University of North Dakota
Department of Physics
Frozen Fury Rocketry Team

NASA Student Launch Initiative
Flight Readiness Review - Report

Submitted by:
The University of North Dakota Frozen Fury Rocketry Team

March 5th, 2018

Abstract:

This is the Flight Readiness Review Report that is submitted to the NASA Student Launch Initiative by the University of North Dakota Frozen Fury Rocketry Team. This document will explain all the design decisions that the team has made, along with safety requirements. It also includes a budget and project timeline. Work verification requirements derived by NASA and the team are included.

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1 - Introduction: Summary of Critical Design Review Report (CDR)

1.1 – Team Summary

School Name:	University of North Dakota
Organization:	Frozen Fury Rocketry Team
Location:	The University of North Dakota Witmer Hall, Room 211 101 Cornell Street Stop 7129 Grand Forks, North Dakota 58201
Project Title:	Frozen Fury Rocketry Team NASA Student Launch Initiative 2017-2018
Name of Mentor:	Tim Young
Certification:	Level II NAR certification (NAR# 76791)
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Foreign Nationals:	Tori Fischer – Canada John Heide – Canada Nelio Batista Do Nascimento Jr. – Brazil

1.2 – Launch Vehicle Summary

The table below shows a general summary of the launch vehicle that will be flown on launch day. This years launch vehicle has been named ‘Some Assembly Required’ and will fly an experimental payload which is a deployable rover. The table below shows some specs of the rocket.

Length (in.)	118
Diameter (in.)	6
Center of Gravity (in.)	72.30
Center of Pressure (in.)	86.65
Mass w/ motor(lbs.)	33.125
Mass w/out motor (lbs.)	28.54
Motor Type	AeroTech L1150-P
Recovery System	Single Deployment
Launch Rail Length (ft.)	12

Table 1: *Launch vehicle summary*

1.3 – Payload Summary: Deployable Rover

The deployable rover was chosen as this year's experimental payload. It has to deploy from the internal airframe of the launch vehicle upon landing. Once the rover has be deployed from the launch vehicle is must autonomously drive a minimum distance of five feet and deploy an array of solar panels. The solar panels must increase in area to be successful. The rover that has been designed is a tank style rover, with two sets of treads. It will be powered by a lithium-polymer battery and be controlled by a Raspberry Pi Zero. There will be two electric motors that will drive the treads on the rover. The solar panels will be deployed by a servo.

Figure 1: *3D render of concept rover*

2 - Changes Made Since Critical Design Review

2.1 – Vehicle Design Changes

Change	Reasoning
Addition of coupler between rover deployment payload and drogue parachute	This was done to help with the construction of the rover deployment payload. It allows for removal of the air frame to allow for construction, modification and testing to be done.
Drogue parachute was shrunk to an 24-inch diameter	This was done to increase descent time, which in turn decreased the drift of the rocket, and kept it in a radius of 2500-foot in up to 20 mile-per hour winds
Main parachute deployment size was increased from 108-inches to 120-inches	This was done to decrease the kinetic energy of the subcomponents. It was found that a ground impact velocity of 20.2 feet per second (fps) was found to be the max velocity the launch vehicle could impact the ground at. Through simulation it was found that the 120-inch diameter parachute had an average ground hit velocity of 19.3 fps. This allowed for the kinetic energy of the subcomponents to be under 85-foot pounds.
Main parachute deployment altitude was lowered from 1000 feet to 700 feet.	This was done to reduce drift, from simulation data it was found that the drift in 20 mile-per hour winds is under the 2500-foot radius specified in the handbook.
Addition of avionics bay	This was implemented into the launch vehicle to serve as a payload section for secondary electronics such as a camera and a data logger.

Table 2: *Changes made to launch vehicle since CDR*

2.2 – Payload Design Changes

Changes	Reasoning
Removal of one servo in solar array deployment system	Upon testing it was realized that only one servo was needed to deploy the array of solar panels. The electronics bay of the rover was also tightly packed so the removal of one servo increased space within the electronics bay.
Removal of gyroscope	The gyroscope was removed from the rover electronics bay because it was deemed unnecessary.

Table 3: *Payload design changes since CDR*

2.3 – Project Plan Changes

The biggest change in the project plan for the launch vehicle was the addition of the avionics bay. It was implemented to house secondary electronics such as a camera and a secondary data logger. Other than the implementation the avionics bay there have been no significant project plan changes. Everything is moving smoothly and getting completed on time.

3 - Safety

Drew Ross is the safety officer for the 2017-2018 Frozen Fury Rocketry Team. The safety officer will be responsible for the safety of the students, team and public throughout the duration of the competition. He is to make sure the team follows all laws and regulations. Many power tools and large machine are used throughout the duration of this project. Our main workspace is a large workshop located in the basement of Witmer Hall, UND's Physics and Mathematics building. The new shop foreman, Jim, is extremely thorough and has spent the past 6-months cleaning the entire workshop. Every machine now has a packet attached that contains operation and safety instructions. Material Safety Data Sheets (MSDS) have been placed out in the open next to each chemical we will be using. At the beginning of this project all team members participated in a safety briefing in the workshop where every machine was discussed, and all safety expectations were reviewed. A culture of safety has been established to ensure that all decisions we make are scrutinized with safety having the most significance.

3.1- Risk Level Assessment

Managing risk is extremely useful so we can identify what areas of our project need additional work to improve safety. To rank the probability and the severity of the hazards associated with building high-powered rockets we will use the following Risk Matrix.

Frozen Fury Risk Matrix

Probability	**Consequence**		
	Severe (1)	Moderate (2)	Minimal (3)
High (A)	A1	A2	A3
Medium (B)	B1	B2	B3
Low (C)	C1	C2	C3

Risk Acceptance and Management Approval Level

Risk Level	Acceptance Level
High Risk	**Unacceptable**. Documented approval from the MSFC EMC or an equivalent level independent management committee.
Medium Risk	**Undesirable**. Documented approval from the facility/operation owner's Department/Laboratory/Office Manager or designee(s) or an equivalent level management committee.
Low Risk	**Acceptable**. Documented approval required from the supervisor directly responsible for operating the facility or performing the operation.

3.1.1 General Project Analysis

General Risk	Impact	Mitigation Tactic	Likelihood of Risk
Time Scheduling for Construction	Due to climate of Northern Midwest, time is of great concern because of limited opportunities for test launches	Accelerated construction, testing and launch scheduling of the rocket	B2
Resources – tools, materials, transportation, PPE,etc.	Can potentially cause a great limit on the project's development for construction of the launch vehicle	Assemble inventory list of procured materials, and check weekly that stock is enough. Prepare a list of suppliers for immediately-needed materials and safety equipment	C3
Budget– costs of materials and tools	Will cause issues with advancement of the project, essentially bring the project to a standstill until funds are available to purchase needed instruments and hardware	Update and periodically monitor Team budget spreadsheet, account for all expenditures and areas of income. Allocate funds needed to meet the requirements of the project goals, and nothing more.	B2
Scope/Functionality-Purpose of Project	Without necessary engineers for the work for needed projects and project phases, efficiency will be low, and the quality of work will be substandard	Have assigned duties for teammates for specific groups on the project, allow a maximum number of people to assist for each team. This will ensure that work on the project progresses smoothly.	B3

3.1.2 Personal Hazard Analysis

General Hazard	Cause of Hazard	Impact	Risk Level	Risk Mitigation	Verification
Power Tools	Improper placement of personnel body or objects near power tools.	Injury to hands, limbs and eyes.	A1	Wear recommended personal protective equipment (PPE). Train team members for all power tools.	Verify that team member using power tools have completed the relevant training from the Frozen Fury Safety Program(FFSP)
Flammable Materials	If flammable material is kept near or used near an open flame or area with sparks	Fire. Burns to skin.	B1	Store flammable materials in flammable metal cabinet. Make sure to return flammable materials to the cabinet once used.	Verify that team member working with flammable materials have completed the relevant training from the FFSP
Hazardous Substance Handling	Inadequate ventilation or lack of PPE	Irritation of skin, eyes, lungs and face	A3	Train team members in proper chemical handling techniques. Wear PPE and handle in properly ventilated area.	Verify that team member working with Hazardous substances have completed the relevant training from the FFSP
Chemical fumes	Inadequate ventilation or lack of PPE	Irritation of skin, eyes, lungs	A3	Wear dust mask when applying. Handle in properly ventilated area.	Verify all team member completed the relevant training from the FFSP
Tripping hazards	Lack of situational awareness or improperly placed objects	Personal injury	B2	Provide proper stations for storage of tools and equipment. Always keep work area clean.	Verify all team member completed the relevant training from the FFSP

Electricity	Electrocution due to bad wiring or situational awareness	Electrocution and burns	B1	Always turn off equipment and tools before working on them for repairs as well as after using them.	Verify that team member using power tools have completed the relevant training from the Frozen Fury Safety Program(FFSP)
Falling Rockets	Parachute failed to deploy	Personal injury	C1	Verify recovery systems before launch, and if parachutes are folded properly	Follow launch operations procedure for recovery
Cold Conditions	Inadequate preparation with clothing or lack of PPE.	Frostbite, Hypothermia.	B2	Wear proper cold gear for cold launch conditions.	Verify all team member completed the relevant training from the FFSP
Falling payloads	Poorly secured payloads or bad rocket structural integrity	Personal injury	C1	Verify payloads are secured before launch. Visually check rocket for any cracks that could compromise structural integrity.	Follow launch operations procedure when preparing rocket. Go through preflight checks with at least two people (one being safety officer) and sign off on the prelaunch check sheet

3.1.3 Environmental Concerns

Environmental Hazard	Cause of Hazard	Impact	Risk Level	Risk Mitigation	Verification
Rocket crashes into water body.	Parachute failed to deploy	Environmental damage	B2	Plan proper launch area without risk of water contamination	Follow all MSDS and safety procedures. Do post flight inspections from the launch operations procedure.
Fume inhalation of hazardous fumes due to proximity to rocket.	Personnel not safe distance from rocket.	Irritation of lung, eyes and nose.	B3	Keep proper distance from rocket before launch. Keep only required crew members around rocket.	NASA USLI Student Handbook, page 40, Minimum Distance Table, for L motor minimum safe distance is 300 feet.
Upon recovery, ground destruction may be discovered, loose propellant may be present	Poorly secured propellant or bad rocket structural integrity	Reversible environmental damage	C2	Verify all rocket component s are secured before launch.	Go through pre launch checks with at least two people (one being safety officer) and sign off on the pre launch check sheet. Do post flight inspections from the launch operations procedure.
Rocket ash can have hazardous effects on the ground below the launch pad.	Poor launch pad setup with blast shield	Environmental damage	B2	Verify blast shield is properly secured before launch. During clean up, properly dispose of the waste materials.	Go through pre launch checks with at least two people (one being safety officer) and sign off on the pre launch check sheet. Do post flight inspections from the launch operations procedure.
Dissolution of rocket fuel into open water causes contamination of water source	Poor situational awareness or unsecure propellant	Severe environment-al damage	B1	Plan proper launch and recovery area. Be mindful of wind conditions as to predict rocket movement.	Follow all MSDS and safety procedures.

Ignition produces sparks capable of setting fire to dry grass and other flammable material.	Poor launch pad setup with blast shield or bad situational awareness	Burns, damage to environment	B1	Keep flammable materials away from rocket. Always have a fire extinguisher handy during launches.	Verify at least three team members present have completed the Emergency Action Plan & Fire Protection training from the FFSP.
Potential hazard to wildlife if small rocket pieces are ingested.	Poor cleanup of rocket parts after launch	Damage to wildlife.	C1	Team will function as cleanup crew at impact and launch site to ensure all rocket parts are recovered.	Go through pre launch checks with at least two people (one being safety officer) and sign off on the pre launch check sheet. Do post flight inspections from the launch operations procedure.
High Winds	Weather conditions	Launch Delayed	B3	Double check the weather while preparing the rocket so it can fly safely under the current conditions, if not delay launch for a different day.	Go through preflight checks with at least two people (one being safety officer) and sign off on the pre launch check sheet.
Rocket drifts outside set limits	High wind conditions	Rocket could be unreachable or lost	B1	Make sure that the rocket can perform as intended in different wind speeds during simulations	Go through preflight checks with at least two people (one being safety officer) and sign off on the pre-launch check sheet.
Wet black powder	Rain	Recovery systems might not fire, Launch delayed	B2	Always properly store black powder in a flameproof metal box. If black powder gets wet, replace powder do another preflight and pre launch check.	The charges will be sealed promptly and only if the black powder has been verified as dry.

Fog or low visibility	Weather conditions	Would lose the rocket during recovery operations, Launch delayed	B2	Double check the weather while preparing the rocket so it can perform its job safely under the current conditions, if not delay launch for a different day.	Go through preflight checks with at least two people (one being safety officer) and sign off on the pre launch check sheet.
Rocket body damage from birds	Wildlife and poor situational awareness	Rocket and wildlife could get damaged and land hard	B2	Observe migratory flight patterns over launch range and cancel launch when birds are overhead.	Go through preflight checks with at least two people (one being safety officer) and sign off on the pre-launch check sheet.

3.1.4 Failure Modes and Effects Analysis (FMEA)

General Failure Modes:

Failure Modes	Cause	Effect	Risk Level	Risk Mitigation	Verification
Parachute deploy at wrong altitude	Late or early deployment of parachute due to faulty altimeter setup	Rocket body could rip apart if parachute deployed when rocket is moving too fast.	B1	Check batteries for altimeter before launch and verify parachutes are properly folded so they deploy without getting tangled. Double check the altimeters on launch day to make sure all wires are hooked up correctly	Follow launch operations procedure for recovery systems and parachutes when preparing rocket. Go through preflight checks with at least two people (one being safety officer) and sign off on the prelaunch check sheet.
Motor failure due to faulty ignitor	Damaged or poorly secured ignitor, or faulty wiring setup	Motor fails to ignite when expected	B3	Check ignitor for any visible faults before attempting to place it. Verify if ignitor is placed and secured properly before launch.	Follow launch operations procedure for motor assembly when preparing rocket. Go through preflight checks with at least two people (one being safety officer) and sign off on the prelaunch check sheet.
Shock cord failure	Damaged or frayed shock cord	Parachute wouldn't work properly and rocket might come down hard	B1	Visually inspect shock cord for any damage before use.	Follow launch operations procedure for recovery systems and parachutes when preparing rocket. Go through preflight checks with at least two people (one being safety officer) and sign off on the prelaunch check sheet.

Parachutes getting entangled	Improperly packed parachute	Parachute might not open properly and rocket might come down at terminal velocity	A1	Verify that the recovery system on launch day and how the parachute is folded to make sure it will not tangle	Follow launch operations procedure for recovery systems and parachutes when preparing rocket. Go through preflight checks with at least two people (one being safety officer) and sign off on the prelaunch check sheet.
Fin damage	Rocket land too fast or in landed in a bad position	Can’t fly rocket until new fins are installed	C1	Inspect fins for structural integrity before launch.	Go through preflight checks with at least two people (one being safety officer) and sign off on the prelaunch check sheet.
Unstable launch pad	Poor launch pad setup	Rocket could launch in an unintended direction. Could lead to injury	B1	Verify launch pad is level and secure with and without the rocket before launch.	Go through preflight checks with at least two people (one being safety officer) and sign off on the prelaunch check sheet. NASA USLI Student Handbook, page 40, Minimum Distance Table, for L motor minimum safe distance is 300 feet.
Torn parachute	Poor inspection of materials	Rocket will fall down faster than intended. Might get damaged	B2	Visually inspect parachutes for any tears or holes before properly folding them.	Follow launch operations procedure for recovery systems and parachutes when preparing rocket. Go through preflight checks with at least two people (one being safety officer) and sign off on the pre launch check sheet.

Ejection charge doesn't ignite	Bad black powder or altimeter setup	Parachutes won't deploy and rocket will land at terminal velocity	A1	Double check the altimeters on launch day to make sure all wires are hooked up correctly. Verify black powder holders are properly secured.	Follow launch operations procedure for recovery systems and altimeter bay when preparing rocket. Go through preflight checks with at least two people (one being safety officer) and sign off on the pre-launch check sheet.
Dead batteries	Poor awareness of equipment	Payload failure	B2	Conduct routine battery checks. Fully charge batteries prior to each launch.	Go through preflight checks with at least two people (one being safety officer) and sign off on the pre-launch check sheet.
Black powder charges damage rocket	Blast damages rocket body because of a weak point on body	The parachutes may not be able to allow soft landing. Rover deployment may be inhibited	C2	Measure correct amount of black powder. Make sure bulkheads and rocket body are in good condition and no weak points.	Make sure the shear pins and other parts offer consistent resistance so that consistent amounts of black powder are used. Thus, blast does not find a "new" weak point.

Rover Subsystem:

Failure Modes	Cause	Effect	Risk Level	Risk Mitigation	Verification
Rover cannot handle terrain	Insufficient ground clearance; Terrain rougher than expected	Rover fails to travel 5 feet	B3	Allow the chassis to ride higher, allowing more clearance. Attach spikes or rubber pads to track for better traction.	The rover would be tested on rough terrain to assure its mobility.
Loss of rover power	Damaged wiring; dead battery	Rover fails completely	C3	Soldering procedure is done with proper technique and equipment. Wiring will be done Properly to ensure no shortages with quality materials.	Check soldering joints to make sure they are sufficient. Make sure there are no shorts in the circuit.
Rover upside down	Improper deployment; Rough terrain	Rover fails completely	B3	Self-righting design?	Test strength of solar panels and torque of servos to know if it can self right
Remote fails to activate rover	Poor signal due to loss of line of sight. Rover located in a ditch, over a hill, behind an obstacle, etc... Damaged receiver	Rover fails to deploy	B3	Apply the correct frequency and transmission strength.	Testing will be done previous to launch with obstacles present at varying distances.

Premature Activation	Interference from other teams signal; Human error	Rover attempts to drive while contained in payload bay; Rover attempts to deploy solar panels in payload bay	C2	Place remote away from students until needed. Switch cover? 2-key activation?	Verifying unique wavelength for activation.
Tracks Jam	Debris lodged between sprockets and the tread.	The rover will become immobile	B3	Apply tracks guards to prevent debris from jamming treads.	The rover would be tested on similar terrain before launch. Make sure tracks are not loose.
No Deployment of Solar Panels	Mech. failure; Power loss; Obstruction; Poor electrical connection	Solar panels don't deploy,	C3	Wiring will be done Properly to ensure no shortages with quality materials. Rover will be right side up	Multiple Tests of solar panel deployment.
Mechanical failure	Tread detaches; Axle breaks; Chassis cracks; etc.	Possible rover failure, likely immobile	B3	Ensure high quality 3D prints, ensure tread is secured on	Do structural analysis on 3D parts, and test 3D parts thoroughly
Rover stepped on after deployment	Wandering livestock	Partial or complete rover failure	🟥	Rover makes noise? Have better luck?	Visually confirm all livestock have evacuated the area

Battery explosion	Overheating	Complete rover failure, potential injury to humans	C1	Battery is charged and wired up correctly, safe from any potential physical damage	Ensure batteries are charged, connected, and placed properly
Rover catches fire	Short circuit; Damaged battery	Rover failure, potential injury to humans	C1	Check wiring thoroughly and have a new battery for launch	Visually verify no wires are shorting or exposed, check that battery has no visual faults

Deployment Subsystem

Failure Modes	Cause	Effect	Risk Level	Risk Mitigation	Verification
Nose Cone separates during flight	-Shear pins not installed properly. -Linear Actuators engage early	-Rocket will become unstable -Rover could fall out	C1	Ensure pins are installed correctly and adequately. Don't push remote trigger before landing	Double check pins and have a safety cover for the remote deployment trigger
Remote does not activate the deployment system	-Parachute deploys too early -RF interference	Rocket drifts out of sight and range of the remote	B3	-Check deployment altitude on altimeter -Use unique RF signal for activation	-Perform RF activation check before launch
The rover deploys incorrectly	-Gyro readings are incorrect -stepper motor failure -Electrical Failure	Deployment system fails to orientate rover correctly	B3	Test gyro before flight.	Check all electrical connections Ensure gyro data is correct

Rovers path is blocked by another part of the rocket.	-Poor landing -parachute covers the rovers exit	-rover will fail to travel required distance. -rover will get caught up in the parachute or other pieces.	C3	Plan carefully to prevent unwanted movements or placement of other components	Test deployment in the test bed to ensure no failures and proper deployment
Rover comes loose during flight	Attachment point fails; Premature release	Damage to rover and deployment mechanism; Improper deployment	B2	Perform a shake test to confirm proper attachment	Make sure all points that hold and maintain the rover's position are secure and intact.
Fire	Battery overheat; short circuit	Damage to rocket/payload; Damage to people; Black powder charges activate prematurely	C1	Check all connections throughout the system before launch	Perform multiple tests before launch. Check to make sure there are no exposed wires.
Nose cone fails to be separated from the rocket	-Batteries aren't charged - not a good connection to the airframe -Actuators not strong enough -Actuators fail to remove nose cone	Rover will not deploy	B3	Test several terrains and rocket orientations for proper deployment	Verify that batteries are fully charged and properly connected. Ensure that the actuators used are strong enough to remove the nose cone.
Deployment structure breaks on impact with ground	-Deployment mechanisms and structure not built sturdy enough -Parachute fails to deploy correctly	-Rover fails to deploy correctly	B2	-Ensure deployment systems can withstand impact with the ground - Ensure parachute deploys correctly	Make a final verification of structural integrity before launch. Check parachute and parachute cords before launch

Parachute fails to deploy	-Charges fail to split rocket at proper joints -Parachute rips at deployment -Altimeter fails	Deployment systems and rover system are damaged on impact, fail to deploy	B1	-Ensure altimeter will not fail -Ensure Charges are strong enough to separate rocket -Ensure parachute will not rip at deployment	See that the parachute does indeed deploy every time during test lauchs and make sure it's under similar conditions for the final.

3.2 – Material Safety Data Sheets (MSDS)

The MSDS documentation for all chemicals and printed out and have been placed clearly next to each chemical. The safety precautions for most of the materials were found on the West Systems Inc online company page and Science Lab.com Each team member has read and will comply to all safety codes dictated on the MSDS sheets. The MSDS will not be attached to the PDR for paper conservation.

The following are materials addressed in our safety information contained within this document:

- NAR High Powered Safety Code
- OSHA Power Tools
- Ammonium-Perchlorate
- Epoxy 105 West systems
- Fast hardener 205 West Systems
- Filler 404 West Systems
- Fiber-Glass 727 West Systems

3.3 – NAR High Powered Rocket Safety Code - Mitigation

The National Association of Rocketry (NAR) High-Powered Safety Code has been printed out and is available in our workshop. All team members have been briefed on the document and will refer to it as the governing document for general rocket safety.

Minimum Distance Table (L-Motor Highlighted)

Total Impulse (Newton-Seconds)	Motor	Minimum Diameter of Cleared Area (ft.)	Minimum Personnel Distance (ft.)	Minimum Personnel Distance (Complex Rocket) (ft.)
0 -- 320.00	H or smaller	50	100	200
320.01 – 640.00	I	50	100	200
640.01 – 1,280.00	J	50	100	200
1,280.01 – 2,560.00	K	75	200	300
2,560.01— 5,120.00	**L**	**100**	**300**	**500**
5,120.01- 10,240.00	M	125	500	1000

High Power Rocket Safety Code – Minimum Distance Table (nar.org).

The Following is a detailed summary of how we intend to comply with the NAR High Power Rocket Safety Code.

Certification:
Team mentor Dr. Tim Young holds a level 2 NAR certification (#76791). He will be present during every one of our flights. Dr. Young will obtain the motors for us and directly supervise their construction.

Materials:
We will use only lightweight materials such as paper, wood, rubber, plastic, fiberglass, or when necessary ductile metal, for the construction of my rocket. Our rocket will be constructed of carbon-fiber tubing and nose cone, with resin fins. The only metal present will be in the form of small rods, bolts and other small hardware.

Motors:
The Aerotech L1150 motor we will use in our rocket was also used last year. Proper safety will be observed by our team regarding the motor, supervised by returning team members who handled the motor last year. A mentor will be present during all motor handling phases.

Ignition System:
Our rocket ignition systems will not be active until it has arrived at the launch site and is adequately prepared for flight. The electric igniter provided with the motor will be the only igniter type used.

Misfires:
The NAR members present will ensure that the misfire guidelines are followed, as well as the team leaders to ensure that all team members and spectators in the area understand the dangers and will not approach the rocket for any means.

Launch Safety:
The team will ensure all individuals present at a launch know the dangers present and will treat each flight attempt as a “heads up flight.” Meaning that, during the countdown and flight, someone will direct everyone to keep an eye on the rocket, and be alert for its descent back to the frozen fields of North Dakota. A ten second count down will always be used to ensure the safety of every person at the launch site.

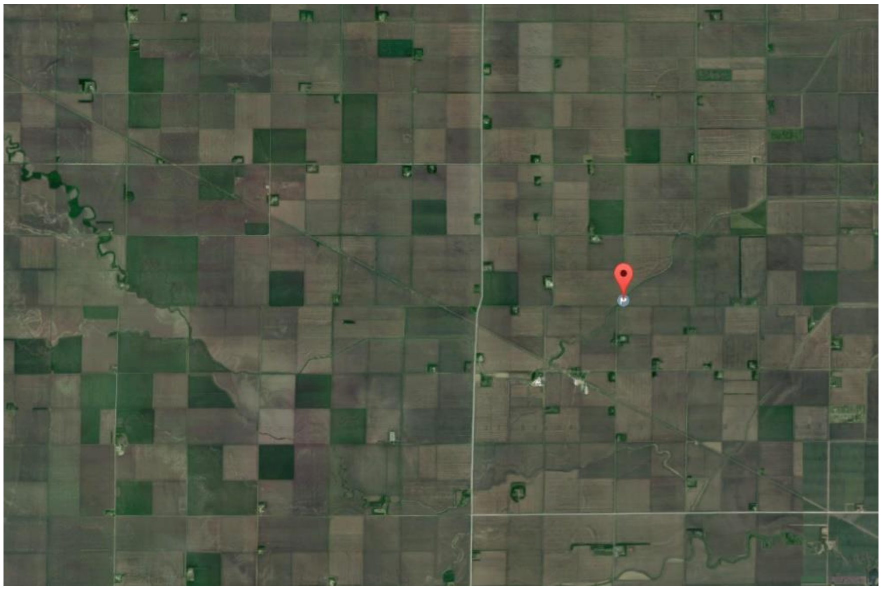
Launcher:
Our rocket will be launched vertically, and we will take necessary precautions if wind speed will affect our launch. We have a steel blast shield to protect the ground from rocket exhaust. Dry grass around our launch pad will be sufficiently cleared away. The rail is long enough, and has been simulated, to ensure the rocket reaches stable flight before exiting.

Size:
The motor we will use has 3489 Ns of Total Impulse. Our rocket will weigh 32.32 pounds, well below one third of the 302.6 maximum-pound thrust the motor will provide.

Flight Safety:
Tim Y. has details on our FAA altitude clearance. We will refrain from launching in high winds or cloudy conditions. There are many flight paths around Grand Forks due to the UND being a large aviation school. A Waiver and/or Notice To All Airmen (NOTAM) will be submitted prior to every flight to ensure all aviation personal can plan accordingly and take necessary precautions to maintain a safe distance from our launch site.

Launch Site:
Our launch site is of an adequate size, with plenty of room for recovery for our planned altitude.

Launch Location:
Our launch site is 60 miles south of Grand Forks, ND. This location provides an adequate amount of space to satisfy minimum distance requirements. The areas surrounding Grand Forks provides miles of flat farmland with excellent visibility. There are not any buildings or highways within 1500ft, and pursuant to the table above, all personal on-site will maintain a 300ft perimeter from the launch site



Launch Location near Fargo, North Dakota

Recovery System:
We will use a 24-inch parachute for drogue, and a 96-inch with a 12-inch spill hole main parachute to ensure rocket recovery. The main parachute and drogue parachute will both be placed in flame-retardant Nomex bags.

Recovery Safety:
Power lines are scarce near our launch site, but we will refrain from recovering if it happens to land in a dangerous location such as up a tree or tangled in power lines. If such an event happens, the local power company will be notified.

3.4 – Launch Operations Procedures

Recovery parachute preparations:

- Inspect shock cords and parachutes for any preexisting damage.
- Secure the parachutes onto the U-bolts attached to the bulkheads inside the rocket.
- Fold the parachutes and insert them into the fire proof bag before placing them inside the rocket.
- Insert the shock cords carefully so they don't get tangled when the parachutes are deployed.
- Assemble all rocket sections together so they are secure.

Motor Preparations:

- Before handling the motor, make sure there are no open flames in the vicinity.
- Inspect the motor and the metal motor casing for any visible damage.
- Evenly coat the outside of the motor with lubricant and insert the motor inside the motor casing. Be careful not to get any lubricant inside of the motor.
- Once the motor is ready, place it in a secure portable magazine until you are ready to go to the launchpad.
- Once ready, insert the motor into the motor mount and secure it with the locking rings. Make sure the motor can't move around once inside the rocket.
- Once the rocket is on the launching rail, test each altimeter to see if they respond properly with 3 beeps each.
- Ensure that the rocket is secure and can only move along one axis as the launching rail is in the upright position.

Igniter Preparations:

- Turn off all electrical input for the ignition system before connecting anything.
- Check ignitor for any preexisting damage and slowly insert it into the motor until it is all the way at the top of the motor.
- After securing the ignitor, attach the wires from the ignition system and ensure that no short will occur.
- Secure the wires and then get to a safe distance before signaling the RSO that the rocket is ready to launch.

Launching the rocket:

- The RSO will signal that the rocket is ready to launch and will do a 5 second countdown and ignite the motor.
- If, in any case the rocket fails to launch, shut of the electrical ignition system and wait 1 full minute before going to inspect the rocket.
- First check for any faulty wiring in the ignition system, check for shorts, faulty connections and continuity.
- If no immediate problem was discovered replace the ignitor with another one and go through the ignitor preparation process again.
- If the rocket still doesn't launch, remove it from the rail and go through a more thorough inspect of the ignitor system and the motor.

Equipment for Main Parachute

- Main parachute – 96 inches with 12-inch spill hole
- Large deployment bag
- 3 large quick links
- Main shock cord

Equipment for Drogue Parachute

- Drogue parachute – 42 inches
- Small deployment bag
- 2 large quick links
- 1 small quick link
- Drogue shock cord

Folding parachute – Main parachute

- When the parachute is already folded as a half circle, and as flat as possible, at least 3 people begin to lay out the chute.
- One person holds the lines to prevent them from becoming tangled.
- The other two individuals hold the parachute along the folded edges.
- The chute is folded in half three times.
- Starting from the top, it is folded into thirds by folding the tip of the chute to the middle, then folding down again.
- The chute is placed into the bag.
- The chute's rip cords are connected to the large quick link in the middle loop of the main shock cord.
- On the top of the chute, but still in the bag, the parachute rip cords and some of the shock cord are carefully placed, to ensure they do not become tangled.

Folding parachute – Drogue parachute

- The drogue is spread between the three people in the same manner as the main parachute.
- While one team member keeps the cords untangled, two members fold the chute in half three times, and then fold it into thirds length wise.
- The parachute is placed in the small bag.
- The rip cord of the parachute is connected to the middle loop in the drogue shock cord using the small quick link.
- The rip cords and part of the shock cord are folded in a manner that doesn't tangle the cords and are placed on top of the parachute inside the bag.

Altimeter bay

- Equipment for Altimeter Bay
    - Altimeter
    - 2 9V batteries
    - 8 washers
    - 4 wing nuts
    - Battery holder
- The altimeter is calibrated, making sure that all parachute deployment numbers are correct
- Two new 9-V batteries are placed on the altimeter board and secure them
- Charges are placed in the charge cups, threading the electric matches through the holes. The charge for the main is 2.5 g and should be placed on the bottom altimeter bay cup. The charge for the drogue is 1.66 g and should be placed in the top altimeter bay cup.
- The wires are connected to the altimeter making sure the positive and negative wires are in the appropriate places.
- The batteries are attached.
- The altimeter board is slid into place and secure with wing nuts.
- The area is cleared of unnecessary personnel and continuity is checked for using the switch on the exterior of the rocket. If there is good continuity, two beeps will be heard after the initial set of beeps. If the continuity is not good there will be double beeps after the initial set of beeps.
- The appropriate side of the main shock is attached to the bottom of the altimeter bay using a large quick link.
- The appropriate side of the drogue shock cord is attached to the top of the altimeter bay using a large quick link.

Assembly

- The appropriate side of main shock cord is attached to the altimeter bay.
- The appropriate side of drogue shock cord is attached to the altimeter bay.
- The main bag is attached to the bottom of the fin can.
- The drogue bag is attached to the bottom of the payload bay.
- The rocket is pushed together.

Motor Preparation

- Equipment for Motor
    - Motor casing
    - Motor grain
    - Motor retainer
    - 3 screws
    - Electric match
- Our engine will come pre-assembled, and will be left in the cardboard tube that it came in until the rocket is ready to be placed on the launch rail
- The motor is placed into the metal casing, making sure the motor is placed fully in its casing, and the motor closure is tightened.
- The casing is inserted into the motor mount tube, being careful since a vacuum is created.
- The rocket is secured with the motor retainer and the three screws
- The red safety cap is left on until the rocket is placed on the launch pad

Launch procedure

- Check to see if the altimeter is turned on, has the right number of beeps, and is functioning properly.
- We will place the rocket onto the launch rail.

Main steps of flight

- Rocket motor ignition
- Motor burnout
- Roll induction system activates
- Arduino, partnered with the gyroscope module takes flight data on induced roll
- After 720 degrees gyroscope module informs Arduino to stabilize
- Arduino communicates stabilization commands to motors

Post Flight Inspection

- We will check to ensure no fires were started by the rocket near the launch site, nor at the landing site.
- The area will be examined for harmful debris.
- We will ensure that the ejection charges are spent before handling the rocket in any capacity.
- We will then check to make sure the motor casing is still in the rocket.

4 - Vehicle Criteria

4.1–Design and Construction of Launch Vehicle

4.1.1 Design Changes

There were multiple changes to the launch vehicle design since the CDR. There was an addition of an avionics bay, along with an addition of a coupler between the rover payload bay and the main parachute bay.

The addition of the avionics bay, which is not to be confused with the altimeter bay, was done so that a camera could be installed along with a data logger. The camera is going to record video of the flight of the rocket. The data logger will act as a black box for the rocket. It is capable of recording air pressure, temperature, acceleration, magnetic heading, and rate of rotation. This data will be compared to that of the commercial flight computer which is in the altimeter bay and used to see how the launch vehicle performed during flight.

The recovery subsystem underwent some changes as well. The first being the main parachute size was increase from 108-inches to 120-inches. The reasoning behind increasing the size of the main parachute was to lower the kinetic energy at ground impact. The kinetic energy at ground impact must be less than 75ft-lbs, increasing the main to 120-inches gives us the desired ground impact velocity of 18.4 feet per second (ft/s), which give us a kinetic energy under 75ft-lbs.

The second change was also regarding the main parachute but pertained to the deployment altitude of the main chute. The deployment altitude of the main was lowered from 1000 feet AGL to 700 feet AGL. The reasoning for the lowering of main deployment altitude was to lower the drift in 20-mile per hour winds. Having the main deploy at 700ft versus 1000ft kept the rocket within the 2500ft drift radius outlined in the hand book.

The third change within the recovery subsystem was the change in the size of the drogue parachute. The drogue parachute was 36-inches in the CDR, now it is 24-inches. This was done to help reduce drift in 20mph winds, the smaller the drogue the faster the launch vehicle drops. With the reduction of the drogue parachute, the launch vehicle will stay within the 2500ft drift radius.

4.1.2 Description of Launch Vehicle Features

The launch vehicle has two key elements in its design. Those elements are the structural elements and the electrical elements. The structural elements that make up the launch vehicle are the airframe, fins, bulkheads, couplers and attachment hardware. The electrical components that make up the key electrical features of the launch vehicle entail switches, wires, batteries, data logger, data logger retention, and camera. These components were chosen and manufactured to ensure that the launch vehicle can perform a safe and successful flight.

4.1.2.1 Structural Elements of Launch Vehicle

The airframe of the rocket is rolled carbon fiber tubing. The tubing was bought pre-rolled from Public Missiles Limited. It has diameter of six inches and a wall thickness 0.056-inches. The carbon fiber airframe is designed to withstand extreme flight conditions.

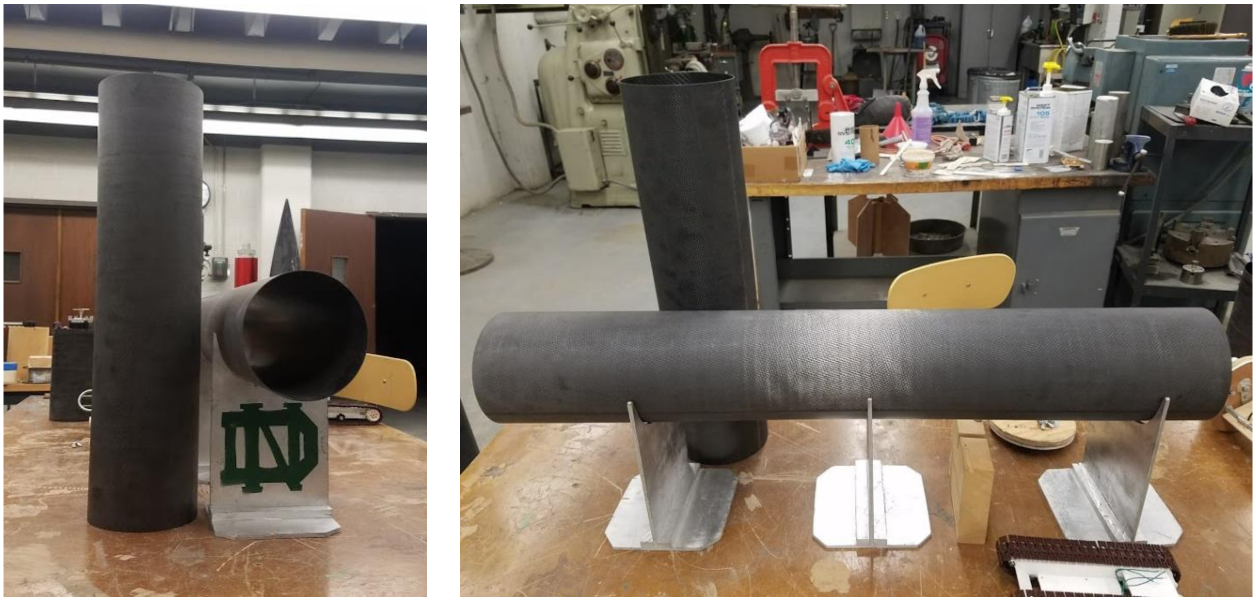


Figure 2: *Carbon Fiber Airframe*

The fins for the fin can are cut out of G-10/FR4 fiber glass sheets. The sheets of fiberglass are also purchased from Public Missiles Limited. Thickness of the sheets are 0.1-inches. This fiberglass is robust and will withstand the flight conditions. It has a proven flight record from previous years rockets.

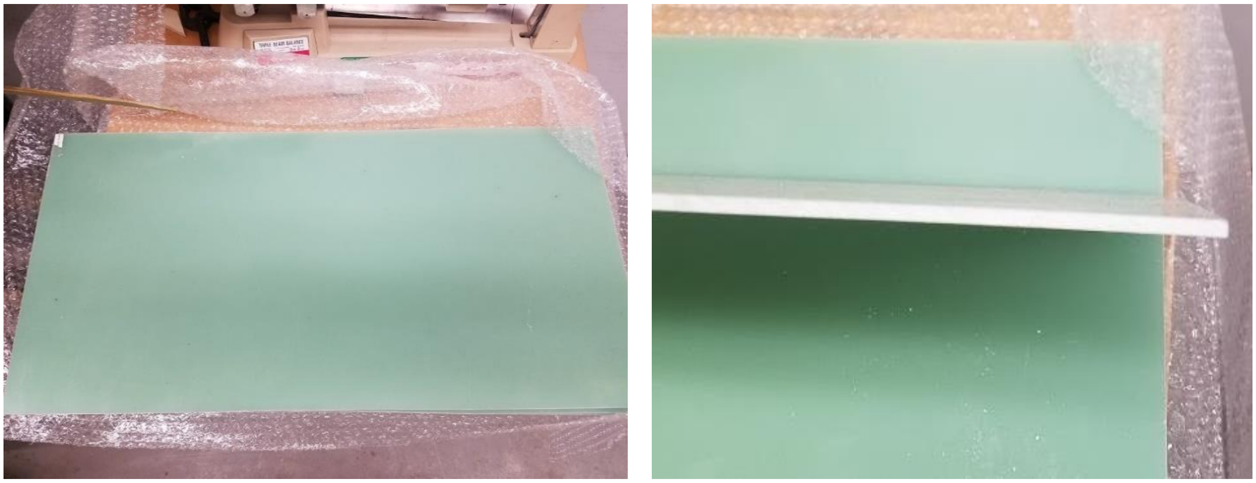


Figure 3: *G-10 Fiber Glass Sheets*

The bulkheads used in the launch vehicle are manufactured out of plywood. The sheets of plywood have a thickness of 0.5-inches. The bulkheads are used to make payload bays and used in the airframe to separate the parachute chambers from other sections of the rocket. Plywood is a relatively durable material and can withstand the forces that are experienced during flight. An example of a force that the bulkhead will experience during flight is when the black powder charge is ignited, and the main parachute deploys. The plywood the bulkhead is made from can withstand this force. Using plywood as bulkheads has been a proven method and was used in previous years launch vehicle design.

***Figure 4:** Plywood bulkhead*

Couplers within the airframe are also made from carbon fiber. They are 11.75-inches long, have a diameter of 6-inches, and have a thickness of 0.056-inches. The couplers are also purchased through Public Missiles Limited and designed just like the carbon fiber air frame. Which means they can withstand the flight conditions the launch vehicle experiences during flight.

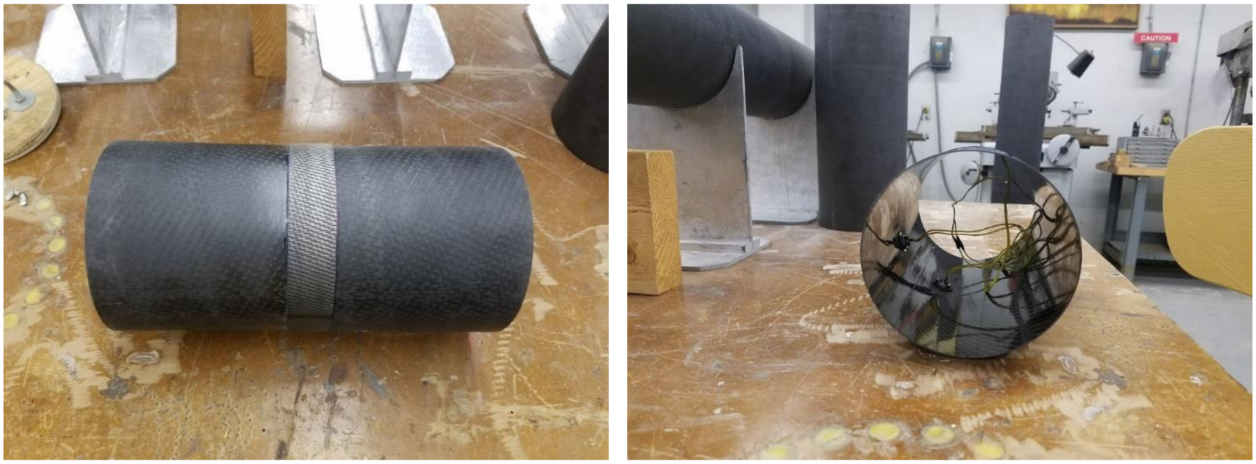


***Figure 5:** Carbon Fiber Coupler*

For the attachment hardware there are two different types of attachment hardware used on the launch vehicle. The two different types are shear pins and bolts and nuts. The nylon shear pins are used to attach the parachute sections to the altimeter bay and used to attach the nose cone to the air frame. The reason behind having shear pins attaching the nose cone to the air frame is because the rover deployment system is in the nose cone. The linear actuators used in the rover deployment system will break the shear pins when they are activated.

The nuts and bolts are used to attach the drogue airframe, avionics bay, and fin can section together and the rover deployment air frame to the main chute air frame. The nut and bolts are 3/16-inch nut and bolts.

Figure 6: *Nut and bolt (left) and shear pins (right)*

4.1.2.2 Electrical Elements of Launch Vehicle

Switches that will be used in the launch vehicle are keylock switches. These switches can be accessed from outside the launch vehicle and cannot be accidentally switched on or off. Accidentally meaning, if a person were to bump the switch on the launch pad it would the keylock switch would not be activated. The keylock switch needs the key to change the switch position. The switches will be used to control the power of the data logger. The same switches will be used on the altimeter bay.

Figure 7: *Keylock Switches*

The onboard camera is a FREDI mini camera. It runs of its own rechargeable lithium-polymer battery and can be turned on or off remotely. It does not need a switch. It is light weight and can record 4 hours a video at 1080p. The camera will be in the avionics bay. There will be a small hole in the air frame from which the camera will protrude. The battery and other necessary circuitry will be housed on the sled of the avionics bay.

Figure 8: *FREDI Flight Camera*

For the wiring of the electronics 20 gauge (AWG) was used. The wire was used to connect leads to the switches and terminals for other electronics. When soldering wire heat shrink was applied to the exposed copper of the connecting wires. This was done to protect the wire and external components that would be placed near the solder connection.

Figure 9: *Roll of 20-gauge wire used when wiring switches*

4.1.3 Launch Vehicle Construction

There are five main sections of the launch vehicle. They are the fin can, altimeter bay, avionics bay, payload bay and parachute chambers. The airframe sections are made from carbon fiber tubing, the bulkheads are constructed out of plywood. The wire gauge used for wiring switches and leads was 20AWG wire.

4.1.3.1 Vehicle Construction – Fin Can

The construction of the fin can is the most critical component of the rocket. It requires the most precision and accuracy when constructing. CAD drawings were done before any manufacturing began. The CAD drawings outlined the fin can dimensions and broke down the fin can into all the key components needed for construction.

The fin construction team this year experimented with creating a jig for perfect fin alignment. The first jig, adeptly name Fin Jig Mk1 was the team's first attempt at creating a fin jig for alignment. It did work in aligning the fins, but not with the precision that was desired. There were multiple problems, the main problem being that the Mk1 was very difficult to align and get the fins in the desired location.

Figure 10: *Fin Jig Mk1 in testing*

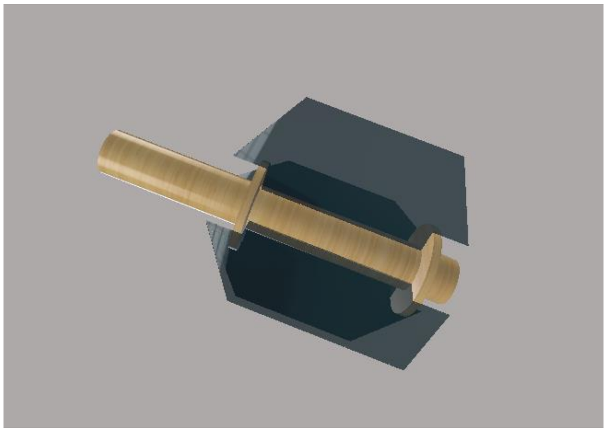


Figure 11: *3D render of fin can using Fusion360*

Through testing the Mk1 and realizing it did not meet the construction team's expectations. To rectify this, the team used 3D modeling software and a 3D printer to create a second jig that fit snugly around the fin can, with four sets of clamps sized to hold the fins. This Fin Jig Mk2 had the advantage of being completely machine-built, and thus free from human error. Fin Jig Mk2 delivered the expected results and was used in during the construction of the fin can.

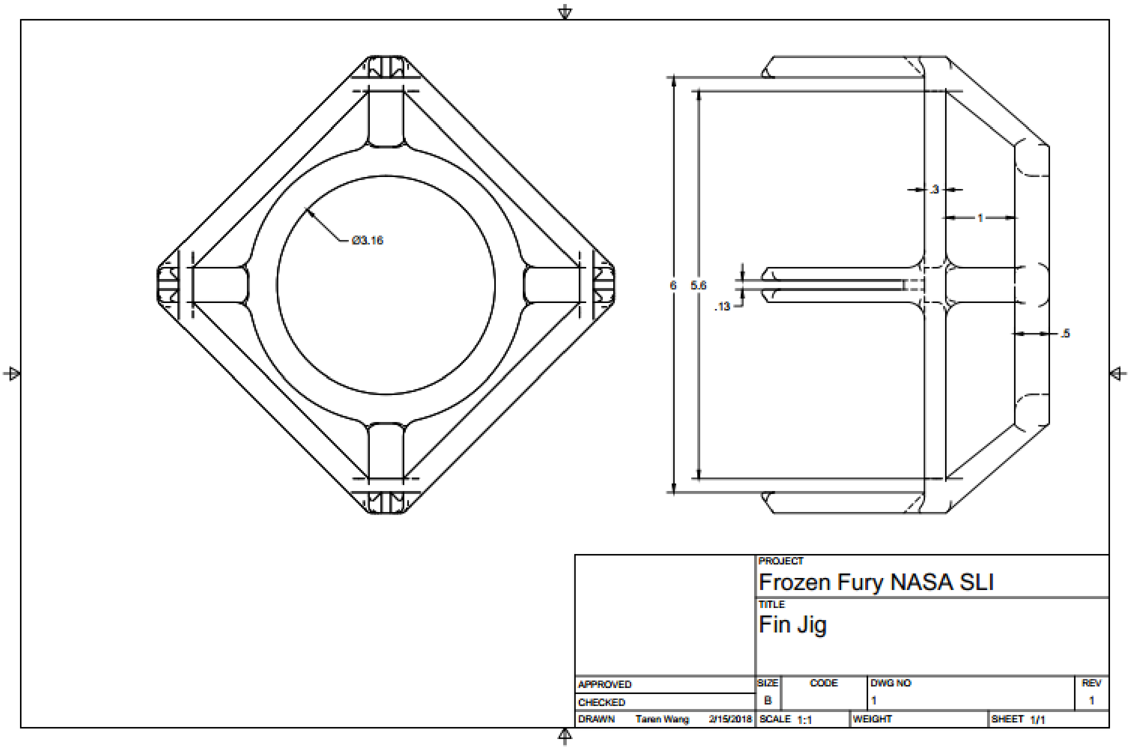


Figure 12: *Schematic of Fin Jig Mk2*

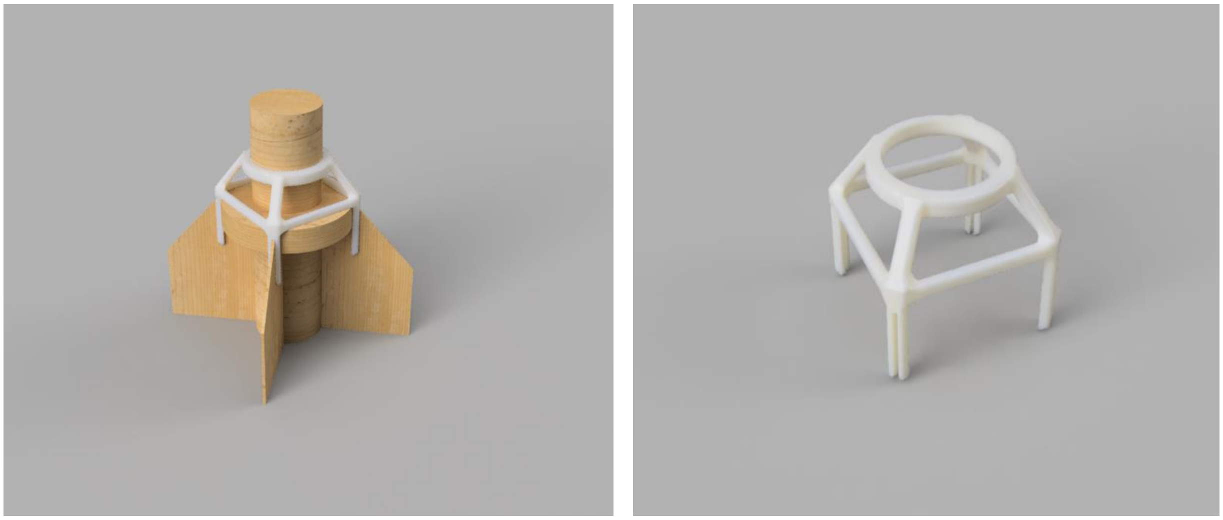


Figure 13: *3D Renders of Fin Jig Mk2*

Figure 14: *Fin Jig Mk2 implemented on inner tube with fins aligned*

Figure # shows the Mk2 being used during construction of the fin tube. Its inner diameter is the size of the inner tubes out diameter which allows the jig to slide over the tube and into place. Once the jig is on the tube the fins are aligned and the jig is orientated into the correct position. When everything is set up and aligned precisely, the next step in the procedure happens. This next step is the applying of the epoxy to the fins and the inner tube. This is done with two-part epoxy mixed with adhesive filler, and it is applied with a thin paint brush.

After application of the epoxy it is set assigned to cure for 24 hours. While the epoxy is curing the fin construction team started work on the body tube for the fin can. The body tube was cut from carbon fiber tubing and is 28 inches in length. After being cut on the table saw the body tube was rigged up to go on the milling machine to mill out the slots for the fins. Using the mill allowed for each slot to 90 degrees from each other. This ensures that the fins will epoxied to the inner tube will integrate perfectly into the fin can body tube.

Figure 15: *Safety Officer Drew Ross milling out the fin slots (left), Team Lead Stefan Tomovic and Drew Ross aligning the mill with the body tube (right)*

After the fin can body tube is milled, and the epoxy has fully cured on the inner tube the next step in the construction of the fin can was to integrate both components together. There were some issues at first. One of the issues was that was encountered during the early stages of integration were the fin slots were to thin and needed to be sanded to increase the width of the gap. Upon sanding down the gaps to the appropriate width, the inner tube and fin can were successfully combined. Once the fin can is completely integrated epoxy is applied between the fin and the body tube to connect the inner tube and body together. The centering rings that are part of the inner ring are also epoxied to the carbon fiber air frame for structural support.

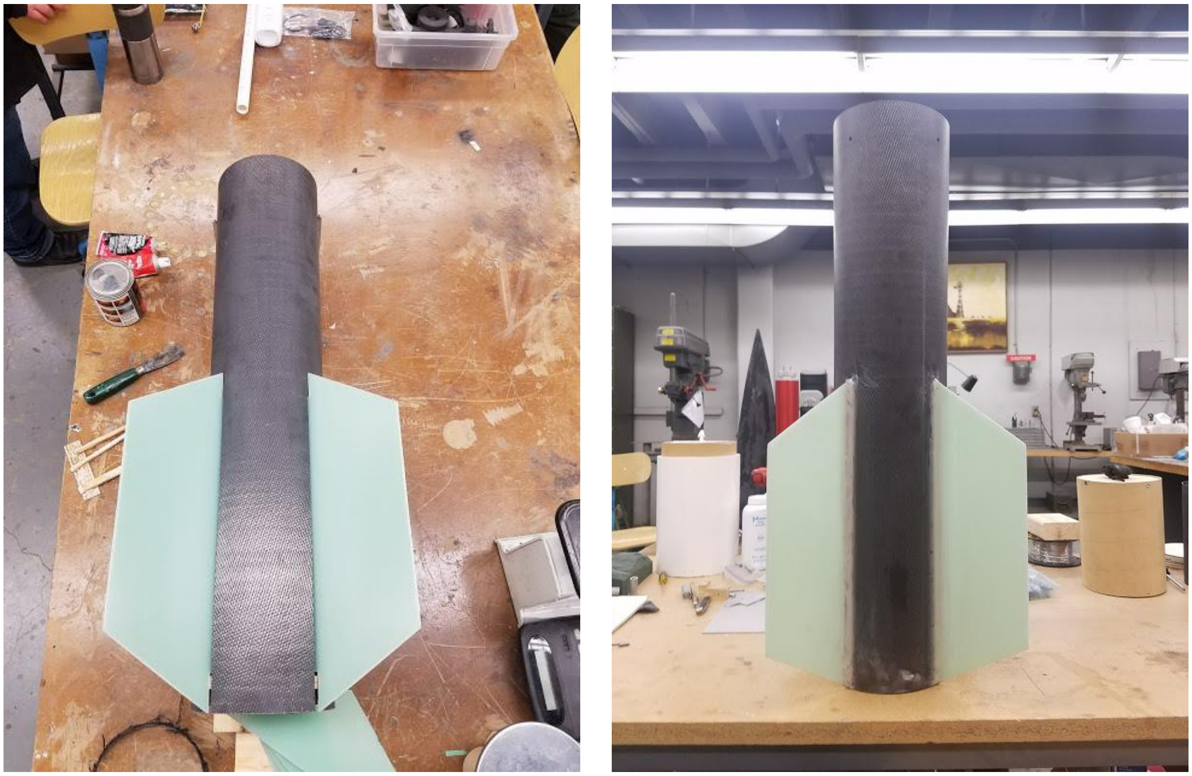


***Figure 16:** Fully integrated fin can before epoxy (left) after epoxy cure (right)*

Once the epoxy is applied the fin can is set aside to cure for 24 hours before sanding the epoxy down to make smooth a smooth edge between the fin and external airframe. Once the sanding has been completed the next stage of construction of the fin can begins. A retainer ring for the motor needs to be attached on the aft end of the fin can, and on the fore end of the fin can screw holes need to be drilled so that the coupler containing the avionics bay can be connected to the drogue chute chamber.

4.1.3.2 Vehicle Construction – Avionics Bay

The avionics bay is a very sturdy part of the rocket. It consists of a sled which slides onto two threaded rods and is attached to two bulkheads on either end. One of the bulkheads is epoxied into the bottom section of the coupler, and the top is removable. That enables the team to work on the components when needed. This also gives the avionics bay a very strong structure. With the avionics bay having its coupler run all the way down to the top of the fin can, this adds more strength and stability to the overall design of the launch vehicle. The avionics bay has four nuts on the upper half and four more on the lower that are epoxied into the coupler. These have bolts that go through the air frame of the rocket and through the coupler and attaches to the nuts on the inside. The team is confident in this design because airframe and the coupler are both made from very sturdy carbon fiber, and when it is all attached there is no wiggle room. Before the full-scale flight, a drop test was performed from roughly ten feet. The avionics bay also held up during the full-scale launch, with only a few bent components to the data logger and one zip tie breaking.

Figure 17: *Avionics Bay sled in coupler (left) avionics bay coupler and sled dissembled (right)*

The figure on the left shows the epoxied bulkhead with camera and battery attached, as well as the key switch to power the data logger attached to the side of the airframe. The image on the right shows the sled outside the coupler with the removable bulkhead to the side. The hole on the external airframe of the coupler is where the camera will be hosed. Also, one can see four of the eight bolts that connect the avionics bay to the fin can and drogue parachute chamber.

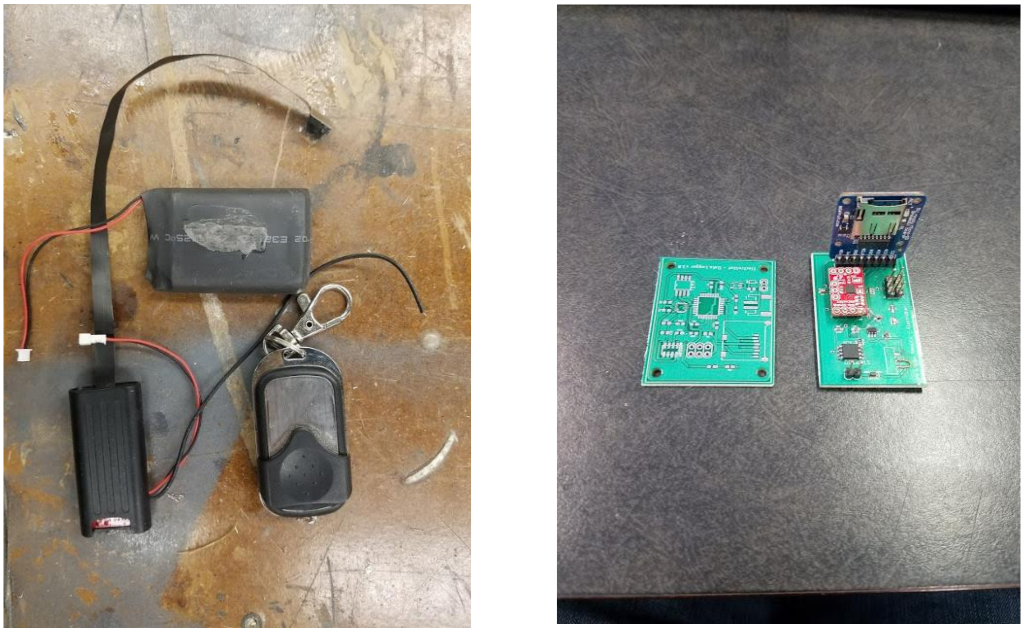


***Figure 18:** Camera (left) data loggers used on flight (right)*

The electronics in the avionics bay consist of a small camera and its 5-volt power supply, and a data logger made by the team. The data logger acts as the rockets black box and record flight data such as acceleration, angular velocity and magnetic heading amongst other things.

The small camera that is attached to a wire allowing it to be easily positioned within the payload bay. A hole was drilled that was the size of the camera, so it stays in, and to keep the camera in for sure a piece of tape is applied inside the coupler and to the back of the camera. The camera is very helpful because it is remote activated, and can start recording right before launch, long after the bay has been sealed for flight. It provides the team with flight video which is used to analyze the flight in the post-flight analysis.

4.1.3.3 Vehicle Construction – Parachute Chambers

There are two parachute chambers in the launch vehicle, one for the drogue chute and one for the main chute. The sections for each chamber were cut out of carbon fiber tubing, and the bulkheads that were used are from wood. U-bolts were epoxied on to each bulk head for the carabiner tied to the shock cord could attach the bulkhead which is epoxied on to the airframe.

The drogue chute airframe is 21-inches in length, however 10-inches of this airframe is taken away from the couplers that attach to this section of the rocket. 5-inches is taken from the altimeter bay coupler and 5-inches is taken from the avionics bay coupler. That leaves 11-inches of space for the shock cord and drogue parachute.

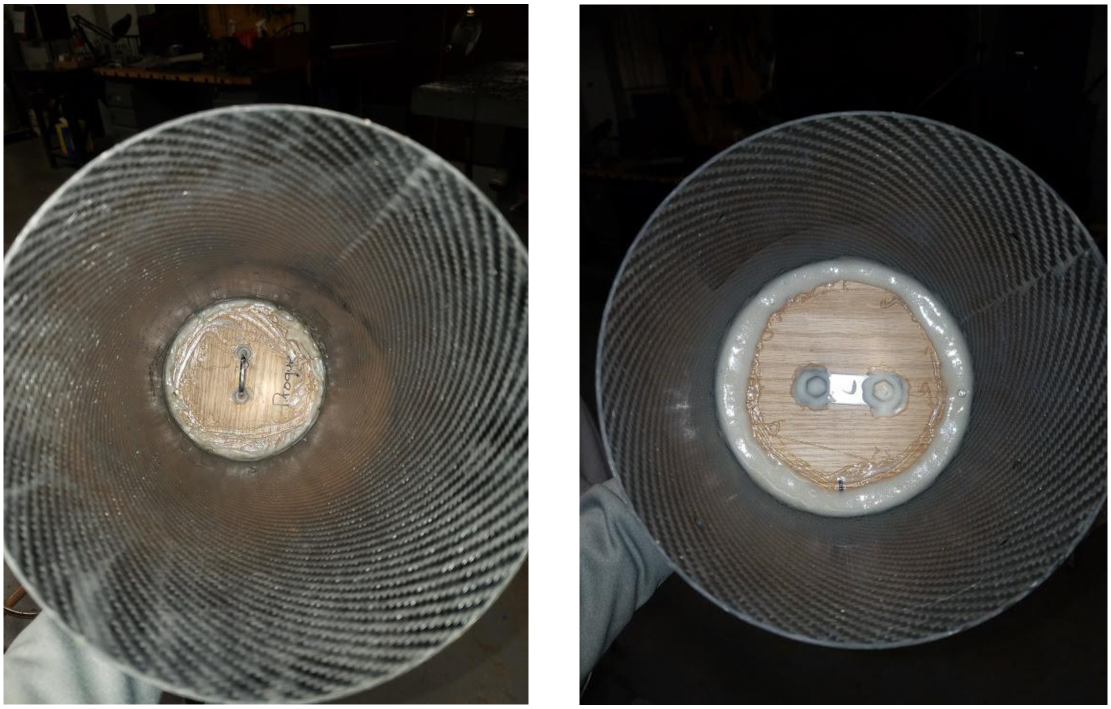


Figure 19: *Fore section of drogue chamber (left) aft section of drogue chamber (right)*

The main chute airframe is 24-inches in length and only 8-inches of internal space is lost to couplers being attached. On the aft section of the main chute chamber 5 inches are lost to the altimeter bay couplers, and 3 inches are lost to the bulkhead that connects the main chute to the rover payload bay. The stepper motor that rotates the rover coupler is attached on the fore section of the main chute chamber. The coupler that the stepper motor is attached to is epoxied into the main chute airframe. It is epoxied in because this will provide for a secure bond between the coupler and airframe and will be strong enough to withstand the force of the main chute deploying upon descent.

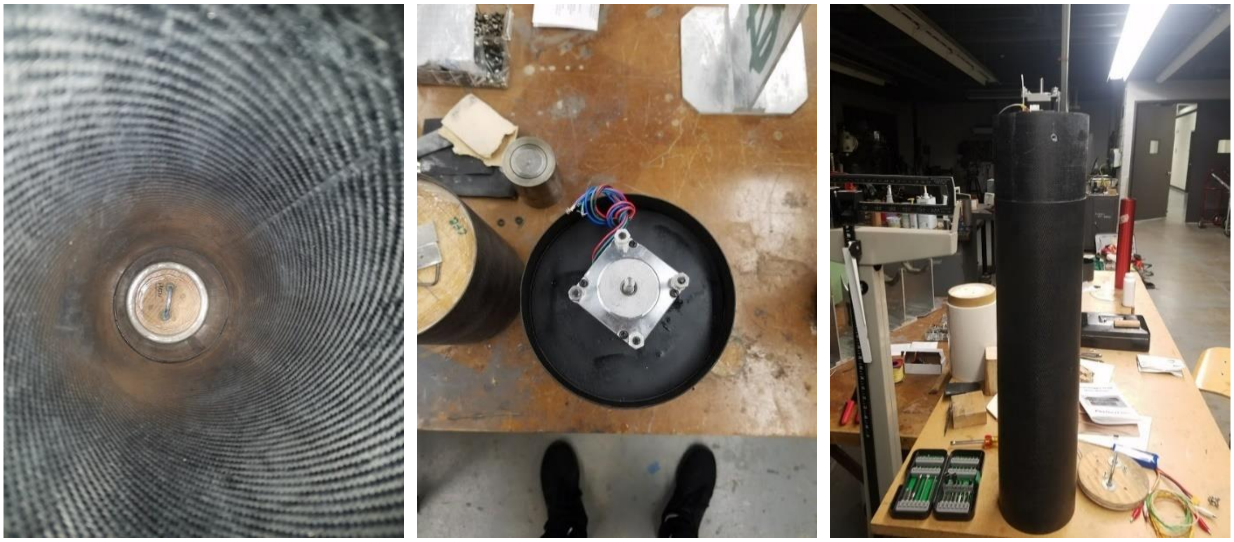


Figure 20: *Aft section of main chute airframe (left), fore section of main chute airframe (middle), completed main chute airframe (right)*

4.1.3.4 Vehicle Construction – Fin Manufacturing

The fins were first designed in CAD software to get the desired fin design. Using the dimensions from the CAD model a stencil of the fin design was made from a sheet of aluminum. A set of test fins were cut out of scarps of wood to ensure the aluminum stencil was correct. After the test cuts the fin construction team proceed to trace out the fins on the fiber glass sheets. The fins were cut on the band saw in the machine shop. Four were manufactured for the fin can used in the test flight.

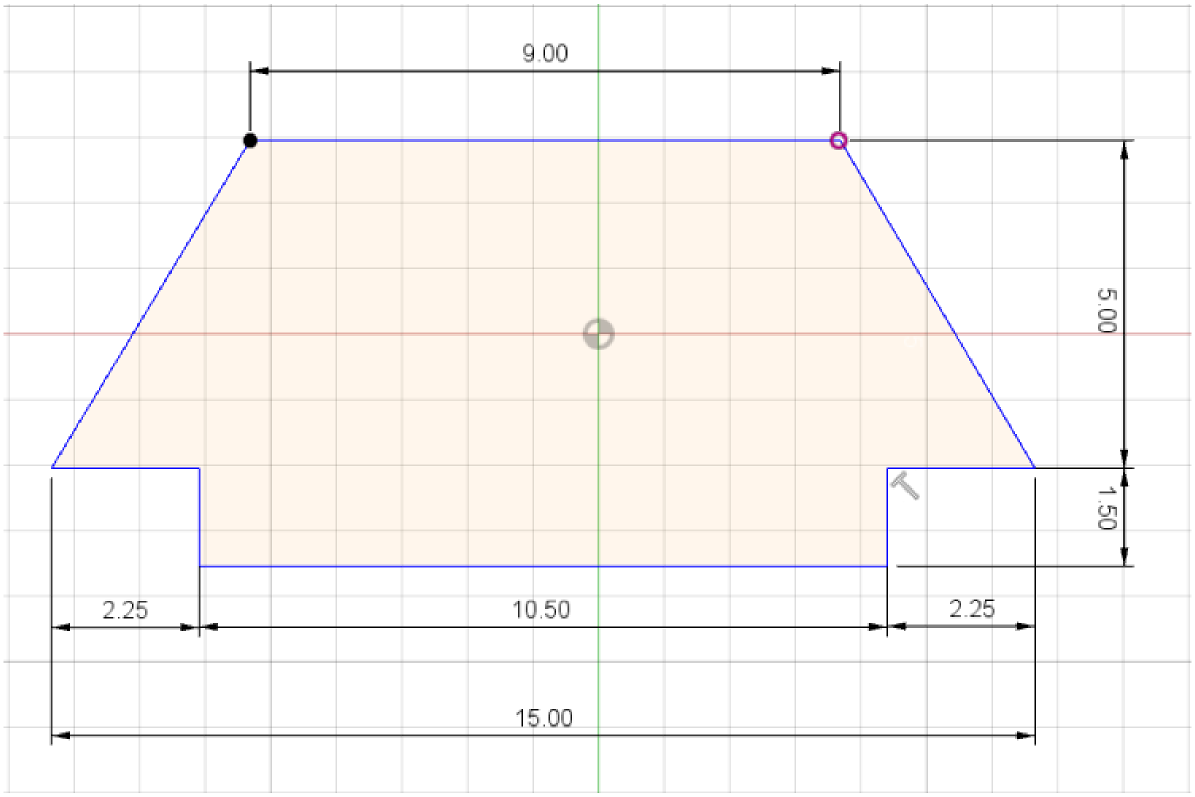


Figure 21: *Fin dimensions from CAD model (left), render of fin in CAD software (right)*

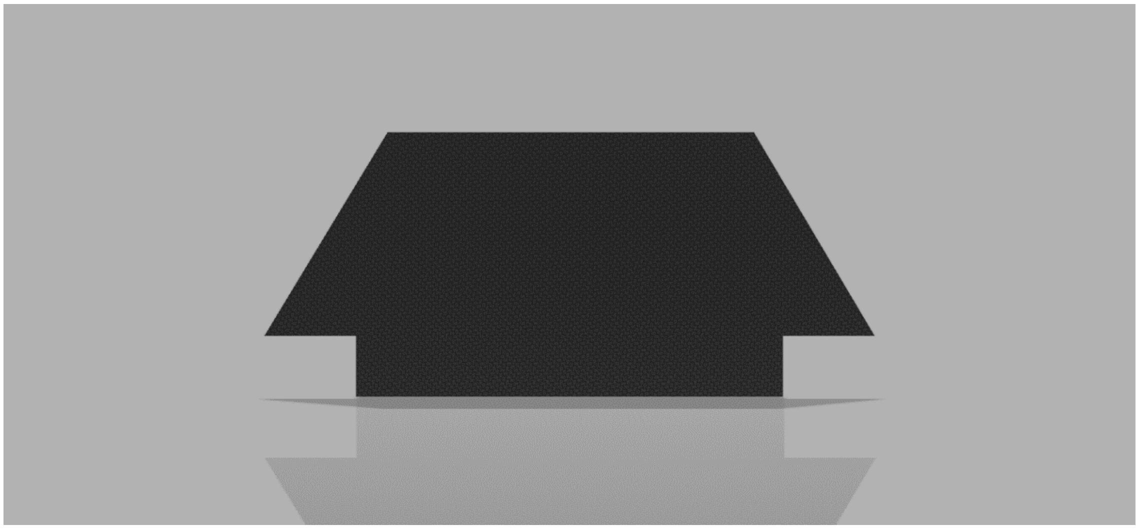


Figure 22: *3D render of fin design*

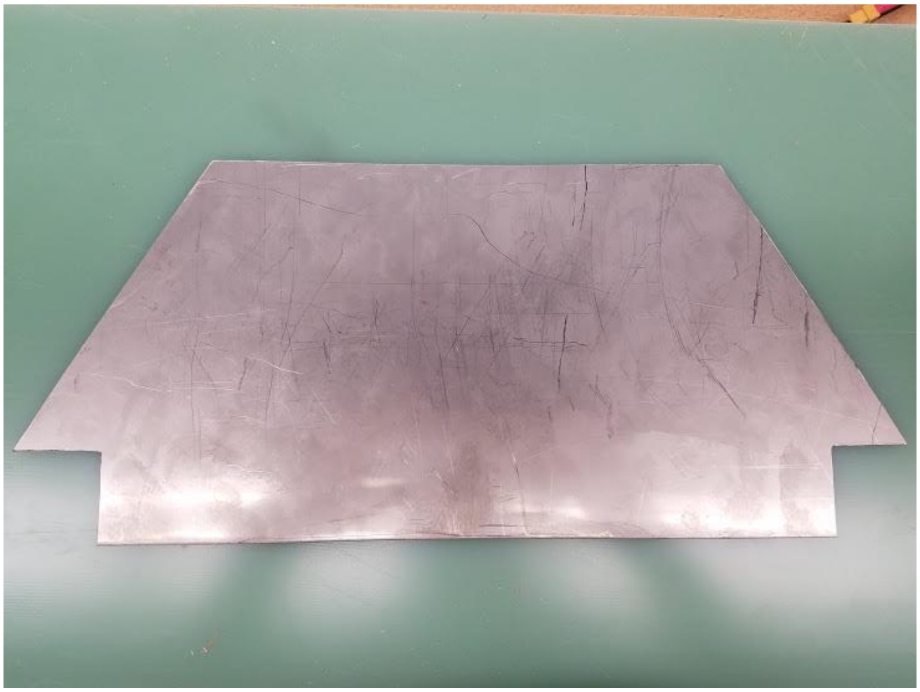


Figure 23: *Aluminum stencil of fin*

4.2 – Recovery Subsystem

The recovery subsystem will employee a drogue parachute, a main parachute, an electronic tracker and an altimeter bay. The altimeter bay will have two PerfectFlite SL100 flight computers on board. There is a primary flight computer, and it has two leads going to the drogue parachutes black powder charges and two leads going to the main parachutes black powder charges. The primary flight computer will be programmed before the flight to have the drogue deploy at apogee, and the main to deploy at 700ft. above ground level. The secondary flight computer is a redundancy within the recovery subsystem. Its purpose is to deploy the drogue parachute after a time delay and the main parachute at 650ft if the primary flight computer were to fail.

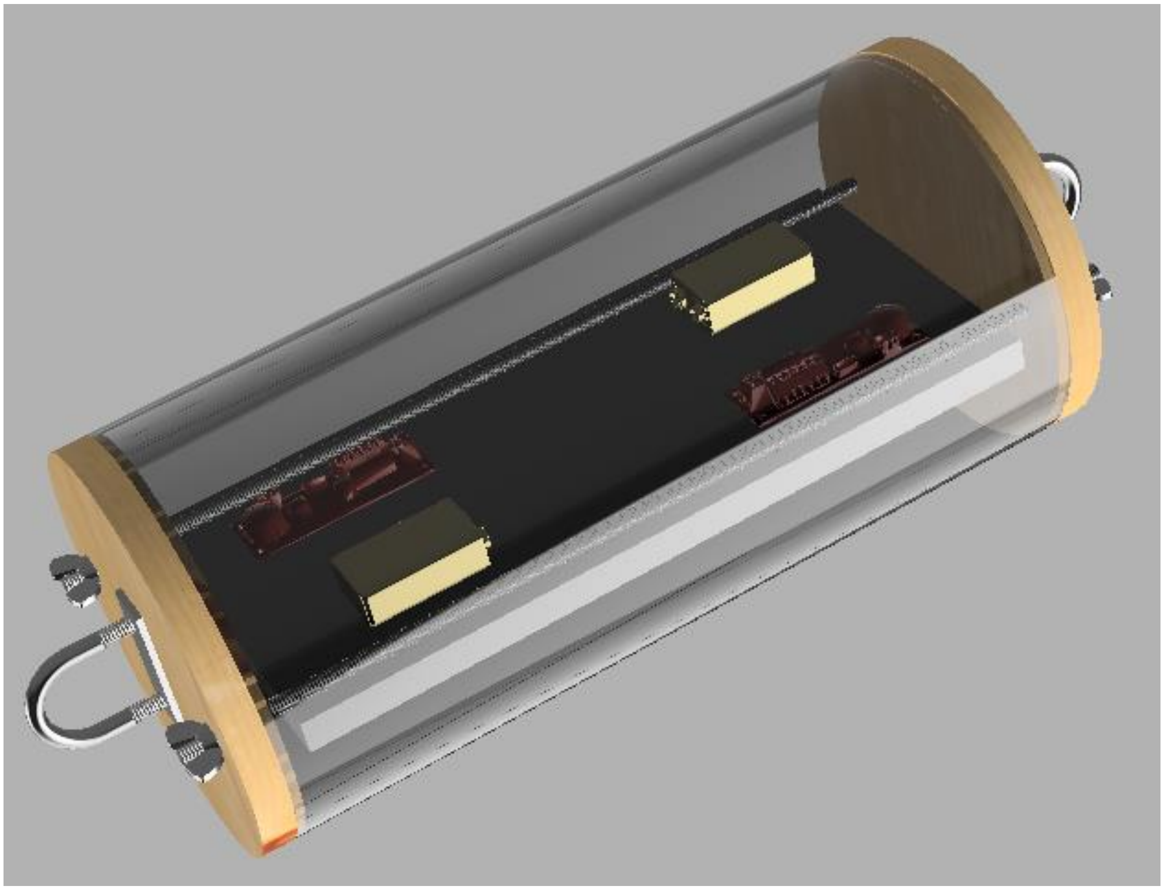
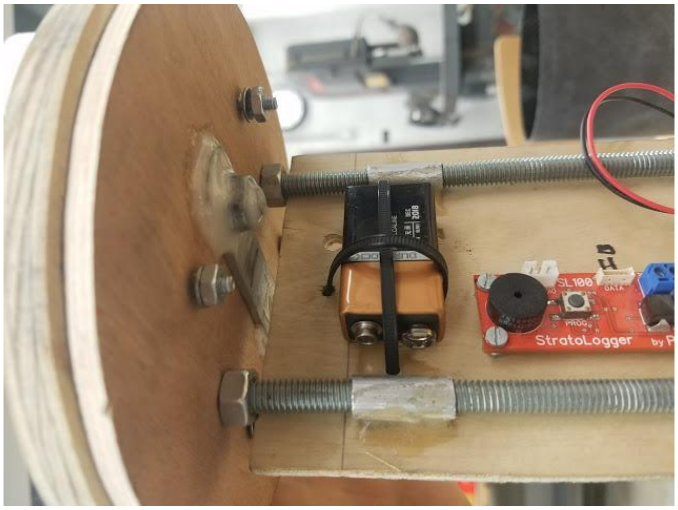


Figure 24: *3D model of Altimeter Bay*

4.2.1 Recovery Subsystem – Altimeter Bay Construction

The altimeter bay's structure is very similar to the avionics bay, but much sturdier with the type of hardware that was used during the construction of the bay. The threaded rods that hold the sled are thick, they have a diameter of 7/16th inch. The altimeter needs to be strong, since the two bulkheads on either end of the bay is where the parachutes are attached. This means that there are no metal bolts to hold the altimeter bay to the surrounding sections of the rocket. Instead of using bolts the team chose shear pins to connect the fore and aft sections of the airframe to the altimeter bay.

Shear pins were used because they allow for easy separation of the airframe when the charges are exploded during descent by the altimeter itself. The shear pins break easy, and do not damage the airframe of the rocket, that is why they are the ideal choice for securing the rocket sections that need to come apart. At the end of each section of the altimeter bay coupler, there are two bulkheads that have two U-bolts connected, one on each end. The U-bolts are connected with a washer and a nut, and then epoxied into place to ensure that there is a secure connection that will not break when the force of the deploying parachute acts on the bulkhead.



<u>Figure 25:</u> *<u>7/16 in rods, battery retention, PerfectFlite SL100, epoxied U-Bolt connection, and screws used to connect the charges to the altimeter bay can be seen</u>*

To hold the black powder charges two small sections of PVC piping was epoxied on each bulkhead. Within these sections is where the blast charges will be placed. These are small cylinders that hold gunpowder, and they detonate releasing gas and forcing the rocket to separate, which causes the parachute to deploy. The team is confident that this design will hold because the stress is mostly on the threaded rods that hold it all together, the bulkhead, the U bolt, and the epoxy.

Figure 26: *Fore bulkhead of altimeter bay. PVC piping for holding the charges can be seen, along with U-bolt for the main parachute, and the small bolts for the e-matches to connect to the altimeter*

Electronics in the altimeter bay consist of two PerfectFlite SL100s which are each independently hooked up to their own nine-volt batteries. These batteries are zip tied onto the sled. The flight computers are connected to the blast charges with four screws that are drilled into the bulkheads. The wires are connected from the computers to screw on the inside of the bulkhead, the next step is to connect the charge match wires to the other end of the screws and the current travels through them and ignites the charges. This is done to not let the gas from the gunpowder explosion to impact the pressure sensors within the altimeter bay. For the sensors to work two small holes were drilled into the airframe and coupler of the altimeter bay in order to allow it to read the pressure during flight. There are two key switches on the outside of the bay, so that the altimeters can easily be armed from the outside.

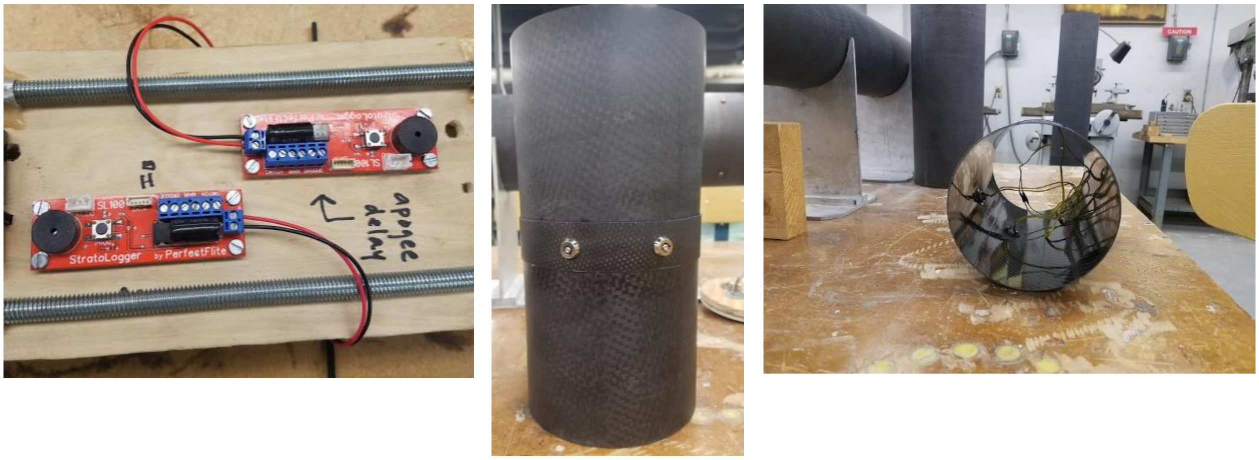


Figure 27: *PerfectFlite SL100 Altimeters (left), key switches (middle), wiring of switches (right)*

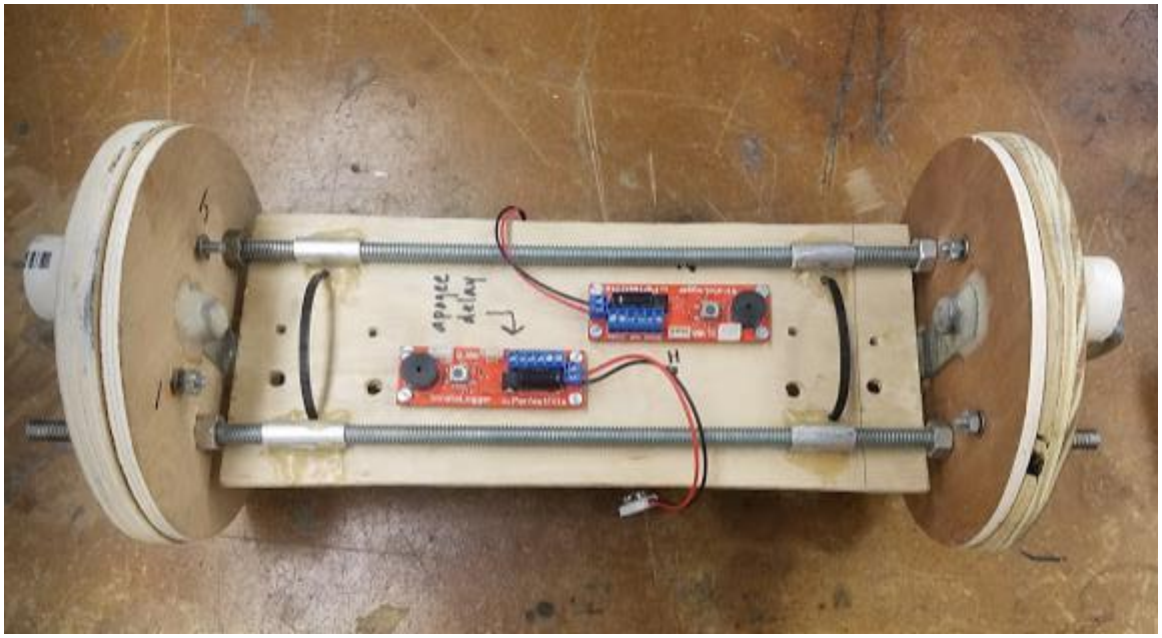


Figure 28: *Complete altimeter bay sled*

Figure # shows the complete electronics sled of the altimeter bay. The two flight computers can be seen. The secondary flight computer is labeled apogee delay, and the primary flight computer is denoted by an H. Next to each of the flight computers there are pre-drilled holes for the zip ties that will hold down the nine-volt batteries used to power the PerfectFlite SL100s during flight.

4.2.2 Recovery Subsystem – Electronics

The flight computers used to control the deployment of the parachutes are two PerfectFlite SL100 Altimeters. They each have their own power supply which is a 9-volt Duracell battery. The flight computers take in air pressure measurements as the rocket is in flight. It takes the pressure measurements and converts it into altitude. It then uses the new altitude measurement to check with the preprogrammed deployment altitudes to know when to ignite the charges.

The primary flight computer ignites the black powder charge for the drogue parachute at apogee. The main chute's black powder charge will blow at 700 feet AGL. If the charges do not successfully deploy their respective parachutes a secondary flight computer is employed to rectify this problem.

The secondary flight computer will ignite the secondary black powder for the drogue parachute after a delay. The secondary charge for the main will ignite at 650 feet AGL. The black powder charges on the secondary altimeter will still ignite even if the primary charges deploy the parachutes successfully.

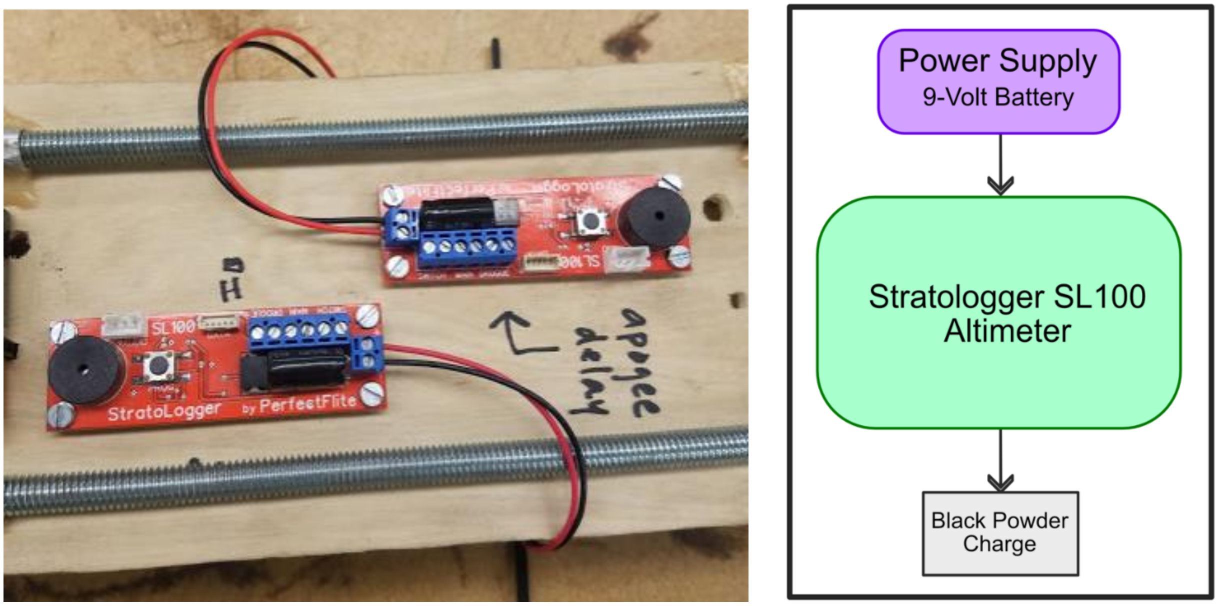


Figure 29: *PerfectFlite SL100 flight computers (right), block diagram describing flight computer electronic connections.*

4.2.3 Recovery Subsystem - Parachutes

There are two parachutes used in the recovery subsystem. A 24-inch drogue parachute, and a 120-inch main parachute. The shock cord used is 1-inch thick tubular nylon. For connections to bulkheads, parachutes and section of shock cord carabiners are used. The shock cord for the main chute and drogue is 144-inches long. The parachutes are stored in a sleeve when placed into the airframe of the rocket. The sleeves are attached to the altimeter bay U-bolt, while the parachute is attached in the middle of the shock cords.

Figure 30: *Drogue and main parachutes with shock cord.*

Figure # shows how the shock cord and parachutes will be packed inside the airframe. The shock cord is folded and wrapped in blue tape. This is to save space inside the airframe, and the painters tape easily rips once the parachute chamber gets blasted off, and the shock cord begins to unravel. The red parachute that is packed inside the sleeve is the main 120-inch parachute, it has a packed length of 16-inches. The drogue parachute has a packed length of 5-inches. The descent rate for the just the drogue is 70 ft/s, and the descent rate for the main chute is 17.2 ft/s.

4.3 – Mission Performance Prediction

This section will describe the launch vehicles flight profile, altitude predictions, component weights and simulated motor thrust curve. The stability margin and center of pressure(CP)/center of gravity locations will be shown and described as well. Drift for five different cases will be displayed.

4.3.1 – Flight Profile

The launch vehicle has been named "Some Assembly Required" and has an overall length of 118-inches and an outer diameter of 6-inches. The length of the rocket has increased from 107-inches to 118-inches. This happened because during construction of the launch vehicle it was realized that there needed to be an avionics bay for the camera and data logger, and that the rover payload bay was too small. After these changes were implemented the final length of the rocket was 118-inches.

The simulated apogee with the AeroTech L1150 motor is 5,386-feet. The weight of the launch vehicle with the motor is 33.06-pounds. The mass of the L1150 is eight pounds, meaning the weight of the launch vehicle unloaded is 25.06-pounds. The center of gravity of the launch vehicle is 72.15-inches from the nosecone and the center of pressure is 86.26-inches from the nosecone giving the rocket a stability of 2.35

Mass of Launch Vehicle (Unloaded)	25.13 lbs.
Mass of Launch Vehicle (Loaded)	33.13 lbs.
Length of Launch Vehicle	118 in.
Diameter of Launch Vehicle	6 in.
Center of Pressure (CP)	86.65 in. from tip nose cone
Center of Gravity (CG)	72.30 in. from tip nose cone
Stability Margin	2.39
Apogee	5,375 ft
Max. Velocity	665 ft/s
Max. Acceleration	262 ft/s^2
Time to Apogee	18.4 seconds (s)
Altitude of Deployment of Drogue	5,375 ft. (Apogee)
Altitude of Deployment of Main Parachute	750 ft.
Ground Impact Velocity	17.6 ft/s

Table 4: *Flight Profile*

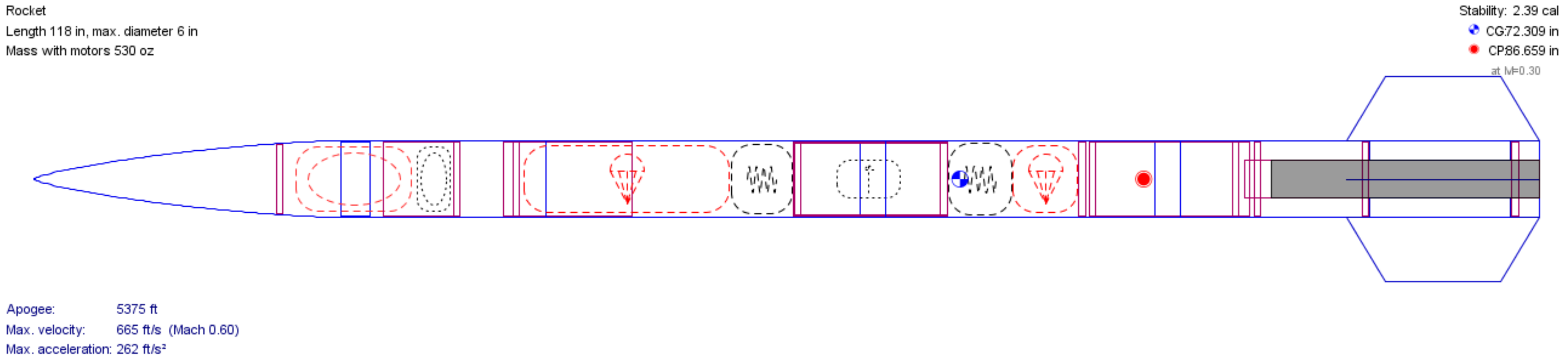
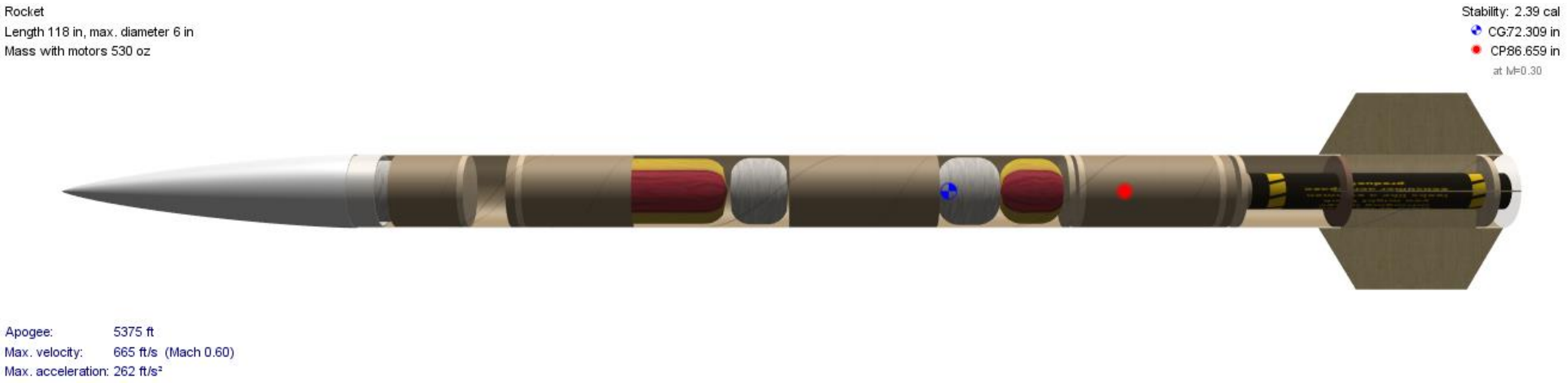


Figure 31: *2D layout of launch vehicle*



Rocket
Length 118 in, max. diameter 6 in
Mass with motors 530 oz

Stability: 2.39 cal
CG:72.309 in
CP:86.659 in
at M=0.30

Apogee: 5375 ft
Max. velocity: 665 ft/s (Mach 0.60)
Max. acceleration: 262 ft/s^2

Figure 32: *3D render of launch Vehicle*

Figure 33: *"Some Assembly Required" on launch rail prior to first full-scale test flight*

4.3.2 – Motor Specifications

The motor is for the launch vehicle is the AeroTech L1150R The L1150R thrust curve data was simulated by using thrustcurve.org. The data in Table 9 was taken from the OpenRocket software used to simulate flights. All simulations, except the thrust curve simulation were completed using OpenRocket.

Manufacturer	AeroTech
Entered	May 25, 2006
Last Update	Jul 22, 2015
Mfr. Designation	L1150R
Common Name	L1150
Motor Type	Reloadable
Delays	P
Diameter	2.95 in.
Length	20.9 in
Total Mass	130 ounces (oz.)
Empty Mass	56.7 oz.
Average Thrust	1148 N
Total Impulse	3489 Ns
Max. Thrust	1310 N
Burn Time	3.1 s

***Table 5:** AeroTech L1150 specs*

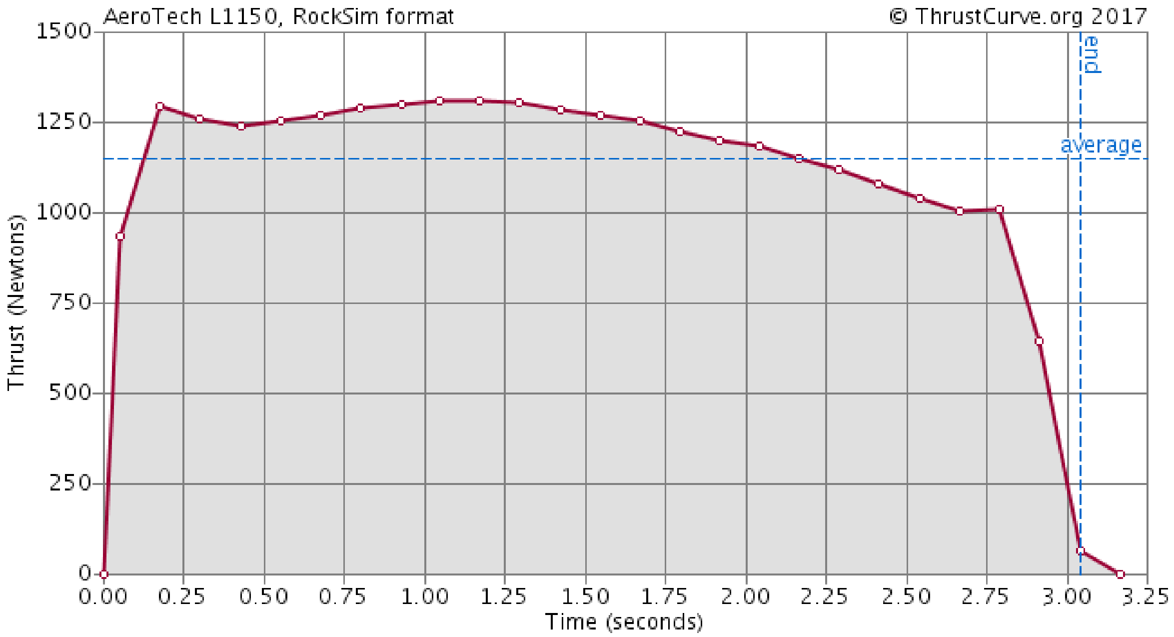


***Figure 34:** Thrust curve of AeroTech L1150*

4.3.3 – Kinetic Energy Calculations

The kinetic energy calculations are done by calculator, the equation used is described by equation #. The kinetic energy upon ground impact was done using both drogue and main ground impact velocities. This was done to see how much kinetic energy there would be if only the drogue deployed, and with the drogue and main fully deployed. The kinetic energy for each section is shown in the table below. The calculations were done in Excel using equation 1.

$$\frac{1}{2}mv^2 = Kinetic\ Energy\ (KE) \qquad Eq.1$$

Section	**Mass (oz)**	**Mass (kg)**	**Velocity (m/s)**	**K.E. (Joules)**	**K.E. (ft-lbs)**
Fore	227.4	6.45	5.24	88.59	**65.34**
Altimeter Bay	3.25	0.09	5.24	1.27	**0.93**
Aft	226.26	6.41	5.24	88.15	**65.01**

***Table 6:** Kinetic Energy calculations*

4.3.4 – Drift Simulations

Drift simulations are performed to see how far the launch vehicle will drift in five different types of wind conditions that could be possible during a launch. The five different winds speeds that the drift will be calculated for are 0-mph, 5-mph, 10-mph, 15-mph, and 20-mph winds. Two different calculations were done, one was taken from the flight simulation software open rocket. The second calculation was done by hand which is described by equation # below.

$$Descent\ Time * Wind\ Speed = Drift \qquad\qquad Eq. 2$$

Using Excel and using the equation 2 the team was able to calculate the drift by hand. The drift calculations from Excel are compared to the drift calculations received from flight simulation data in OpenRocket. This is done because OpenRocket is not entirely correct when simulating drift, so there needs to be another method to calculate drift to ensure that the rocket stays within the drift radius outlined in the student launch handbook. The average descent time of the launch vehicle is 83.3 seconds, this number was taken from OpenRocket simulation data.

Wind Speed (miles per hour)	**Excel Calculations (ft)**	**OpenRocket Calculations (ft)**
0	0	8.5
5	598.86	500
10	1198.54	1100
15	1797.40	1700
20	2396.261	2450

***Table 7:** Drift calculations*

The table above shows that the rocket will theoretically stay within the 2,500-foot drift radius outlined in the student launch handbook. Getting the drift to be under 2,500-feet in 20-mph winds was a problem for the team during the beginning of the year. To resolve this problem a smaller drogue was chosen, and the main chute deployment was lowered to 750-feet.

There is a difference between the drift calculations, the calculations done in Excel are more precise. While the drift numbers from OpenRocket are taken from the graphs and are subject to rounding error. However, the difference between the two calculations is minor and both sets of data match up with each other.

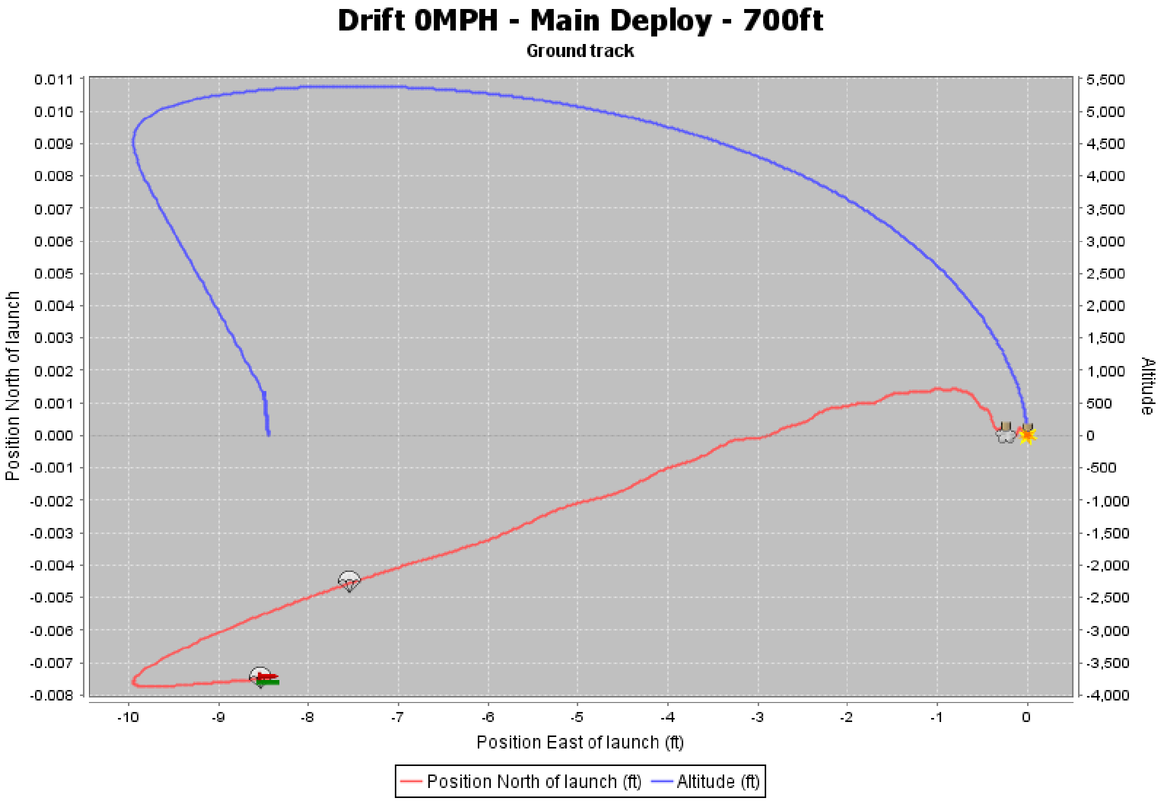


Figure 35: *Drift in 0 mph wind*

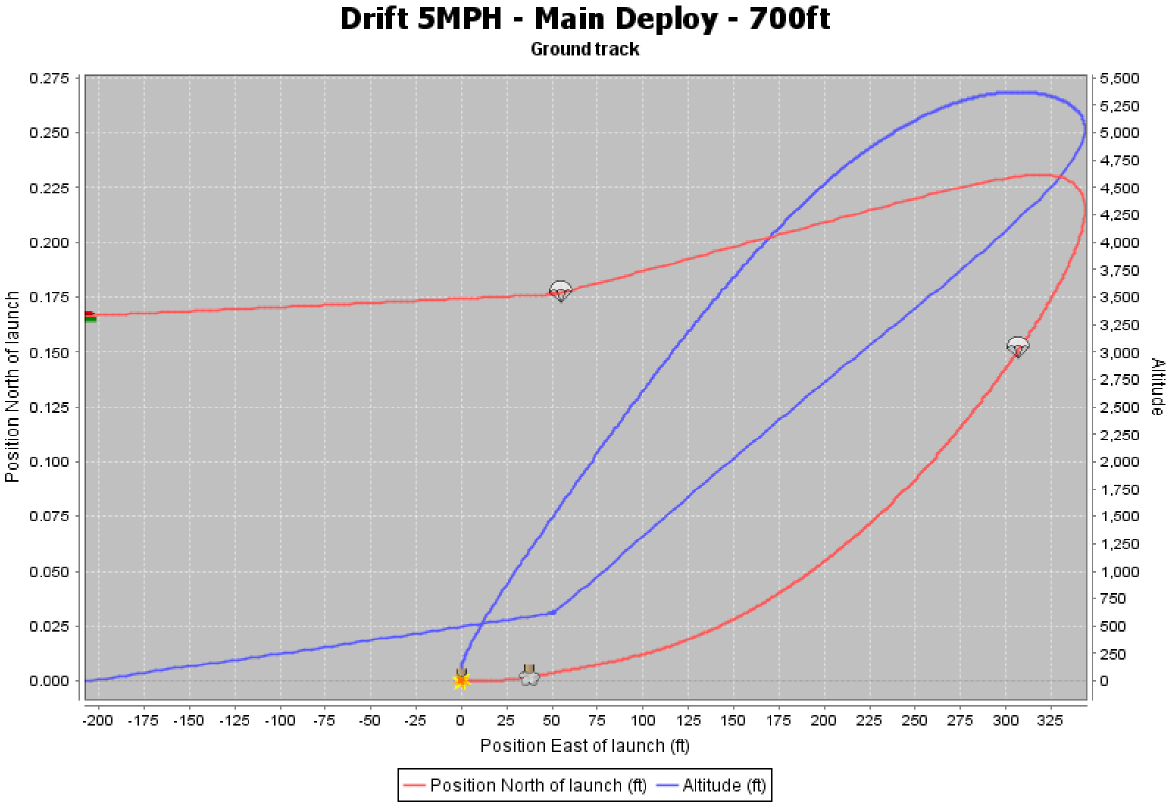


Figure 36: *Drift in 5 mph wind*

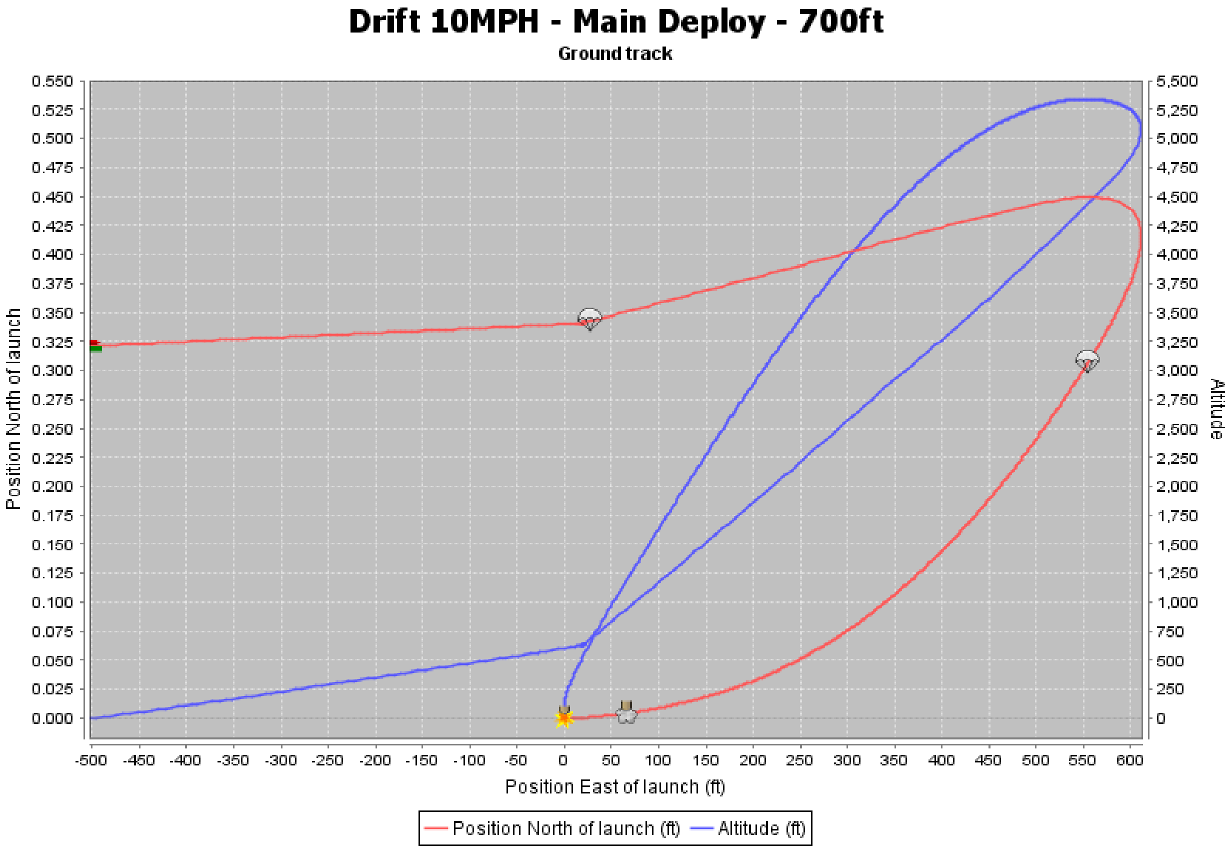


***Figure 37:** Drift in 10 mph wind*

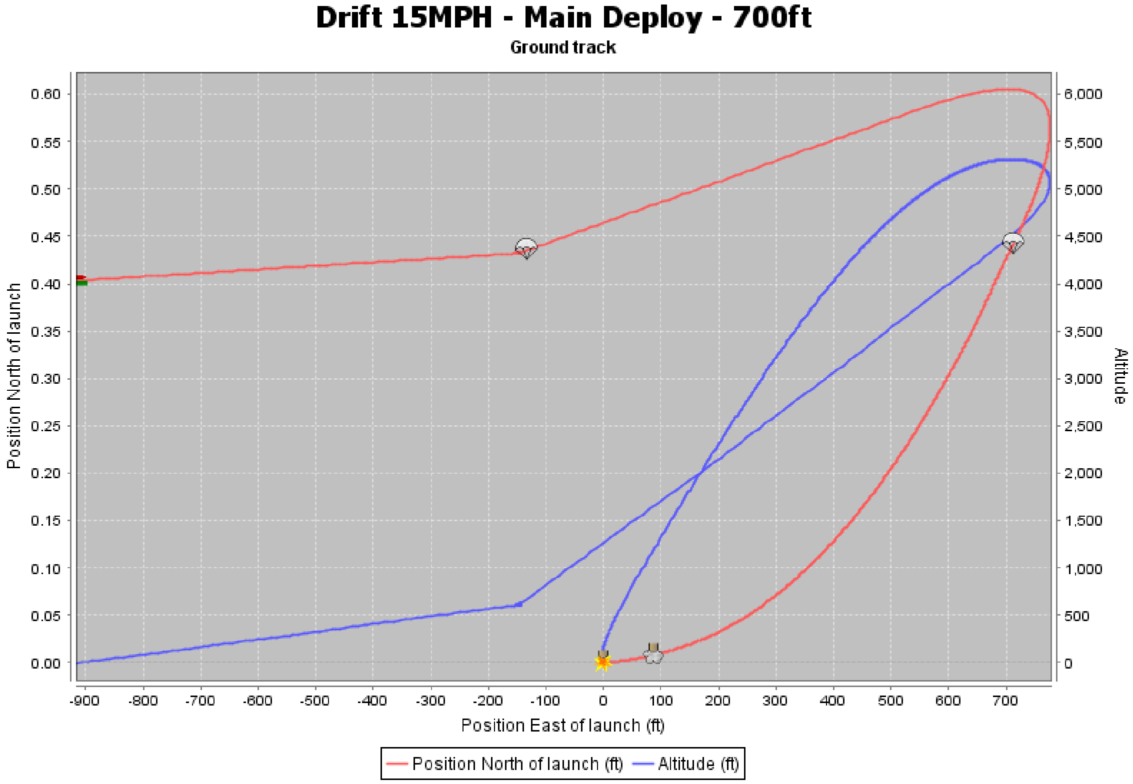


***Figure 38:** Drift in 15 mph wind*

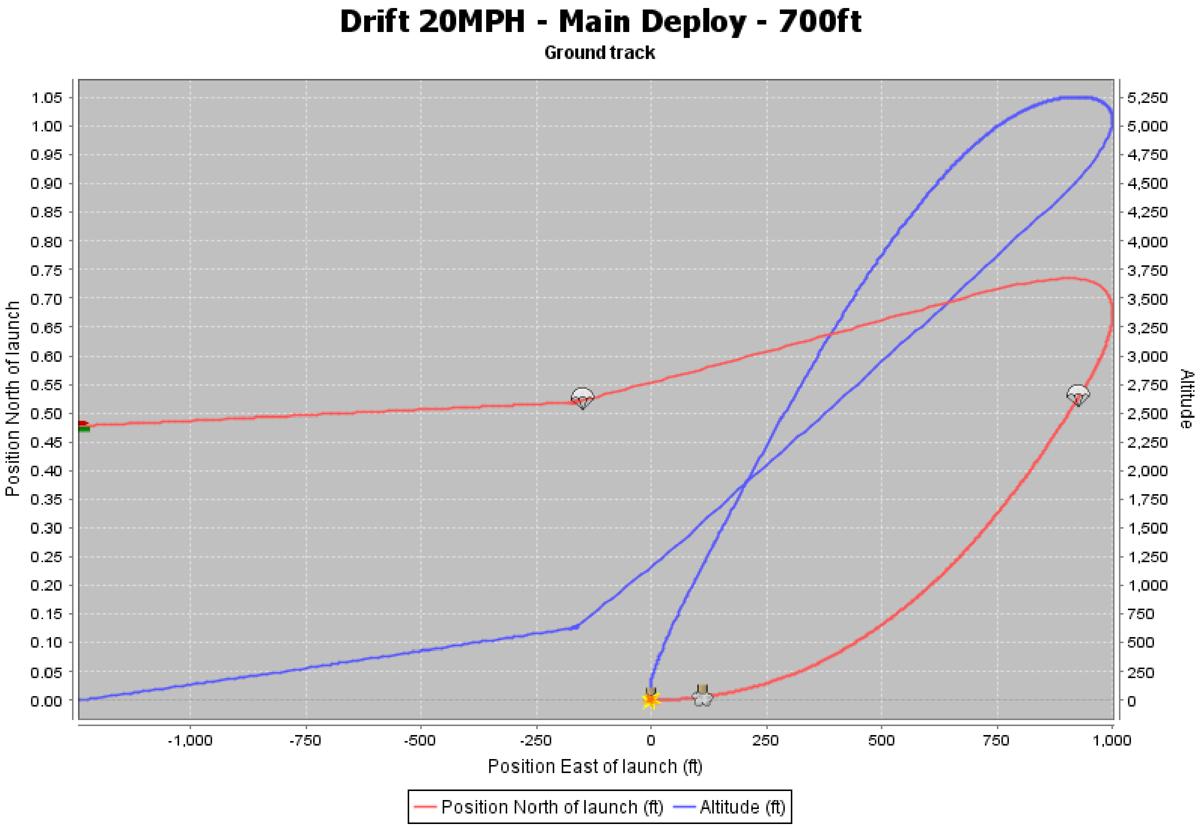


Figure 39: *Drift in 20 mph wind*

4.3.5 – Stability Margin

The stability of the rocket while it is on the rail is 2.49. While lifting off the stability increases as it climbs off the rail. When leaving the rail, the stability margin is 2.49 off the rail and increases to about 3.25 at motor burnout. It stays around 3.25 until the launch vehicle nears apogee and the recovery systems start deploying. The rail exit stability of 2.49 is above the required stability margin of 2. The rail exit velocity according to simulation data is an average of 78 ft/s. This shows that the rocket is stable while leaving the launch rail and will have a stable flight.

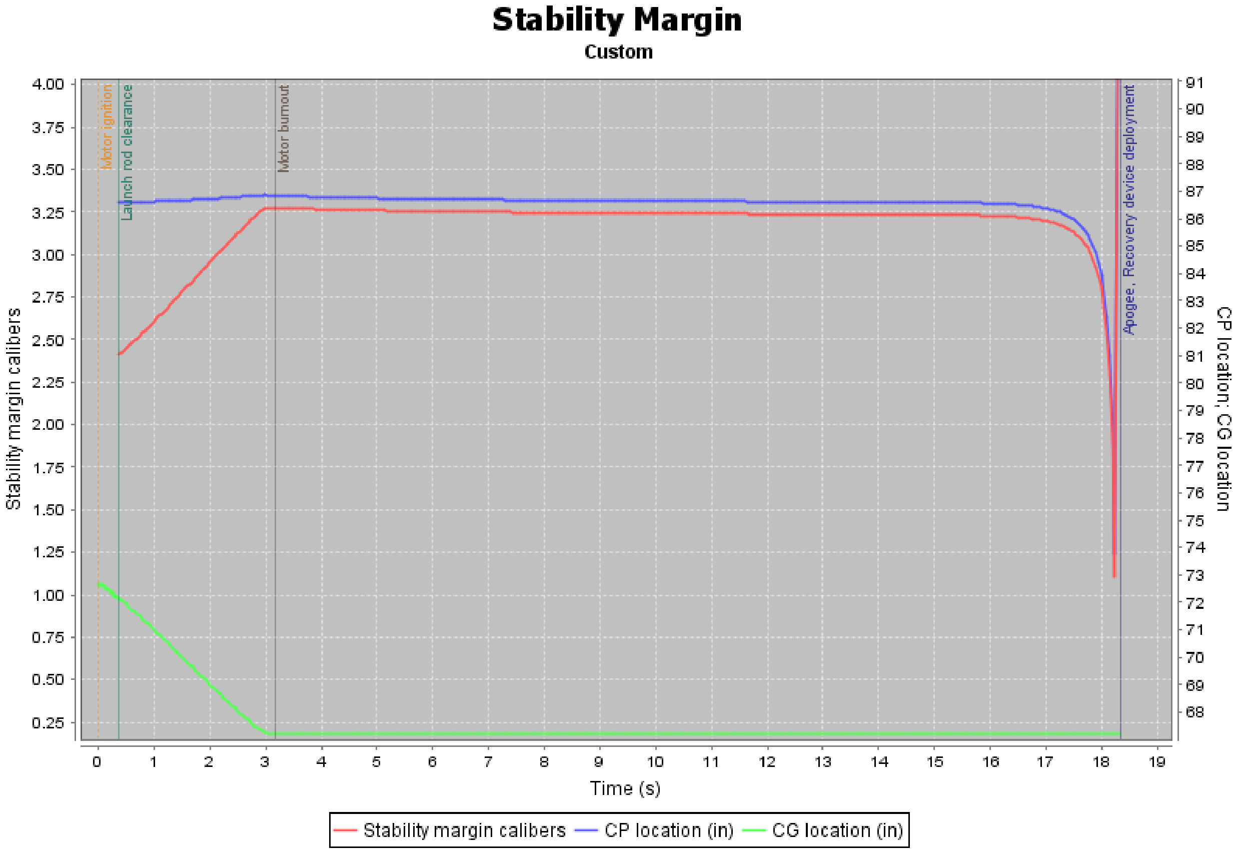


***Figure 40:** Stability margin*

4.3.6 – Mach Number

The Mach number for the launch vehicle in simulation is shown to be 0.60, which is 665 ft/s. This is under Mach 1, which the launch vehicle cannot exceed. The graph below compares Mach number with drag coefficients. The drag coefficients are friction, base, and pressure.

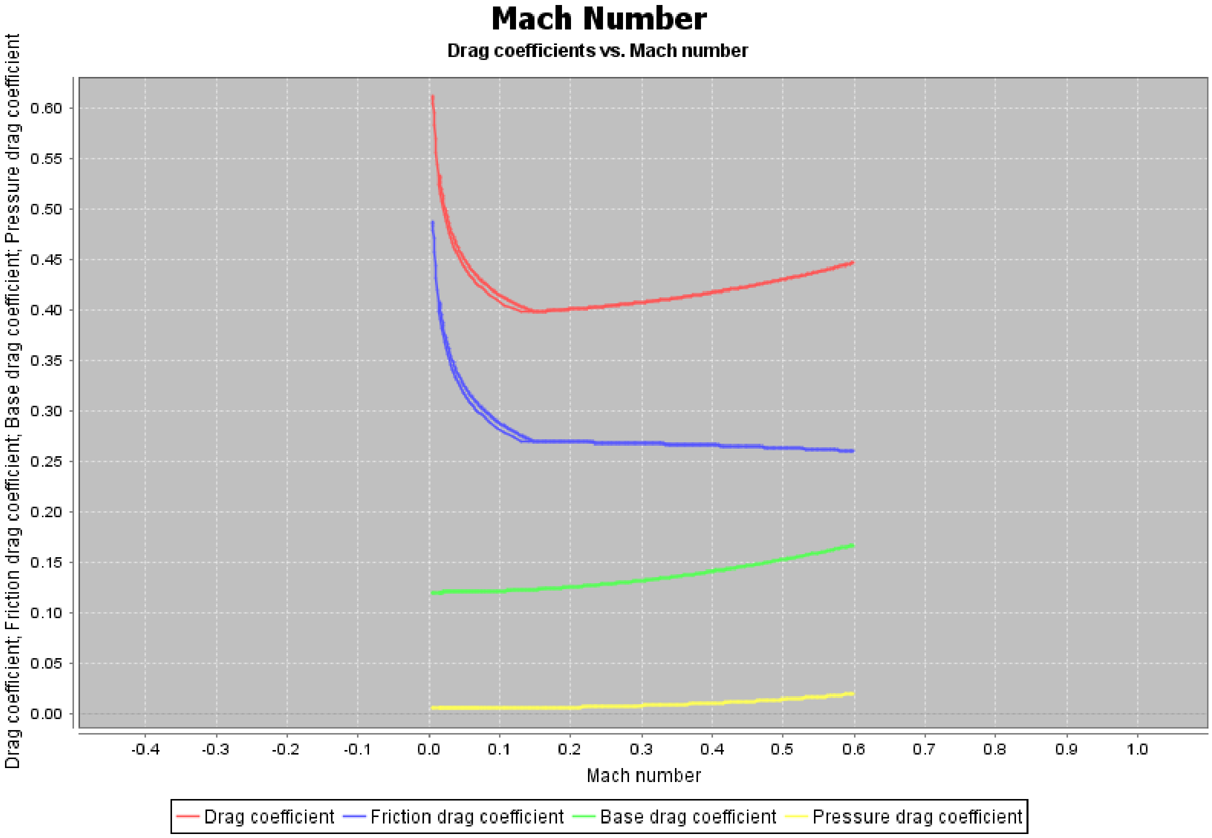


***Figure 41:** Drag coefficients vs Mach number*

4.4 – Full-Scale Test Flight

A full-scale flight of “Some Assembly Required” was completed on March 1st, 2018. It was unsuccessful. There was a rapid unscheduled disassembly (RUD) that happened during descent. The motor that was used on the first full-scale launch was the AeroTech L850W. There was no wind with gusts under 5-mph. The rocket was simulation showed that it would reach an apogee of 5,777 feet. The altimeter data showed otherwise.

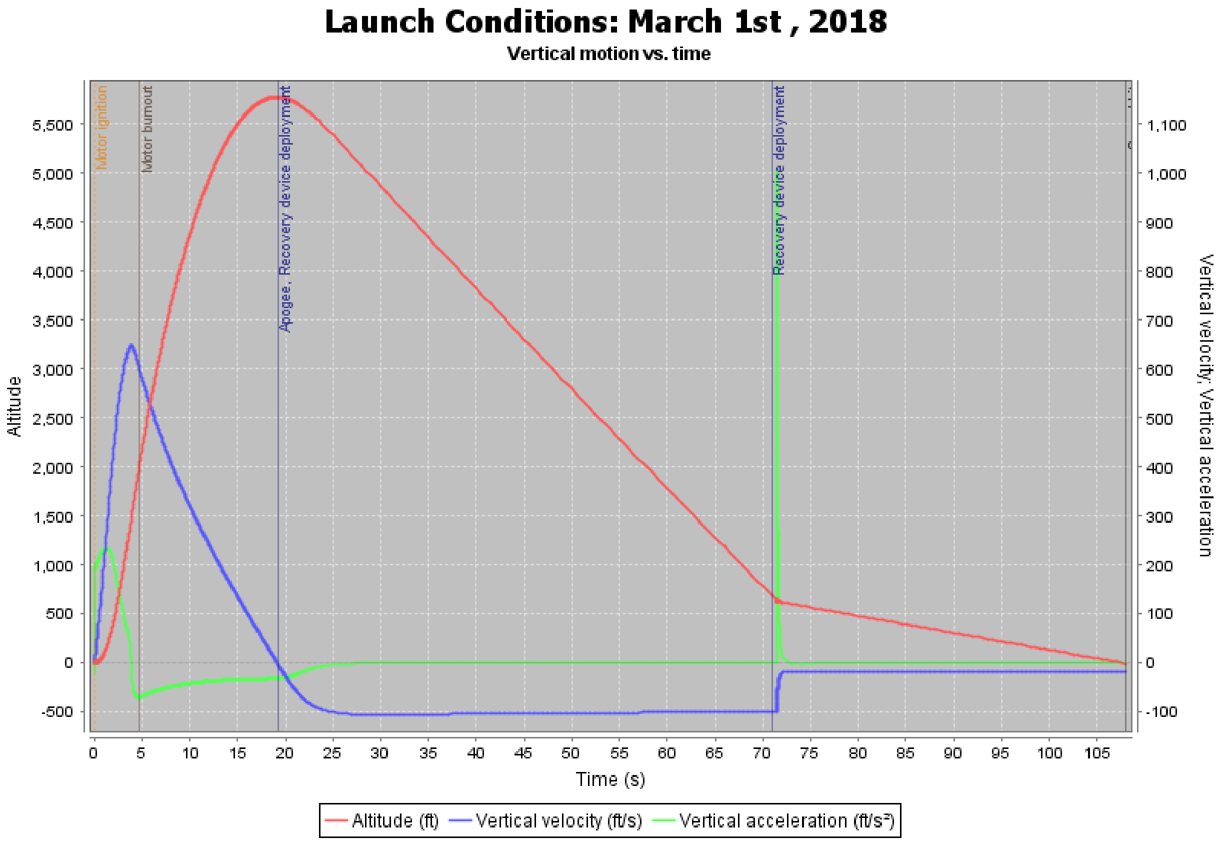


***Figure 42:** Simulation of flight in OpenRocket with 850W as motor used in launch*

Velocity off Road	71.2 ft/s
Apogee	5,777 ft
Max. Velocity	649 ft/s
Max. Acceleration	233 ft/s^2
Flight Time	108 seconds
Ground impact velocity	17.1 ft/s

***Table 8:** Table describing the data the simulation provided*

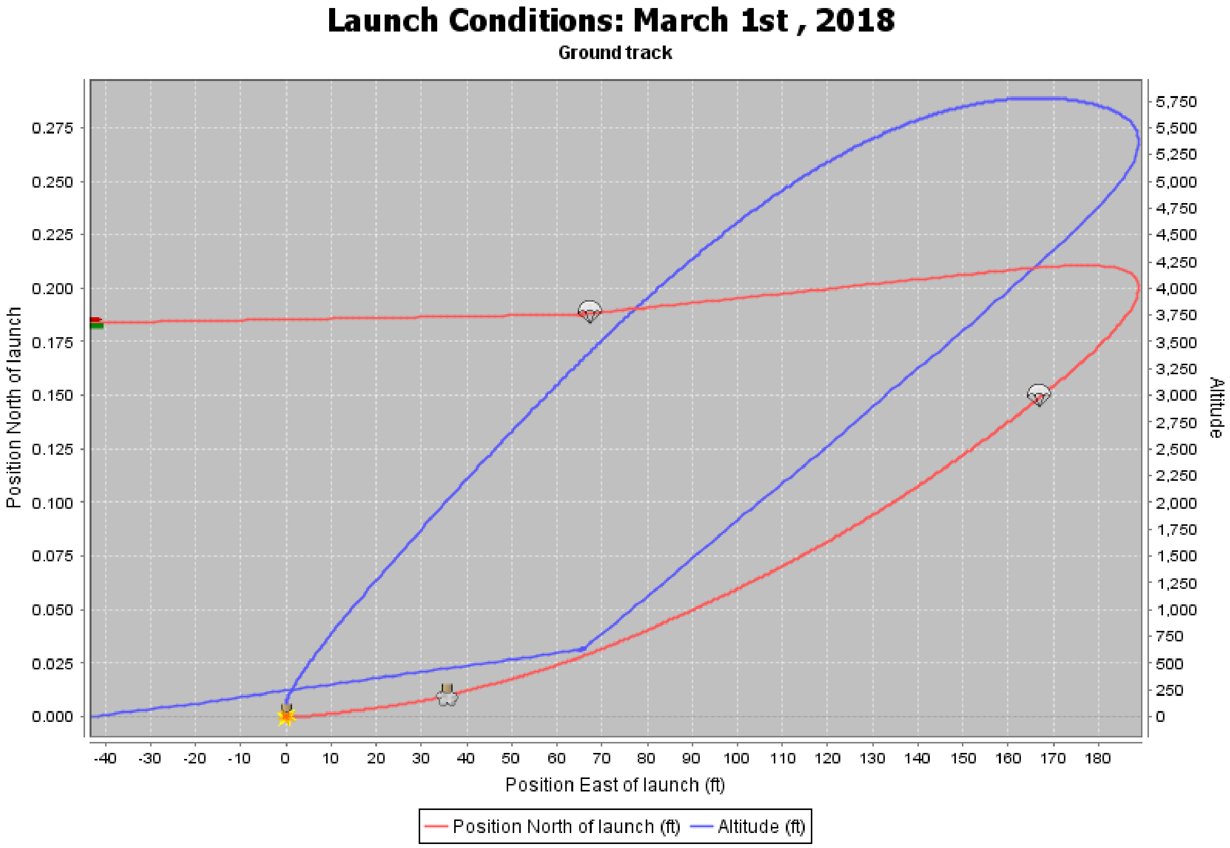


***Figure 43:** Drift of launch vehicle using L850W motor in 2 mph wind*

4.4.1 Full Scale Launch – Post-Flight Analysis

Upon analysis of the launch vehicle after flight it was determined that the carabiner that attaches the drogue air frame to the altimeter bay was not connected. The drogue airframe is attached to the avionics bay and fin can. These three sections only had the drogue parachute deployed when landing. The main parachute deployed with the altimeter bay, nosecone and rover deployment bay attached. This made a safe landing, and no structural damage to the air frame was done.

Figure 44: *Upper section landing configuration*

Upon review of the check list it was realized that a step in the launch procedure had been skipped when assembling the rocket at the launch site. However, there was minimal damage to the fin can. Some epoxy adhering the fin can airframe to the body tube had broken off, and a small part of the out airframe had cosmetic damage. The impact energy the fin can absorbed was 1,378 ft/lbs, the velocity the fin can impacted the ground was 68.9 ft/s. The figures below will show a visual representation of the damage that was done.

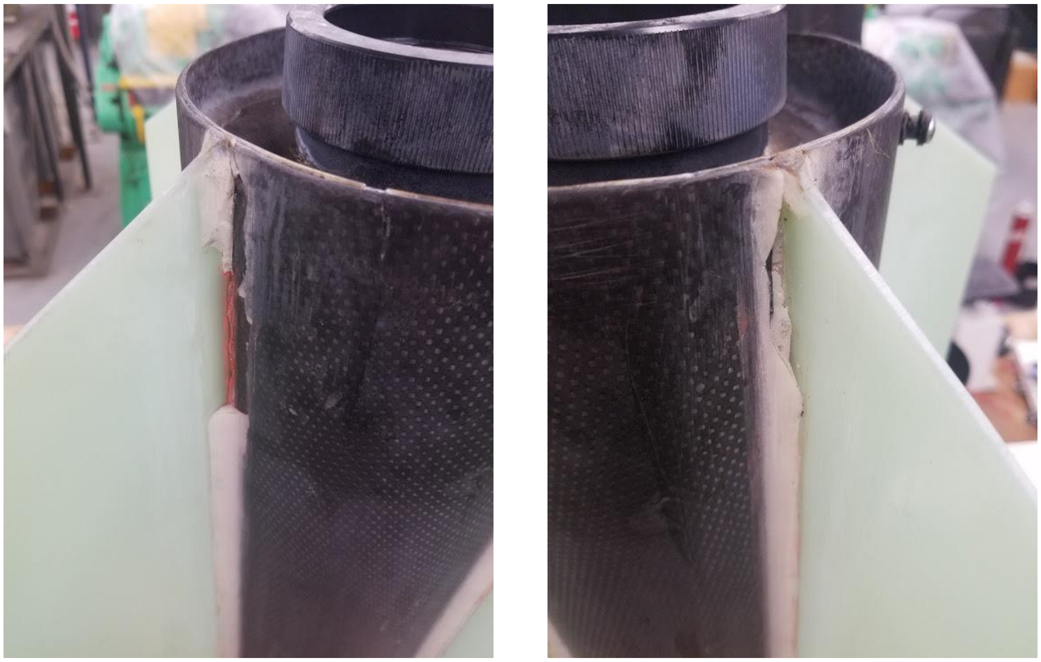


***Figure 45:** Damage on the epoxy adhering the fins to the airframe*

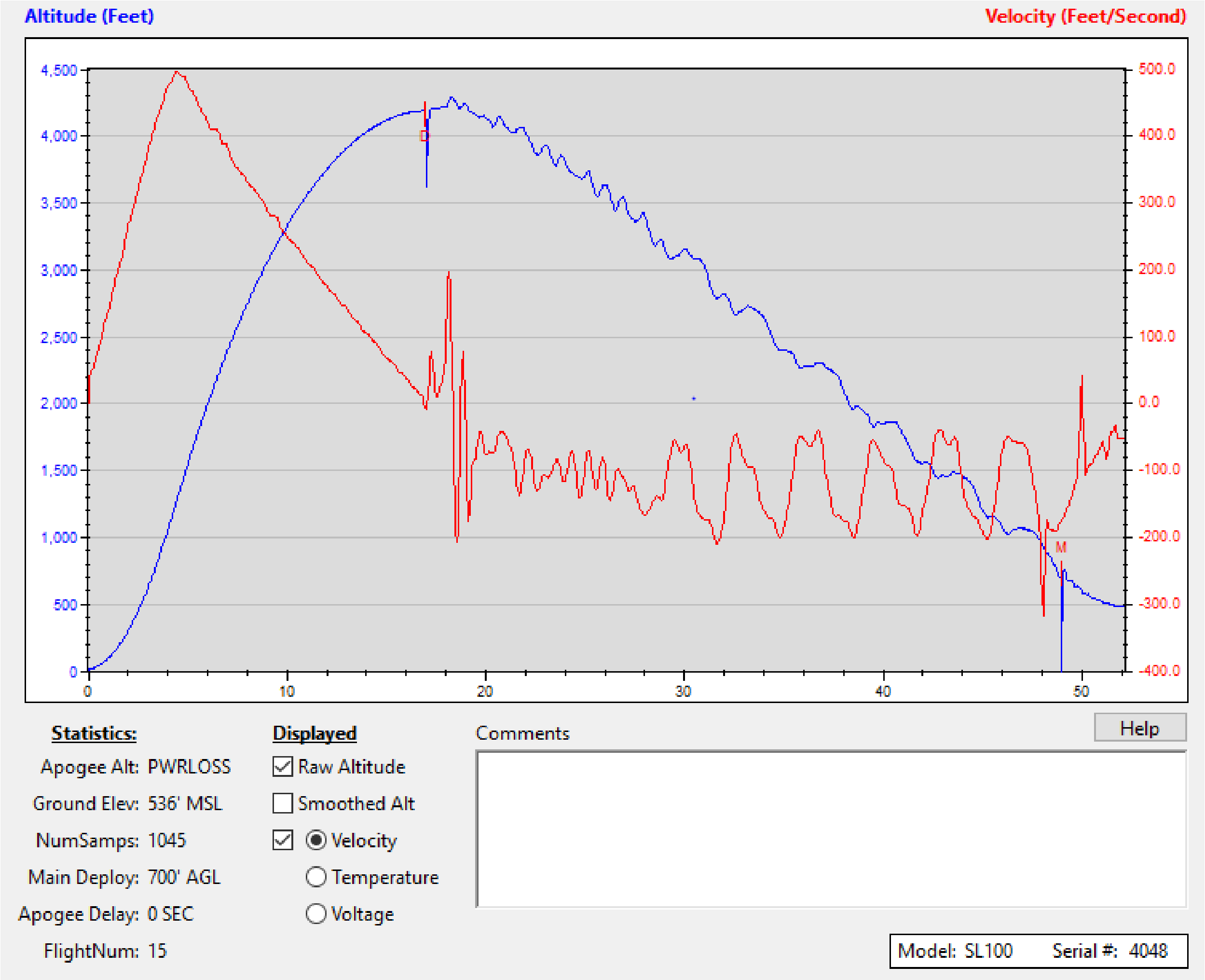
***Figure 46:** Airframe damage it was very minimal*

4.4.1.1 Post Flight Analysis – Altimeter Data

The launch vehicle flew with two flight computers on board. The primary flight computer experienced power loss at apogee and could not record the altitude, however it recovered an was able to deploy the main when it reached 700ft. The secondary altimeter was able to record apogee and deploy the drogue parachute after its delay. There are spikes in the data, those spikes represent the pressure drops when the black powder charges ignite. This means that the altimeter bay was not fully sealed.

The recorded apogee was 4,271 feet, which is over 1000 feet short of the simulation data which predicted the launch vehicle would reach an altitude of 5,777 feet. The motor that was used was a 10-year-old AeroTech L850W.

It is believed that the age of the motor may have impacted the overall apogee. While on the launch pad the motor experienced chuffing. Chuffing is when the engine emits smoke and attempts to ignite but does not fully ignite. There were three chuffs before the motor fully lit and the rocket started to lift off the launch rail. However, chuffing is not supposed to affect the motors performance. The consensus after debate was that the launch vehicle was heavier than what was recorded in the simulation.



Statistics:

Apogee Alt: PWRLOSS
Ground Elev: 536' MSL
NumSamps: 1045
Main Deploy: 700' AGL
Apogee Delay: 0 SEC
FlightNum: 15

Displayed

☑ Raw Altitude
☐ Smoothed Alt
☑ ● Velocity
○ Temperature
○ Voltage

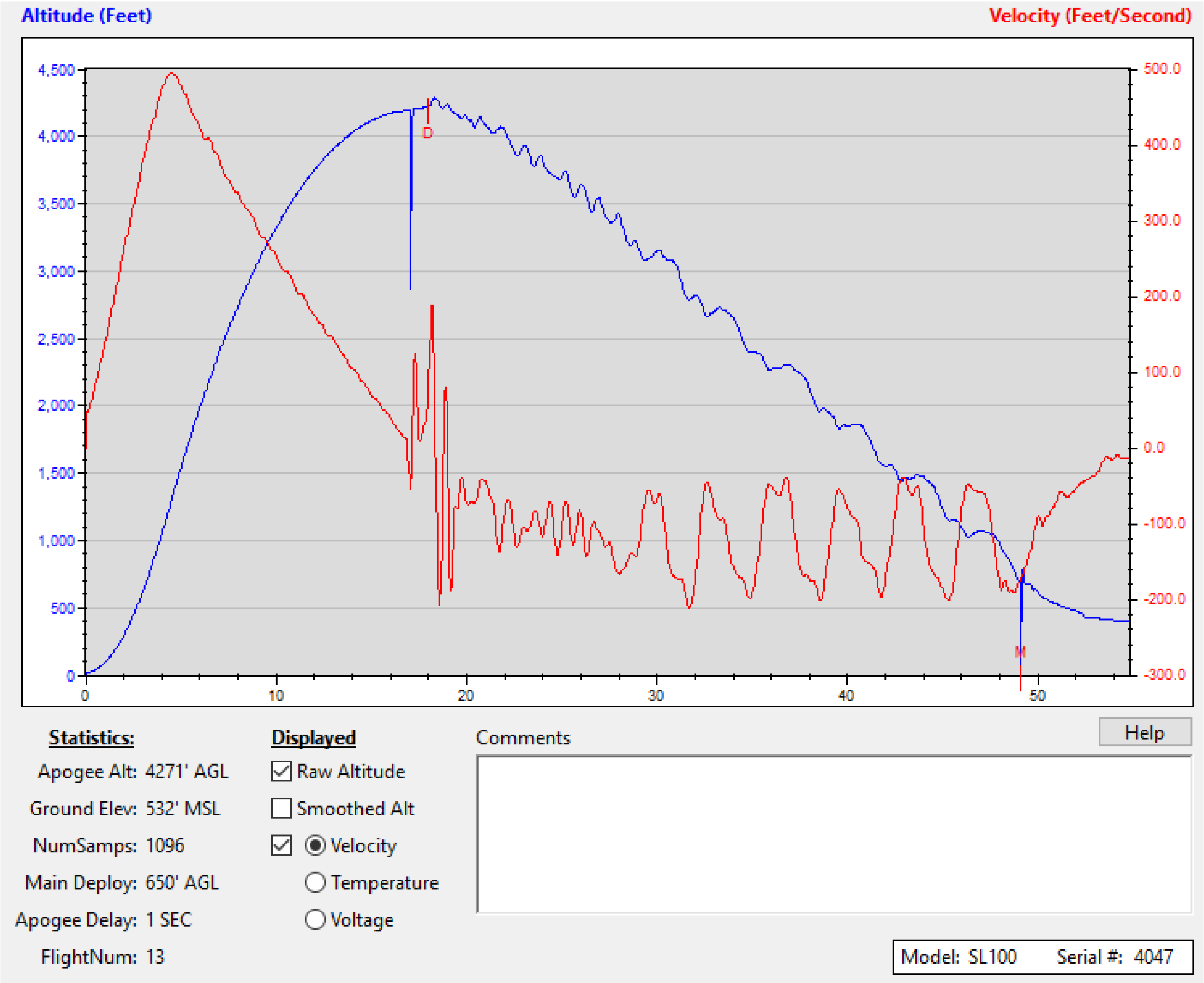
Comments

Model: SL100 Serial #: 4048

Figure 47: *Primary flight computer data. Notice at apogee altitude there was a power loss*

After inspecting the altimeter bay, it was found that the negative lead from the nine-volt battery that powers the primary altimeter had broken and lost connection with is terminal. This was due to the forces experienced during flight. The secondary flight computer performed nominally and did not experience a power loss. Both flight computers ignited their respective charges. It is not known how the primary flight computer regained power.

There will be changes in the design of the altimeter bay. These changes will not affect the external airframe of the launch vehicle, the changes will be more focused on sealing the altimeter bay properly. The team will experiment with rubber O-Rings and silicon. They will be placed in the observed gaps that the team decides could be letting air through. It is expected that using these materials will help seal the gaps and ensure that the altimeters are not affected by the pressure spikes experienced when the black powder charges are ignited.



Statistics:

Apogee Alt: 4271' AGL
Ground Elev: 532' MSL
NumSamps: 1096
Main Deploy: 650' AGL
Apogee Delay: 1 SEC
FlightNum: 13

Displayed

☑ Raw Altitude
☐ Smoothed Alt
☑ ● Velocity
○ Temperature
○ Voltage

Model: SL100 Serial #: 4047

Figure 48: *Secondary flight computer, shows apogee of launch vehicle to be 4,271 feet AG*

The first attempt at a full-scale launch was unsuccessful because the rocket performance did not meet the criteria for a successful launch. A second attempt will be requested in order to ensure that the launch vehicle is flight ready and can be flown on launch day. Repairs are being conducted to prep the launch vehicle for a second flight. The motor used in the second flight will be the motor used on launch day down in Huntsville, Alabama which is the AeroTech L1150.

5 - Payload Criteria

5.1 – Experimental Payload Design

For this NASA competition, an experimental payload was proposed for the teams. This experimental payload was to construct of a Robotic Rover(RR). The requirements for the rover was after landing, the rover would be deployed from the launch vehicle and drive autonomsly for at least 5 feet. Upon driving 5 feet the rover would stop and deploy a set of foldable solar panels. The experimental payload team has been working on development of the rover and all the preliminary concept, design and tests until today are following in this document.

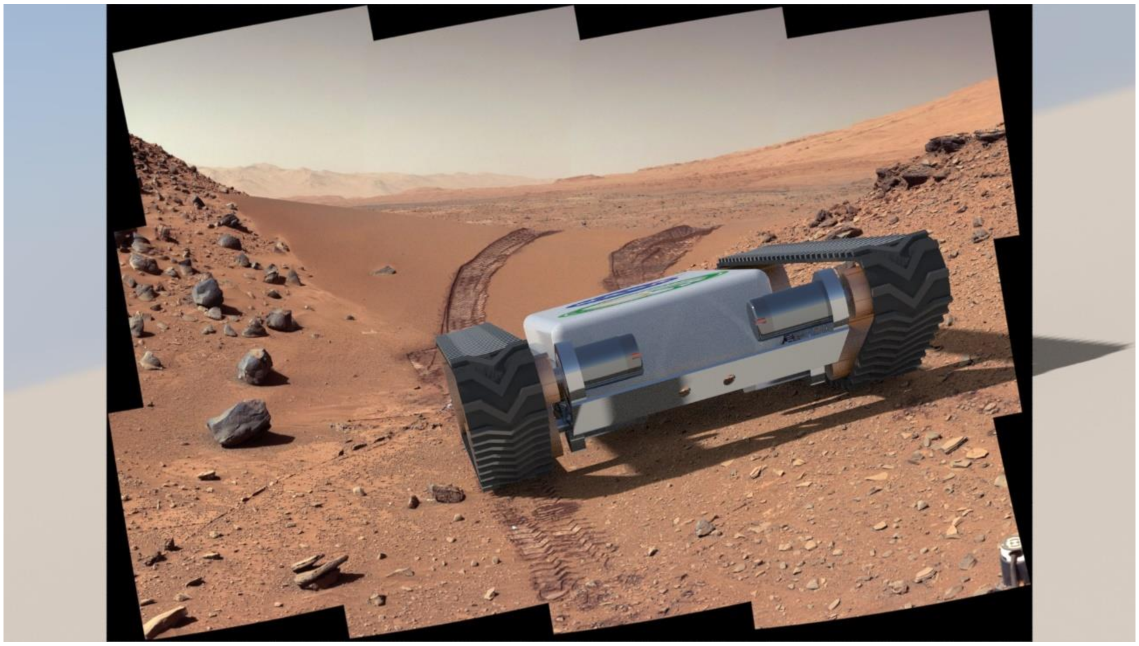


Figure 49: *3D render of Frozen Fury Rover on Martian surface*

5.1.1 Experimental Payload – Changes Made

These changes include using one S3154 Fubata servo and removing the accelerometer from the rover. The decision to remove the second servo from the design because it would decrease the overall weight of the rover and proved itself to be unnecessary to the overall design of deploying the solar panels. The experimental payload team was able to design a part that would allow them to deploy the solar panels with one servo and fit perfectly within their design. They eliminated the accelerometer from their design because the Raspberry Pi onboard the rover will be able to control the rover using a set of time derived from testing. Therefore, the Pi will not need the assistance from the accelerometer, and this will also decrease the weight of the rover.

5.1.2 Experimental Payload – Structural Elements of Rover

The rover is the first component of our design that will be reviewed. The white bodied rover is the prototype rover and is 3D printed using a MakerBot Replicator 2. The Replicator 2 prints PLA plastic. After the rover has gone through all the testing needed, and the final design is set the chassis, body panels, and axles for the rover will be printed of a FormLab printer. The resin that will be used to print the final rover is Tough Resin and needs to be cured under UV light and at a temperature of 160F. The treads of for the rover are standard Lego tank treads, along with the wheels on which the treads ride upon. Structural component is made in house, other than the treads.

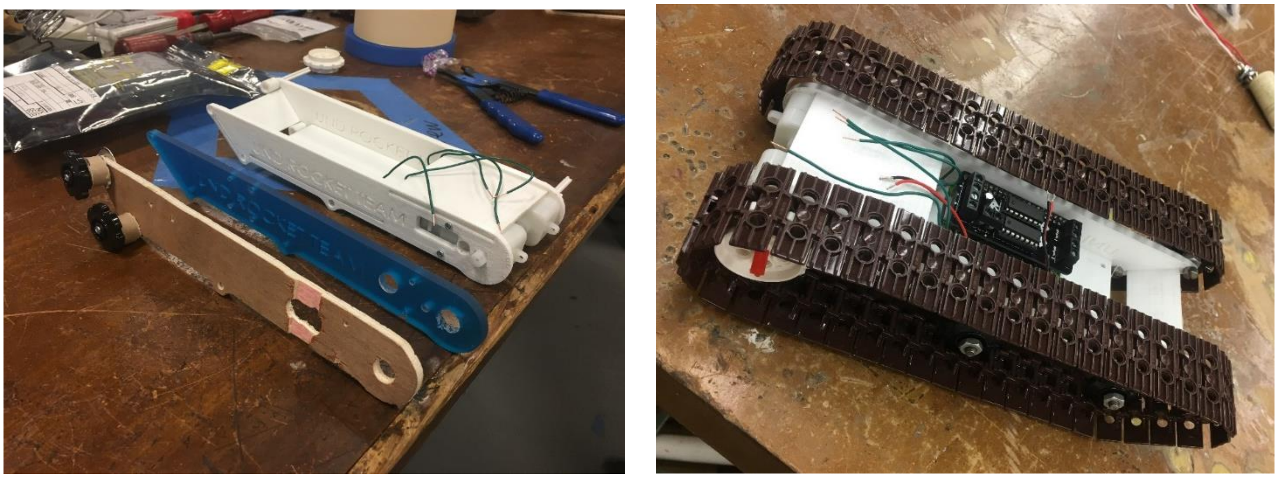


Figure 50: *Rover side rails (left), 3^{rd} rover prototype (right)*

5.1.3 Experimental Payload – Electrical Elements of Rover

The rover will be controlled by the Raspberry PI ZeroW. The PI will be tasked with controlling the motors and making sure the rover will drive five feet. The W at the end of the Zero the Raspberry-Pi means that is wireless which allows the team to view voltage and wattage readings real time wirelessly. Stacked on the Raspberry-Pi Zero there is a motor controller. The motor controller is the MotoZero and allows the PI to control the two electric DC motors.

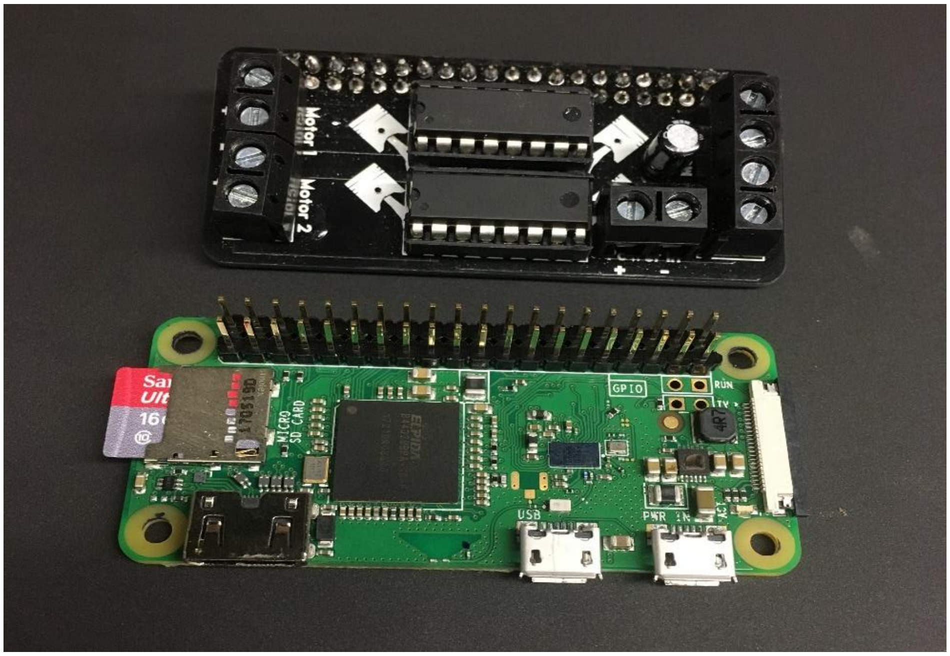


***Figure 51:** MotoZero DC motor controller (black), Raspberry Pi ZeroW (green)*

The two electric motors are two 224:1 geared DC (direct current) motors 90-degree shaft motors. The 90-degree output shaft allows for easy integration of the DC motor into the embedded systems bay. The servo is a S3154 Futaba servo. It has a stall torque of 20.8 oz/in which is within the safety margin for the torque necessary to deploy the solar panels.

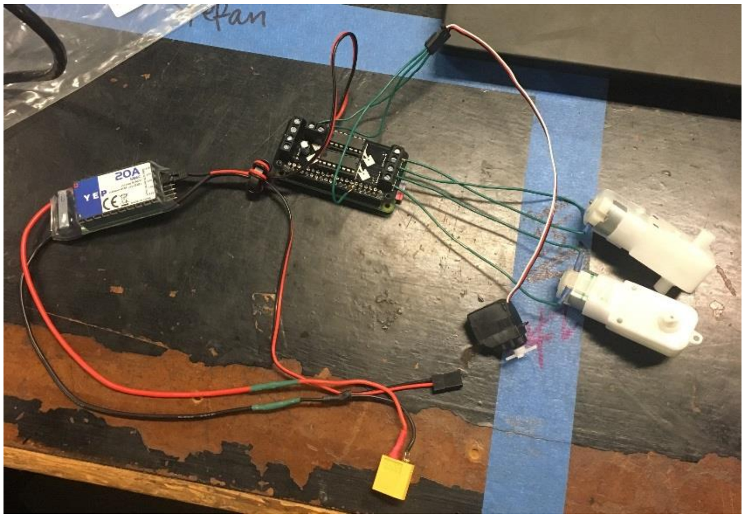


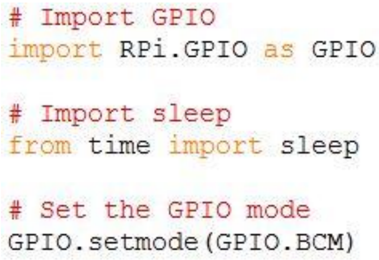
***Figure 52:** DC motors connected to MotoZero*

The solar panels are mini solar panels that weigh 0.32 oz. (ounces) each. They attach to the servo control horn. The method of attachment is using a 3D printed design that unfolds and will be screwed to the servo horn.

Powering the entire system is two 3.7V 1100mAh LiPo batteries. With the two batteries, the total voltage will sum to 7.4V. To step the voltage down to the necessary 5V the team is using a voltage regulator.

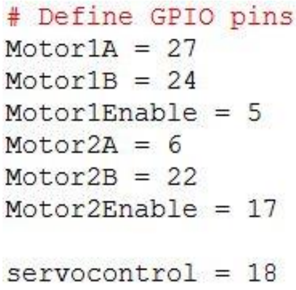
Figure 53: *Turnigy voltage regulator*

The Raspberry Pi ZeroW has been programmed using Python coding. The code will tell the rover to rotate out of the rocket, drive away from the rocket 5 feet, and engage the servo to deploy the solar panels.



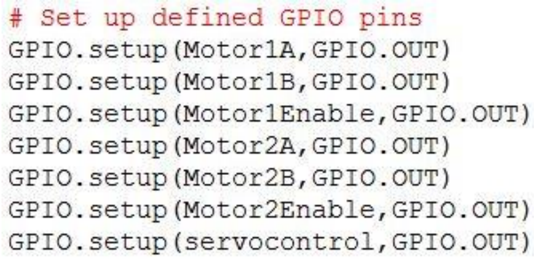
```
# Import GPIO
import RPi.GPIO as GPIO

# Import sleep
from time import sleep

# Set the GPIO mode
GPIO.setmode(GPIO.BCM)
```

In the beginning of the code for the rover we first added the GPIO library to the Python code by importing the GPIO pins. After that, time and sleep is imported into the code. Since there are two types of GPIO pins on the Raspberry Pi Zero (GPIO.Board, GPIO.BCM), the team had to choose the type of pins they wanted to use. The rover team declared GPIO.BCM for their pin numbers and the last line of code defines this.



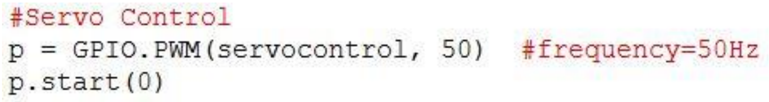
```
# Define GPIO pins
Motor1A = 27
Motor1B = 24
Motor1Enable = 5
Motor2A = 6
Motor2B = 22
Motor2Enable = 17

servocontrol = 18
```

For the second part of the rover's code, the team defines the GPIO pins that control the two motors and servo. Motor1A is set to pin 27 which is a negative terminal. Motor1B is set to pin 24 which is a positive terminal. Motor1Enable is set to pin 5 which controls when Motor1 turns on and off. Motor2A is set to pin 6 which is a negative terminal. Motor2B is set to pin 22 which is a positive terminal. Motor2Enable is set to pin 17 which controls when Motor2 turns on off. The servocontrol is set to pin 18. The servo will be directly wired to power. In order to activate the servo, pin 18 will send a signal when to move the servo arm. By defining the pins, the team is able to use the labels in the rest of their code to make it more streamlined



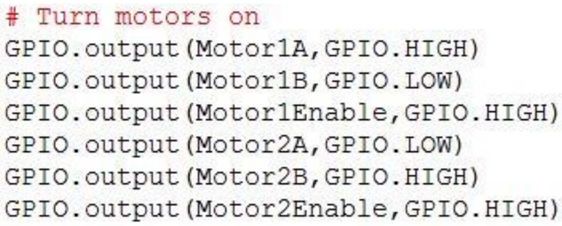
```
# Set up defined GPIO pins
GPIO.setup(Motor1A,GPIO.OUT)
GPIO.setup(Motor1B,GPIO.OUT)
GPIO.setup(Motor1Enable,GPIO.OUT)
GPIO.setup(Motor2A,GPIO.OUT)
GPIO.setup(Motor2B,GPIO.OUT)
GPIO.setup(Motor2Enable,GPIO.OUT)
GPIO.setup(servocontrol,GPIO.OUT)
```

Since each GPIO pin is set to its correct label, Through the code it is shown that each pin will be an output. This means that each pin for both motors and the servo are output pins and send signals from the PI to the motor controller and servo.



```
#Servo Control
p = GPIO.PWM(servocontrol, 50)  #frequency=50Hz
p.start(0)
```

For the servo control, the team utilized GPIO.PWM (pulse width modulation) to declare the channel and frequency. The channel is servocontrol and the frequency is 50hz (hertz). Pulse width modulation is a technique for getting analog results with digital means. The digital control is used to create a square wave to signal on and off.



```
# Turn motors on
GPIO.output(Motor1A,GPIO.HIGH)
GPIO.output(Motor1B,GPIO.LOW)
GPIO.output(Motor1Enable,GPIO.HIGH)
GPIO.output(Motor2A,GPIO.LOW)
GPIO.output(Motor2B,GPIO.HIGH)
GPIO.output(Motor2Enable,GPIO.HIGH)
```

5.1.4 Experimental Payload - Rover Construction

The rover team developed a few concepts of a tank style rover capable of navigating terrain similar to that at the launch site down in Huntsville. There were two concept ideas that the team discussed. The second concept drawing of the rover won based on extensive trade studies conducted during the early stages of the competition.

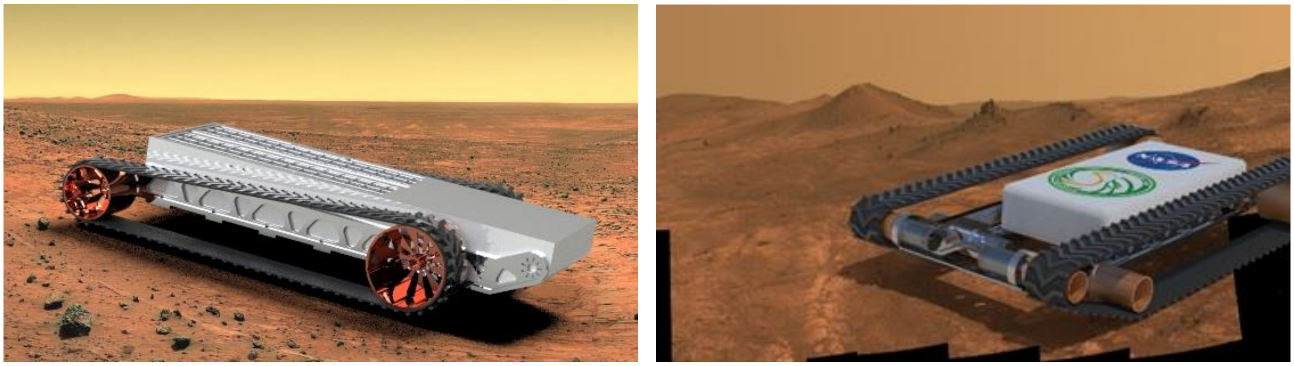


Figure 54: *Concept 1 (left) Concept 2 (right)*

5.1.4.1 Rover Concept– Prototyping and Testing

After the rover design was chosen the rover team had to work with the rover deployment designers and rocket integration team to size the rover correctly so that it would be able to fit inside the rocket. The teams had to figure out the size of the rover that would work within the confines of the airframe and limitations of the rover deployment system. It was decided that the rover would exit from the nosecone.

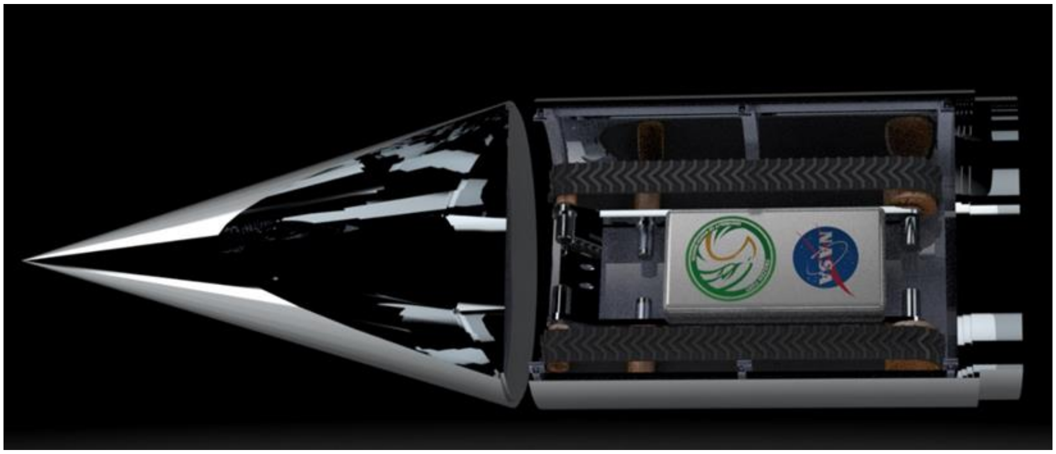


Figure 55: *Concept of rover inside launch vehicle*

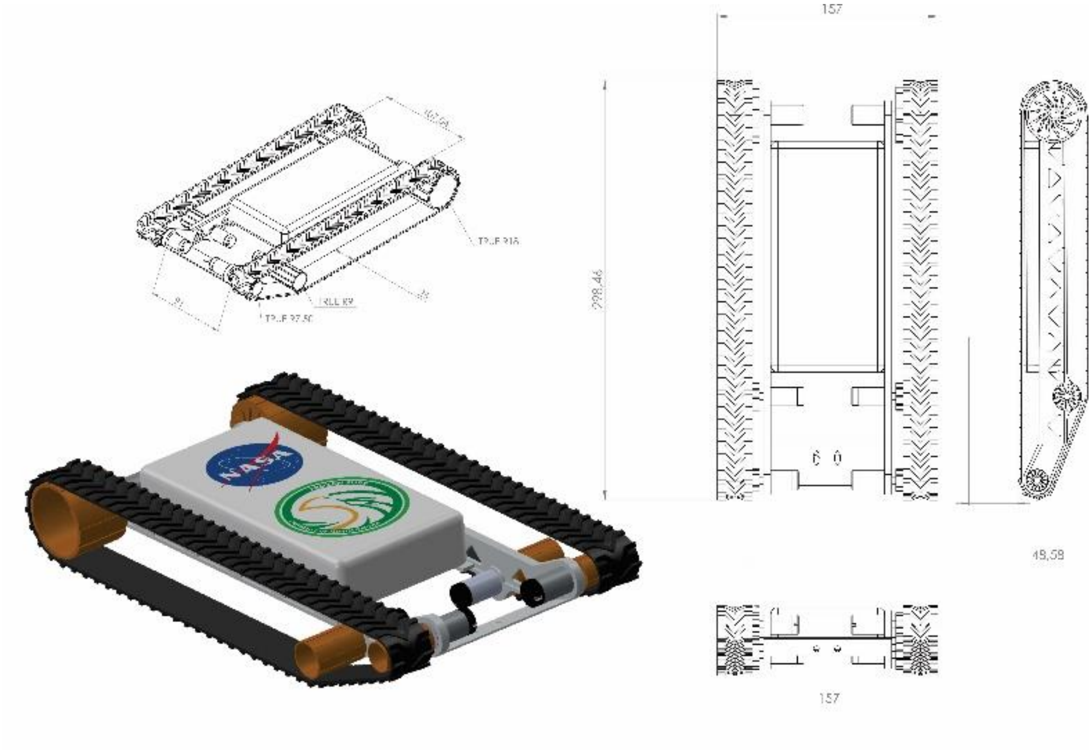


***Figure 56:** Rover Schematics*

For prototyping the rover team chose to create various models to prove the concept. The prototype models would allow the team to conduct necessary tests to see how well the idea works and see if changes to the original idea need to be made. In the concept designs the team wanted to create their own rubber tracks but due to fabrication and funding issues the team decided to go with the Lego technic mobility tracks. This was more feasible than the manufacturing and design of the rubber treads.

***Figure 57:** Wood mockup of rover*

Three rover mockups were made in real scale. The first rover model was constructed out of wood and was used to test the dimensions of the rover inside the Rover Deployment System (RDS). The first prototype was built out of wood, so the team did not waste plastic that was used for the printers. Upon completion of the wood mockup of the rover it was test fitted inside the coupler in which it would sit during flight. The fit was successful, and the rover length and width measurement had been set.

Figure 58: *Rover inside Rover Deployment System coupler*

The next progression in the construction process of the autonomous rover was to 3D print the rails of the rover. The dimensions for the length of the rails had been set during the test of the wooden mockup. The integration of some of the wooden components, such as the base plate, were used when creating the second mockup. This was done to see how well the FormLabs resin performed during construction. It performed how the team expected, it was able to be drilled into multiple times and not crack. Along with being able to support the 2 electric motors that will drive the rover.

The conclusion from building the model was the rover would be lighter than expected and the rover body would not dissemble during flight. The decision to make the entire chassis out of the FormLabs Resin for the final model was made as well.

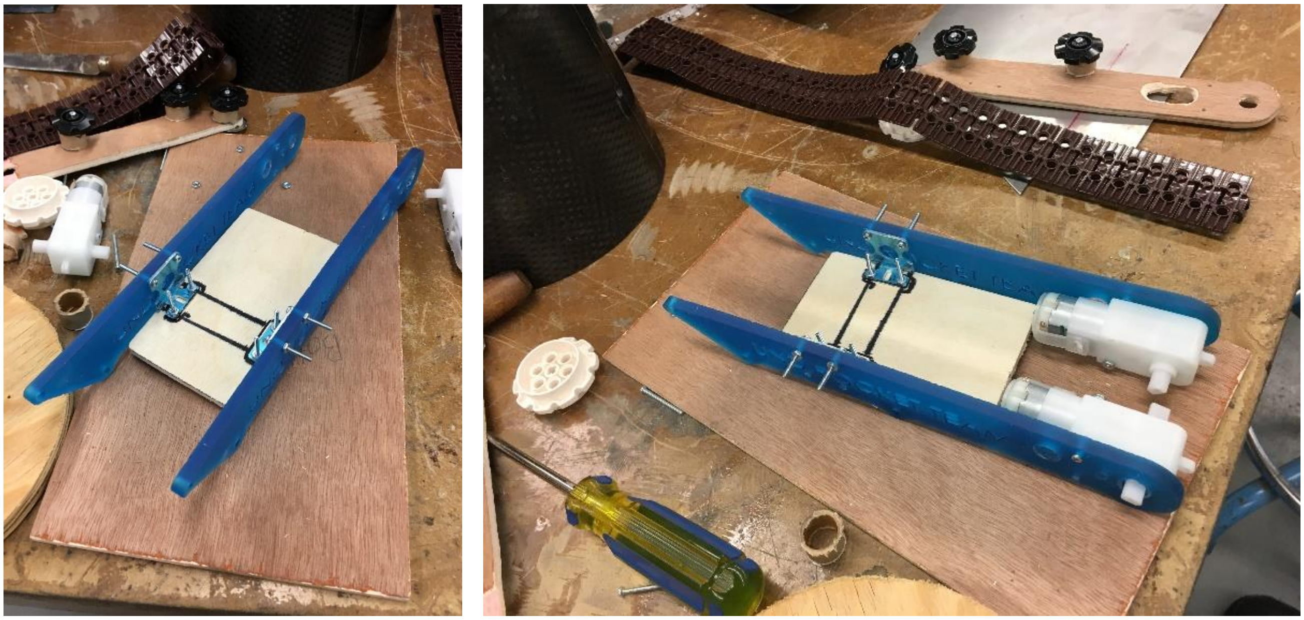


Figure 59: *Second prototype of autonomous rover*

The third model that was made is the current model that is being put through testing. This model focused on integrating everything into the rover. This means putting all the embedded systems within the embedded systems bay and testing to see if everything can fit. The model was made using PLA plastic and printed on a MakerBot Replicator 2. The PLA plastic is weaker than the FormLabs Tough Resin but it is cheaper and faster to print which allows for fast prototyping during the testing phase of the project.

Figure 60: *MakerBot rover, third prototype of autonomous rover*

This model was important for the rover development team because they started to run the electronics inside the rover for the first time. The rover was tested in a test bed that resembles that of the terrain that the rover will traverse. The terrain was given the name Alabama Simulated Terrain (AST). It is an 8’x8’ sand box.

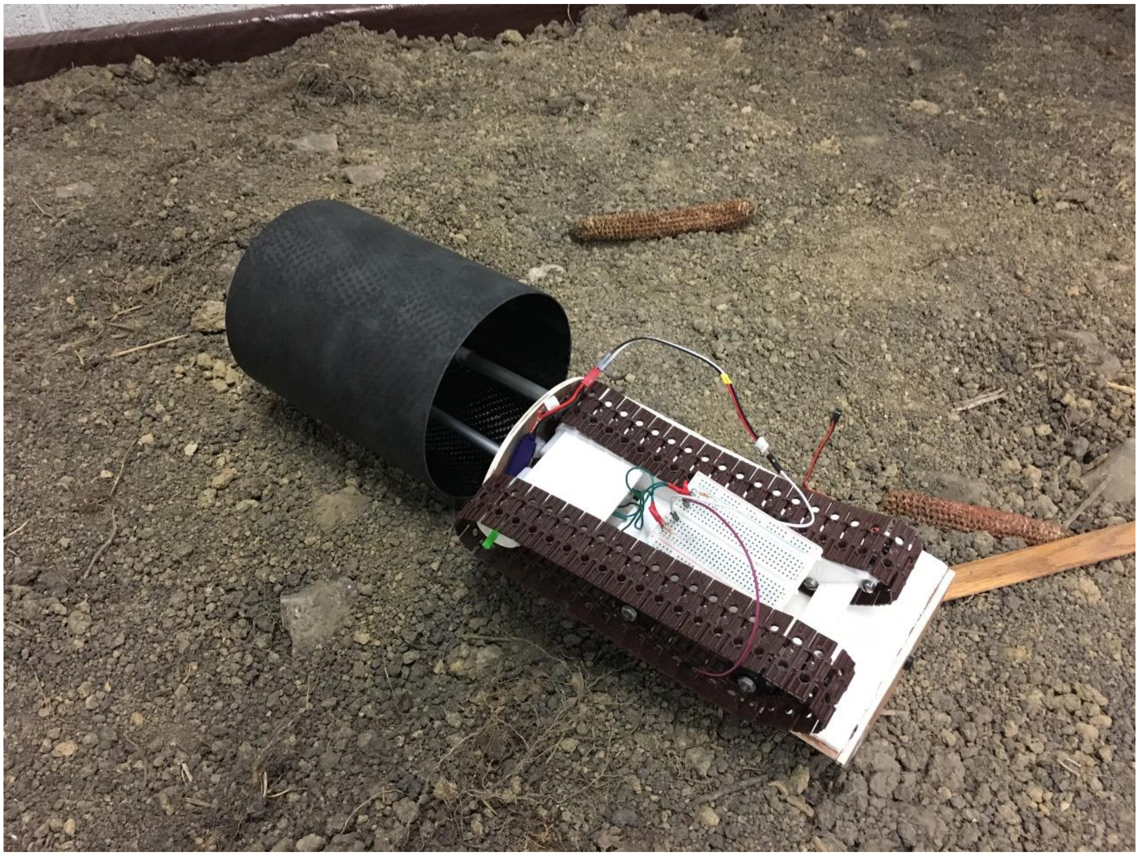


Figure 61: *Testing the rover in the AST environment*

The final model of the rover is now being manufactured. The team is able to create a 3D model of the final rover with the correct dimensions and specifications that were realized during testing and manufacturing of the previous rover models. The final model will incorporate the integration of the solar array deployment system.

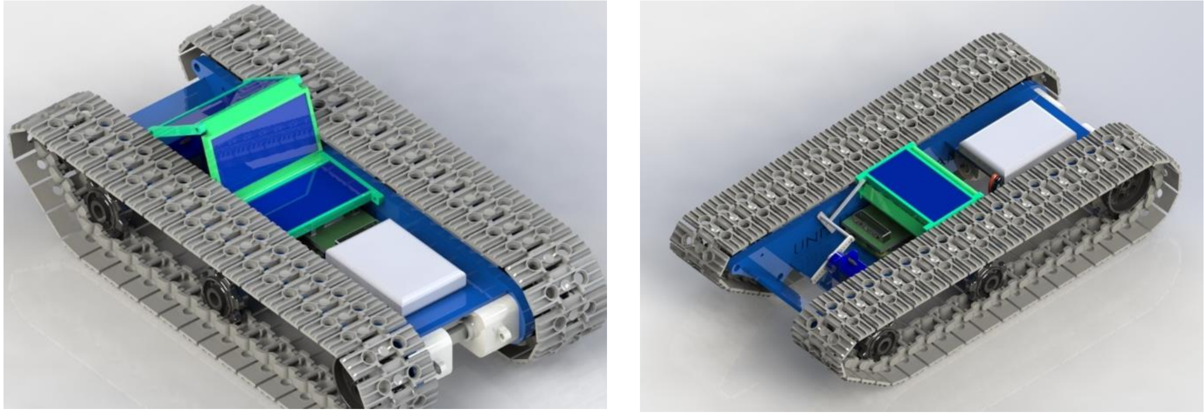


***Figure 62:** Depicts how the solar panels will sit inside the rover*

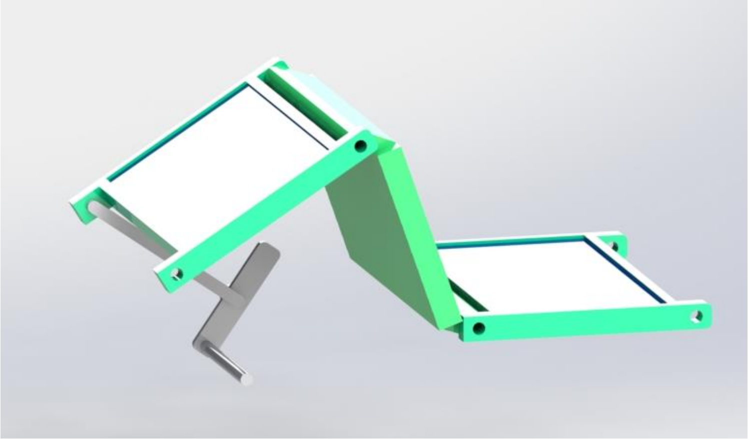


***Figure 63:** Solar panels deployed*

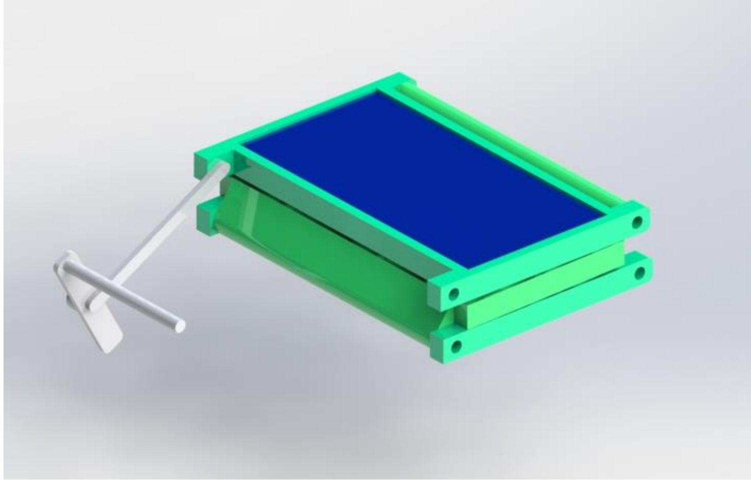


***Figure 64:** Solar panels packed*

5.1.5 Rover Deployment System (RDS) – Structural Elements & Construction

The use of the coupler does not change any of the electrical components such as the linear actuator that is used to get the nose cone off after landing, or the stepper motor that will be used to rotate the payload deployment system and the rover. The coupler was decided on due to the fact that it will provide extra support and help with aligning everything inside the payload section of the rocket. The coupler has a smooth finish, which helps reduce the friction and allow the stepper motor to rotate the deployment system with ease.

One issue with the deployment system without the coupler was that it would have to be pushed back into the rocket until there was enough room for the nose cone to fit in. This also meant that the shoulder of the nose cone would have to be trimmed down. Pushing back the deployment system also meant that linear actuators would not be able to extend far enough to get the rover 100 percent out of the rocket. This in turn, would have required the rover to drive forward then turn to leave the rocket. Since the coupler is the same diameter as the shoulder of the nose cone, it allows the deployment system to fit five inches into the nose cone and five inches into the airframe, this allows for maximum extension and plenty of room for the rover to operate.

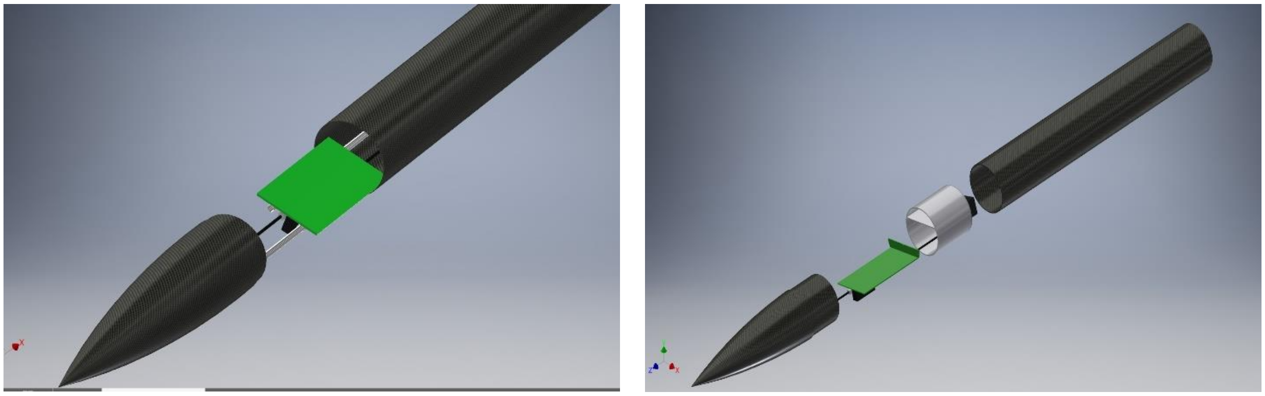


Figure 65: *Original design (left), newest design (right) which is the design of the RDS*

The deployment system uses various materials. The rover plate is made from of 3/16" plywood. This allowed for ease of bolting the linear actuators down to the plate. Notice in figure 66 there is partial circle plate. This plate is also made from 3/16" and its function is to keep the actuator arms at a consistent distance relative to the center of the circle as the system is opening.

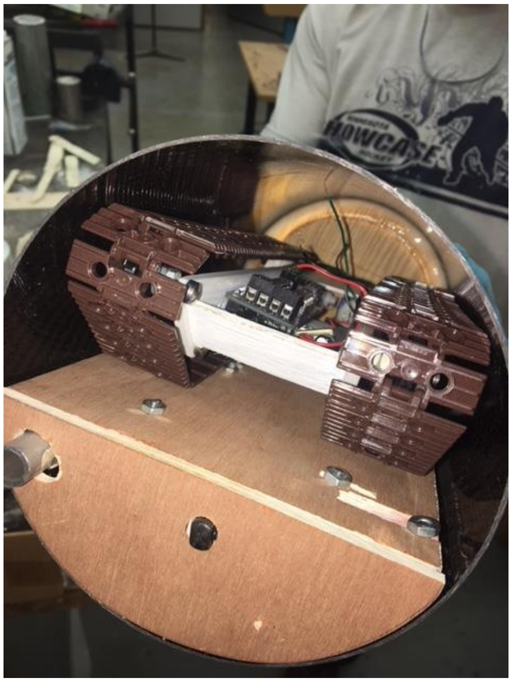


Figure 66: *Rover test fit in RDS coupler*

Figure 67 and 68 show the bottom of the rover plate, running next to the actuators are two aircraft aluminum pipes. Inside each pipe is another pipe, both of these pipes are made from aircraft aluminum. The inner pipe is facing connected to the rear bulkhead of the deployment section on one side and on the adjacent side the other inner pipe is connected to the front partial circle plate (figure 68 and 69). The function of these pipes is to help support the actuators and maintain the desired distance inside the nose cone and inside the airframe and the deployment system is opening.

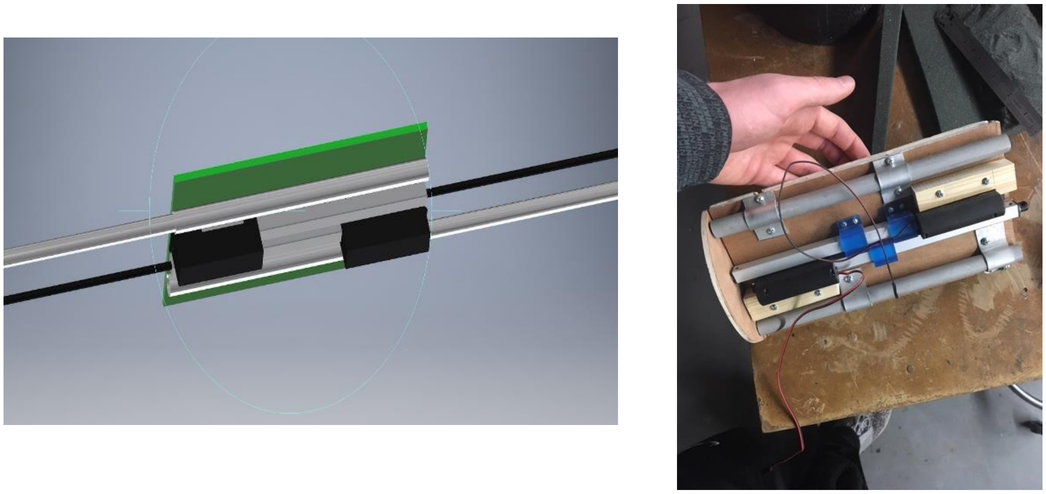


Figure 67: *3D model of base plate and linear actuator (left), constructed base plate and linear actuators (right)*

Figure 68: Aircraft aluminum pipe

In figure 67 there are also various crafted brackets to hold the pipes and the actuators in place. The brackets holding the actuators in place are made out of ABS plastic and the other out of plywood. The brackets holding the pieces of 1/16" aluminum sheeting cut and bent to the proper size.

Figure 69 shows the stepper motor and figure seven shows the bracket that connects the stepper motor to the rotating section of the deployment system, this bracket uses a set screw to attach the shaft of the stepper. The final figure eight shows the stepper motor attached to the rocket body.

Figure 69: *Stepper motor (left), stepper motor bracket attachment (right)*

5.1.6 Rover Deployment System (RDS) – Radio Communications

***Figure 70:** RFM95 Radio Module*

An RFM95 Radio module was selected to handle communication for the rover deployment payload. This radio can transmit and receive modulated data packets with a max output power of 20dBm (100 mW). It will be transmitting using LoRa spread spectrum modulation with a center frequency of 916Mhz and a bandwidth of 31.25 kHz. The team's specific receiver will be listening for a specific packet containing a unique code before initiating the rover deployment sequence to ensure the team defined activation signal is the only transmission that will be accepted. An Adafruit circuit board (Feather M0 LoRa) containing the RFM95 module and a ATSAMD21 32-bit microcontroller was chosen for the transmitter and receiver because of its compact size and powerful functionality.

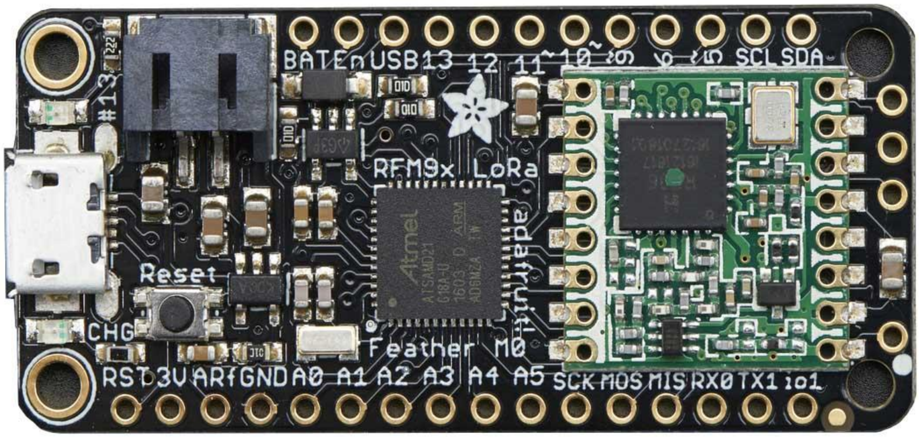


***Figure 71:** Adafruit Feather M0 Lora Radio*

In addition to acting as a receiver, the board housed in the rocket will control the entire deployment subsystem. The RDS team selected a motor driver from Adafruit that is compatible with the Feather M0 LoRa board. This motor driver board was intended to be used to drive two linear actuators and a stepper motor, but the team figured out it wouldn't work properly for all three motors.

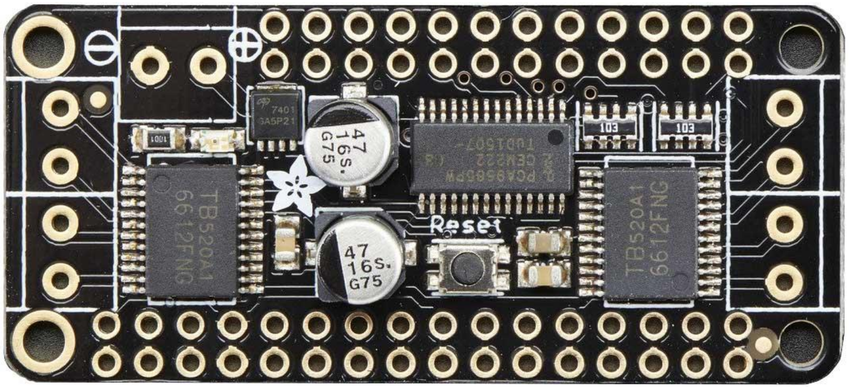


Figure 72: *Adafruit motor driver*

The linear actuators run on 12V, but the stepper motor has a rated voltage of 3V, so this board was not going to be able to drive both motors since it only has one power source. The RDS team wanted to power all three motors with a single 12V LiPo battery, so a second motor driver circuit board was developed to limit the current going to the stepper motor using dual H-Bridge motor drivers (Texas Instruments DRV8871).

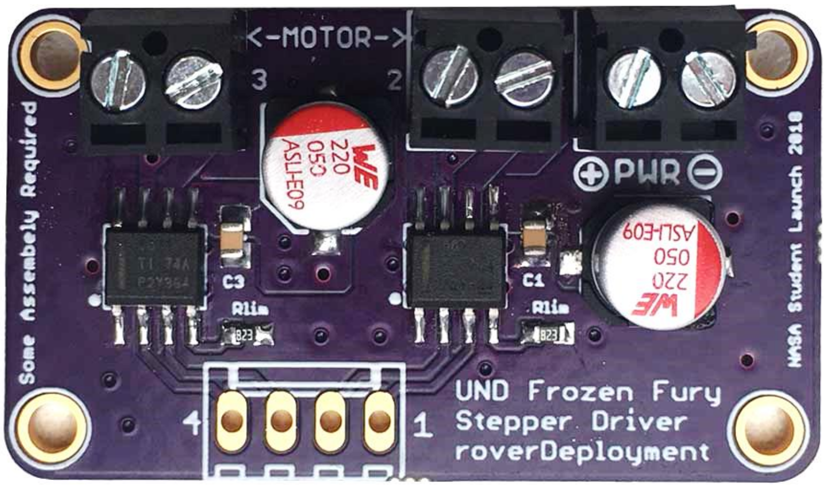


Figure 73: *Current Limiting Stepper Motor Driver*

By limiting the current, the stepper motor was able be powered by 12V, and it gets better performance when powered by a higher voltage than the rated voltage if the rated current is not exceeded. The max current value is set by adjusting two resistors on the board. A range of configurations was tested with the stepper motor to minimize heat dissipation on the board, while still maintaining adequate torque to rotate the rover bay.

6 - Project Plan

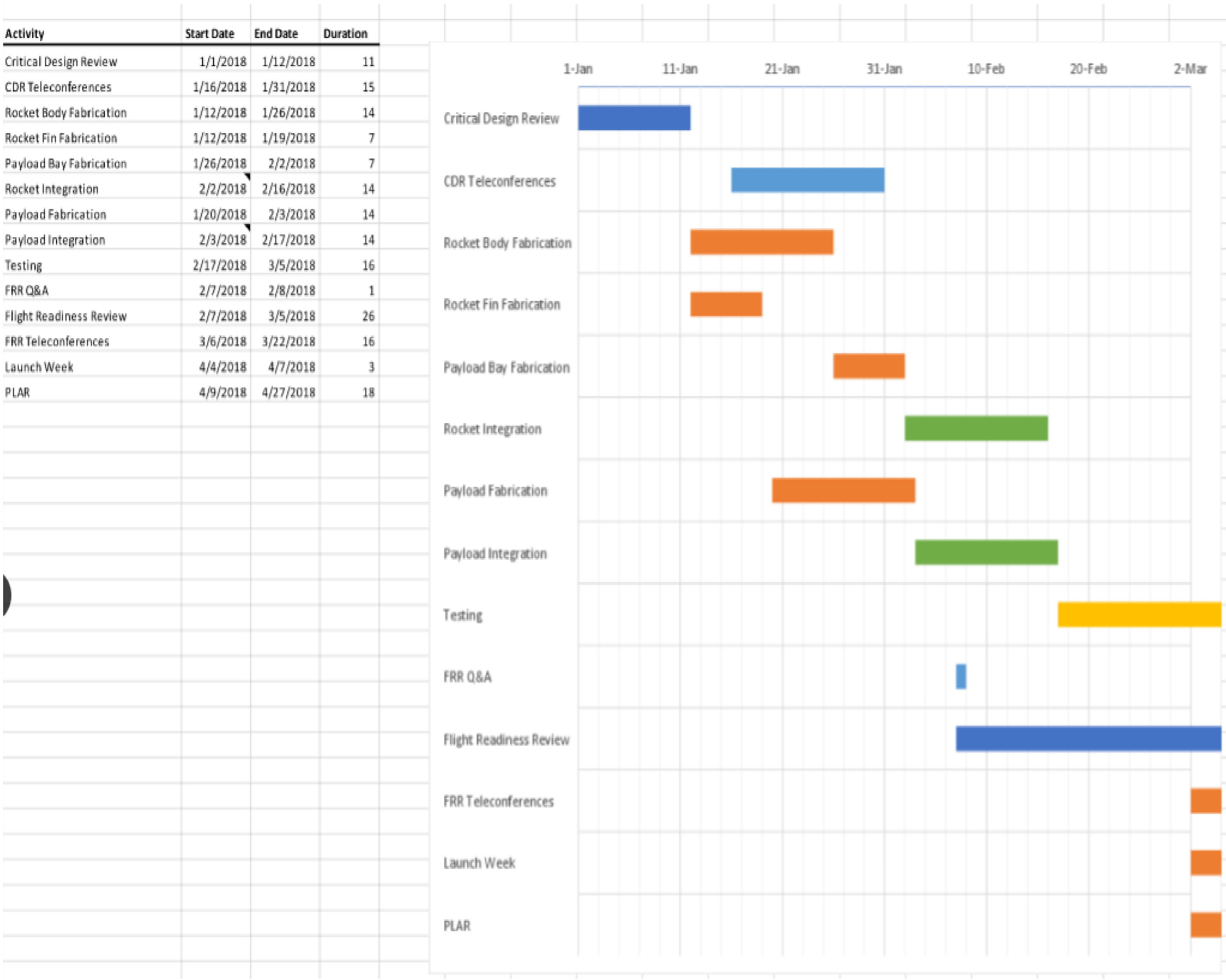
6.1 – Timeline

The following is a projected schedule for the year. We normally have team meetings every Tuesday and Thursday with construction expected on weekends. As we get further into the project, we will add more detailed timeline for the completion of rocket and payload construction, and educational outreach.

Date	Event
Oct. 06, 2017	Awarded proposals announced
Oct. 12, 2017	Kickoff and Preliminary Design Report (PDR) Q&A
Oct. 16, 2017	Preliminary team website meeting
Oct. 23, 2017	PDR draft meeting
Oct. 30, 2017	Team website Final Review
Oct. 30, 2017	PDR Final Review
Nov. 03, 2017	Team web presence established
Nov. 03, 2017	PDR report, presentation slides, and flysheet posted on the team website by 8:00 a.m. CST
Nov. 06 - Nov. 29, 2017	PDR video teleconferences
Dec. 06, 2017	Critical Design Review (CDR) Q&A
Dec. 11 2017	CDR
Dec. 15, 2017	CDR
Dec. 16, 2017 - Jan. 09, 2018	Winter Break

Jan. 12, 2018	CDR report, presentation slides, and flysheet posted on the team website by 8:00 a.m. CST
Jan 16 – Jan 31, 2018	CDR video teleconferences
Feb. 07, 2018	Flight Readiness Review (FRR) Q&A
Feb. 12, 2018	FRR draft meeting
Mar. 05, 2018	FRR reports, presentation slides, and flysheet posted to team Website by 8:00 a.m. CDT
Mar. 06 - Mar. 22, 2018	FRR video teleconferences
Apr. 04, 2018	Teams travel to Huntsville, AL and Launch Readiness Review (LRR)
Apr. 05 2018	LRR's and safety briefing
Apr. 06, 2018	Rocket Fair and Tours of MSFC
Apr. 07, 2018	Launch Day
Apr. 08, 2018	Backup launch day
Apr. 27, 2018	PLAR posted on the team Website by 8:00 a.m. CDT.

Table 1: Project Timeline



Activity	Start Date	End Date	Duration
Critical Design Review	1/1/2018	1/12/2018	11
CDR Teleconferences	1/16/2018	1/31/2018	15
Rocket Body Fabrication	1/12/2018	1/26/2018	14
Rocket Fin Fabrication	1/12/2018	1/19/2018	7
Payload Bay Fabrication	1/26/2018	2/2/2018	7
Rocket Integration	2/2/2018	2/16/2018	14
Payload Fabrication	1/20/2018	2/3/2018	14
Payload Integration	2/3/2018	2/17/2018	14
Testing	2/17/2018	3/5/2018	16
FRR Q&A	2/7/2018	2/8/2018	1
Flight Readiness Review	2/7/2018	3/5/2018	26
FRR Teleconferences	3/6/2018	3/22/2018	16
Launch Week	4/4/2018	4/7/2018	3
PLAR	4/9/2018	4/27/2018	18

Figure 25: Gantt Chart of development, testing and competition (side)

6.2 – Budget

The following is a preliminary budget for the year. Several items such as the parachute can likely be re-used from previous rockets, so the total cost may be less than projected. Some parts may be printed in the 3D printers available on campus to save money.

2016-17 UND Rocket Team "Frozen Fury" Budget			
Scale Launch			
Materials	Quantity	Unit Cost ($)	Total Cost
Rocket Kit	1	80	80
Scale Rocket Motors	2	35	70
Total for Scale Launch			$ 150.00
Full Scale Launch			
Materials	Quantity	Unit Cost ($)	Total Cost
Retrieval			
Parachute (96")	1	90	90
Drogue Parachute (36")	1	21	21
Shock Cord	6	1.1	6.6
Sub Total			$ 117.60
Engine			
K780R	4	136	544
Casing	1	450	450
Motor Mount Tube	1	15	15
Sub Total			$ 1,009.00
Body			
6" G12 Fiberglass Filament Wound Tube 48" long	2	207	414
6" Diameter Phenolic Coupler Tube	4	15	60
Sub Total			$ 474.00
Nose Cone			
6" Fiberglass Conical 5:1 Nose Cone	1	116	116
Sub Total			$ 116.00
Electronics			
Arduino MEGA 2560 REV3 Circuit Board	2	50	100
Gyro and Accelerometer Module	3	5	15
25' 20 Gauge Red/Black Wire	1	6.5	6.5
Logitech Webcam	1	40	40
D/C Motor	1	28	28

Li-Po Battery 5000mAh	2	54.67	109.34
Battery Charger	1	37	37
StratoLogger CF Altimeter	3	55	165
Sub Total			$ 500.84
Fabrication			
Nuts & Washers	20	.50	10
1/4" by 6' Plywood	1	15	15
1/8" by 6' Plywood	1	15	15
Xacto Knife	1	2	2
Paint and Gloss	1	30	30
Sub Total			$ 72.00
Total for Full Scale Launch			$ 2,289.44
Travel			
Items	Quantity	Unit Cost ($)	Total Cost
ND State Van	1	700	700
4/5/18 Hotel Room	11	85	935
4/6/18 Hotel Room	11	85	935
4/7/18 Hotel Room	11	85	935
4/8/18 Hotel Room	11	85	935
4/9/18 Hotel Room	11	85	935
Total for Travel			$ 5,375.00
Grand Total			**$ 7,814.44**

Table 2: Budget

6.4 – Requirements Verification

The requirements verifications are derived from the NASA SLI requirements that are given within the NASA SLI 2017-2018 Handbook. There are four major sections that have requirements that need to be met in order to be competitive in this year's competition

6.4.1 – General Requirements

Requirement Number	Requirement	Method of Verification
1.1	Students on the team will do 100% of the project, including design, construction, written reports, presentations, and flight preparation with the exception of assembling the motors and handling black powder or any variant of ejection charges, or preparing and installing electric matches (to be done by the team's mentor).	Senior members of the team will be given different leadership tasks to guide newer members and promote a learning environment for all aspects of the project.
1.2	The team will provide and maintain a project plan to include, but not limited to the following items: project milestones, budget and community support, checklists, personnel assigned, educational engagement events, and risks and mitigations.	Calendar, checklists, and outreach goals will be accessible to team members via the team website and cloud-based archives such as Google drive, Dropbox, and GroupMe.
1.3	Foreign National (FN) team members must be identified by the Preliminary Design Review (PDR) and may or may not have access to certain activities during launch week due to security restrictions. In addition, FN's may be separated from their team during these activities.	Upon initial meetings login sheets were supplied to new team members inquiring about FN status. All FN team members must be identified by the team lead and were included in Section I.
1.4	The team must identify all team members attending launch week activities by the Critical Design Review (CDR). Team members will include: 1.4.1, 1.4.2, and 1.4.3.	Written verification will be handed out and completed after completion of sub-scale launch to account for those members attending the trip to Huntsville.
1.4.1	Students actively engaged in the project throughout the entire year	Weekly and special meetings are posted on the team calendar and members are subscribed to team chat applications.
1.4.2	One mentor (see requirement 1.14).	see Section I
1.4.3	No more than two adult educators.	see Section I

1.5	The team will engage a minimum of 200 participants in educational, hands-on science, technology, engineering, and mathematics (STEM) activities, as defined in the Educational Engagement Activity Report, by FRR. An educational engagement activity report will be completed and submitted within two weeks after completion of an event. A sample of the educational engagement activity report can be found on page 31 of the handbook. To satisfy this requirement, all events must occur between project acceptance and the FRR due date.	Outreach events and checklists will be posted on the website once the initial event is planned.
1.6	The team will develop and host a Web site for project documentation.	see sites.und.edu/rocketteam
1.7	Teams will post, and make available for download, the required deliverables to the team Web site by the due dates specified in the project timeline.	Senior members have access to all online extensions of the team and will supply all required materials promptly.
1.8	All deliverables must be in PDF format.	All documents will be created within applications that support PDF export.
1.9	In every report, teams will provide a table of contents including major sections and their respective sub-sections.	Table of contents will promptly be updated after the completion of all documents.
1.10	In every report, the team will include the page number at the bottom of the page.	Application functions will perform automated numbering for all pages.
1.11	The team will provide any computer equipment necessary to perform a video teleconference with the review panel. This includes, but is not limited to, a computer system, video camera, speaker telephone, and a broadband Internet connection. Cellular phones can be used for speakerphone capability only as a last resort.	The team has access to the department of Physics and Astrophysics' conference room. All required equipment is supplied.
1.12	All teams will be required to use the launch pads provided by Student Launch's launch service provider. No custom pads will be permitted on the launch field. Launch services will have 8 ft. 1010 rails, and 8 and 12 ft. 1515 rails available for use.	The fullscale design will be fabricated and tested on a 1515 rail before the competition to abide by required regulations.
1.13	Teams must implement the Architectural and Transportation Barriers Compliance Board Electronic and Information Technology (EIT) Accessibility Standards (36 CFR Part 1194)	Web design will follow guidelines set out in 1194.22

	Subpart B-Technical Standards (http://www.section508.gov): 1194.21 Software application and operating systems and 1194.22 Web-based intranet and Internet information and applications.	
1.14	Each team must identify a "mentor." A mentor is defined as an adult who is included as a team member, who will be supporting the team (or multiple teams) throughout the project year, and may or may not be affiliated with the school, institution, or organization. The mentor must maintain a current certification, and be in good standing, through the National Association of Rocketry (NAR) or Tripoli Rocketry Association (TRA) for the motor impulse of the launch vehicle and must have flown and successfully recovered (using electronic, staged recovery) a minimum of 2 flights in this or a higher impulse class, prior to PDR. The mentor is designated as the individual owner of the rocket for liability purposes and must travel with the team to launch week. One travel stipend will be provided per mentor regardless of the number of teams he or she supports. The stipend will only be provided if the team passes FRR and the team and mentor attends launch week in April.	see Section I

6.4.2 – Vehicle Requirements

Requirement Number	**Requirement**	**Method of Verification**
2.1	The vehicle will deliver the payload to an apogee altitude of 5,280 feet above ground level (AGL).	Computer simulations through OpenRocket will model needed parameters of the construction to reach the appropriate altitude. During physical launches the launch vehicle's altimeter will log ascension to verify after recovery.
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	All full sub scale launches will be equipped with a legal barometric altimeter to log altitude data.

	maximum number of altitude points (5,280) if the official scoring altimeter reads a value of exactly 5280 feet AGL. The team will lose one point for every foot above or below the required altitude.	
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.	The subscale model has been wired with a toggle switch. The full-scale launch vehicle will be wired with a key switch to arm altimeter.
2.4	Each altimeter will have a dedicated power supply.	A fully charged 9-volt battery will supply the altimeter with power and a cache of backup batteries will be on hand for all launches.
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).	A key switch will be used for arming all electronics within the launch vehicle.
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.	All sections of the launch vehicle will be able to be reassembled immediately after recover with exception of shear pins.
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.	Design of launch vehicle will be carried out in OpenRocket. Fabrication will strictly follow these designs, this includes limiting the number of maximum sections to 4.
2.8	The launch vehicle will be limited to a single stage.	The design of the launch vehicle will be limited to a single motor decided during design and simulations.
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.	Design of both launch vehicle and payload will take into consideration assembly time restriction.
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.	All electronics will be powered by independent power supplies and designed to be able to last a time period longer than the given hour.
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	All field tests will be carried out by a 12-volt battery system to verify compatibility of NASA provided systems.

	provided by the NASA-designated Range Services Provider.	
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).	All electronics are internally driven and power supplied within the launch vehicle.
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 full-scale launch vehicle will use an AeroTech L1150-P motor. See Section II. Motors will be acquired by team mentors.
2.13.1	Final motor choices must be made by the Critical Design Review (CDR).	Evaluation of the initial chosen motor will be carried out after full scale launch. This launch and evaluation will be finalized before and included in the CDR.
2.13.2	Any motor changes after CDR must be approved by the NASA Range Safety Officer (RSO) and will only be approved if the change is for the sole purpose of increasing the safety margin.	A priority on full scale fabrication and launch will be emphasized to evaluate motor options before the due date of the CDR given weather conditions.
2.14	Pressure vessels on the vehicle will be approved by the RSO and will meet the following criteria: 2.14.1, 2.14.2, 2.14.13	As of current design no pressure vessels are to be implemented. If design is to change over the course of fabrication the guidelines given by the following subsections will be evaluated and followed carefully.
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.	N/A
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.	N/A
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,	N/A

	including the number of pressure cycles put on the tank, by whom, and when.	
2.15	The total impulse provided by a College and/or University launch vehicle will not exceed 5,120 Newton-seconds (L-class).	The current modeled motor has reached motor class limits. If motor fails to supply appropriate impulse for desired altitude, then redesign will be carried out to other parameters of the launch vehicle. L-class will not be exceeded.
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.	Stability margins will be modeled with OpenRocket. Static margin will be achieved before fabrication proceeds.
2.17	The launch vehicle will accelerate to a minimum velocity of 52 fps at rail exit.	Velocity data will be collected from altimeter logs after field tests to verify that the launch vehicle performs between minimum and maximum velocities.
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.	A subscale model build has been completed. Launch will commence November 4, 2017. A successful launch should be completed before the PDR teleconference.
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 model is a 1:2 ratio to the launch vehicle. After a successful subscale launch fabrication will begin on a separate full-scale launch vehicle.
2.18.2	The subscale model will carry an altimeter capable of reporting the model’s apogee altitude.	Completed
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	Fabrication of a full-scale launch vehicle will begin prior to the winter break. Weather permitted, a full-scale launch will be attempted before CDR and several before FRR.

	flight. A successful flight is defined as a launch in which all hardware is functioning properly (i.e. drogue chute at apogee, main chute at a lower altitude, functioning tracking devices, etc.). The following criteria must be met during the full-scale demonstration flight: 2.19.1-2.19.7.	
2.19.1	The vehicle and recovery system will have functioned as designed.	
2.19.2	The payload does not have to be flown during the full-scale test flight. The following requirements still apply.	Initial launches will be carried out on only the launch vehicle. Following launches will include actual payload.
2.19.2.1	If the payload is not flown, mass simulators will be used to simulate the payload mass.	Mass simulations will be constructed or printed for initial launch.
2.19.2.1.1	The mass simulators will be located in the same approximate location on the rocket as the missing payload mass.	Mass-model will be placed in the bay designed for the actual payload.
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.	Payload internal N/A. Camera system will be completed and installed before initial launch.
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.	All motors will be ordered and acquired by team mentors. Team lead will give the team mentor appropriate time to order and supply team with motors that are identical or closely simulate the appropriate L-class motor.
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.	No addition to vehicle construction will be carried out after the final field launch.
2.19.6	After successfully completing the full-scale demonstration flight, the launch vehicle or any of its components will not be modified	No addition to vehicle construction will be carried out after the final field launch.

	without the concurrence of the NASA Range Safety Officer (RSO).	
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.	Planned launches will be organized on the team calendar and amongst team member during the start of the spring semester. These guidelines will be followed to ensure successful launches before required due dates.
2.20	Any structural protuberance on the rocket will be located aft of the burnout center of gravity.	Structural and aerodynamic analysis to be carried out by graduate students and incorporated into design and construction.
2.21	**Vehicle Prohibitions**	
2.21.1	The launch vehicle will not utilize forward canards.	Payload internal.
2.21.2	The launch vehicle will not utilize forward firing motors.	Single motor in aft of vehicle.
2.21.3	The launch vehicle will not utilize motors that expel titanium sponges (Sparky, Skidmark, MetalStorm, etc.)	see Section II
2.21.4	The launch vehicle will not utilize hybrid motors.	see Section II
2.21.5	The launch vehicle will not utilize a cluster of motors.	Single motor in aft of vehicle.
2.21.6	The launch vehicle will not utilize friction fitting for motors.	Motor is secured with motor retainer.
2.21.7	The launch vehicle will not exceed Mach 1 at any point during flight.	Velocity data will be collected from altimeter logs after field tests to verify that the launch vehicle performs between minimum and maximum velocities.
2.21.8	Vehicle ballast will not exceed 10% of the total weight of the rocket.	Additional ballasting will be evaluated after field test launches.

6.4.3– Recovery System Requirements

Requirement Number	Requirement	Method of Verification
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.	Simulations will assess the velocity and kinetic energy of the descending vehicle. Initial simulations will model drogue and main sizes. After field data is recovered from the altimeter log evaluation of impact energy can be used to reassess size choice.
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.	All charge tests are carried out after fabrication is completed and again prior to launch.
3.3	At landing, each independent sections of the launch vehicle will have a maximum kinetic energy of 75 ft-lbf.	Kinetic energy will be calculated from data gathered from the altimeter.
3.4	The recovery system electrical circuits will be completely independent of any payload electrical circuits.	All power supplies and circuits operate independently of one another.
3.5	All recovery electronics will be powered by commercially available batteries.	9-volt batteries are used to supply energy to circuits. Backup batteries will be kept on hand at every launch.
3.6	The recovery system will contain redundant, commercially available altimeters. The term “altimeters” includes both simple altimeters and more sophisticated flight computers.	Redundancy will be built into the system to ensure parachute deployment occurs even after error in initial deployment at proper altitudes.
3.7	Motor ejection is not a permissible form of primary or secondary deployment.	Motor casing is held in place by motor retainer. No multistage motors are used.
3.8	Removable shear pins will be used for both the main parachute compartment and the drogue parachute compartment.	Shear pins will be abundantly on hand at all launch sites and used for recovery compartments.
3.9	Recovery area will be limited to a 2500 ft. radius from the launch pads.	Design will focus on well balanced and ballasted launch vehicle to ensure a lunch normal to the surface.

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.	Radio tracking beacons will be installed within one of the compartments.
3.10.1	Any rocket section, or payload component, which lands untethered to the launch vehicle, will also carry an active electronic tracking device.	Current design emphasizes the tethering of all compartments.
3.10.2	The electronic tracking device will be fully functional during the official flight on launch day.	Beacons will be tested regularly before all launches, including official launch day.
3.11	The recovery system electronics will not be adversely affected by any other on-board electronic devices during flight (from launch until landing).	All other transmitters and receivers used for the payload will be tested and designed to work at frequencies that does not interfere with beacons.
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.	Altimeter bay is separate and isolated.
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 altimeter bay will be shield with adhesive copper tape.
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.	Altimeter bay is separate and isolated. The altimeter bay will be shield with adhesive copper tape.
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.	Altimeter bay is separate and isolated. The altimeter bay will be shield with adhesive copper tape.

6.4.4 – Experiment Requirements

Requirement Number	Requirement	Method of Verification
4.1	Each team will choose one design experiment option from the following list.	The team has chosen the deployable rover project.
4.2	Additional experiments (limit of 1) are allowed, and may be flown, but they will not contribute to scoring.	Only one experiment will be chosen this year.
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.	Only one experiment will be flown this year.
4.5.1	Teams will design a custom rover that will deploy from the internal structure of the launch vehicle.	See Payload Criteria.
4.5.2	At landing, the team will remotely activate a trigger to deploy the rover from the rocket.	Receiver circuitry will be housed in the payload bay and powered by an independent power supply.
4.5.3	After deployment, the rover will autonomously move at least 5 ft. (in any direction) from the launch vehicle.	See Payload Criteria.
4.5.4	Once the rover has reached its final destination, it will deploy a set of foldable solar cell panels.	See Payload Criteria.

6.5.5 Safety Requirements

5.1	Each team will use a launch and safety checklist.	Final Checklists will be included in the FRR and will be used during the LRR and any Launch Day operations.
5.2	Each team must identify a student safety officer who will be responsible for all items in section 5.3.	Drew Ross is our Safety Officer. He is responsible for verifying any safety items listed in this document.
5.3.1	The Safety officer will Monitor team activities with an emphasis on Safety during: (see below)	
5.3.1.1	Design of vehicle and payload	Design completed with redundancies built in

5.3.1.2	Construction of vehicle and payload	Construction of vehicle completed following proper safety procedures and checklists
5.3.1.3	Assembly of vehicle and payload	Assembly completed following proper safety guidelines and checklists
5.3.1.4	Ground testing of vehicle and payload	Ground tests completed following proper safety checklists and proximity guidelines
5.3.1.5	Sub-scale launch test(s)	Successfully completed with proximity guidelines and safety concerns addressed
5.3.1.6	Full-scale launch test(s)	Will follow proper safety checklists and proximity guidelines
5.3.1.7	Launch day	Correct safety guidelines and procedures will be followed according to Safety checklist
5.3.1.8	Recovery activities	Flight only recovered after receiving confirmation and approval for RSO
5.3.1.9	Educational Engagement Activities	Engagement activities are done with safety and inclusion of younger individuals in mind
5.3.2	The Safety Officer will implement procedures developed by the team for construction, assembly, launch, and recovery activities	Safety procedures implemented
5.3.3	The Safety Officer will manage and maintain current revisions of the team's hazard analyses, failure modes analyses, procedures, and MSDS/chemical inventory data	Hazard analysis, failure mode analysis, procedures, and chemical inventory all maintained and managed to current revisions
5.3.4	The Safety Officer will assist in the writing and development of the team's hazard analyses, failure modes analyses, and procedures.	Hazard analysis, failure modes analysis, and safety procedures written

5.4	During test flights, teams will abide by the rules and guidance of the local rocketry club's RSO.	Rocketry club's RSO rules and guidance abided by
5.5	Teams will abide by all rules set forth by the FAA.	Will receive Full scale flight clearance from the FAA and issue a NOTAM.

6.4.6 Team Derived Requirements

Requirement Number	**Requirement**	**Verification Plan**
6.1.1 - Mission	Reach a target altitude of 5,280 feet AGL	Record data from the altimeter onboard the launch vehicle
6.1.2 - Launch Day	The launch vehicle should be ready to fly the day of launch day	All testing and development will be completed two weeks before competition launch date.
6.1.3 - Altimeter	The altimeter must work during all launches of the rocket	Testing of the batteries that power the altimeter will be conducted, along with tests of the altimeter themselves.
6.1.4 - Launch Vehicle Guidelines	The launch vehicle must fit all the creteria outlined in the NASA SLI Handbook	Through PDR, CDR, and FRR will receive verification from NASA that the launch vehicle meets all the neccassry requirements outlined in the handbook
6.1.5 - Subscale Model	Launch a subscale model of the rocket before the CDR.	Subscale launch completed before CDR.
6.1.6 - Full Scale Launch	The full-scale launch will be conducted before March 1st, 2018	Have not yet started construction on the rocket
6.2 - Recovery Devices	The rocket will deploy a drogue and main parachute	Drogue is deployed at apogee, main is deployed at 1500 feet

6.2.1 - Ejection Test	An ejection test will be performed before each full-scale launch to ensure that the recovery system is working properly	Ground ejection test has yet to be completed
6.3.1/6.3.2 - Experiment Requirements: Deployable Rover/ Rover Deployment System		
6.3.1.1- Rover Housing	Rover must be contained within the main body of the rocket for the duration of flight.	A dedicated payload bay will be placed inside the rocket and the rover is designed to fit inside. Visual pre-launch inspection will ensure that the rover is entirely contained.
6.3.1.2 – Rover Autonomy	The rover must be fully autonomous	The rover will have a Raspberry Pi Zero as the computer that will control and monitor all the systems on board the rover
6.3.1.3 – Distance Traveled	Rover must travel at least 5 feet from the landed rocket.	• Previous testing on the rover will determine how long it must drive to travel at least 5 feet. The motors will run for at least this length of time. • The rover's onboard accelerometer will measure its displacement via dead reckoning.

		The rover will drive until it reckons at least 5 feet. • Once both the timer and accelerometer checks are passed, the rover will stop driving. Additionally, the rover’s final distance from the rocket will be measured via tape
6.3.1.4 – Solar Panel Deployment	Rover must deploy solar panels	Rover’s onboard computer will record voltage across solar panels. If voltage is within 30% of nominal value for the panels, then deployment will be considered successful.
6.3.2.1 – Deployment of Rover	Rover must be extracted from rocket.	In lab testing will ensure that the system works. Visual confirmation on after launch.
6.3.2.2 – Rover Deployment Platform	Rover must turn and leave rover plate.	In lab testing to insure rover is able to turn. Tracks must run in opposite directions for specific amount of time. Visual confirmation of the rover turning. Accelerometer will record rover motion to check if it has left the rover plate.

7 - Conclusion & Recommendations

The 2017-2018 Frozen Fury team’s enthusiasm is at an all time despite the full-scale launch being a failure. The team is overall pleased with the build of the launch vehicle. The development of the rover and RDS have also boosted moral. The team waits in anticipation for the competition and launch day.