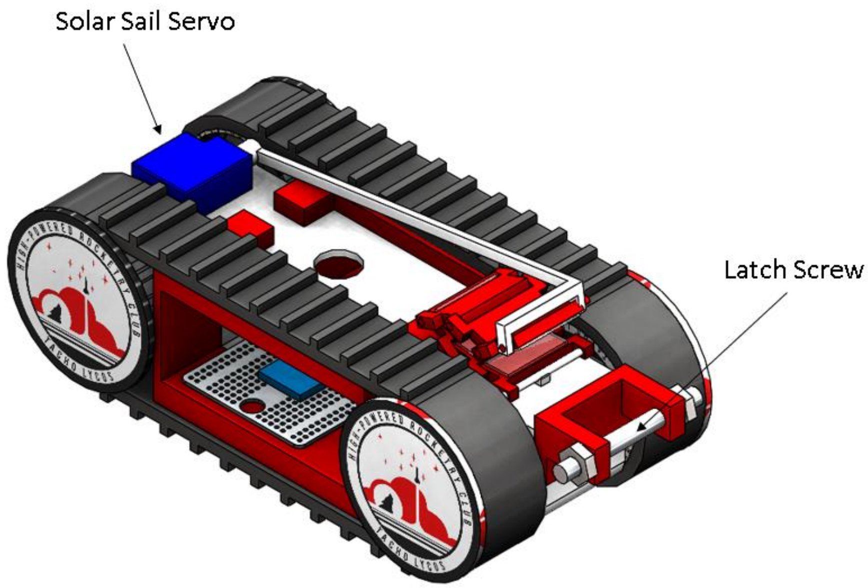

Figure 7-12: Current Rover Model with Solar Panels Stowed

The electronic rotary latch, attached to the sled, wraps around the latch screw and unlatches when it receives a signal from the team upon landing.

7.5.1 Dimensions and Technical Specifications

Due to size constraints set forth by the payload tube dimensions, the rover is constricted to 8.6 in. length, 3.8 in. width, and 2.2 in. height with solar panels stowed and 5.5 in. when solar panels are deployed. Below is a table outlining the parts list necessary for the rover as well as the total weight in pounds.

Table 7-3: Rover Parts List

Part	Material	Weight (lb)	Quantity	Total Weight (lb)
Body	ABS	0.203	1	0.203
Opening	ABS	0.094	2	0.188
Rear Wheel	ABS	0.078	2	0.156
Servo Wheel	ABS	0.047	2	0.094
Tread	Rubber	0.094	2	0.188
Arm	ABS	0.010	1	0.010
Rear Axle	Steel	0.130	1	0.130
Latch Screw	Steel	0.0313	1	0.031
Latch Nuts	Aluminum	0.007	2	0.014

Part	Material	Weight (lb)	Quantity	Total Weight (lb)
Arduino Micro with Headers	Assorted	0.0143	1	0.014
Adafruit Perma-Proto ½ Sized Breadboard	Assorted	0.0313	1	0.031
Panasonic - BSG AM-1456CA Solar Panels	Assorted	0.002	7	0.014
9V Battery	Assorted	0.100	1	0.100
Accordion	Paper/Plastic	0.010	1	0.010
FEETECH FS90R	Assorted	0.030	3	0.090
Misc. Wires (estimate)	Assorted	0.020	1	0.020
			Total	**1.293**

When combined with the 5.90 lb payload bay structure, the entire assembly will weigh approximately 7.19 lb which is 2.7% greater than the predicted weight. The final weight will be determined after fabrication and assembly is complete.

7.5.2 Rover Body

The rover body consists of two 3D printed shells and two track housing pieces designed to hold all the electronics. These electronic components include an Arduino Micro, an Adafruit Perma-Proto ½ Sized Breadboard, a 9V battery pack, and three servos. The main body is printed in two pieces at a 40% infill to simplify the process of inserting components and minimize the likelihood of defects during printing. The geometry of the body, specifically the axle slots, makes it difficult to print in one piece, so splitting it in half reduces the possibility of printing malfunctions taking place in high risk areas. The team decided to 3D print rather than use other methods because 3D printing allows for rapid prototyping and is much simpler than traditional manufacturing methods. Changes can be made quickly and at a low cost, and they can be tested in a timely manner. The shell design allows for quick and easy rover assembly, and the track housing pieces protect the electrical components from dirt and debris after exiting the payload. Figure 7-13, below, shows the side view of the rover with solar panels deployed.

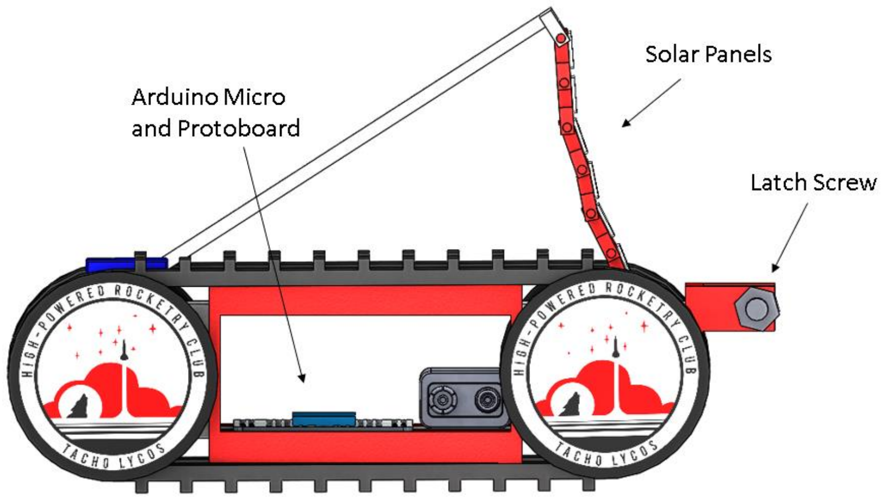

Figure 7-13: Side View of Current Rover Model

A more space efficient design was created after running into sizing issues with the initial proposal design. The main body interior allows for sensitive components such as the Arduino to be stored away from potential hazards. A protective layer of plastic film will be placed over the openings before flight to add an extra line of protection from dirt and debris.

7.5.2.1 Body Structure

After constructing the first rover, it was found that there was little contact area between the body and the track housings, so tabs were added to allow for screws to be used. Figure 7-14, below, shows the 3D printed track housing with added tabs.

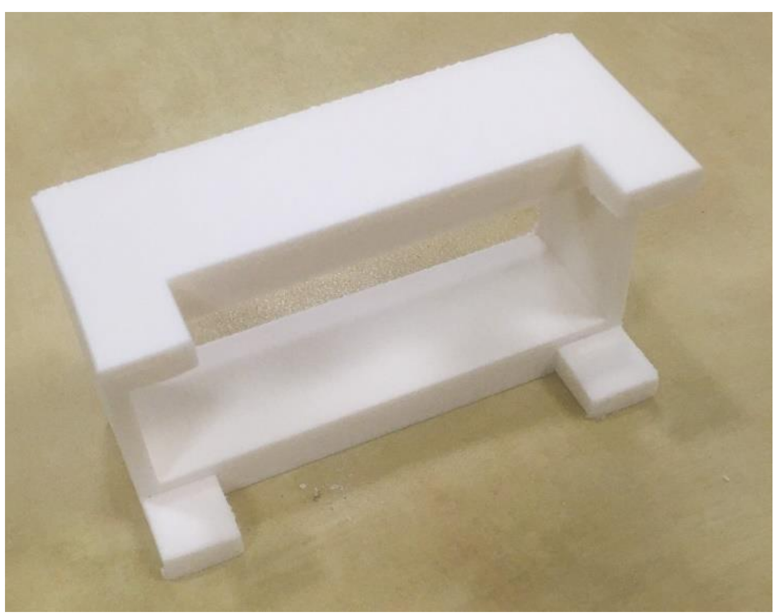

Figure 7-14: Modified Track Housing with Added Tabs

It was also noted that the rover was too long for the treads to wrap around the wheels, so the rover was shortened. This shortened body is the same design as discussed in the CDR; however, it is shorter by approximately 0.5 in.

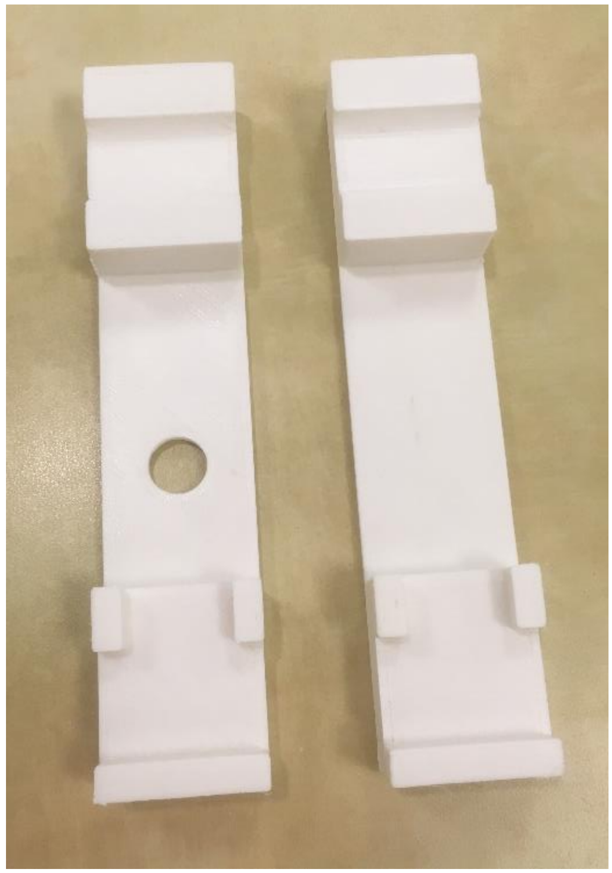

Figure 7-15: Shortened body split into two parts to increase print quality

When fabricating the rover body, each component will be adhered using Loctite plastic epoxy. The mass simulator rover used on the full-scale test launch used this adhesive which survived the launch and landing without any damage.

7.5.2.2 Wheels

The front and back wheels differ slightly from each other, but will both be fabricated on the 3D printer with a 40% infill. The front wheels, attached to the servos, have a small hole for the horn of the servo to snap into and a larger cavity to allow for rotation around the servo. Figure 7-16, below, shows the 3D printed front wheel of the rover with a small hole included to lock onto the servo horn.

Figure 7-16: Front Wheel

Figure 7-17, below, shows the 3D printed real wheels which feature a larger center hole to fit the threaded rod axle.

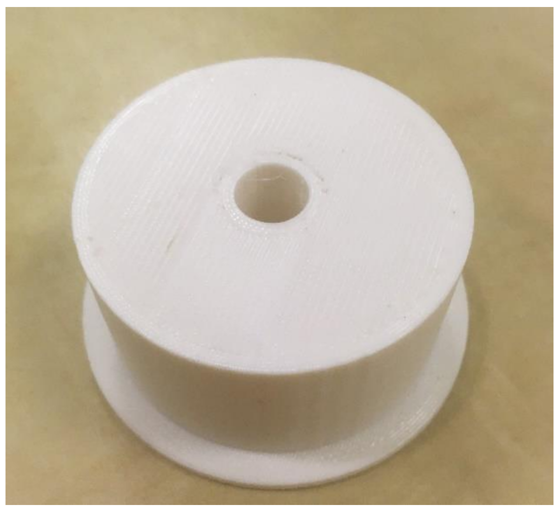

Figure 7-17: Rear Wheel

The rover wheels are designed to be installed or replaced quickly to improve the reliability of the rover. The team also intends to bring several spare wheels to the competition launch.

7.5.2.3 Rubber Tracks

To get proper traction on the rough terrain of the launch site, rubber treads were selected as the method of forward motion. The treads pictured below were chosen specifically because of their size and the ridges lining the outside. They are thin enough so as not to add any height to the rover and they are long enough to fit the newly shortened body. The ridges, which will dig into the dirt, provide maximum traction. Figure 7-18, below, shows the two rubber treads that will be installed on the rover.

Figure 7-18: Rubber treads

A small screw drilled through the top of the rover body into the rear axle housing allows the team to tighten and release the treads. The screw holds the rear axle in such a way that the treads are in tension and when the screw is undone, the team can remove the tread. This ensures that treads are in optimal tension and makes it easier for the team to assemble the rover.

7.5.2.4 Solar Sail

In order to meet the requirements of deployable solar panels, the rover must contain a folded set of solar panels that deploy after reaching its destination. In this design, called the "Solar Sail," the solar panels are folded in an accordion style. To create the accordion, the panels are mounted either on a foldable surface such as paper or plastic or attached to links that can be stowed in a folded state. One end of the accordion is attached to a rotating arm spanning the length of the rover that is controlled by a servo at the front. The other end of the accordion is linked to the body of the rover at the rear. In its stowed position, the arm is nearly parallel with the top of the rover body, and the panels are folded and not receiving sunlight. The arm is an extension attached to an existing attachment for the continuous servos. Figure 7-19, below, shows the solar panels in their deployed position, where the arm is upright with the solar panels extended, which resembles the sail of a ship.

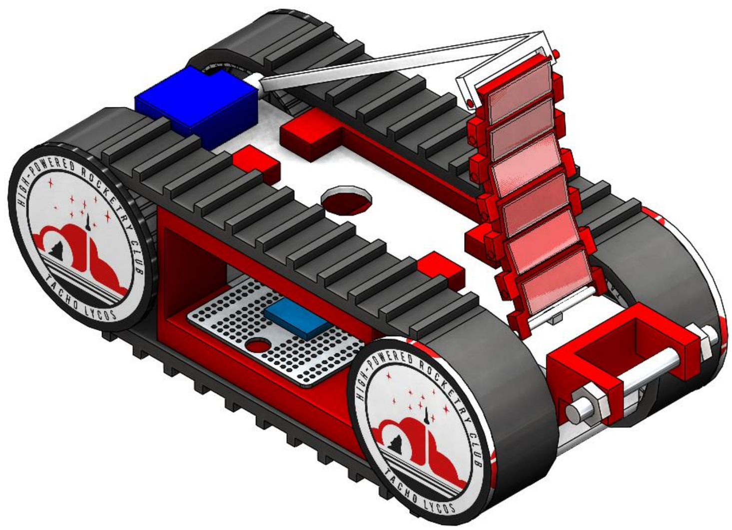

Figure 7-19: Current Rover Model with Solar Panels Deployed

When the servo activates, it will rotate the arm, thus deploying the solar panels. Although no power will be generated by the solar panels, this serves as an analogue of a real solar panel deployment.

The Panasonic - BSG AM-1456CA solar cells were selected because of their small size, light weight, and low cost. The solar cell can ship quickly and in large quantities. Its size and weight are ideal because they will not require large amounts of torque to be lifted out of the folded position, so a small servo can still be used. This keeps the weight of the entire rover low.

7.5.3 Rover Electronics

For the rover to perform completely autonomously, the on-board microcontroller must be pre-programmed to run through its mission of at least 5 ft of travel and solar panel deployment. This means that there are five key events that need to happen for a successful rover mission:

1. Receive signal from receiver
2. Front servos run for allotted time
3. Front servos stop after allotted time
4. Solar Sail servo activates
5. Solar Sail servo stops after deploying the sail

Since this is a mission with few operations, a relatively simple microcontroller was chosen to handle the tasks.

7.5.3.1 Onboard Computer

After initial coding with the MSP430 microprocessor outlined in the CDR, it was determined that using an Arduino board would be simpler and quicker. Hours of troubleshooting the MSP430 to control servos proved to be unsuccessful while the team was able to have servos running off an available Arduino board in minutes. Because of this, the team has moved forward with an Arduino Micro. The Micro has all the processing power of an Arduino Leonardo but in a much smaller form factor. Figure 7-20, below, shows the Arduino Micro with fixed headers for integration with other rover components.

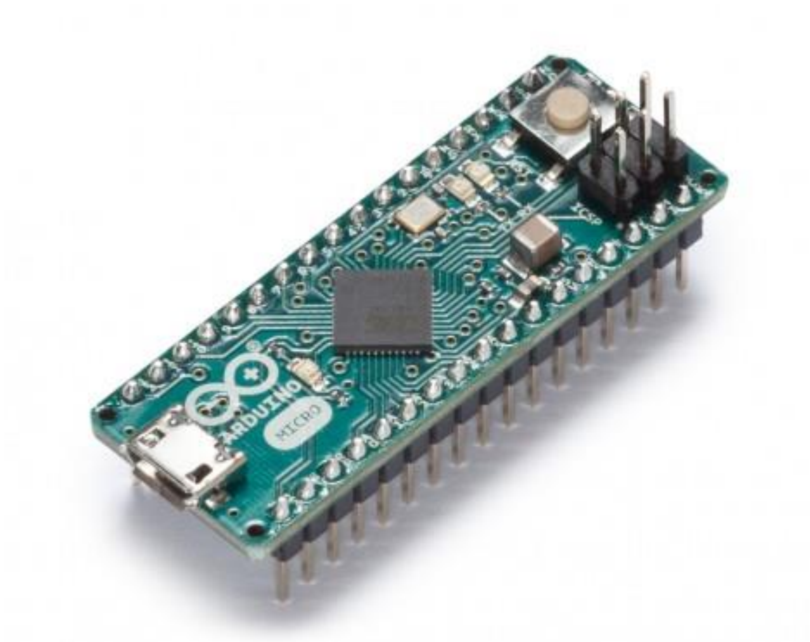

Figure 7-20: Arduino Micro with Headers

The Arduino Micro will be purchased on March 9, 2018 and will be assembled with the rover immediately after its arrival.

7.5.3.2 Remote Activation

During the CDR presentation, the team was informed that they would not be able to approach the vehicle after landing for safety reasons. Because of this, the original design that used Bluetooth would be impossible and the latch system would also need a range upgrade. After selecting a new transmitter and receiver for the latch, it was discovered that the receiver had multiple digital I/O pins that could be used for the rover. The rover is now activated by the signal from the latch receiver rather than its own transmitter/receiver pair. The system uses two Male-to-Female wires:

1. Receiver wire: The female end is connected to the digital I/O pin with the male end connecting to the male end of the rover wire.
2. Rover wire: The male end is soldered in place on the protoboard and the female end is connected to the receiver wire.

The wires will be held in place during flight, and since the rover is held in place by the latch and slots, it is not expected that the connection will become undone. Once the rover receives the signal to start its expedition, it will move forward out of the payload bay. This forward motion will disconnect the rover from the receiver and allow the mission to continue.

7.5.3.3 Servos

All three servos will be FEETECH FS90 Continuous Rotation servos. These are space efficient yet powerful enough to move the rover the necessary distance, and they are easy to control using Arduino code.

Figure 7-21: FEETECH FS90 Continuous Rotation Servo

Three FEETECH FS90 servos were included in the simulated payload assembly on the full-scale test launch which all successfully survived launch and landing and still able to operate without losses.

7.5.3.4 Battery

The Arduino Micro's operating voltage is between 7V and 12V which will allow the team to use a 9V battery that will take up considerably less space than the 4 AA battery pack outlined in the CDR.

7.5.3.5 Electrical Schematic for Rover

Pictured below is the electrical schematic for the rover. The 9V battery provides power to the Arduino Micro which controls the three servos on board. The latch receiver is connected to a single pin on the Arduino Micro which activates the rover.

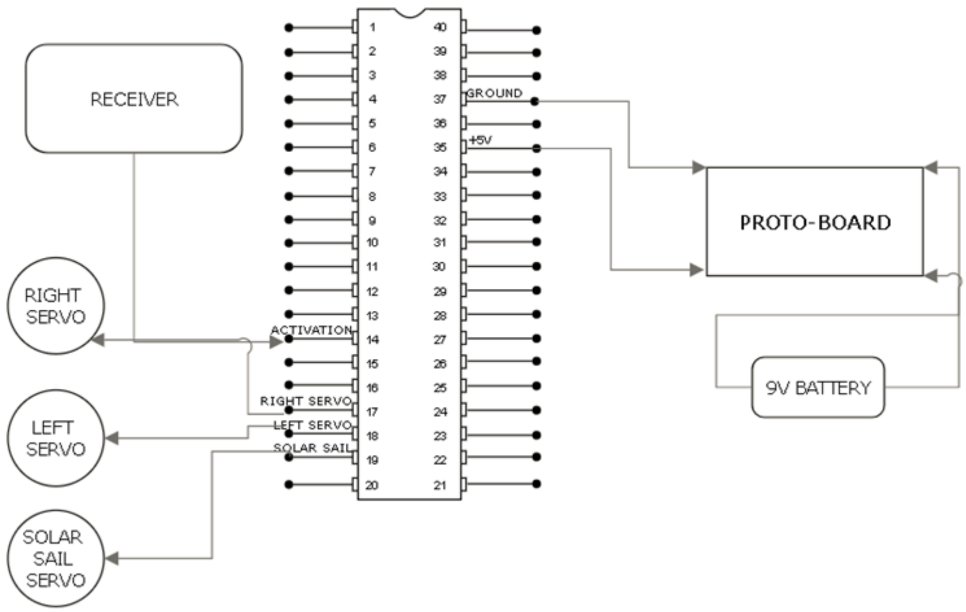

Figure 7-22: Electrical Schematic of Rover Components

8. Safety

8.1 Compliance to Handbook Requirements

Table 8-1, below, contains the safety requirements listed in the 2018 NASA SL handbook as well as the respective compliance actions, verification methods, and status.

Table 8-1: Launch Vehicle Safety Handbook Item Compliance

Handbook Item	Description of Requirement	Compliance	Verification Method	Verification Description	Report Section Location
5.1	Each team will use a launch and safety checklist. The final checklists will be included in the FRR report and used during the Launch Readiness Review (LRR) and any launch day operations.	The team uses a detailed checklist to assembly, launch, and recover the full-scale launch vehicle.	Demonstration. The team will employ the use of a checklist for all launches of the full-scale rocket.	Complete. The team created a checklist prior to the full-scale test launch and has included the final version in this report.	Section 9
5.2	Each team must identify a student safety officer who will be responsible for all items in Section 5.3.	The club has elected Erik Benson to serve as the team safety officer during the year.	Demonstration. The team will elect a safety officer to serve the club throughout the competition year.	Complete. The club has elected Erik Benson to serve as the safety officer for the competition year.	N/A
5.3	The role and responsibilities of each safety officer will include, but are not limited to, handbook items 5.3.1-5.3.4, below.	The safety officer will review the required handbook items and ensure that all items are complete throughout the competition year.	See Below	Complete.	N/A
5.3.1	Monitor team activities with an emphasis on safety during: Design of vehicle and payload Construction of vehicle and payload Assembly of vehicle and payload Ground testing of vehicle and payload Sub-scale launch test(s) Full-scale launch test(s) Launch day activities Recovery activities Educational engagement activities	The assembly and construction of the vehicle will be monitored at all times by officers if not the safety officer. Ground testing will be conducted in a manner that is approved by the HPRC mentors and in accordance with established safety procedures. All launch activities will be conducted in accordance with the wishes of the relevant RSO and advice of our mentors.	Demonstration. The safety officer will provide a safety briefing to all club members at the beginning of each academic semester. If the safety officer cannot attend a fabrication or assembly session, another qualified officer will assume their duties.	Complete. The safety officer has given multiple safety briefings throughout the academic year. All team members are required to adhere to the policies set by the team safety officer. The PDR Report contains signatures of those team members who had completed the safety briefing offered in August 2017.	N/A
5.3.2	Implement procedures developed by the team for construction, assembly, launch, and recovery activities.	The safety officer will advocate the continued adherence to the vision of the team design leads and the current design itself.	Demonstration. The safety officer will be present during design, fabrication, assembly, launch, and recovery activities.	Complete. The safety officer, or another qualified officer, has been present at all times for design, fabrication, assembly, launch, and recovery of the full-scale launch vehicle.	N/A
5.3.3	Manage and maintain current revisions of the team's hazard analyses, failure modes analyses, procedures, and MSDS/chemical inventory data.	The safety items listed in this report have been overseen and reviewed by the safety officer prior to submission.	Demonstration. The safety officer will be involved with all safety items within the design reports.	Complete. The safety officer has overseen the completion of and reviewed all safety items within this report.	N/A
5.3.4	Assist in the writing and development of the team's hazard analyses, failure modes analyses, and procedures.	The safety items listed in this report have been overseen and reviewed by the safety officer prior to submission.	Demonstration. The safety officer will be involved with all safety items within the design reports.	Complete. The safety officer has overseen the completion of and reviewed all safety items within this report.	N/A

Handbook Item	Description of Requirement	Compliance	Verification Method	Verification Description	Report Section Location
5.4	During test flights, teams will abide by the rules and guidance of the local rocketry club's RSO. The allowance of certain vehicle configurations and/or payloads at the NASA Student Launch Initiative does not give explicit or implicit authority for teams to fly those certain vehicle configurations and/or payloads at other club launches. Teams should communicate their intentions to the local club's President or Prefect and RSO before attending any NAR or TRA launch.	The safety officer will notify the local rocketry club's prefect about any upcoming launches as well as any relevant changes to the rocket design, ensuring strict compliance to all local rules and regulations before any flight. The club will utilize the knowledge of their mentor Alan Whitmore, the prefect of the local rocketry club.	Demonstration. The safety officer will be the team's direct communication line to the RSO at each launch of the subscale and/or full-scale rocket.	Complete. The safety officer attended the subscale launch to oversee assembly, launch, and recovery efforts. The safety officer was unable to attend the full-scale test launch, and the club president represented the safety officer during the assembly, launch, and recovery process.	N/A

8.2 Personnel Hazard Analysis

Table 8-2, below, contains the specific hazards that members of the team and others may face. Table 8-2 also details the strategies used to combat the associated risks of each hazard with its confidence.

Table 8-2: Personnel Hazard Analysis

Category	Concern	Mitigation	Confidence	Effectiveness
Operational	Assembly and Handling of Motor	Minimal individuals will be allowed contact with the motor. The primary handlers of the motor would be the safety officer and club advisors. In unforeseen circumstances another club officer may be necessary but unlikely. The directions of the manufacturer will be followed strictly	The motor will be in optimal conditions to perform to specifications due to the proper care given by the adherence to the instructions of the manufacturer in addition to guidance given by HPRC club advisors.	As supervision and guidance was provided during all steps of assembly, utilizing the checklists, no injuries have resulted from any portion of assembly as well no damage to the vehicle due to any part of the assembly process.
	Transport and Handling of the Launch Vehicle	The launch will consistently be supported by multiple points of contact in effort to reduce the risk of damage to the body or internal components. This will be paid special attention to when being transported to and from road vehicles.	With these concerns and wishes expressed to all members, an effective pool of members will be available at any moment to be called upon or take initiative at any time that a need may arise.	As responsible members have transported the vehicles every time no injuries have occurred due to vehicle transport as well as no damage to a vehicle due to transport.
	Launch Vicinity	Careful management of all personnel and bystanders present at the launch site and enforcing the rule, specifically the safe distance, will be necessary at all launches.	These actions will promote a safe launch and allow officials to maintain focus on other launch related tasks.	As a safe distance has been properly observed at all HPRC launch no injuries have occurred due to proximity to the launch vehicle.
	Location	The team will only launch at NAR/TRA approved launch sites. The team plans to launch its subscale and full-scale rockets at the Bayboro, NC launch site which meets the minimum range requirements described. The final, competition launch will occur at another NAR/TRA approved launch site near Huntsville, AL.	This will ensure the launches are able to be safely conducted with the expectation that all other safety protocols are followed.	As all HPRC launches have occurred at sanctioned launch sites no injuries have occurred due to an unsafe launch site.

Category	Concern	Mitigation	Confidence	Effectiveness
Rocket Construction	Sharp Objects	When construction is happening on the rocket or adjustments must be made, care will be taken to make everyone in the vicinity aware that sharp objects are out. Additionally, the sharp objects will be store in consistent locations to mitigate the possibility of wounds while searching for objects.	With attention paid to sharp objects, preventable injuries due to them will be reduced and a safe, clean working environment can be guaranteed.	The policy of awareness in tandem with a clean environment has been effective with the exception being two minor cuts due to X-Acto Knives. A remedial safety brief pertaining to sharp objects is scheduled for March 22, 2018 in effort to eliminate injuries.
	Hot Objects	When construction is happening on the rocket or adjustments must be made, care will be taken to make everyone in the vicinity aware that hot objects are in use. When objects that can be heated are not in use they will be stored away to eliminate risk.	To limit use of hot objects to a minimum and heightening awareness to their us, preventable injuries can be brought to a minimum.	Between awareness and appropriate PPE (deemed on a case by case basis) no injuries have resulted from heat generating equipment or materials.
	3D-Printer	The 3D printer as a computer-controlled device can perform unintended actions. As such no member without recognized experience with the HPRC 3D Printer should not interact with it whatsoever without direct supervision of a member with experience.	Using experience as a barrier of usage, personal injuries such as mechanical pinching or burns can be limited as well as causing costly damage to the 3D printing unit.	Only members that have demonstrated suitable capability have used the 3D printer. No injuries have resulted from the 3D printer.
	Laser Cutter	The laser cutter is under the care of the Entrepreneurship Initiative group on campus which requires a regimented certification class to use it. HPRC members will take the certification class and abide by EI's policies at all times.	With EI's policies followed HPRC can effectively keep injuries due to the laser cutter to a minimum.	Only members of the Entrepreneurship Initiative have used the Laser Cutter, abiding to the standards set by the certification course. No injuries have resulted from laser equipment.
	Airborne Hazards	Some of the materials that HPRC uses can create fumes or airborne particulates. When these materials the member using it must first verbally identify the hazard and then begin use once all members in the vicinity are wearing masks.	With the appropriate use of masks the risk of respiratory injury is greatly reduced.	When a source of respiratory risk or injury is used in the lab all members don masks or are compelled. No injuries have resulted from respiratory irritation.

8.2.1 Personnel Reference Material

Table 8-3, below, contains descriptions of various lab items and what personnel protective equipment (PPE) is required when handling each item.

Table 8-3: Personnel Protective Equipment Reference Material

Item Description (hyperlink)	Mentor or Safety Officer Presence Required?	Required PPE				
		Safety Glasses	Mask	Gloves	Earplugs	Covered Clothing
Dewalt Power Drill DC 759	No	No	No	No	No	No
Dewalt Power Sander D26450	No	Yes	No	No	No	No
Delta Belt Sander 90183	No	Yes	No	No	No	No
Craftsman 137.216020 Scroll Saw	No	Yes	No	Yes	No	No
Delta Band Saw 28-180	No	Yes	No	Yes	No	No
GOEX Black Powder	Yes	Yes	No	Yes	No	No
Klean-Strip Acetone	No	No	Yes	Yes	No	No
West System 105 Epoxy Resin	No	No	Yes	Yes	No	No
West System 206 Slow Hardener	No	No	Yes	Yes	No	No
Fiberglass Fabric	No	Yes	Yes	Yes	No	Yes
Batteries	No	No	No	No	No	No
Cotton Flock	No	Yes	Yes	Yes	No	No
Baby Wipes	No	No	No	No	No	No
Igniters	Yes	No	No	No	No	No
Liquid Nails	No	No	No	No	No	No
Glass Microspheres	No	Yes	Yes	Yes	No	No
WD-40	No	No	No	No	No	No
Blue Tube	No	No	No	No	No	No

8.3 Environmental Impact Analysis

The environment exterior to the rocket poses many risks to the system both during flight and due to impact during recovery. The physical interaction between the rocket and atmosphere generates aerodynamic forces including lift and drag which are critical to understanding how the launch vehicle will perform in varying conditions. Unexpected interactions between the atmosphere and rocket or ground and rocket can cause a variety of system failures lead to a loss of the vehicle. Table 8-2 contains a breakdown of these hazards and the mitigation techniques that the team has employed to reduce or eliminate the environmental effects on the system.

Table 8-4: Environmental Hazards to the System and Personnel

Environmental Concern	Hazard	Mitigation	Verification
Cloud Cover	Cloud cover can obscure the rocket creating an uncertain and therefore unsafe condition when the rocket is airborne.	The vehicle will not be launched when significant cloud cover is present. Note: NAR Safety Code does not allow for launches into cloudy conditions.	The safety officer will make the determination of the significance of cloud cover and make the determination as to if postponing the launch is necessary
Active Precipitation	Precipitation puts the electrical components at higher risk of being damaged and malfunctioning. It also may weaken the structural integrity of the body tube which is not designed to get wet.	Weather forecasts will be used to find a launch date with favorable conditions. Protective equipment will be brought to the launch site to shelter the rocket and its components in the event of unexpected/intermittent precipitation. If exposure to precipitation is unavoidable, components that get significantly wet will not be used until their integrity can be verified on the ground.	The launch will be postponed in the event of precipitation after arriving to the launch site. The determination to cancel the launch all together if precipitation is deemed significant. The integrity of components that get wet will be determined by the teammates whom are most familiar with said components in addition to the safety officer.

Environmental Concern	Hazard	Mitigation	Verification
Residual Precipitation	Water on the ground puts components and structural parts at risk of malfunctioning It also may weaken the structural integrity of the body tube which is not designed to get wet.	The team intends to use a spray-on waterproof coating on the body tube in addition to paint application. Also, launch will be postponed in the event of unfavorable wind conditions that increase the likelihood of the landing zone being in a waterlogged area. Launch sites that contain no or minimal water features in the feasible landing area will be preferred.	The application of a waterproofing coating in addition to the paint will be tested prior to launch to determine the effectiveness of the process. The integrity of components that get wet will be determined by the teammates whom are most familiar with said components in addition to the safety officer.
High Wind	High wind speeds may result in wind shear that may reduce stability of the flight or render the vehicle unrecoverable. High wind speeds may also affect the altimeter's pressure readings.	Weather forecasts will be used to select a launch date with favorable wind conditions. Conditions will also be checked at the launch site with an on-hand anemometer. Launch will be postponed until the wind has died down if wind speeds gust above 20 miles per hour. Note: NAR Safety Code prohibits launching in wind conditions exceeding 20 miles per hour.	Launches will only proceed in conditions that favor stable flights. The safety officer along with other team members will confirm that wind speeds remain below safe levels leading up to launch.
Severe Weather	Severe weather such as thunderstorms, heavy rain, hail, and but not limited to tornados can pose a variety of risks to the well-being of team members, attendees as well as the safety of the launch vehicle.	Weather forecasts will be used to select a launch date with favorable conditions. Conditions will also be assessed at the launch site. In the event of severe weather or if it appears to be likely, the launch will be aborted. Note: NAR and TRA regulations regarding severe weather will be followed to ensure a safe and responsible launch	Launches will only proceed in conditions that favor stable flights. The safety officer, in addition to other team members will confirm that the weather conditions are acceptable for flight.
Severe Cold/Heat	Extreme cold/hot temperatures can cause power sources to discharge more rapidly and can weaken the structural integrity of the rocket itself. Team members and launch attendees are also at risk of contracting hypothermia or heat exhaustion	Weather forecasts will be used to find a launch date with favorable conditions. If the outdoor temperatures are determined to be detrimental, thermally shelter the rocket and components. In event of cold or hot weather that does not compromise vehicle launch safety, team members, and launch attendees will be strongly encouraged to dress appropriately and stay hydrated. The team will bring water for the team and launch attendees.	The team members will ensure that electronics and other components are not subject to extreme temperatures. Components that are believed to have been compromised by shifts in temperatures will be inspected and verified by team members familiar with said components. Team members who are not dressed appropriately will not be permitted to attend the launch event. Frequent hydration will be actively encouraged.
Severe Humidity (>95% noncondensing)	The moisture in the air can compromise the integrity of the black powder charges as well as affecting the calibration of altimeters.	The team will keep electronic components and charges stored in dry containers/environments prior to the launch.	Components exposed to extreme humidity will have their integrity verified by the teammates whom are most familiar with said components in addition to the safety officer.
Severe Ultraviolet (UV) Exposure	UV exposure can be detrimental to the integrity of adhesives used on the rocket as well as degrading the material of the parachute. UV exposure can also induce sunburns on the team members and launch attendees.	Limit the amount of direct sunlight that are experienced and periodically inspect the rocket for degradation of components. If degradation is determined to be present, postpone launch until component integrity can be verified or replaced. Personnel will be provided with sunscreen to reduce risk/severity of sunburn and the team will encourage frequent reapplications.	Components exposed to extreme UV radiation will have their integrity verified by the teammates whom are most familiar with said components in addition to the safety officer prior to launch. The use of sunscreen by team members and launch attendees will be strongly encouraged.

Environmental Concern	Hazard	Mitigation	Verification
Hard Landing Surface	Hard surfaces such as concrete or asphalt can damage the rocket components upon landing.	Launch sites with minimal concrete, asphalt, or other hard surfaces in the vicinity will be avoided when selecting a launch site for test flights.	If the vehicle or vehicle components land on a hard surface, all components will be inspected for damage.
Vehicle/Component(s) Land in a Tree	The rocket and parachute may become lodged into the trees making the recovery difficult or even impossible or may fall on and injury the retrieval team.	The rocket will not be launched in environments where significant tree coverage is present in probable landing zones. The launch will also be postponed if wind speeds exceed 20 miles per hour as determined by an onsite anemometer.	If components must be recovered from trees, the safety officer will verify that it can be done safely before attempting. Parachutes that are damaged by the tree will be retired.
Parachute Damaged from Sharp Object	Damaged parachutes may not function properly.	After each launch parachutes will be thoroughly inspected for tangles, snags, tears, and any other form of damage.	Before launch, parachutes will again be checked for any damage. The launch vehicle will only use parachutes which have passed inspection.
Chemical and/or Acid Leakage	Chemical/Acid such as battery acid leakage may damage internal components and/or the recovery system resulting in failure of electronics or recovery devices such as parachutes as well as cause injury to anyone who comes into contact with such chemicals.	Materials will be purchased from reputable sources and inspected prior to each use to minimize defective components. Additionally, components will be stored in environments devoid of extreme temperature fluctuations. After launch, components will be inspected to verify that it is suitable for future launches. If a component is not flyable it will be disposed of according the MSDS standards.	In the event of chemical leakage, components will be handled with gloves, a respirator/face mask, and goggles.

The launch system and team activities also pose significant hazards to the environment. Most of these hazards are arise in the event of a catastrophe of takeoff or a failure of the recovery systems. These hazards a that may affect both the biotic and abiotic factors of the surrounding ecosystem. These hazards are discussed in Table 8-5.

Table 8-5: System and Personnel Hazards to the Environment

Hazard	Cause	Impact	Mitigation	Verification
Fire around the launch site related to motor exhaust.	Motor exhaust starts a fire or damages the ground around the launch rail during launch.	The ground around the launch site becomes scorched, killing any flora or micro fauna directly beneath or around the launch site.	A blast deflector will be used beneath the launch vehicle, protecting the ground from exhaust in compliance with NAR Safety Code.	The safety officer will verify that a blast deflector is in place prior to each launch and inspect the ground afterwards around the launch pad with a fire extinguisher on hand.
A fire is started due to a punctured battery and spreads from the launch vehicle to the environment.	Loose components during flight or improper handling at any point causes an object to puncture the battery.	The ground around the site of the fire becomes scorched, killing or seriously injuring any flora or fauna in the area. In more serious cases, the fire may grow and become out of control causing serious and lasting damage to the ecosystem.	All components used in the launch vehicle are designed to be strongly secured to the vehicle.	The safety officer will verify that only batteries and electronics that have been handled and stored properly are used in the launch vehicle and will ensure that all electronics and batteries are inspected for leakages prior to their use.
A fire is started due to an electrical short or related to the electronics	Exposed or incorrect wiring leads to an electrical short or electronics overheat and start a fire.	The ground around the site of the fire becomes scorched, killing or seriously injuring any flora or fauna in the area. In more serious cases, the fire may grow and become out of control causing serious and lasting damage to the ecosystem.	There will be no exposed wires in the launch vehicle. Electronics will be stored in a secure environment devoid of extreme temperature fluctuations or contact with other components that may cause damage.	The team will verify the quality of the wiring and ensure that there are no exposed wires prior to each launch. Only electronics that are determined by the safety officer to be in good physical condition will be used in the vehicle.
Noise pollution related to the launch.	The launch event generates high decibel levels of noise	The noise generated disturbs local fauna.	The team will avoid launching when fauna such a birds or land mammals are near the launch site.	The team will always have at least one member watching for fauna in the relative vicinity of the launch site.

Hazard	Cause	Impact	Mitigation	Verification
Non-biodegradable waste is left at the launch site or the surrounding environment.	Components may be unintentionally ejected or fall off of the launch vehicle due to the forces of launch or are rendered not recoverable through a failure of the recovery system. Additionally, the team may unintentionally leave debris at the launch field.	Non-biodegradable components or waste may be ingested by local fauna and cause injury, sickness, or premature death. Waste may also be detrimental to plant life or soil/water quality in the surrounding environment.	All components used in the launch vehicle are designed to be strongly secured to the vehicle and no non-recoverable components will be used.	Components will be inspected prior to launch to ensure they are securely attached to the launch vehicle. The launch site and the landing zone will be inspected for components or debris that had fallen off the launch vehicle. Prior to leaving the launch field, the team will ensure to remove any waste left by their activities. Each of these inspections will be verified by the safety officer to ensure all waste has been collected.
High kinetic energy ground impact of the launch vehicle.	A failure of the recovery system in which the parachutes do not deploy, deploy too late, deploy incorrectly, or are not properly secured to components leading to freefall.	Components of the launch vehicle may be strewn across the ground leaving material in the environment which may be ingested by local fauna and cause injury, sickness, or premature death. Waste may also be detrimental to plant life or soil/water quality in the surrounding environment.	Redundant ejection charges as well as a redundant altimeter will be used in the event the primary charges/altimeter fails. Parachutes will be folded the same way each time and stored in safe conditions when not in use.	Black power charges will all be carefully measured and checked the faculty advisor, Dr. Chuck Hall for accuracy and by other team members to ensure they are triggered at the proper time. A larger redundant charge will be used for each ejection event to ensure that proper and complete ejection occurs. The redundant altimeter will be purchased from a different manufacturer.
Battery acid or other electronic based chemicals are introduced to the environment.	Improper handling or puncture of the batteries installed in the launch vehicle.	Battery acid and other chemicals may be ingested by or cause injury to local flora and fauna and/or pollute the surrounding soil and/or water.	Batteries will be stored in a secure environment devoid of extreme temperature fluctuations or contact with other components that may cause damage. After and prior to launch, batteries will be inspected and tested to verify that it is suitable for use. If a battery is not flyable it will be disposed of according the MSDS standards.	The safety officer will verify that only batteries and electronics that have been handled and stored properly are used in the launch vehicle and will ensure that all electronics and batteries are inspected for leakages prior to their use.
Damage to trees around the launch site.	The launch vehicle lands in one or several trees near the launch area.	Removing components from a tree could result in lasting damage to the tree and the habitat it provides to other organisms.	The launch will be postponed in the event that high wind speeds makes landing in a tree more likely. Also, launch sites with trees nearby will be avoided where possible.	In the event that components must be retrieved from a tree(s), the team will ensure that the process is done in a way that minimizes damage to the tree(s) without compromising the safety of personnel.
Carbon dioxide (CO_2) pollution from club related activities adds excess CO_2 to the atmosphere.	CO_2 is released to the atmosphere from club related travel to the launch events and supply store.	Adding excess CO_2 to the atmosphere contributes to anthropogenic climate change, may be absorbed by water bodies to form carbonic acid which would have a negative impact on aquatic organisms especially those who use carbonate to form protective shells.	The team will attempt to cut travel/shipping related carbon emissions when possible.	The team will carpool to all launch events and prefer driving over flying when travelling long distances. When ordering parts, local options will be preferred if part quality is deemed to be equal or superior to that of other options.

8.4 Failure Modes, Effects, and Criticality Analysis (FMECA)

See Section 11 (Appendix A) for the FMECA tables relevant to this project

9. Launch Operation Procedures

9.1 Packing Checklist

Key:

PPE Required

Explosive - DANGER

Night Before Checklist:

1. Charge batteries:
    a. Payload: HobbyTiger blue lipo (2)
    b. Handheld Drill: DeWalt drill batteries (2)
    c. BRB 900 Lipo
    d. Laptop
    e. BigRedBee 900 GPS LCD Reciever
2. Test 9V batteries:
    a. Use multimeter to select (6) batteries that contain *at least* 9.0V
3. Measure and store black powder charges:
    a. (2) primary black powder charges
    b. (2) redundant black powder charges
4. Coordinate carpool plans and confirm cars/drivers
5. Encourage:
    a. Full night of sleep
    b. Large breakfast before leaving
    c. Clothes that protect against weather (sunscreen, heavy coat, hat, etc.)
    d. Packing the night prior to launch

Packing List:

1. Nosecone
2. Midsection:
    - Hatch with (8) screws
    - Payload supplies (see payload checklist)
    - Avionics bay supplies (see avionics checklist)
    - Hatch switches installed
3. Fin can:
    - Retainer ring
    - Rail buttons
4. Recovery box:
    - Main parachute: 120in Iris Ultra Compact
    - Drogue parachute: 24in Elliptical
    - LARD: 60in Iris Ultra Standard
    - Main parachute deployment bag

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- Drogue parachute nomex sheet
- LARD deployment bag
- Pilot parachute
- Pilot parachute nomex sheet
- Main parachute shock cord with loops and one untied end
- Drogue parachute shock cord with loops
- LARD Jolly Logic
- Rubber bands
- (10) Quicklinks
  - (3) Size 1 Quicklinks
  - (7) Size 2 Quicklinks
- paper for funnels
- Scotch tape

5. Avionics box:
   - (6) e-matches (Hall)
   - Extra rotary switches
   - (4) Key switch keys
   - (6) tested 9V batteries
   - Extra battery caps
   - Extra wires of all shapes and sizes!
   - E-match test switch and wire
   - Black electrical tape
   - Blue painter's tape
   - Small Graham (gram) scale
   - Shear pins
   - Circle stickers
   - Altimeters:
     - (2) StratoLoggerCF
     - (2) Entacore
   - StratoLoggerCF user manual
   - PerfectFlite computer connection wire
   - Micro-USB to computer USB (USB Type A) wire
   - BigRedBee 900 GPS Transmitter
   - BigRedBee 900 GPS LCD Receiver
   - BigRedBee 900 USB interface and charger
   - Mini-usb to computer USB (USB Type A) wire
   - Black jewelers' screwdriver kit:
     - Black screwdriver with red tip
   - Standoffs set box (black)
   - (10) black standoff screws
6. Payload box:

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- Payload tube with epoxied bearing
- Forward payload bulkhead
- Forward bearing cap
- Payload centering ring
- Payload center bearing
- Payload sled
- (20) ¼" nuts
- (10) ¼" lock washers
- (2) bags of ball bearings
- Adjustable wrench
- Vice grip pliers
- Straight forceps
- Curved forceps
- Paper funnel
- (8) Hatch screws

7. Motor reload:
   - AeroTech L2200G motor reload kit (yellow tube)
   - RMS 75/5120 motor casing with capped forward seal (Alan/Hall)
   - Propellant sleeve
   - Silicone grease
   - Motor igniter (Alan)
   - Dowel rod (for igniter)
8. DeWalt battery-powered drill
   - (2) charged batteries
9. Black drill bit case
10. Harvey's car battery pack
11. Folding table
12. (2) paper towel rolls
13. (2) clipboards with pens
14. First-aid kit
15. Water bottles
16. Red box with extra screws
17. Launch day toolbox:
    - (4) safety glasses
    - Gloves:
      - Nitrile
      - Heavy duty (yellow)
    - Baby wipes
    - Baby powder
    - Band-aid box
    - (2) trash bags

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- Zipties
- Blue painter's tape
- Black electrical tape
  - 3M and cheap brands
- Black duct tape
- Black powder containers:
  - Large container of 4G Black powder
  - (2) small pink main separation charge containers
  - (2) small blue drogue separation charge containers
- Multimeter
- WD-40
- Mallet
- Screwdriver kits:
  - Blue kit
  - Clear box with extra screws
  - Extra shear pins
- (2) scissors
- Forceps
- Multitool in black case
- Set of allen wrenches (red plastic)
- Vaseline
- Wire cutters
- (2) Needle-nose pliers
- Set of vise grip pliers
- Tape measure
- Rope for measuring CG
- Handheld fish scale
- (3) black pens
- (2) sharpie markers
- (2) walkie-talkies
- Thick dowel rod
- (2) putty containers
- Ejection testing switch
- Sandpaper of varying grit
- (4) spare 3D-printed blast caps
- Hot Glue Gun
  - glue stick reloads

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9.2 Payload Assembly

New Payload

Items needed:

1. 16" Phillips head screwdriver
2. Small flathead screwdriver
3. Southco Latch
4. 2 small washers
5. 2 #8-32 x 1-½" bolt
6. 2 #8-32 nuts
7. 2x #6-32 x ½" screws
8. 12V A23 batteries
9. A23 battery clip
10. Standoffs
11. Standoffs screws
12. Wire - red and black

Procedure:

1. Connect the two AA battery clips together by connecting the red wire of the forward clip to the black wire of the aft clip
2. Connect the red wire on the aft AA battery clip to the red power input pin on the Southco latch
3. Connect the three C batteries together by connecting the rewire on the right C battery to the black wire on the left C battery
4. Then connect the red wire on the left C battery to the black wire on the aft C battery
5. Connect the red wire on the aft C battery to the VDD pin on the Seeedstudio receiver
6. Connect the black wire of the right C battery to the VT pin on the receiver
7. Using a wire, connect the GND pin on the receiver to the brown GND pin on the Southco latch
8. Using a wire, connect the data 1 pin to the orange control pin on the Southco latch
9. Using a wire, connect the data 2 pin to the arduino pin on the rover
10. Connect the black wire on the forward AA battery clip to the black common pin on the latch
11. Attach the battery clip to the bottom of the platform
12. Insert the AA batteries into the AA battery clips and the C batteries into the C battery clips
13. Fit the latch into its mount and secure it with the two #8-32 bolts
14. Slide two washers on the bolts and screw the two #8-32 nuts until it is secure
15. Screw payload platform into the disk at the aft end of the payload tube. Use the 16" phillips head screwdriver to screw the two #6-32 x ½" screws. Make sure someone applies opposing pressure to ensure screws go in.
16. Attach the 9V battery to the transmitter

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17. Close the latch, then activate it to ensure it unlatches properly using the transmitter.
18. Insert the rover on the platform and push it towards the aft end until the latch is closed around the ¼" threaded rod.

Rover

Rover should be assembled and ready to be inserted onto the platform prior to arriving at launch site.

Items

1. Rover with all components
   a. Rover body
   b. Two treads
   c. 9V battery
   d. Arduino Micro
   e. Protoboard
   f. Two motion servos
   g. One Solar Sail servo
   h. Umbilical Cord

Procedure

1. Connect 9V battery to protoboard
2. Verify the integrity of the software for performance
3. Inspect the Rover for Structural Faults
4. Inspect the Mechanical Systems of the Rover for Foreign Objects
5. Connect umbilical cord to latch receiver
6. Insert the rover on the platform and push it towards the aft end until the latch is closed around the ¼" threaded rod. (Coincides with step 17 in payload procedure)
7. Verify that rover sits flat on its platform

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9.3 Avionics Bay

Avionics Bay:

1. Required items:
   a. Payload box
   b. Rocket midsection
   c. Avionics box
2. Test continuity on both key switches with multimeter - ensure they are in OFF position
3. Build avionics sled:
   a. Place StratoLogger altimeter over standoffs labelled "StratoLogger"
      i. Align battery terminals facing the "V" marking on the sled
   b. Place Entacore altimeter over standoffs labelled "Entacore"
      i. Align battery terminals facing the "V" marking on the sled
   c. Test (2) fresh 9V batteries with multimeter to ensure they are 9±0.4V
   d. Place the (2) batteries from c) into battery slots with terminals facing forward
      i. +/- battery terminals should aligned with the +/- symbols
   e. Place 9V battery caps over each battery
   f. Feed (1) ziptie through each hole next to the batteries
      i. Wrap each ziptie around the entire payload sled and over the battery
      ii. Tighten ziptie to secure batteries
      iii. Ensure ziptie heads are flush next to the batteries
   g. Clip extra length of ziptie at each head
   h. Connect red lead from Battery 1 to Entacore terminal between V+ and V-
      i. Tighten lead in terminal using small screwdriver
   i. Connect black lead from Battery 1 to Entacore V- terminal
      i. Tighten lead in terminal using small screwdriver
   j. Connect black lead from Battery 2 to StratoLogger NEG terminal
      i. Tighten lead in terminal using small screwdriver
   k. Connect red lead from Battery 2 to terminal adjacent to NEG terminal
      i. Tighten lead in terminal using small screwdriver
4. Slide avionics sled down the threaded rods until the battery side is flush with the L-brackets
   a. Ensure that the orientation of the sled follows the "FWD" and "AFT" markings
5. Fit (1) ¼" nut over each threaded rod to secure the avionics sled to the L-brackets
   a. Tighten all 4 screws with a wrench
6. Wire Stratologger parachute electronics:
   a. Find Green/Black wire labelled "Main P" and feed wire through holes marked with an X
      i. Connect exposed end to StratoLogger MAIN terminals
         1. Tighten leads in terminal using small screwdriver
   b. Find Red/Black wire labelled "Drogue P"
      i. Connect exposed end to StratoLogger DROGUE terminals

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            1. Tighten leads in terminal using small screwdriver
    c. Use another teammate to check wire security
7. Wire Entacore parachute electronics:
    a. Find Green/Green wire labelled "Main S" and feed wire through holes marked with an X
        i. Connect one exposed end to Entacore A and leave the other exposed
            1. Tighten lead in terminal using small screwdriver
    b. Find Red/Red wire labelled "Drogue S"
        i. Connect one exposed end to Entacore B and leave the other exposed
            1. Tighten lead in terminal using small screwdriver
        ii. Take the two remaining exposed wires, one red and one green, and twist the ends together before connect to the middle terminal on the Entacore
            1. Tighten lead in terminal using small screwdriver
    c. Use another teammate to check wire security
8. Connect key switches to altimeters
    a. Ensure key switches are turned to OFF during installation
    b. Switch to the right of the hatch should connect to the Stratologger
        i. Connect red lead to SWITCH terminal, black lead to adjacent
    c. Switch to the left of the hatch should connect to the Entacore
    d. Use another teammate to check wire security
9. Connect red lead to V+ terminal, black lead to adjacent
    a. Use another teammate to check wire security
10. Assemble main parachute e-matches **(see Main Parachute Black Powder checklist)**
11. Assemble drogue parachute e-matches **(see Drogue Parachute Black Powder checklist)**
12. Slide payload into forward opening of midsection with avionics sled at the bottom
    a. The A-side on the bulkhead and avionics sled should face the hatch opening
    b. DO NOT insert payload all the way to the bottom of the midsection tube
    c. Align threaded rods with aft midsection bulkhead holes

9.4 Main Parachute

Main Parachute Recovery Assembly:

1. Required items:
    a. Recovery box
    b. Nosecone
    c. Midsection
    d. Main parachute
    e. Large deployment bag
    f. Main parachute shock cord
    g. (4) nylon 4-40 shear pins
    h. (4) size 2 quicklinks
    i. (2) rubber bands
    j. Safety Goggles
    k. Black capsule containing hatch nuts and bolts/screws
    l. Putty
    m. Hatch
    n. Small wrench for Hatch nuts
    o. Screwdriver for Hatch screws
2. Install MAIN PARACHUTE COMPARTMENT BLACK POWDER CHARGES PRIMARY AND REDUNDANT **(see Main Black Powder Checklist)**
3. Attach BigRedBee GPS to nosecone bulkhead
    a. Turn on GPS transmitter
    b. Hold the Transmitter with an unobstructed view of the sky to obtain GPS lock
        i. Lock is obtained when the LED light switches from rapid flashing to blinking around once per second
    c. Turn on LCD display receiver
        i. Ensure receiver is displaying correct Latitude and Longitude using google earth on the laptop
    d. Velcro Transmitter to nosecone bulkhead
        i. Ensure that the attachment holes are aligned with the standoffs
    e. Attach Transmitter to standoffs using (3) black screws
    f. Tape transmitter whip antenna along the length of the body tube
4. Remove all rubber bands holding parachute fabric and shroud lines, but not shock cord
5. Inspect full length of Main parachute shock cord for rips, tears, or other damage
6. Remove any tape or anything else attached to parachute.
7. Shake out main parachute, remove all attachments, disconnect from any quicklinks
8. Untangle shroud lines
9. Inspect Main parachute and shroud lines for rips, tears, fraying, or other damage
10. Stuff inner deployment bag attachment into deployment bag without attaching to anything
11. Fold main parachute and insert into deployment bag

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   a. Ensure shroud lines are not tangled
   b. Starting at the cord loop, bring all shroud lines together without letting them tangle
   c. Make a u-bend close the fixture point of shroud lines, put a rubber band around this bend to make sure shroud lines stay together and untangled
   d. Lay the parachute out
   e. Find the seam between two sections, and bring the next seam together so they touch, making sure the fabric loop created is on the "outside"
   f. Repeat the step above until the entire parachute is folded seam on seam
   g. **Remove the rubber band on shroud lines**
   h. Stuff folded parachute in deployment bag, ensuring all parachute fabric is within the bag, generally oriented so the top of the parachute is at the bottom of the bag
   i. Fold shroud lines of MAIN in Z formation and loop through exterior deployment bag elastic loops so that the full length is contained under elastic loops and does not exceed the length of the deployment bag
   j. Ask Amy to confirm
   k. Fold flap of deployment bag over secured shroud lines.
   l. Have Amy confirm
12. Check that there are no rubber bands or tape (besides labels) on kevlar shock cord
13. Make sure size 2 quick links exist on every loop and one end is un-tied (** to be inserted into payload compartment later)
14. Weave un-tied end of shock cord through payload
   a. Tie bowline knot, TIGHTEN
   b. Attach new size 2 quick link to aft payload bulkhead U-bolt and newly tied bowline
      i. Have second team member confirm secured U-bolt
   c. Pull shock cord away from payload until there is no slack between the U-bolt and the slot in centering ring
   d. Putty around the shock cord passing through the centering ring to ensure ejection gasses don't pass into payload area.
15. Attach quick-link labelled "PLUG" to the Plug for the payload
16. Attach deployment bag to "NOSECONE" quicklink
17. Attach "NOSECONE" quick link to nose cone
18. Attach Main Chute to "MAIN" quicklink
19. Prepare Midsection for Shock Cord Insertion:
   a. Use putty to seal both sides of forward payload bulkhead
   b. Use putty to seal all wire holes
   c. Place hatch over the opening with forward side up and align holes
   d. Attach Hatch:
      i. Locate black capsule containing nuts and attached bolts

ii. Remove nuts from bolts
iii. Use small wrench to hold nuts in place while screwing on the FWD hatch screws
iv. Hand screw remaining screws starting at the AFT side of the hatch
v. Putty FWD hatch section door

20. Inspect the inside of both sides of airframe for any structural damage
21. ASK RAVEN IF HATCH IS ATTACHED AND BOLTS SECURE/ PUTTY AROUND HATCH AND READY FOR SHOCK CORD INSERTION
22. Accordian style fold excess shock cord between nose cone and deployment bag and secure with single rubber band
    a. Insert into nose cone
23. Fold excess shock cord between plug, nose cone, and payload accordian style, secure with single rubber band and insert into midsection/nosecone
24. Slide nosecone shoulder into midsection cavity using inner symbols to align holes, taking care to ensure no shock cord or deployment bag fabric is pinched between sections
25. insert (4) 4-40 nylon shear pins into shear pin holes until tight
26. If shear pins are loose, place small piece of electrical tape over shear pin heads
27. Nose cone and midsection should be able to hold their own weight from shear pins alone
28. Inspect the outside of airframe for any cracks, chips, or other structural damage

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9.5 Drogue and LARD

Drogue Parachute and LARD Parachute Recovery Assembly:

Required items:

a. Recovery box
b. Fin can
c. Midsection
d. Drogue parachute
e. LARD parachute
f. Small nomex cloth (drogue)
g. LARD deployment bag
h. Pilot parachute
i. Pilot nomex cloth
j. 2 large Jolly Logic Rubber bands
k. Jolly Logic Chute Release with extra rubber bands
l. Drogue parachute shock cord
m. (4) nylon 4-40 shear pins
n. (6) quicklinks (3 size 1 quicklinks, 3 size 2 quicklinks)
o. (2) rubber bands
p. Safety Goggles

1. Install drogue parachute black powder charges, both Primary and Redundant (**see Drogue Black Powder Checklist**)
2. Inspect full length of drogue parachute shock cord for rips, tears, or damage
3. Drogue Parachute
   a. Remove all rubber bands holding drogue parachute fabric and shroud lines, but NOT shock cord
   b. Inspect drogue parachute and shroud lines to ensure there are no rips, tears, fraying, or other damage
   c. Fold and roll drogue parachute, with shroud lines in the roll.
      i. Fully inflate drogue parachute to ensure shroud lines are not tangled.
      ii. Starting at the eye-bolt, bring all shroud lines together without letting them tangle
      iii. Make a u-bend close the fixture point of shroud lines, put a rubber band around this bend to make sure shroud lines stay together and untangled
      iv. Lay the parachute out
      v. Find the seam between two section, and bring the next seam together so they touch, making sure the fabric loop created is on the "outside"
      vi. Repeat the step above until the entire parachute is folded seam on seam
      vii. Divide the flaps up evenly so there is a stack of 3 flaps on either side.

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viii. Remove the rubber band on shroud lines, lay them across parachute down the middle, doubling over as necessary so that all shroud lines lay on top of parachute and eye-bolt comes out the bottom end
ix. Fold parachute over middle line with shroud lines inside
x. Z-fold parachute, then roll from side to side starting with the end eye-bolt peeks out from so that it is in the middle of the roll

d. Use (1) size 1 quicklink to attach tan nomex cloth to shock cord parachute loop labeled "Drogue"
e. Use same quicklink to attach drogue parachute eye-bolt to shock cord parachute loop labeled "Drogue"
   i. Final check that no rubber bands are on parachute or shroud lines
   ii. Tighten quicklink by hand
   iii. Have another member check the secure link.
f. Wrap nomex cloth around rolled Drogue parachute like a burrito.
   i. Place rubber band around burrito for time being

4. LARD Parachute
   a. Inspect LARD Parachute, Pilot Chute, and corresponding shroud lines for rips, tears, fraying, or other damage
   b. Fold and roll pilot chute with shroud lines wrapped internally.
      i. Fully inflate pilot parachute to ensure shroud lines are not tangled.
      ii. Starting at the eye-bolt, bring all shroud lines together without letting them tangle
      iii. Make a u-bend close the fixture point of shroud lines, put a rubber band around this bend to make sure shroud lines stay together and untangled
      iv. Lay the parachute out
      v. Find the seam between two section, and bring the next seam together so they touch, making sure the fabric loop created is on the "outside"
      vi. Repeat the step above until the entire parachute is folded seam on seam
      vii. Divide the flaps up evenly so there is a stack of 3 flaps on either side.
      viii. Remove the rubber band on shroud lines, lay them across parachute down the middle, doubling over as necessary so that all shroud lines lay on top of parachute and eye-bolt comes out the bottom end
      ix. Fold parachute over middle line with shroud lines inside
      x. Z-fold parachute, then roll from side to side starting with the end eye-bolt peeks out from so that it is in the middle of the roll
   c. Place rubber band around pilot chute for now
   d. Attach Pilot chute to size 1 quick link and external fabric loop on bottom of deployment bag
      i. tighten quick link and have a second member verify solidly attached
   e. Remove all rubber bands holding LARD fabric and shroud lines
   f. Detach everything attached to LARD parachute

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    i. Ask Amy to confirm
    ii. Ask Raven to confirm
g. Use (1) size 1 quicklink to attach the long inner attachment from the LARD deployment bag to the top black fabric loop on the inner diameter of the LARD Canopy, exterior of parachute.
h. Insert LARD parachute to deployment bag while Amy supervises
    i. Ensure shroud lines are not tangled
    ii. Starting at the cord loop, bring all shroud lines together without letting them tangle
    iii. Make a u-bend close the fixture point of shroud lines, put a rubber band around this bend to make sure shroud lines stay together and untangled
    iv. Lay the parachute out
    v. Find the seam between two sections, and bring the next seam together so they touch, making sure the fabric loop created is on the "outside"
    vi. Repeat the step above until the entire parachute is folded seam on seam
    vii. Remove the rubber band on shroud lines
    viii. Stuff folded parachute in deployment bag, ensuring all parachute fabric is within the bag, generally oriented so the top of the parachute is at the bottom of the bag
    ix. Fold shroud lines of LARD in Z formation and loop through exterior deployment bag elastic loops so that the full length is contained under elastic loops and does not exceed the length of the deployment bag
    x. Ask Amy to confirm
    xi. Fold flap of deployment bag over secured shroud lines.
    xii. Ask Amy to confirm
i. Fold end attachment of parachute on outside of deployment bag.
j. Attach parachute loop to drogue/LARD shock cord loop labelled "LARD" using size 2 quicklink, DO NOT CLOSE QUICK LINK yet
k. Attach orange attachment loop of jolly logic to the opened quicklink
l. Attach red Pilot nomex cloth to quick link
    i. Ask Amy to confirm
    ii. Ask Raven to confirm
m. Close quick link, tighten and ask a second person to confirm.
    i. Make sure Key is not locked into or attached to jolly logic
    <u>NOTE:</u> If it is locked in: , press "on" and press down towards the open option and allow the green light to run from top "close" to bottom "open"
    ii. Make sure Jolly Logic is charged
        1. If not, use back-up Jolly Logic
        2. Make sure when turned on that Jolly logic light is next to "700" for altitude

3. Ask Amy to confirm

iii. Attach two linked rubber bands to the Jolly Logic loop and the open end of the rubber band link to the Jolly Logic key
    1. Ask Amy to Confirm.
    2. Ask Raven to Confirm

iv. Insert the key-end of the Jolly Logic through the LARD parachute attachment loop
    1. Ask Amy to Confirm
    2. Ask Raven to Confirm

v. **<u>Remove the rubber band around pilot chute</u>**

vi. Place rolled pilot chute on top of flap of deployment bag, then lay red nomex cloth over the pilot chute

vii. Stretch key end around closed deployment bag and pilot chute / pilot nomex cloth and insert key
    1. Ask Amy to Confirm
    2. Ask Raven to Confirm

5. Attach FWD size 2 quicklink to midsection aft bulkhead U-bolt and tighten by hand
    a. Have a second team member confirm the quicklink is secured to the midsection aft bulkhead U-bolt by visual inspection and pulling on shock cord
6. Attach AFT size 2 quicklink to fin can bulkhead U-bolt and tighten by hand
    a. Have a second team member confirm the quicklink is secured to the fin can bulkhead U-bolt by visual inspection and pulling on shock cord
7. **<u>Remove rubber band around drogue/tan burrito</u>**
8. Final check that all rubber bands are removed from parachute and shroud lines
9. Shock Cord Insertion
    a. Fold FWD length of shock cord accordion-style and secure with a single rubber band
        i. DO NOT make rubber band too tight (If it looks like it may break, add another band or a larger band)
        ii. Ensure rubber band is not covering any part of parachute
    b. Fold AFT length of shock cord accordion-style and secure with a single rubber band
        i. DO NOT make rubber band too tight
        ii. Ensure rubber band is not covering any part of parachute
    c. Fold middle length of shock cord accordion-style and secure with a single rubber band
        i. DO NOT make rubber band too tight
        ii. Ensure rubber band is not covering any part of parachute
    d. Inspect the inside of both sides of airframe for any structural damage
    e. Carefully insert the AFT shock cord length into fin can cavity
    f. Carefully insert the FWD shock cord length into the midsection cavity

g. Carefully insert the wrapped parachutes and middle shock cord into the space between stowed shock cords
h. Slide midsection coupler into fin can cavity using inner symbols to align holes, taking care to not catch parachutes or shock cords in between sections
i. Insert (4) 4-40 nylon shear pins to size and insert into shear pin holes until tight
j. If shear pins are loose, place small piece of electrical tape over shear pin heads
k. Fin can and midsection should be able to hold their own weight from shear pins alone
l. Inspect the outside of airframe for any cracks, chips, or other structural damage

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9.6 Motor Preparation & Assembly

Motor Assembly:

1. Required items:
    a. AeroTech L2200G reload kit
    b. AeroTech RMS 75/5120 motor casing with forward seal
    c. Lube
    d. Needle-nose pliers
    e. Baby wipes
2. Under guidance of L3 mentor, Safety Officer, and potentially RSO:
    a. Follow instructions for motor assembly from L3 mentor
    b. Inspect motor and motor casing for damage
    c. Unscrew motor retainer and slide motor casing into motor tube
    d. Secure motor casing using retainer screw
    e. Use another team member to ensure motor retainer screw is tight

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9.7 Pre-Launch Items

Pre Launch Procedure:

1. Required items
    a. Fully assembled rocket with payload and motor assembled
    b. Stickers for CP and CG
    c. Pen / Sharpie for stickers
    d. Fish Scale
    e. Rope
    f. Foam
    g. 3 or 4 people
2. Lay out foam on ground to protect rocket from damage
3. Tie the rope in a loop, then fit around rocket
4. Hook rope onto fish scale
5. Lift rocket by fish scale, recording weight and adjusting location of rope until balanced
6. Mark location of rope with CG sticker
7. Remove the rope and set rocket down on the foam
8. Measure the distance between nosecone tip and CG location
9. Place CP sticker 81.8 in from the nosecone.
10. Calculate distance between CG and CP
11. Divide this distance by 7.5 in to find stability ratio
12. Carry rocket over to judging/launch prep table

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9.8 Launch Procedure

Launch Pad Procedure:

1. Required items:
    a. Fully assembled rocket with payload and motor installed
    b. Motor igniter
    c. 6ft x 1515 launch rail
    d. Small, black screwdriver with red tip
    e. Blue painter's tape
    f. Safety glasses
    g. Launch rail lubricant
    h. Stepladder (if necessary)
2. Grease rocket rail buttons and launch rail track
3. Carefully slide rocket onto launch rail
4. Rotate launch rail into upright position and lock into place
    a. Rocket must be pointed downwind and 5° from vertical
5. Verify the structural integrity of the launch buttons; ensure they hold the rocket firmly in place.
6. Use another team member and L3 mentor to confirm launch rail is locked and structurally secure
7. Take team picture in front of rocket
8. All non-essential personnel must be directed to leave the launch pad
    a. All individuals remaining at launch pad must wear safety glasses
9. Arm both altimeters:
    a. Unlock key switch on the right of the hatch to the ON position.
        i. Fill out the middle column of the chart on the next page.
        ii. Each sequence of beeps is separated by 2 seconds of silence.
        iii. Stratologger displays "0" as a sequence of 10 beeps.
        iv. The first column of the chart says what each sequence of beeps means.
        v. Confirm that Stratologger beeping lines up with expected values in the third column.

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A siren and error code if an error was encountered during the last flight.		Ignore, currently not important
A one digit number (range of 1 to 9) corresponding to the currently-selected program preset.		Ignore, all presets are set to the same settings
A two second pause, and then a three or four digit number corresponding to the main deploy altitude setting.		IMPORTANT: Should be 500
(optional) only if you have added an apogee delay to the currently selected preset: A two second pause, and then a five second continuous tone to warn you that your apogee firing is set to be delayed.		IMPORTANT: Should not sound
A two second pause, and then a three to six digit number representing the apogee altitude of the last flight.		Ignore, currently not important
A two second pause, and then a two or three digit number representing the battery voltage in tenths of a volt (e.g. 9.2 volts would report as 92).		IMPORTANT: Should be between 8.6 and 9.4.
A two second pause, and then continuity beeps repeated every 0.8 seconds – a single beep means drogue ematch continuity is OK, two beeps means main ematch continuity is OK, three beeps means both drogue and main have good continuity.		IMPORTANT: Should be 3

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b. Unlock key switch on the left of the hatch to the ON position.
   i. Fill out the middle column of the chart below
   ii. 3 short beeps indicate success, 3 long beeps indicate failure
   iii. The first column of the chart indicates what the current sequence of beeps means.
   iv. Confirm that Entacore beeping lines up with expected values in the third column.

If the device produces a long 4 second beep initially, then the settings on the device have reverted back to their default values.		IMPORTANT: Should not sound
Free memory: Success indicates enough free memory for a full flight.		IMPORTANT: Should be 3 short beeps
Battery voltage: Success indicates the the battery voltage is above the minimum setting (8.4 volts)		IMPORTANT: Should be 3 short beeps
Line A continuity		IMPORTANT: Should be 3 short beeps
Line B continuity		IMPORTANT: Should be 3 short beeps

10. Under guidance of the L3 mentor, RSO, and Safety Officer:
    a. Insert igniter fully into motor tube against the inner side of the motor.
    b. Tape igniter into place at the bottom of rocket
    c. Confirm that launch pad power is cut off
    d. Connect igniter to launch pad power
    e. Ensure pad continuity
    f. Inspect entire rocket for cracks, chips, or other damage during assembly
11. All personnel must navigate to safe locations behind launch table
12. LAUNCH!

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9.9 Post-Flight Recovery

After flight the Stratologger will report in this sequence:

- An extra-long tone to indicate the start of the reporting sequence.
- A three to six digit number representing the peak altitude in feet.
- A long separator tone followed by a two to five digit number representing the maximum velocity during the flight in miles per hour.
- If the "siren delay" number is set to a number greater than zero , the altimeter will wait for the specified siren delay time, and then emit a 10 second warbling siren tone to aid in locating the rocket if it is hidden from sight in a tree, tall grass, etc.

Entacore should be beeping out the altitude in feet (or feet if you changed the default setting). The altitude is beeped out in digits. Wait for a long pause so as to make sure you are at the beginning of the beep-out cycle. Count the number of beeps between pauses to obtain the value of that digit. If the digit is a "0", a short beep will be heard.

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10. Project Plan

10.1 Testing

The description, procedure, results, and analysis for various tests performed by the team to validate the full-scale design are contained within their relevant sections of this report. Table 10-1, below, lists each test item, the relevant section within the report, and a summary of the results.

Table 10-1: Testing Required to Validate Full-Scale Launch Vehicle Design

Subsystem	Test Item	Report Section	Summary of Test
Structure	Blue Tube Material Properties	3.5.1.1	A section of Blue Tube material was crushed in a hydraulic press to determine its material properties. The peak stress was found to be 5,670 psi.
	Midsection Access Hatch Flight Forces	3.5.1.2	The midsection access hatch was subjected to simulated flight forces. The peak stress in the hatch was 565 psi which gives a safety factor of 10.0.
	Fin Can Flight Forces	3.5.1.3	The fin can was subjected to simulated flight forces. The peak stress on the fin can was 890 psi which gives a safety factor of 4.5 and it was shown that the bulkheads will fail before the Blue Tube.
	LARD Deployment Forces	3.5.1.4	The force caused by rapid inflation of the LARD was applied to the fin can U-bolt to simulate flight conditions. The peak stress across the fin can bulkhead was 123 psi which gives a safety factor of 32.5 for the birch bulkhead.
Recovery	Black Powder Ground Ejection Testing	4.3.6	The full-scale rocket was assembled to simulate flight conditions at the time of separation. The nosecone and fin can sections both separated with 4.0 g of black powder. The launch configuration

			will use primary charges of 4.0 g and redundant charges of 4.5 g.
	LARD Drop Test	6.8.1	Incomplete. Test planned for March 8, 2018.
Avionics	Altimeter Testing	4.4.3.4	Each altimeter unit was tested in a vacuum chamber to simulate changing altitude conditions. All four altimeters showed positive results during the test and can be used to launch the full-scale rocket.
	GPS Transmitter Testing	4.4.4.2	A team member rode a campus bus while carrying the GPS transmitter to determine if any discrepancies between the bus GPS and the rocket GPS existed. No major discrepancies were found between the two datasets and the GPS transmitted perfectly during the full-scale test launch.
Payload	Rover Drive Testing	7.5	Incomplete. Testing planned for March 9-30, 2018.
	Long-Range Receiver Testing	7.4.5.1	Incomplete. Testing planned for March 9-30, 2018.

10.2 Compliance Verification

Table 3-1, Table 4-1, Table 7-1, and Table 8-1 contain the handbook compliance items with their respective verification methods, verification status, and links to relevant text within this report.

10.3 Team-Derived Requirements

Table 10-2, below, contains the compliance plan for team-derived requirements.

Table 10-2: Team-Derived Requirements and Verification Plan

Subsystem	Description of Requirement	Verification Method	Status

Recovery	Prioritize Hardware available to decrease budget.	For the LARD parachute, quick links, and shear pins are examples of hardware currently available and were prioritized before purchasing new materials. This process of taking inventory of available parts will continue during full-scale construction. Shear pins were readily available and are being used, the parachute for the LARD is the same parachute as the subscale main parachute, which was used in previous years. The quick links are being reused from previous years. All of these parts are in good, working condition and in the end will save the team money.	Complete. See Sections 4.3
Recovery	Utilize deployment bag for the main parachute.	A Fruity Chutes 7.5 in. deployment bag is being utilized in order to delay the deployment and inflation of the main parachute following the main separation. The deployment bag requires the shroud lines to be inserted and woven in a z-formation and therefore delays the time that it takes for the shroud lines to fully extend and the canopy to inflate.	Complete. See Section 4.3.3
Recovery	Decrease wind drift through the employment of a third parachute, the Low Altitude Recovery Device (LARD).	A third parachute (LARD) is being installed along the shock cord of the drogue compartment. The LARD will be located 120 inches from the aft bulkhead of the midsection and 180 in. from the drogue parachute. The LARD will decrease the amount of motion and force transferred from the main parachute deployment to the rover latching mechanism. The rover latching mechanism may only withstand 1.5 lb of force. With the LARD, the midsection avoids a 180 degree maneuver to re-orient once the main parachute is deployed. The LARD parachute is a 60 in. Iris Ultra Standard parachute, and was used as the main parachute for the subscale rocket.	Complete. See Section 4.3.2
Structures	Minimize cost of materials by using scraps or off-the-	Buckling experiment will be conducted using leftover Blue Tube samples from previous projects. Experiment will consist of axially compressing three Blue Tube	Complete. See Section 3.4

	shelf materials when possible.	cylindrical sections until buckling occurs in a hydraulic press. By using small samples, the team will avoid purchasing extra Blue Tube.	
Rover	Complete a completely custom body with no pre-manufactured parts.	The body, axles, and wheels of the rover will be 3D printed by members of the team and tested for strength and functionality. The team-manufactured parts will be tested and compared to pre-manufactured part performance. The parts will be incorporated and tested for mission completion to ensure that they perform as intended.	Incomplete. Fabrication, assembly, and testing to be completed prior to the full-scale re-flight on March 24, 2018.

10.4 Budget

Table 10-3, below, contains the line-item list of all projected expenses for the team to compete in the 2017-18 NASA Student Launch challenge.

Table 10-3: Line-Item Budget

	Item	Quantity	Price per Unit	Item Total
Subscale Rocket	4” Phenolic Airframe Tube	2	$20.99	$41.98
	4" Phenolic Tube Coupler	1	$4.99	$4.99
	4" Plastic Nose Cone Standard	1	$23.95	$23.95
	Aircraft Spruce Domestic Birch Plywood 1/4"x4x4	2	$56.38	$112.76
	¼” Threaded Rods	2	$4.54	$70.00
	Rail Buttons	1	$7.35	$7.35
	U-Bolts	4	$2.96	$11.84
	I435T Motor	2	$55.99	$111.98
	Motor Casing (subscale)	1	$240.00	$240.00
	Motor Retainer	1	$33.50	$33.50
	12” Motor Mounting Tube MMT-1.525 (38mm)	1	$5.49	$5.49
	StratoLoggerCF Altimeters	2	$55.00	$110.00
	Entacore Altimeters	2	$115.00	$230.00
	Key Switches	2	$12.00	$24.00
	1 in PVC Pipe Caps	4	$0.83	$3.32
	Acrylic Tubing (OD 2.75”, 1/8” thick)	1	$43.27	$43.27
	Terminal Blocks	3	$7.00	$21.00
	3mm Ball Bearings (1000 count)	2	$8.22	$16.44
	Adafruit BNO055 10DoF sensor	1	$28.05	$28.05
			Subtotal:	**$1,139.92**
Full-Scale Rocket	Ogive Nose Cone	1	$88.00	$88.00
	7.5"x 0.08 wall x 12" Blue Tube ARR Standard Coupler	2	$30.00	$60.00
	7.5" x 0.08 wall x 48" ARR Airframe Blue Tube	2	$90.00	$180.00
	Aircraft Spruce Domestic Birch Plywood 1/8"x4x4	3	$50.00	$150.00
	Aircraft Spruce Domestic Birch Plywood 3/8"x2x4	2	$70.00	$140.00
	Rail Buttons	4	$2.50	$10.00
	U-Bolts	3	$1.00	$3.00
	Aerotech L2200G-P	3	$260.00	$780.00
	Motor Casing	1	$390.00	$390.00
	3" G12 Fiberglass Filament Wound Tube 48" Long	1	$91.00	$91.00
	Motor Retainer	1	$25.00	$25.00
	Wires	1	$30.00	$30.00
	Connectors	1	$20.00	$20.00
	StratoLoggerCF Altimeter	1	$55.00	$55.00
	Entacore Altimeter	1	$115.00	$115.00

	Item	Quantity	Price per Unit	Item Total
Full-Scale Rocket	BRB 900 Transmitter	1	$200.00	$200.00
	Key Switches	2	$12.00	$24.00
	Blast Caps	4	$2.50	$10.00
	Terminal Blocks	3	$7.00	$21.00
	E-matches	-	$20.00	$20.00
	Black Powder (lb)	1	$30.00	$30.00
	Sanding Sealer (qt)	1	$17.00	$17.00
	Epoxy and Hardener	1	$50.00	$50.00
	Paint	1	$70.00	$70.00
	Nuts (box)	1	$5.50	$5.50
	Screws (box)	1	$5.00	$5.00
			Subtotal:	**$2,590.50**
Payload	5.25" x .125" Wall Acrylic Tube	1	$61.00	$122.00
	LiPo Batteries	2	$15.00	$30.00
	Servo Motor	1	$20.00	$20.00
	Arduino Nano	1	$22.00	$22.00
	120mm Lazy Susan Bearing	2	$9.37	$18.74
	5mm Diameter Chrome Steel ball Bearing	1	$9.00	$9.00
	5" Schedule 40 PVC Coupling SxS	2	$6.35	$12.70
	Southco R4-EM 4&6 Series Electronic Rotary Latch	1	$45.00	$45.00
	1” Brass Hinges (4 pack)	1	$6.28	$6.28
	Rubber Adhesive-Back Strip, 2" x 36", 1/8" Thick	2	$16.34	$32.68
	Rubber Adhesive-Back Strip, 2" x 36", 1/16" Thick	2	$11.51	$23.02
	U-Channel Push-on Trim 3/16" Wide x 3/8" High Inside	1	$14.70	$14.70
	U-Channel Push-on Trim 1/16" Wide x 1/4" High Inside	1	$9.00	$9.00
	Aluminum Plate	1	$40.00	$40.00
			Subtotal:	**$406.00**
Rover	Arduino Pro Mini 238	1	$9.95	$9.95
	XBee Pro 900 XSC S3B Wire Rx	1	$66.95	$66.95
	FS90 Servo	3	$4.95	$14.85
	Turnigy 1000mAh 25 20C LiPoly Pack	1	$4.73	$4.73
	Black Rubber Belt 1" wide 48 Tooth	2	$8.84	$8.84
	Solar Cell AM 25mm x 10mm	7	$1.55	$10.85
	4AA Battery Holder - w/Wires and Switch	1	$4.00	$4.00
	MSP430 LaunchPad Value Line Development kit	1	$10.00	$10.00
	SparkFun Bluetooth Modem - BlueSMiRF Silver	1	$25.00	$25.00
	Duracell AA Batteries	1	$22.00	$22.00
	ABS 3D Printer Filament	1	$22.00	$22.00
	Transmitter and Receiver Pair	1	$18.00	$18.00
			Subtotal:	**$217.00**

	Item	Quantity	Price per Unit	Item Total
Recovery	Jolly Logic Chute Release	1	$130.00	$130.00
	18 in. Standard Elliptical Parachute	1	$36.00	$36.00
	120 in. Iris Ultra Compact Parachute	1	$685.00	$685.00
	60” Iris Ultra Compact Parachute	1	$225.00	$225.00
	7.5” deployment bag	1	$69.00	$69.00
	Kevlar Shock Cord (yd) (full-scale)	28	$4.34	$121.50
	Quick Links	5	$1.25	$6.25
			Subtotal:	**$1,272.00**
Travel	Student Hotel Rooms (price per day)	4	$791.70	$3,166.80
	Mentor Hotel Rooms (price per day)	3	$1,178.10	$3,534.30
	Van Rental (2 vans, 1,144 miles each)	2,288	$0.69	$1,578.72
	Gas	-	-	$686.40
			Subtotal:	**$8,966.22**
Promotional	T-Shirts	25	$15.00	$375.00
	Polos	25	$30.00	$750.00
	Pens	500	$0.24	$120.00
	Stickers	500	$0.26	$130.00
			Subtotal:	**$1,375.00**
Other	Incidentals (replacement tools, hardware, safety items)	-	-	$1,000.00
	Shipping Costs	-	-	$1,000.00
			Subtotal:	**$2,000.00**
			Total Expenses:	**$17,966.64**

10.4.1 Funding Plan

The team receives funding from multiple NC State University organizations as well as the North Carolina Space Grant (NCSG).

The Engineering Technology Fee (ETF) fund from the MAE department at NC State provides monetary support to any student organizations that satisfy the Senior Design project curriculum requirements. Since the NASA SL project will complete the requirements for the Aerospace Engineering Senior Design course, the team will receive approximately $2,000 from the ETF fund for the entire school year.

The Engineers’ Council (E-Council) at NC State University is a student-led organization that oversees events hosted by the College of Engineering. E-Council also allocates funds to different engineering organizations through a proposal, presentation, and appeals process that occurs twice per school year. This academic year, HPRC has received $850 from E-Council for the Fall session and $450 for the Spring session.

The NC State University Student Government Association’s Appropriations Committee is responsible for distributing university funds to campus organizations. The application process is similar to E-Council with a proposal, presentation, and an in-person interview. This academic year, HPRC has received $865 for the Fall session and $1,450 for the Spring session.

The Department of Mechanical and Aerospace Engineering at NC State has committed to paying for the club's travel costs for the year. This includes the cost of student hotel rooms and transportation to and from Student Launch.

In addition to funding through NC State organizations, the North Carolina Space Grant will provide a large amount of monetary support to the club. NCSG has awarded the team $5,000 for group participation and $3,000 for senior design to participate in the 2018 NASA SL competition.

Our sponsor, Southco, has offered to provide the electronic latches and additional equipment required for our full-scale payload design.

With the funding described above, HPRC's working capital for the academic year is $20,615. About half of this, $10,470, has been spent on subscale and travel; leaving $10,145 for full-scale fabrication, promotional materials, and incidentals. Full-scale fabrication has cost about $4,500 at this point, promotional materials is $1,375, and incidentals and shipping is $1,750. These estimated values leave $2,650 extra for incidentals and club expansion.

These totals are listed in Table 10-4, below, which compares the projected costs and incoming grants for the 2017-18 school year.

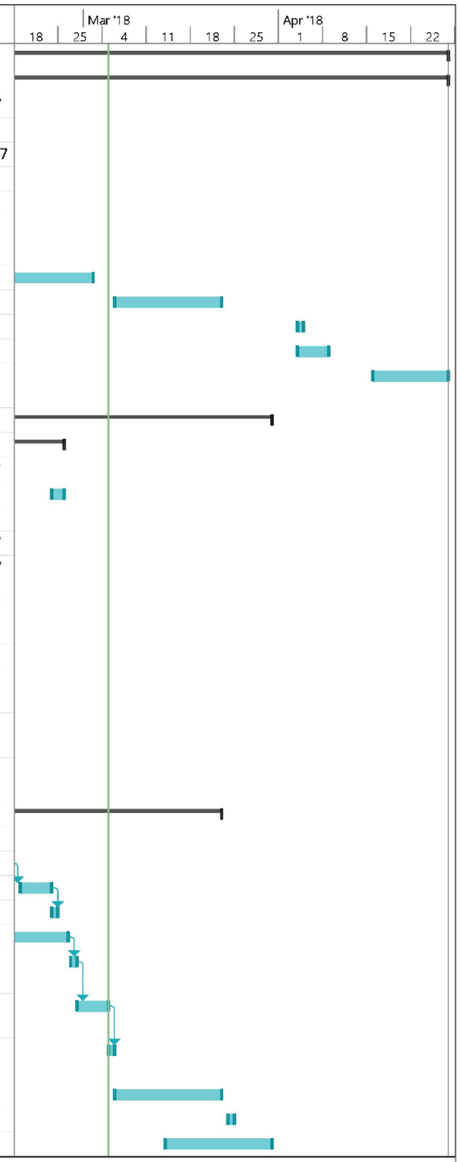
Table 10-4: HPRC Projected Funding for 2017-18 School Year

Organization	Fall Semester Amount	Spring Semester Amount	School Year Total
E-Council	$850.00	$450.00	$1,300.00
SGA Appropriations	$865.00	$1,450.00	$2,315.00
NC Space Grant	-	-	$8,000.00
ETF Fund	-	-	$2,000.00
MAE Department	-	-	$7,000.00
		Total Funding:	**$20,615.00**
		Total Expenses:	**$17,966.64**
		Difference:	**+$2,648.36**

10.5 Timeline

Figure 10-1, below, shows the remaining action items following the submission of the FRR.

ID	Task Name	Duration	Start	Finish
1	**2017-2018_Tacho_Lycos_HPRC_Schedule**	**143.25 days**	**Thu 10/12/17**	**Fri 4/27/18**
2	**NASA Student Launch Schedule**	**143.25 days**	**Thu 10/12/17**	**Fri 4/27/18**
3	Preliminary Design Review (PDR) Q&/	1 day	Thu 10/12/17	Thu 10/12/17
4	PDR	17 days	Fri 10/13/17	Mon 11/6/17
5	PDR Team Teleconference Window	18 days	Mon 11/6/17	Wed 11/29/17
6	Critical Design Review (CDR) Q&A	1 day	Wed 12/6/17	Wed 12/6/17
7	CDR	28 days	Wed 12/6/17	Fri 1/12/18
8	CDR Team Teleconference Window	11 days	Wed 1/17/18	Wed 1/31/18
9	Flight Readiness Review (FRR) Q&A	1 day	Wed 2/7/18	Wed 2/7/18
10	FRR	19 days	Wed 2/7/18	Fri 3/2/18
11	FRR Team Teleconference Window	13 days	Tue 3/6/18	Thu 3/22/18
12	Launch Readiness Review (LRR)	1 day	Wed 4/4/18	Wed 4/4/18
13	NASA Launch Week Events	4 days	Wed 4/4/18	Sun 4/8/18
14	Post-Launc Assessment Review (PLAR)	10 days	Mon 4/16/18	Fri 4/27/18
15	**Tacho Lycos Schedule**	**106.25 days**	**Mon 11/6/17**	**Fri 3/30/18**
16	**Subscale and CDR**	**81.25 days**	**Mon 11/6/17**	**Sun 2/25/18**
17	Subscale Flight Test	2 days	Sat 11/18/17	Sun 11/19/17
18	Full-Scale Flight Test Window	2 days	Sat 2/24/18	Sun 2/25/18
19	Subscale construction and testing	10 days	Mon 11/6/17	Fri 11/17/17
20	Subscale Flight Test	2 days	Mon 11/20/17	Tue 11/21/17
21	Review subscale data & and analyze results	2 days	Wed 11/22/17	Thu 11/23/17
22	Incorporate design changes to full scale, finalize motor selection	5 days	Mon 11/27/17	Fri 12/1/17
23	Write first draft of CDR	16 days	Sat 12/16/17	Fri 1/5/18
24	Submit CDR draft to advisors/mentors for review	1 day	Mon 1/8/18	Mon 1/8/18
25	Fine-tune CDR and incorporate changes	5 days	Sat 1/6/18	Thu 1/11/18
26	Post CDR to website and email NASA SL office	1 day	Fri 1/12/18	Fri 1/12/18
27	**Full-Scale and FRR**	**50.25 days**	**Sat 1/13/18**	**Thu 3/22/18**
28	Purchase orders for full-scale	6 days	Sat 1/13/18	Fri 1/19/18
29	Full-scale construction	20 days	Mon 1/22/18	Fri 2/16/18
30	Full-scale pre-flight-test testing	5 days	Mon 2/19/18	Fri 2/23/18
31	Full-scale flight test	1 day	Sat 2/24/18	Sat 2/24/18
32	Write first draft of FRR	12 days	Mon 2/12/18	Mon 2/26/18
33	Submit FRR draft to advisors/mentors for review	1 day	Tue 2/27/18	Tue 2/27/18
34	Fine-tune FRR and incorporate changes	4 days	Wed 2/28/18	Sun 3/4/18
35	Post FRR to website and email NASA SL office	1 day	Mon 3/5/18	Mon 3/5/18
36	FRR video conference TBD	13 days	Tue 3/6/18	Thu 3/22/18
37	Re-flight Test	1 day	Sat 3/24/18	Sat 3/24/18
38	Rover Testing	13 days	Wed 3/14/18	Fri 3/30/18



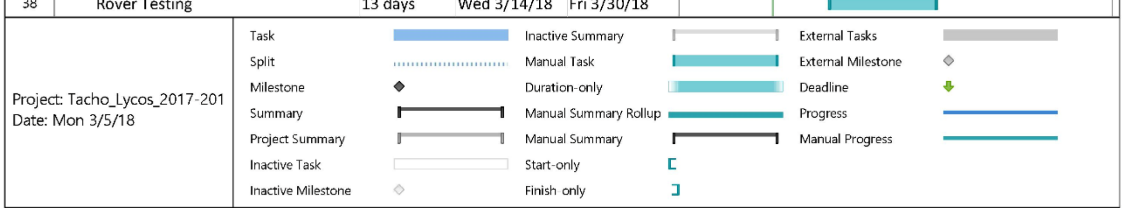


Figure 10-1: Remaining Project Timeline

11. Appendix A – FMECA Table

The FMECA table below uses the following hazard level classification:

1) Rocket mission failure; rocket is not recoverable; payload is not recoverable; rover mission failure
2) Rocket mission failure; rocket is recoverable; payload may be recoverable; rover mission may be complete
3) Rocket mission complete; rocket is recoverable; payload is not recoverable; rover mission failure
4) Rocket mission complete; rocket is recoverable; payload is recoverable; rover mission failure

System	Subsystem/Component	Failure Mode	Causal Factors	Failure Effects		Hazard	Recommendations	Verifications
				Subsystem	System			
Launch Vehicle	Nosecone	Cracks or breaks	Object in flight path	Loss of nose cone recoverability	Loss of controlled and stabilized flight	2	Ensure that skies are clear of any foreign objects per NAR operations. HPRC will also follow the directions of the RSO and have no premature launches.	The team will not launch the rocket until a NAR supervisor and HPRC RSO officially clears for launch.
			Damaged during handling or assembly			2	Inspect for cracks, chips, or other damage during assembly directly prior to the launch	Step 28 of Main Parachute Recovery Assembly: Inspect the outside of airframe for any cracks, chips, or other structural damage
			Nosecone collides with other rocket component during recovery		N/A	2	Ensure that shock cord is appropriate length to space the nosecone during descent	In Section 4.3.5, it is detailed that the required length of the shock cord is 80-in of 1⁄2-in tubular Kevlar shock cord.
			Ground impact			2	The recovery system is designed so that the rocket landing should not damage the rocket.	In section 1.2.3 the desired impact speed of the vehicle that has been calculated has been listed as 13.3 ft/s
		Premature separation from midsection	Damaged during handling or assembly	Potential for permanent structural damage	Loss of controlled and stabilized flight	2	Inspect for cracks, chips, or other damage during assembly directly prior to the launch	Step 28 of Main Parachute Recovery Assembly: Inspect the outside of airframe for any cracks, chips, or other structural damage
			Shear pins not installed correctly			2	Follow design specifications for sizing, inspecting, and installing shear pins during assembly see Section 4.3.5	Steps 25 and 26 of Main Parachute Recovery Assembly: Insert (4) 4-40 nylon shear pins into shear pin holes until tight If shear pins are loose, place small piece of electrical tape over shear pin heads
			Epoxy not cured properly			2	Follow proper procedures for mixing, applying, and curing West System's Two Part Epoxy	West System's 206 and 105 Epoxy was mixed with West System's 406 accelerator according to the manufacturer's provided ratios. The epoxy was then cured at the manufacturer's recommended cure time of 15 hours to allow ample time to secure the hardening effects of the epoxy.
	Blue Tube Airframe	Cracks or breaks	Manufacturing defect	Loss of structural integrity or usability of	Premature separation of launch vehicle Sections during flight	1	Senior Design Team will perform a visual inspection after shipping and before assembly	Team members have thoroughly inspected the blue tube for defects and finding none have approved it for use.

Launch Vehicle			Loads experienced beyond design specifications	Blue Tube body Sections or components		1	Ensure body tube components can hold flight forces in accordance with design specifications by not exceeding design limitations as described by the part manufacturer, further reducing the risk of upper limit loads ensure that all components can maintain a factor of safety of at least 1.5 during all regimes of flight.	Section 3.5.1.1: Launch Vehicle Pre-Launch Testing Body Tube Material Selection: The compressive strength of the Blue Tube was analyzed and the total compressive strength was found to be 698.99 lbs, which does not exceed the design limitations of the part described by the manufacturer. The factor of safety for the Blue Tube airframe was 4.3, which also heeded to the appropriate limitations.
			Damaged during handling or assembly			1	Senior Design Team will inspect each body tube component for cracks, bends, warping, or other damage during assembly.	The senior design team has inspected the blue tube and made the appropriate fiberglass, epoxy, and Bondo repairs to identified damage.
			Improper storage			1	Store Blue Tube in a dry space, free of items on top and avoid any liquid spills on the product.	The team stored the Blue Tube in a dry cardboard box, away from liquid hazards while in the lab.
	Fins	Severe weather-cocking	Fin dimensions are not cut according to design	N/A	Decreased flight stability, unpredictable flightpath, and possible damage to other components	2	Laser cut fins to ensure manufacturing precision as well as ensure that excessive material is not removed during sanding by having a secondary team member monitor the sanding process	In Section 3.4.5.5, fin dimensions and methods for ensuring the accuracy of fin design are listed.
			Fins not installed at even increments around fin can (90 degrees to each other)			2	Use laser-cut jig with slots for fins exactly 90 degrees from each other	In Section 3.4.5.5, fin dimensions and methods for ensuring the accuracy of fin design are listed.
			Assembled rocket CG is too far forward (Stability Margin >> 2.0)			2	Ensure components and masses are installed according to design specifications	In Section 3.4.5.5, fin dimensions and methods for ensuring the accuracy of fin design are listed.
		Fin separation	Loads experienced beyond design specifications	N/A	Any one failure of a fin could lead to additional fin failures which will decrease flight stability and will likely cause a catastrophic failure	1	Analyze flight data and simulations to confirm that factor of safety is sufficient	Open Rocket simulation data and structural analysis in Section 3.5.1: Launch Vehicle Pre-Launch Testing indicated that the proper factor of safety of 1.5 was observed. Post-flight inspection of the rocket discussed in section 6.7 confirmed those simulations.
			Damaged during handling or assembly			1	Inspect for cracks, chips, or other damage during assembly	The checklist section for the drogue parachute and LARD parachute recovery assembly addresses inspecting for structural damage to the airframe. Further inspections were conducted throughout construction and any damaged components were replaced when noticed.

Launch Vehicle							Replace any damaged components	The checklist section for the drogue parachute and LARD parachute recovery assembly addresses inspecting for structural damage to the airframe. Further inspections were conducted throughout construction and any damaged components were replaced when noticed.
			Fin flutter			2	Rocket will not exceed velocity necessary to induce significant flutter	Fin flutter analysis was not performed, but fin design and construction were done in a manner that reduces the risk of fin flutter, with the span not exceeding the root chord length, outlined in section 3.4.5.5.
			Ground impact			2	Implement a recover system design that ensures a low-speed surface impact	As outlined in section 5.3.2 the impact of the velocity confirmed by open rocket simulations will not exceed 75ft-lbf and impact velocity of 13.55ft/s.
	Motor	Motor fails to ignite	Igniter not installed correctly	Failure of vehicle to start launch	Team member and RSO must insert new igniter and restart launch sequence	4	Follow launch checklist and use mentor/RSO supervision to install igniter fully into the motor tube and taped to the bottom of the rocket	As per the Launch Day Checklist, under Launch Pad Procedure Steps 10-11, the igniter is to be inserted fully into the motor tube with the supervision and approval of a mentor and/or the RSO.
			Faulty igniter used			4	Test a small batch of newly purchased igniters prior to launch day to ensure quality of larger order	New igniters have been ordered to be used for our launch, and a small batch will be tested to analyze for manufacturing errors.
			Motor assembled incorrectly			4	Follow launch checklist and use mentor/RSO supervision to assemble motor according to Aerotech L2200P APCP instructions	As per the Launch Day Checklist, under Motor Assembly Step 2, the motor is to be assembled using instructions from and under the supervision of the L3 mentor.
		Catastrophic motor failure	Damaged during handling or assembly	Possible destruction of launch vehicle	Complete mission failure and additional hazard to ground crew and spectators	1	Carefully inspect for cracks, chips, or other damage to the motor during assembly with the supervision of the L3 mentor and/or Safety Officer	As per the Launch Day Checklist, under Motor Assembly Step 2, the motor is to be assembled using instructions from and under the supervision of the L3 mentor.
			Motor assembled incorrectly			1	Follow launch checklist and use mentor/RSO supervision to assemble motor according to Aerotech L2200P APCP instructions	As per the Launch Day Checklist, under Motor Assembly Step 2, the motor is to be installed using instructions from and under the supervision of the L3 mentor.
			Motor casing dislodged during motor burn			1	Ensure all connection points between motor tube, centering rings, and fins are joined in accordance to design specifications using epoxy	As per section 3.4.5.4, the motor tube, centering rings, and fin assembly are fabricated using epoxy and left to cure over several days. This final assembly is then analyzed and approved by the component build team.
							Metal screws joining the motor retainer to the engine block will be tested for tightness prior to launch. Screws on motor retainer cap will be tightened and checked by multiple team members.	As per the Launch Day Checklist, under Motor Assembly Steps 3-5, the motor is to be inserted into its casing, installed fully inside the motor tube, and screwed in and approved by multiple team members.
		Damage to motor casing	Superficial damage	Motor casing cannot be used	Rocket is not safe to launch if damage is major	4	Carefully inspect for cracks, chips, or other damage to the motor casing during assembly with the supervision of the L3 mentor and/or Safety Officer.	As per the Launch Day Checklist, under Motor Assembly Step 2, the motor is to be installed using instructions from and under the supervision of the L3 mentor.

Launch Vehicle		Propellant contamination	Rocket fails to launch	Reduced performance of rocket motor	Rocket does not launch or perform as expected	2	Store and maintain motor fuel properly and in isolation/ order from reputable source	As per section 3.4, the ammonium perchlorate composite propellant is under supervision of the Safety Officer.
			Over-oxidized reaction			2		As per section 3.4, the ammonium perchlorate composite propellant is under supervision of the Safety Officer.
			Reduced fuel efficiency			3		As per section 3.4, the ammonium perchlorate composite propellant is under supervision of the Safety Officer.
	Bulkheads	Bulkhead separation from airframe during motor burn	Manufacturing defect			1	The team will inspect all received plywood from manufacturers for defects.	Team members have removed all defect pieces of plywood from the workspace and utilized approved plywood.
			Loads experienced beyond design specifications			1	Ensure body tube components can hold flight forces in accordance with design specifications	Section 3.5.1: Launch Vehicle Pre-Launch Testing
							Ensure that all components can maintain a factor of safety of at least 1.5 during all regimes of flight	Section 3.5.1: Launch Vehicle Pre-Launch Testing
			Damaged during handling or assembly			1	Inspect each bulkhead for cracks, warping, chips, or other damage during assembly	As per section 3.4.2, bulkheads have been fabricated in accordance to set procedures with the supervision of multiple team members.
							Replace any damaged bulkheads	As per section 3.4.2, bulkheads have been inspected in detail by team members post-fabrication and after testing/launches.
			Epoxy not cured properly			1	Follow proper procedures for mixing, applying, and curing epoxy	As per section 3.4.2, bulkheads have been fabricated in accordance to set procedures by multiple team members and with the supervision of the Safety Officer.
		U-bolt separation from bulkhead during recovery	Loads experienced beyond design specifications	Launch vehicle components not tethered to a parachute will continue accelerating during descent	Loss of safe and effective recovery system	1	Ensure U-bolt fasteners can handle near-instantaneous loading from parachute deployment	Section 3.5.1: Launch Vehicle Pre-Launch Testing
			Epoxy not cured properly			1	Follow proper procedures for mixing, applying, and curing West System's Two Part Epoxy	West System's 206 and 105 Epoxy was mixed with West System's 406 accelerator according to the manufacturer's provided ratios. The epoxy was then cured at the manufacturer's recommended cure time of 15 hours to allow ample time to secure the hardening effects of the epoxy.
	Rail Buttons/	Vehicle does not leave launch rail as intended	Rail button(s) separate from launch vehicle	Vehicle leaves rail at unpredictable orientation and velocity	Possible mission failure and additional hazard to ground crew and spectators	1	Rail buttons were installed into the engine block and forward motor tube centering ring, after giving ample time for each component to cure, using the manufacturer recommended screws.	Section 3.4.5.6 Launch Rail Buttons
	Launch Rail		Damaged during handling or assembly			1	Rail buttons were inspected prior to launch, with spare buttons on hand to replace if installed buttons had become damaged.	

Launch Vehicle								Step 5 for Launch Pad Procedure: Verify the structural integrity of the launch buttons; ensure they hold the rocket firmly in place.
			Launch rail breaks			2	Launch rail was assembled, locked in place, and inspected for damage with the assistance of our L3 mentor.	Step 6 for Launch Pad Procedure: Use another team member and L3 mentor to confirm launch rail is locked and structurally secure.
		Vehicle does not leave launch rail at all	Rail button(s) becomes stuck in launch rail	N/A	Mission failure as flight does not take place	2	Rail buttons were purchased for 1.5” by 1.5” rail, as well as tested to ensure a proper fit using a length of 1515 launch rail.	Section 3.4.5.6 Launch Rail Buttons
							The launch rail and rail buttons were lubricated before being mounted for launch.	Step 2 of Launch Pad Procedure: Grease rocket rail buttons and launch rail track
							During assembly rail buttons were tested for alignment with a length of 1515 launch rail identical to the kind used for launch. Proper alignment and smooth movement was tested on the pad prior to launch as well.	Section 3.4.5.6 Step 2 of Launch Pad Procedure: Grease rocket rail buttons and launch rail track
	Shear Pins	Pins break before charge detonation	Manufacturing defect	Loose assembly of compartment	Premature rocket separation and recovery system deployment	2	Team members inspected shear pins individually once delivered to ensure quality. Team members inspected shear pins again prior to launch to confirm functionality.	Step 9.k of Drogue Parachute and LARD: Fin can and midsection should be able to hold their own weight from shear pins alone Step 26 of Main Parachute Recovery Assembly: Nose cone and midsection should be able to hold their own weight from shear pins alone
			Pins fall out of respective holes			2	During assembly pins were checked to ensure they were snug, and were covered with a strip of electrical tape if loose	Step 9.j of Drogue Parachute and LARD Parachute Recovery Assembly: If shear pins are loose, place small piece of electrical tape over shear pin heads Step 26 of Main Parachute Recovery Assembly: If shear pins are loose, place small piece of electrical tape over shear pin heads
			Loads beyond design specifications			2	Force required to break the 4 shear pins used at each joint was calculated to be 304 lbs, while drogue and main ejection charges were calculated to produce 635 and 730 lbs respectively, which is at least twice as much as required to shear the pins.	Section 4.3.7 Black Powder Charges
		Pins don't break at charge detonation	Manufacturing defect	Failure to separate compartment	Loss of safe and effective recovery system	1	Team members inspected shear pins individually once delivered to ensure quality. Team members inspected shear pins again prior to launch to confirm functionality.	Launch checklist under Main Parachute Recovery Assembly heading and Drogue Parachute Recovery Assembly heading.
			Pins too tight in body tube holes			1	Shear pin holes were drilled with a No. 43 tap drill to properly fit the 4-40 size nylon shear pins used, and after drilling pins were inserted to ensure a proper fit and alignment	Section 4.3.6

Launch Vehicle			Improper quantity of pins			1	Force required to break the 4 shear pins used at each joint was calculated to be 304 lbs, while drogue and main ejection charges were calculated to produce 635 and 730 lbs respectively, which is at least twice as much as required to shear the pins.	Section 4.3.6
	Shock Cord	Incorrect or partial deployment of shock cord	Snags, tears, or rips during ejection	Parachute no longer tethered to entirety of launch vehicle airframe	Loss of safe and effective recovery system	1	Shock cord is inspected prior to every launch	Multiple steps on Launch Checklist under Drogue Parachute Recovery Assembly and Main Parachute Recovery Assembly headings.
							Ensured high-strength shock cord is used with a maximum loading greater than 1,500 lb	Section 4.3.5
							Shock cord is stored in an accordion fold and not packed too tightly in its respective body cavity	Multiple steps on Launch Checklist under Drogue Parachute Recovery Assembly and Main Parachute Recovery Assembly headings.
							The edges of each cavity have been sanded down to a round so that there are no sharp edges to cut or saw on shock cord	Section 3.4.4
			Shock cord disconnects from airframe or parachutes			1	Bowlines which will not slip, tighten, or loosen are tied by experienced members wherever connections will be made. All quick links are double-checked by team members during assembly to ensure they are tight and secure.	Multiple steps on Launch Checklist under Drogue Parachute Recovery Assembly and Main Parachute Recovery Assembly headings.
			Shock cord stuck within launch vehicle airframe	Parachute not entirely deployed		1	Shock cord is folded accordion style and secured with a single, not too tight rubber band. Parachutes are folded according to the article provided by Fruity Chutes, the manufacturer of our parachutes.	Multiple steps on Launch Checklist under Drogue Parachute Recovery Assembly and Main Parachute Recovery Assembly. "Learn how to fold a Iris Parachute" - fruitychutes.com
							The edges of each cavity have been sanded down to a round so that there are no sharp edges to cut or saw on shock cord	Section 3.4.4
	Parachute Deployment	Drogue parachute fails to deploy correctly	Drogue shock cord tangling	Parachute does not deploy correctly	Rocket is recoverable	2	Team members confirm that shock cords and parachutes are folded and positioned in the correct orientation. The LARD is attached 120 in. from the midsection aft avionics bulkhead. The drogue is attached 180 in. aft of the LARD and 180 in. from the fin can bulkhead. The shock cord is folded accordion-style with a loose rubber band holding it together.	In the Drogue Parachute and LARD Parachute Recovery Assembly Checklist, items 4(a) and 4(b) confirm that the shock cord is folded accordion-style and secured loosely with a rubber band. In Section 4.3.5, the proper spacing of the parachutes on the shock cord is detailed. These positions are set by tying loops in the shock cord prior to launch day.
			Shock cord connections come loose			2	Team members test shock cord connections prior to flight, make sure secured properly before insertion	In the Drogue Parachute and LARD Parachute Recovery Assembly Checklist, item 2(c) ensures the drogue parachute's quick link connection to the shock cord has been securely tightened using a wrench. Items 2(d) and 2(e) ensure the shock cord's quick link connections to the midsection and fin can bulkhead U-Bolts have been securely tightened using a wrench.

Launch Vehicle		Parachute does not perform as expected	Tears/holes	Parachute deploys but does not perform as expected	Rocket is recoverable	2	Team members inspect parachute for rips, tears, worn fabric, tangled lines, and worn lines before folding and packing into rocket body	In the Drogue Parachute and LARD Parachute Recovery Assembly Checklist, item 2(c)(i) confirms that there is no visible damage to the drogue parachute before it is packed and inserted.
		Main parachute fails to deploy correctly	Charge is inadequate	Parachute does not deploy correctly	Separation 2 is not successful, rocket is not recovered safely	1	Ejection charge measurements for both parachutes are tested properly on the ground before flight day. The calculated ejection charges are placed into the blast caps, and the launch vehicle is fully assembled. The charges are then set off to ensure that separation occurs completely and without causing damage to the launch vehicle.	In Section 4.3.6, the method for calculating ejection charge sizes is listed, along with the calculated measurements. Section 4.1 requires that ground testing of the charges occurs before launch.
			Payload blocks parachute		Separation 2 is not successful, rocket is not recovered safely	1	Team members designed payload compartment to ensure payload ejection hardware does not impede parachute release path	In Section 4.2, the design of recovery systems to not be affected by the payload is detailed.
			Shock cords tangled		Rocket is recoverable	2	Prior to flight, team members ensure shock cords and parachutes are folded correctly. The shock cord is folded accordion-style with a loose rubber band holding it together. The main parachute is attached halfway down its shock cord, 240 in. from the nosecone bulkhead.	In the Main Parachute Recovery Assembly Checklist, item 4 confirm that the shock cord is folded accordion-style and secured loosely with a rubber band. In Section 4.3.5, the proper spacing of the main parachute on the shock cord is detailed. This position is set by tying a loop in the shock cord prior to launch day.
			Shock cord connections loose		Rocket is not recovered safely	1	Team members test shock cord connections prior to flight, make sure secured properly before insertion. The shock cord is attached to the nosecone bulkhead, plug, and midsection aft bulkhead U-Bolts using quick links. The main parachute is attached to the shock cord using a quick link.	In the Main Parachute Recovery Assembly Checklist, items 11(b), 12, and 14 ensure the shock cord's quick links are securely attached to the appropriate bulkhead and plug U-Bolts.
		LARD	Shock cord and shroud lines tangled	Parachute does not deploy correctly	Payload is not recovered safely	3	Fold the parachute to ensure the proper deployment as well as securing shroud lines and attaching the parachute to the shock cord. The shroud lines are folded into the deployment bag in a Z-pattern. The parachute is inserted into this deployment bag, with a pilot chute attached to the LARD parachute with a quick link.	In the Drogue Parachute and LARD Parachute Recovery Assembly Checklist, items 3(d) and 3(e) ensure proper folding of the parachute and shroud lines into the deployment bag. Items 3(f) and 3(j) ensure the quick link attaching the LARD parachute to the shock cord is secure.
			Jolly Logic fails to deploy	Parachute does not deploy		3	Test the jolly logic during full scale test flight to evaluate the release occurs at the correct altitude.	In Section 4.3.2, the use of the Jolly Logic is detailed. In the Drogue Parachute and LARD Parachute Recovery Assembly Checklist, items 3(g) and 3(j) ensure the Jolly Logic is correctly attached to the LARD parachute.
	Black Powder Charges	Single detonation failure	E-match doesn't light	Failure of one or more black powder charges	Will result in loss of safe and effective recovery system if redundant black powder charge(s) do not detonate	2	The Safety Officer, club advisors, and members experienced with the avionics will ensure that the connections are correct and that a valid E-match is inserted.	In the Main Parachute Separation Black Powder Charge Assembly Checklist, items 4(a) through 4(h) ensure the e-matches for the primary and redundant charges for the main parachute are correctly installed and connected into the avionics system. In the Drogue Parachute Separation Black Powder Charge Assembly

								Checklist, items 4(a) through 4(h) ensure the e-matches for the primary and redundant charges for the drogue parachute are correctly installed and connected into the avionics system.
Launch Vehicle			Altimeter Malfunction			2	The Avionics Lead, and members experienced with the avionics will test the altimeters prior to launch and periodically to maintain an accurate evaluation of integrity. The Avionics Lead and members experienced with avionics will also ensure that the altimeters have been properly connected to the avionics system.	In the Payload Checklist, items 20, 22, 25, and 27 ensure the altimeters are properly connected into the avionics system.
		Redundant detonation failure	E-match doesn't light	Failure of both ejection charges	Rocket fails to separate and deploy parachutes	1	The Safety Officer, club advisors, and members experienced with the avionics will ensure that the connections are correct and that a valid E-match is inserted.	In the Main Parachute Separation Black Powder Charge Assembly Checklist, items 4(a) through 4(h) ensure the e-matches for the primary and redundant charges for the main parachute are correctly installed and connected into the avionics system. In the Drogue Parachute Separation Black Powder Charge Assembly Checklist, items 4(a) through 4(h) ensure the e-matches for the primary and redundant charges for the drogue parachute are correctly installed and connected into the avionics system.
			Altimeter Malfunction			1	The Avionics Lead, and members experienced with the avionics will test the altimeters prior to launch and periodically to maintain an accurate evaluation of integrity. The Avionics Lead and members experienced with avionics will also ensure that the altimeters have been properly connected to the avionics system.	In the Payload Checklist, items 20, 22, 25, and 27 ensure the altimeters are properly connected into the avionics system.
		Charge causes damage to any component other than shear pins	Charge is too big	Causes violent separation and/or damage to surrounding area	Potential to cause permanent damage to bulkheads or shock cord, resulting in a possible failure of parachute deployment	2	The Safety Officer with supervision of the Club Advisors will insert the correct amount of black powder that was confirmed in the ejection tests. Following, will be a physical and visual check of the rocket interior for accuracy.	In Section 4.3.6, the appropriate black powder charges are listed. In the Night Before Checklist, item 3 ensures the proper black powder charges are prepared for insertion before launch day.
		Charge ignites but fails to cause separation	Charge is too small	No ejection	Failure of parachute deployment	1	The Safety Officer with supervision of the Club Advisors will insert the correct amount of black powder that was confirmed in the ejection tests. Following, will be a physical and visual check of the rocket interior for accuracy.	In Section 4.3.6, the appropriate black powder charges are listed. In the Night Before Checklist, item 3 ensures the proper black powder charges are prepared for insertion before launch day.

	Altimeters	No power to altimeters	Uncharged or insufficiently charged batteries	Loss of real-time altitude data, failure to ignite e-match	Failure of parachute deployment	1	Categorically the batteries for any launch must be fresh and unused. Prior to installation, the voltage will be measured with a voltmeter to confirm the constitution of the battery.	In the Night Before Checklist section 2a, it is stated that a multimeter is used to choose six batteries with at least 9.0V for the launch.
	Black Powder Charges	Single detonation failure	Battery becomes disconnected from altimeter	Failure of one or more black powder charges	Will result in loss of safe and effective recovery system if redundant black powder charge(s) do not detonate	1	The Avionics Lead will connect the leads from the power source to the altimeters. An evaluation of the physical security of the connections will be made. The electronic viability is evaluated through the audio cues of each altimeter.	In the Payload Checklist section 17, the leads from the batteries to the altimeters are secured by tightening the leads with a screwdriver. In the Launch Pad Procedure Checklist section 9, altimeters' audio cues are compared with the expected values.
Launch Vehicle			Wiring short			1	The Avionics Lead will connect the leads from the power source to the altimeters. An evaluation of the physical security of the connections will be made. The electronic viability is evaluated through the audio cues of each altimeter.	In the Payload Checklist section 17, the leads from the batteries to the altimeters are secured by tightening the leads with a screwdriver. In the Launch Pad Procedure Checklist section 9, altimeters' audio cues are compared with the expected values.
		No launch detected	Manufacturing defect	Lack of flight data	Failure of parachute deployment	1	The altimeters will be tested by the avionics team in a vacuum chamber to simulate a flight. The audio cues will be used to continue monitoring immediately before launch.	In Section 3.5.1, the altimeters' values from the simulation are compared to the values programmed to confirm proper function. In the Launch Pad Procedure Checklist section 9, altimeters' audio cues are compared with the expected values.
		False apogee detected	Manufacturing defect	Premature/late ejection of drogue parachutes	Increased load on drogue recovery hardware and bulkheads	2	The altimeters will be tested by the avionics team in a vacuum chamber to simulate a flight. The audio cues will be used to continue monitoring immediately before launch.	In Section 3.5.1, the altimeters' values from the simulation are compared to the values programmed to confirm proper function. In the Launch Pad Procedure Checklist section 9, altimeters' audio cues are compared with the expected values.
		Charge causes damage to any component other than shear pins	Incorrect altimeter readings	Causes violent separation and/or damage to surrounding area	Potential to cause permanent damage to bulkheads or shock cord, resulting in a possible failure of parachute deployment	2	The pressure ports will be checked for having adequate size and the audio cues will be used to continue monitoring immediately before launch.	In section 3.4.4.6, four 1/4" diameter holes are drilled in the body tube near the altimeters are used for pressure ports. In the Launch Pad Procedure Checklist section 9, altimeters' audio cues are compared with the expected values.

Launch Vehicle		Main parachute deploys at wrong altitude	Incorrect pressure readings or improper programming	Main deployment between apogee and 1,200 ft	Excessive drift, but surface impact will remain below required maximums	2	The altimeters will be tested by the Avionics Team in a vacuum chamber to simulate flight pressures of relevant altimeters. The pressure ports will be checked for having adequate size against altimeter specifications and the audio cues will be used to continue monitoring immediately before launch.	Section 3.5.1
	Altimeters	No power to altimeters	Uncharged or insufficiently charged batteries	Main deployment lower than	Kinetic energy at surface impact will likely exceed 75 ft-lb parachute	1	Categorically the batteries for any launch must be fresh and unused. Prior to installation, the voltage will be measured with a voltmeter to confirm the constitution of the battery and that all batteries are outputting voltage at the specified level.	Batteries are tested with a multimeter in payload checklist item 17. All batteries brought to the launch site are checked further during the night before checklist to ensure proper 9V output.
	GPS	Ground system failure	Loss of power to ground receiver or the laptop	800 ft	Inability to track and recover the rocket in less than an hour	3	The Avionics Team will check that the club laptop and GPS receiver will be charging before the launch and must be fully charged prior to launch.	Laptops and receivers are to be charged per the night before checklist.
		Loss of signal	Environment or rocket materials blocking signal	Inability to receive data from the GPS		3	The club led by the Avionics Lead at least one week prior to launch will perform a range test to evaluate the adequacy of the GPS system. The system is expected to meet standards as it is the same system used from previous years.	GPS range testing was conducted and discussed in the testing portion of section 10 of the FRR.
	Avionics Sled	Radio interference	Multiple radio devices on the same local frequency and channel	Lack of flight data	Failure of parachute deployment	3	Although there are multiple devices transmitting on the same band of frequencies, they utilize different specific frequencies and will be tested near ensure that they do not interfere with each other. Furthermore, transmitting devices are separated from each other in the rocket to ensure they do not interfere.	FRR section 4.4.4 details how the GPS transmitter will be isolated from other electronic components. Section 7.4.5 details the payload bay transmitters and receivers and their EM isolation.
		Loss of power	Flight forces cause GPS to disconnect from power supply	Premature/late ejection of drogue parachutes	Increased load on drogue recovery hardware and bulkheads	3	The Avionics Team will be sure to charge the GPS unit so that when the GPS is mounted in the rocket it will be fully charged. Launch simulations will be done to confirm mounting methods will be sufficient.	GPS charging is mandated in the night before section of the preflight checklist. GPS trackers are mounted to the nosecone bulkhead and padded by the parachute and deployment bag from flight forces as discussed in FRR section 4.4.4
		Detaches from secure position	Loads beyond design specifications	Damage to/loose wiring of avionics components	Loss of recovery system initiation	1	Simulated load tests will be carried out on the avionics sled design, with the final design meeting requirements with an included safety factor.	Data from simulated load testing is detailed in FRR. All wiring is to be properly secured and checked per the payload sections of the launch checklists.

Launch Vehicle		Main parachute deploys at wrong altitude	Damage during handling	Main deployment between apogee and 1,200 ft	Excessive drift, but surface impact will remain below required maximums	1	Avionics team members practiced wiring and inserting the sled and will be handling and installing the sled using sufficient care and detail.	The Payload Checklist goes through detailed instructions on how to wire and install the sled. These instructions are used to properly inform the avionics team of the sled.
			Improper maintenance	Main deployment lower than	Kinetic energy at surface impact will likely exceed 75 ft-lb parachute	1	Avionics team members will be briefed on the proper functioning of the sled so that detailed inspections can be carried out before and after each launch.	The Payload Checklist goes through detailed instructions on how to wire and install the sled. These instructions are used to properly inform the avionics team of the sled.
	Payload Exterior	Acrylic Tube	Manufacturing defects	Rover Systems at Risk	Electronics and rover can be damaged	3	Before construction begins, the length of tubing will be inspected closely by the Payload Integration team for any cracks, deformation, or other manufacturing quality defects.	All fabrication materials were inspected for manufacturing defects prior to construction 3.4
		Door Fails to Open		Prevents Rover Deployment	Rover will not complete its task			
		Door Pin System Breaks		Prevents Rover Deployment	Rover will not complete its task			
		Door Hinges Come Off		Prevents Rover Deployment	Possible structural damage to the payload			
		Loss of signal	Servo fails			3	Payload Integration team will test servo and connection to the rover latch to ensure latch opens correctly before construction and before leaving for a launch day.	As part of the rover assembly checklist the latch will be tested to make sure that the transmitter is communicating properly with the latching system. The range of the transmitter signal is also verified to be 2000m in 7.4.5.1
		Radio interference	Blocked by dirt after landing			3	During the design and testing phase of the full-scale, Payload Integration team will ensure the body will land angled upwards to ensure proper deployment.	Payload sled will be constructed with the center of mass below the lateral axis to ensure proper orientation of all payload components following landing. Full scale launch flight in section 6.7 verified that that orientation was maintained following recovery.
		Loss of power	Blocked by centering ring			3	The rover door will be designed with a fair margin of 1.2in difference in width between centering ring and the widest dimension of the rover so that a significant shift still won't block the door.	Construction is performed within defined measurements and checked after the centering ring was laid up. Section 7.4.1
		Detaches from secure position	Fracture from Force	Unable to transfer loads	Increased loads on other structural members	3	The blue tube, i.e. the body tube, will bear most if not all the forces associated with the launch, so the acrylic will can handle any extraneous forces associated with launch.	Simulations detailed in Section 3.5.1 show that the blue tube will can handle all forces associated with the launch, in addition the free-floating design of the payload reduces forces transferred through the payload exterior.
			Improper Attachment	Door may Detach	Rover will not complete its task	3	Payload Integration team will inspect door hinge screws and ensure fasteners are secure and tight before each launch.	All fasteners are checked by multiple people for proper attachment throughout the rover and payload checklists.

Launch Vehicle			Improper maintenance			1	Avionics team members will be briefed on the proper functioning of the sled so that detailed inspections of the layout and attachment of the payload can be carried out before and after each launch.	Proper functioning of the payload is outlined in section 7.4. Proper assembly of the payload components is detailed in the payload and rover sections of the launch checklist supplied to all teams working on rocket assembly.
Payload	Payload Bulkhead	Bulkhead Separation from payload	Poor Design	Load Transfer Failure	Unintended Structures Bear the Load	2	Stress Analysis testing on fixed support will be conducted by the Structures team to ensure bulkhead can take the loads.	Section 3.5.1
		Separation of Rover from platform	Manufacturing Defect	Prevents Rover Deployment	Rover will not complete its task	2	All construction materials will be closely inspected for damage and defects before and after construction.	Section 3.5.1
			Loads Greater than Designed	Prevents Rover Deployment	Rover will not complete its task	2	Construction team will ensure strict adherence to design documents so that loads will remain within safety margins.	Section 3.5.1
			Damaged During Handling	Prevents Rover Deployment	Possible structural damage to the payload	2	Proper care will be taken whenever transporting or handling to prevent damage, as well as inspections before and after each launch.	Step 3 of Rover Checklist: Inspect the Rover for Structural Faults
			Improper Attachment	Unable to transfer loads	Increased loads on other structural members	2	Payload Integration and Structures teams will inspect each bulkhead to ensure proper attachment before and after each launch	Step 5a of Drogue Parachute and LARD Parachute Recovery Assembly: Have a second team member confirm the quick link is secured to the midsection
	Rover Bay	Structural Damage	Improper attachment	Rocket weight imbalance during flight	Rocket flight disrupted	3	Team members will test the attachment rover with manual application of force in the direction of forces experienced during flight and ensure it is secured properly	The design of the payload is such that the rocket will not be unbalanced during flight, detailed in FRR section 7.4.2
				Rover fails to rest at bottom of the tube	Prevents proper deployment	3		
	Payload Bulkhead	Electronics Fail	Circuitry becomes damaged	Payload hardware experiences catastrophic failure	Rover fails to deploy	3	Team members will test the electronics on the rover to ensure they are operating and defect free	Team members will test the electronics on the rover to ensure they are operating and defect free, per section 7.4.5
	Rover Tracks	Malfunction	Unable to gain traction	Rover cannot move forward	Prevents rover from deploying at the correct orientation	4	Prior to launch, rover will be tested on all expected terrains	Rover has not been tested on expected terrain, per section 10.1
			Incorrect tread depth					

Payload	Hardware	Break	Damage during flight	Rover cannot complete mission	Prevents rover from deploying at the correct orientation	4	Team members will test the structural integrity and run structural analysis of the parts to ensure that parts do not contain defects and can withstand loads applied during flight	Rover hardware has met durability requirements, per section 7.5.2
Payload	Rover Battery	Do not deploy	Dead battery	Rover cannot complete mission	N/A	4	Ensure proper battery charging and handling techniques are followed	Steps 1 and 2 of Night Before Checklist: (Describes that charging of batteries must be done in advance as well as verifying voltages of single-use batteries)
Payload	Rover Software	Rover Malfunction	Programming bug	Rover cannot complete mission	N/A	4	Run tests on Arduino to ensure high performance	Step 2 of Rover Checklist: Verify the integrity of the software for performance
Payload	Rover Body	Cracks or Breaks	Improper Handling of Rover during Assembly	Design challenge is not completed	N/A	4	On the day of the launch the rover will be checked for damage.	Step 3 of Rover Checklist: Inspect the Rover for Structural Faults
Payload	Motor System	Jammed	Foreign objects obstruct the mechanics of the Rover	Design challenge is not completed	N/A	4	On launch day the rover will be checked to verify the fidelity of the mechanical systems.	Step 4 of Rover Checklist: Inspect the Mechanical Systems of the Rover for Foreign Objects
Payload	Solar Panels	Fail to Deploy	Foreign objects obstruct the mechanics of the Rover	Design challenge is not completed	N/A	4	On launch day the rover will be checked to verify the fidelity of the mechanical systems.	Step 4 of Rover Checklist: Inspect the Mechanical Systems of the Rover for Foreign Objects