By:

The Georgia Institute of Technology Launch Initiative Team

(GIT LIT)

NASA Student Launch

2017-2018 Critical Design Review

January 12th, 2018

Georgia Institute of Technology

School of Aerospace Engineering

270 Ferst Drive, Atlanta GA 30332-0150

Table Of Contents

1. Summary of CDR Report

1.1. Team Summary

Team Name: Georgia Institute of Technology Launch Initiative Team (GIT LIT)

Mentor: Alton Schultheis

NAR Number: 98790

Certification Level: Level 2 Certified for HPR by NAR

Contact Information: alton.schultheis@gmail.com

1.2. Launch Vehicle Summary

Vehicle Feature	**Value**
Vehicle Length/Diameter	107 in. / 5.562 in.
Mass	37.38 lbm
Motor	Aerotech L1390G
Drogue Parachute Model/Diameter	Apogee 29095 / 36 in.
Main Parachute Model/Diameter	Fruity Chutes IFC-96 / 96 in.
Rail Size	1010 / 120 in.

1.3. Payload Summary

Our selected payload is the Deployable Rover. Our rover system consists of a four-wheeled, battery powered rover, which is mounted in a lead-screw separation deployment system. Once the rocket has landed, the team will trigger the separation of the body tube using an RC transmitter, and the rover will then autonomously drive out, perpendicular to the body tube. Once moving at least five feet away from the launch vehicle, the rover will deploy servo-mounted, foldable solar panels.

2. Changes Made Since PDR

2.1. Changes to Vehicle

A pitot tube for an airspeed sensor will be mounted to the exterior of the rocket. It will be positioned on the ATS section just below the bulkhead. A telemetry system transmitting on 433 MHz has also been added. Voltage sensors comprise another critical edition to act as a forewarning of low battery or impending battery failure condition. The rocket airframe has changed slightly in terms of mass and size, which is detailed in the body of the document below. Due to this, the team has implemented the use of different parachutes for both the drogue and main parachutes. The launch vehicle still meets all competition requirements and safety standards, and this information is detailed in the Flysheet and additionally in the body of the document below.

2.2. Changes to Payload

The Rover has gained a flushed out solar panel design, consisting of a two part housing. The housing is comprised of an upward and downward opening segment with a stepper motor to drive the mechanisms actuation. The outer profile of the wheels changed slightly. Currently, the pointy spikes have been blunted to increase the ease of manufacturing, allow for better clearance and looser tolerance requirements inside the deployment housing. The wheels have been further modified by the addition of greater support material to the extended axle portion. This change came about from inspecting parts that were test printed. That inspection revealed that the outer surfaces of the wheel came out well and resulted in a very strong structure, but the axle that connects the wheel to the body of the rover came out very weak. It was a weak point due to the fact that the direction the printer stacks layers is perpendicular to the direction of application of force and thereby creates a shear force that snaps the axle at the point of greatest stress concentration, which was the point where the axle and wheel meet. The new design greatly decreases the lever arm over which the forces have to act. Advanced details about each of these changes are detailed later in the document.

2.3. Changes to Project Plan

There are no substantial changes to the Project Plan since completion of the PDR.

3. Safety

3.1. Assembly and launch procedures

3.1.1. Recovery Preparation

Procedure Title: Folding and Packing Parachutes

Min Personnel Requirements: 2 people

Materials (ref 3.6. Material Handling)

- Nylon parachute
- Kevlar sheet
- Nylon shock cord

Safety Equipment Required

- N/A

Procedure

1. Folding Parachute
    a. "Fluff", or lay out, chute on a flat surface
    b. Straighten the lines so they come to a point away from the chute
        i. Untangle lines if tangled
    c. Grab all shroud lines and organize the panels of the chute
    d. Fold on the panel lines toward the center
    e. Continue folding until width is approx 2X length you desire it occupy in the rocket

    f. Bring shroud line bundle up through center, then fold over and pull back down so a small length lies outside the parachute
    g. Fold one more time, over the shroud lines
    h. Wrap up the chute from the tip, tightly packing as you go
2. Attaching to Shock Cord
    a. Tie a knot in the shock cord line, about ⅓ the length from the connection point to the above section
    b. Use a quicklink to connect the knotted loop to the end of the shroud lines sticking out of the packed parachute
3. Assembling into Tube
    a. Thread a kevlar parachute protector sheet over the shock cord until it reach the parachute (in its packed form still)
    b. Have another person bundle up the shock cord to one side of the parachute in a figure 8 pattern
    c. Push the bundled shock cord and packed parachute (now partially covered by the kevlar sheet) into the tube and push until it hits the bulkhead on the other end
    d. Bundle the shock cord on the other end of the parachute in a similar way and shove into tube
    e. Connect the two sections of the rocket to encapsulate the parachute+shock cord assembly in between the two sections of the rocket

Safety Officer Signature: ______________________________

- -

3.1.2. Motor Preparation

Procedure Title: Launch Motor Preparation

Min Personnel Requirements: 2 people

Materials (ref 3.6. Material Handling)

- Aluminum particles
- Ammonium perchlorate
- Iron oxide

Safety Equipment Required

- Safety glasses
- Latex/Nitrile gloves

Procedure

1. Delay Grain Assembly
    a. Without touching the ends of the delay grain, place the grey propellant cylinder into the delay insulator
    b. Slide this assembly into the delay spacer
    c. Grease the o-ring with synthetic teflon lube and place over exposed section of propellant grain
        - Be careful not to get any grease on the end of the propellant grain
2. Assembly of Delay Grain into FWD Closure
    a. Grease the inside of the fwd closure, make sure to clean the small hole if it become filled with grease in this step
    b. Place neoprene washer at the bottom on the well
    c. Press the delay grain assembly into the well, o-ring-side entering first
    d. Grease the main fwd o-ring, and place over the end of the fwd closure

3. Liner Insertion into Main Casing
    a. Slide liner into casing, check to ensure that it slides smoothly
        - If not, maybe have to sand down liner
    b. After ensuring fit, pull out liner, thoroughly grease the outsides, and push back in, wiping grease as it builds up around the edge. Leave .5" exposed
        - Do not grease if liner is black phenolic
    c. Place an insulator disk on top of the exposed liner, and push in until internal threads are exposed
    d. Screw on FWD closure assembly so that o-ring presses against the insulator disk
4. Grain Assembly into Casing
    a. Stand motor on FWD closure
    b. Pull liner out .5"
    c. Without touching the ends of the grain, drop the two propellant tubes into the liner
    d. Press insulator disk on top, and push down until liner stops moving
5. Aft Closure Assembly
    a. Place the nozzle into the hole
    b. Place a greased o-ring into casing, over the nozzle, so it sits on top of the insulator disk
    c. Screw the aft closure over the nozzle/o-ring
6. Final Steps
    a. Place the plastic nozzles over the aft and fwd closures

Safety Officer Signature: ______________________________

- -

3.1.3. Setup on Launcher

Procedure Title: Vehicle Setup on Launchpad

*Must have safety officer present

Safety Officer: _______________

Procedure

1. Connect two fill lines to the ground system
2. Have one person angle rail guide and another slide the rocket rail buttons into the rail guide
    a. Be sure to slide the rocket on carefully, and try to minimize impact with the bottom of the rail guide, as the jostled movement may cause the propellant to become misaligned or crack
3. Once the rocket is safely placed onto the rail, reposition the rail so the rocket is pointing vertically into the sky
4. With the ignition lines still not connected to the rocket motor, turn the power switches one at a time
    a. Listen for beeping that confirms altimeter connection to both the main and drogue deployment ejection charges
    b. Repeat for the other altimeter
5. Turn any additional power switches to activate remaining systems
6. Remove the plastic cap from the bottom of the motor and push the e-match up inside until it become lodged at the very top of the motor casing
7. Take team picture (very important)
8. Walk to the control station and await launchpad activation by the NAR or Tripoli officer

3.1.4. Igniter Installation

Title: Ejection Charge Assembly and Testing

Min Personnel Requirements: 2 people

Materials (ref 3.6. Material Handling)
- FFFF Black Powder
- Fiberglass insulation
- 9V Battery

Safety Equipment Required
- Safety glasses
- Latex/Nitrile gloves
- P95 Respirator Mask

Assembling Charges
1. Sizing Charges
    a. Using body tube diameter, and length of parachute sections, utilize online ejection charge calculator to estimate the amount of black powder needed
        i. Note: 4-shear pin design requires approx 40lb shear force to break
        ii. Using P = F / A, calculate the pressure needed to cause an appropriate shear force
        iii. Use F = P * A to calculate the force on the bulkheads during ejection events
2. Bagging and Storage
    a. Black powder is plastic-safe, but easily corrodes metals, so be sure to store in a plastic container
    b. Black powder must be stored in a dry environment so ensure water-seal

3. Placing in Vehicle
    a. With the ejection wells oriented upward, carefully pour the black powder into each well
    b. With the leads twisted together, place an e-match in each well so that the igniter lies inside the black powder
    c. Pack fiberglass insulation into the well and place a strip of tape over the top to keep the assembly packed inside the well
    d. Untwist the leads on the e-matches, and place them into the correct holes in the terminal block on the bulkhead
    e. Screw down the wires to secure them into the terminal block

Testing Charges

1. Lead Extension
    a. Measure out two strips of at least 5 ft long 22 AWG wire, preferably of different colors
    b. Strip end of wire
    c. Route ends of wire into respective holes in terminal block to connect to one of the e-matches connected to the other end of the terminal block
2. Vehicle Assembly
    a. Route the extension wires out of an access hole
    b. Close sections of rocket, with parachutes packed inside and protected with kevlar sheets
    c. Insert shear pins
3. Vehicle Positioning
    a. Position vehicle so it lies on its side
    b. Ensure the bottom is placed against a wall, or other solid surface
    c. Ensure the trajectory is clear of obstacles
    d. Angle rocket slightly so nose does not aim toward the ground
    e. Preferably tested outside on grass to prevent damage to tubes during impact

4. Personnel Hazard Mitigation
    a. Test outside, in an open space (>50 ft radius without other people or obstacles around)
    b. Stand at least 5 ft away from the vehicle, to its side, when shorting the leads to create the ejection event
    c. Make sure there are no loose object in the compartments that are undergoing ejection charge testing to minimize risk of ejecting solid objects at high velocities away from the rocket
    d. Have a fire extinguisher nearby in the case that a fire results from the ejection event
5. Test
    a. Standing >5 ft to the side of the vehicle, short the leads of the extension wire across a 9V battery
    b. Watch for flames
    c. Wait approximately 30s before touching components of rocket, as they may be hot

Safety Officer Signature: _____________________________

\- -

3.1.5. Vehicle Assembly

Title: Shear Pin / Rivet Installation

Min Personnel Requirements: 1 person

Materials (ref 3.6. Material Handling)

- Fiberglass (depending on tube material)

Safety Equipment Required

- Safety glasses
- >P90 Respirator (if fiberglass tubing used)
- Safety gloves (if fiberglass tubing used)

Procedure

1. Shear Pin Installation
    a. Assemble rocket
    b. Using permanent marker, create two “witness marks” across the separation line between two sections of the rocket (for consistent future orientation)
    c. Drill X number of 1/16” dia holes, equally spaced, around the perimeter of the tube
        i. Ensure that sections do not “wiggle” while drilling holes as may cause misaligned of previously drilled holes
        ii. Ensure that rocket tube is empty before drilling, as there is a high risk of drilling into parachute or shock cord and causing damage
    d. If tube is paper: place drop of glue inside to stiffen the walls of the hole
    e. If tube is hard (fiberglass, carbon fiber): tap the hole to create threads for the plastic screw, aka “shear pin”
    f. Thread or push shear pins into holes after aligning with the “witness marks”
2. Shear Pin Removal
    a. unscrew /pry out head of shear pin
    b. Use small drill bit to push in the other section of the pin lodged in the hole of the inner tube
3. Rivet Installation
    a. Repeat steps a & b from “Shear Pin Installation”, above
    b. Drill X number of 11/64” holes, equally spaced, around perimeter of tube
        i. Ensure that sections do not “wiggle” while drilling holes as may cause misaligned of previously drilled holes

        - ii. Ensure that rocket tube is empty before drilling, as there is a high risk of drilling into parachute or shock cord and causing damage
    - c. Assemble rocket sections
    - d. Push shear pins into each of the holes
    - e. Push heads of pins into the hole on top of each pin until it stops
4. Rivet Removal
    - a. Pull head out of rivet
        - i. May require flathead screwdriver to pry out
    - b. Pry out rivet body

Safety Officer Signature: ______________________________

- -

3.1.6. Troubleshooting

Disarming Procedure & Re-Setup on Launchpad

1. If motor does not ignite, remove ignition interlock
2. Wait approx one minute to allow gases to disperse
3. Walk out to launchpad
4. Disarm all electronics by turning off switches
5. Carefully remove rocket from pad
6. Reinstall instal e-match igniter
7. Remount rocket on guide (follow “Setup on Launch” procedure)
8. Re-arm electronics
    - a. Listen for altimeter beeping to check for connection to deployment charges
9. Walk back to control station and retry launch

3.1.7. Post-flight Inspection

ATS Inspection

1. Mechanical
    a. Check to make sure flaps are fully intact
    b. Check to see if flaps have bent (could be cause by impact with ground)
    c. Move flaps in and out by hand to ensure that they are still locked in sync with each other, proving the internal linkage mechanism has not failed
2. Data Collection
    a. Remove rivets holding ATS bay to Booster section
    b. Unscrew ATS unit from sides of tube
    c. With flaps fully recoiled, slide out ATS mechanism and the electronics equipment
    d. Interface computer with Raspberry Pi SD-card to pull data from the flight
    e. Check flight velocity and acceleration curves to see impacts of ATS on flight
    f. Check altitude curve to see how close apogee was to 5280 ft

Rover Inspection

1. Visually observe whether Rover deployed from tube or not
2. If it did, use a tape measure to record distance rover traveled from vehicle
3. Check to see if vehicle is intact, as landing impact may have damaged wheels/mounting
4. If rover was never deployed, try to trigger remote once again to see diagnose if it was a transmission range-related problem
5. If rover bay opened by rover was not deployed, observe what mechanical failure prevented rover vehicle from leave the rocket

Launch Vehicle Inspection

1. Check for visible cracks in the tubing or nose cone
2. Observe whether or not any piece came down, untethered to the rocket

3. Check parachutes for burn damage, indicating poor packing of protective material around them
4. Check shock cord for burn or fraying damage
5. Check bulkheads for cracks around the area where the u-bolts/eye-bolts are secured

3.2. FMEA/Personal Hazard/Environmental Concerns

Table 3.2.1: FMEA Criteria

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

Severity-Probability Correlation	**Acceptance Level / Approving Authority**
High Risk	Unacceptable. Requires approval from Avionics and Vehicle Leads, as well as Safety Officer. Must
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 from the supervisor directly responsible for operating the facility or performing the operation.
Minimal Risk	Acceptable. Documented approval not required, but an informal review by the supervisor directly responsible for operation the facility or performing the operation is highly recommended. Use of a generic JHA posted on the SHE Web page is recommended, if a generic JHA has been developed.

Table 3.2.2: Airframe FMEA Chart

Hazard	Causes	Impacts	Risk	Mitigation Strategy
Structural cracks in the body airframe	heat from motor	rocket buckles mid-flight and make the rocket fail and not land safely	1C	insulate motor from airframe body
	impulses from parachute deployment			verify there are no cracks in body before launch
thrust plate structural integrity fails	material used to make the thrust plate was already compromised and wasn't checked before manufacturing	motor shoots through rocket, damaging all systems	1B	verify there are no cracks in thrust plate before it is inserted into body
	epoxy used to secure thrust plate failed			use enough epoxy to estabish acceptable factor of safety
motor explodes	motor manufacture error	rocket disintegrates or falls uncontrollably to the ground, most if not all sub-systems useless	1B	verify motor housing and mount are free of defects before insertion into the body
	inappropriate propellant was used			verify that the correct propelant was selected, order and used
motor does not ignite	ignition wire not connected properly to the motor	rocket does not fly and sub-systems do not get a chance to be used	2B	verify all wires are connected properly/ use a voltmeter to ensure charge is flowing
all centering rings break during flight	epoxy failed because it was not made properly	motor in the booster section tilts, forcing the rocket to arc; altimeter may deploy drogue chute early if it thinks the rocket reached apogee as the rocket arcs	1B	ensure enough epoxy is used to enable a proper factor of safety
	material used was not strong enough			ensure appropriate selection of centering ring material
	centering rings not aligned properly		2C	use measuring devices to verify centering rings are actually centered
fins separate from airframe during flight	epoxy failed because it was not made properly	rocket loses stability and arcs during flight, causing failures in altimeters and ATS system	1B	ensure enough epoxy is used to enable a proper factor of safety

fins do not direct the rocket perfectly up	fins not aligned properly during manufacturing	rocket loses stability and arcs during flight, causing failures in altimeters and ATS system	3C	use template for mounting the fins to the body correctly
Rover section separates during flight	someone sits on the receiver and prematurely separates the rover section	rover falls to the ground and is destroyed, so rover challenge cannot be completed	2B	store receiver somewhere it cannot be accidentally actuated
ATS flaps are not pushed out symmetrically	not enough lubricant for the flaps	rocket loses stability and arcs during flight, causing failures in altimeters and ATS system	1A	use enough lubricant to allow the flaps to push out correctly
couplers break during the flight	couplers cannot withstand the moments applied during flight	rocket comes apart mid-flight, causing all sub-systems to malfunction, rover falls to ground, ATS cannot be deployed, parachutes could get tangled or damaged, avionics bay wires get disconnected, motor falls away from booster section, causing what's left of the rocket to arc	1B	ensure correct material is selected for each of the couplers so that each connection has an appropriate factor of safety
shear pins and rivets break mid-flight prematurely	shear pins vibrate out during flight	rocket comes apart mid-flight, causing all sub-systems to malfunction, rover falls to ground, ATS cannot be deployed, parachutes could get tangled or damaged, avionics bay wires get disconnected, motor falls away from booster section, causing what's left of the rocket to arc	1A	verify that shear pins are mounted correctly
	cannot withstand external forces			ensure correct shear pins are purchased to allow for an appropriate factor of safety
Rivets do not come apart when needed	there is not enough force to break them	subsystems work, but ejection charges are not strong enough to break rivets, so parachutes do not deploy, the rocket crashes into the ground, and the rover challenge is not possible	1B	ensure both ejection charges and rivets are correctly selected given the amount of force in the separation
bulkheads and U-bolt (attached to shock cord) breaks during flight	epoxy was not properly made	parachutes do not deploy, the rocket crashes into the ground, and the rover challenge is not possible	1B	ensure enough epoxy is used to enable a proper factor of safety

	bulkhead structure is not strong enough			ensure both the U-Bolt and bulkhead are fastened properly
shock cords are damaged by the ejection charges	shock cords were not packed properly	subsystems work, but shock cords become tangled and hinder its performance or ejection charges damage the shock cords, so parachutes deploy damaged, causing the rocket to drift or crash into the ground, and the rover challenge is not possible	1B	verify that the shock cords and parachutes are packed correctly
	incorrect ejection charge was used			ensure the ejection charges are selected appropriately
Main parachute malfunctions during flight	altimeters fail, causing parachute to not deploy or deploy at the wrong time	subsystems work, but when main parachute doesn't deploy correctly, the rocket drifts and crashes into the ground, so the rover challenge is not possible	1B	verify that both the primary altimeter and secodary altimeters are functioning correctly before launch
	parachute wasn't packed properly			verify that the shock cords and parachutes are packed correctly
	ejection charges go off incorrectly and deploy damaged	subsystems work, but when main parachute is damaged when deployed: the rocket falls too fast, hits the ground hard, but rover subsystem survives (best case scenario) or the main parachute is completely destroyed and the rocket crashes into the ground, making the rover challenge impossible		ensure that the ejection charges are both correctly selected and correctly fastened to the body
drogue parachute malfunctions during flight	altimeters fail, causing parachute to not deploy or deploy at the wrong time	rocket falls too fast, which may cause the rocket to crash into the ground if the main parachute doesn't deploy correctly, which means the rover challenge is not possible	2B	verify that both the primary altimeter and secodary altimeters are functioning correctly before launch
	parachute wasn't packed properly	parachute cords become tangled and hinder its performance, causing the rocket to drift or crash into the ground, hinder the performance of the main parachute, and the rover		verify that the shock cords and parachutes are packed correctly

		challenge is not possible		
	ejection charges go off incorrectly and deploy damaged	rocket falls too fast, which may cause the rocket to crash into the ground if the main parachute doesn't deploy correctly, which means the rover challenge is not possible		ensure that the ejection charges are both correctly selected and correctly fastened to the body
nose cone does not properly direct the rocket	incorrect nose cone selected	rocket loses stability and arcs during flight, causing failures in altimeters and ATS system	3E	verify that correct nose cone was selected, purchased, and installed
	nose cone improperly manufactured			verify that the nose cone is devoid of any manufacturing errors

Table 3.2.3: Recovery FMEA Chart

Hazard	Causes	Impacts	Risk	Mitigation Strategy
Ejection charge does not ignite	no signal from the avionics bay	The parachutes do not deploy and the rocket freefalls to the ground	1B	ejection charge testing
	the powder is oxidized			
	the powder does not catch fire			
Ejection charge does not separate rocket	not enough black powder to provide sufficient pressure	The parachutes do not deploy and the rocket free falls to the ground	1B	ejection charge testing
	there is not sufficient space for the ejection charge to build pressure			black powder weight calculations
bulkheads break	insufficient epoxy applied to bulkheads	The rocket is no longer tethered and part of the rocket will free fall potentially causing harm to observers	1C	visual inspection of epoxy during manufacturing
	i bolt breaks the bulkhead			FEA on the bulkheads will be performed

main shock cord or drogue shock cord breaks	excess force is applied on the shock cord	The rocket is no longer tethered and part of the rocket will free fall potentially causing harm to observers	1C	Exceess shock cord will be used to provide a factor of safety of 2 greater than manufactuers specifications
	the manufacturer provides shock cords that can take force below the rated specifications			
ejection charge burns parachute	too much black powder is used	The parachute is damaged and the rocket will be more unstable when falling	3B	Safety officer will oversee the packing of the parachutes
	the parachute is not properly packed with the thermal barrier			ejection charge testing
main parachute does not come out of body tube	parachute chords snag on i-bolt	The rocket falls with only the drogue parachute slowing it down	1D	Safety officer will oversee the packing of parachutes
	parachute packed too tightly			will inspect the ability of parachutes to come out after packing
drogue parachute does not come out of body tube	parachute chords snag on i-bolt	The rocket falls with only the main parachute slowing it down	2D	Safety officer will oversee the packing of parachutes
	parachute packed too tightly			will inspect the ability of parachutes to come out after packing
main parachute does not unfold	parachute chords are extremely tangled	The rocket falls with only the drogue parachute slowing it down	1E	Safety officer will oversee the packing of parachutes
				The parachute chords will be carefully placed when packing
drogue parachute does not come out of body tube	parachute chords are extremely tangled	The rocket falls with only the main parachute slowing it down	2E	Safety officer will oversee the packing of parachutes
				The parachute chords will be carefully placed when packing

Table 3.2.4: Rover FMEA Chart

Hazard	Causes	Impacts	Risk	Mitigation Strategy
Rover deployment actuates during flight	Signal interference Coding error Improper wiring Component failure in a non safe mode	Creates highly unstable flight leading to loss of vehicle, Challenge incomplete	1C	Rover deployment system does not actuate unless sensors indicate that the rocket has landed
Rover deployment mechanism structural failure	Preexisting crack propagation Delamination of printed material Adhesive improperly mixed and set Hard impact with ground	Slight imbalance affecting flight path, Premature rover deployment, Rover unable to deploy, Challenge incomplete	2D	Deployment mechanism components will undergo structural testing to ensure they can withstand all loads with a factor of safety of 2
Rover deployment does not activate	No signal reception Depleted 9V battery Component structural failure Coding error	Solar panels unable to actuate, Rover drivetrain unable to move, Challenge incomplete	4C	System will be tested in advance, receiver will have a large antenna
Solar panels do not actuate	No signal reception Physical obstruction Structural failure Coding error	No power generation, LED not lit, Challenge incomplete	4D	System will be tested in advance, simple design with a high torque servo minimizes chance of failure due to obstruction or structural failure

Rover encounters obstacles	Unfavorable landing location	Rover unable to move, Battery depletion, Challenge incomplete	4B	Wheels will be large and have strong traction and high-torque motors, lead screw deployment mechanism is strong and can open despite obstacles
	Deployment system obstruction			
	Challenging terrain			
	Inadequate ground clearance			
Rover drivetrain unable to move	No signal reception	Rover unable to leave rocket navigate or avoid obstacles, Challenge incomplete	2C	Rover will use accelerometer data to adjust course if stuck
	Depletion of LiPo battery			
	Component failure			
	Coding error			

Table 3.2.5: Propulsion FMEA Chart

Hazard	Causes	Impacts	Risk	Mitigation Strategy
Improper assembly of motor	Incorrect spacing between propellant grains	Motor failure; unstable flight; target altitude not reached; damage or loss of rocket	1A	Ensure proper training and supervision by safety advisor for motor assembly by student safety officer
	Motor case improperly cleaned			
	End caps improperly secured			
Motor detachment from rocket body during flight	Lack of epoxy for connecting components to each other in the motor retention system	Loss of thrust; Uncontrolled flight; Target altitude not met; Main parachute may not deploy; Injury from being hit by the motor falling	1C	Finite element analysis of each component of the booster section as well as the assembly itself; Visual inspection of sufficient usage of epoxy; Ground static fire test of motor to ensure that the retention system withstands high stress
	Breakage of screws attaching the retention ring onto the body tube			

	Breakage of retention ring			
Premature propellant burnout	Improper motor assembly	Insufficient total impulse; Target altitude not reached; Main parachute may not deploy;	1C	Motor assembly by student safety officer which is overseen by safety advisor; Utilize motor from a reliable supplier;
	Insufficient propellant			
	Propellant became wet before motor assembly			
	Faulty propellant			
Centering ring failure	Centering ring's structure not durable to force	Unstable flight; Unexpected flight trajectory; Damage/loss of rocket;	2B	Usage of high yield strength material for the centering ring; Design that allows the centering ring to withstand force resulting from failure of another centering or retention ring; Visual inspection to ensure that sufficient epoxy is used in the assembly; Stress test on the centering ring
	Material used for centering ring has low yield strength			
	Insufficient epoxy used to attach the centering ring onto the body tube and motor mount tube			
Thrust plate failure	Propellant burning through motor casing	Unstable flight; Unexpected flight trajectory; Motor shoots through the rocket; Destruction of ATS system; Destruction of drogue parachute Damage/loss of rocket;	2B	Usage of high yield strength material for the thrust plate; Usage of thicker material; Visual inspection of sufficiency of the epoxy;
	Material used for thrust plate not capable to withstand the mechanical stress and thermal stress			
	Insufficient thickness			
	Insufficient epoxy used to attach the thrust plate to the body tube			
Propellant burns through casing	Improper motor assembly	Loss of thrust; Loss of stability; Destruction of ATS;	1D	Motor assembly by student safety officer which is overseen by safety advisor;

	Damage on motor casing during transportation	Unexpected flight trajectory; Destruction of drogue parachute; Loss/catastrophic failure of rocket;		Thermal/structural design analysis of thrust plate;
	Damage/destruction of thrust plate			
	Faulty propellant			
Propellant explosion	Faulty propellant	Destruction of motor casing; Loss of rocket;	1D	Motor assembly by student safety officer which is overseen by safety advisor;
	Improper motor assembly			
Propellant ignition failure	Defective igniter	Rocket does not launch; Replacement required	3B	Inspection of the igniter before launch; Inspection of the connection between the igniter and the motor, and igniter with the power source;
	Loose connection of the igniter			
	Improper motor assembly			
	Faulty propellant			
Motor misalignment	Centering rings not equally sized	Unanticipated, arched flight trajectory; Unstable flight;	3B	Manufacturing of centering ring with careful consideration of tolerance; Assembly of fins and centering rings onto the motor mount tube using fin alignment jig
	Centering rings not aligned properly			
	Fins not attached to motor mount tube perpendicularly			

Table 3.2.6: ATS FMEA Chart

Hazard	Causes	Impacts	Risk	Mitigation Strategy
ATS disintegration	Mechanical failure of components	Creates moment, Insufficient Drag	1C	Accurate stress analysis
	Loose bolts			Thorough inspection after assembly
	Threadlocker disintegration			Application of threadlocker according to the manual
ATS deployed during burnout	Wrong Input sent from Raspberry Pi	creates moment	1D	Flight simulation before actual flight
				Thorough code Inspection

No response from ATS	Depleted LiPo battery	Insufficient or excessive drag	3A	Check battery status before flight
	Depleted 9V battery			
	No input from Raspberry Pi			Flight simulation before actual flight
				Thorough code Inspection
	Wrong data from altimeters			Test/inspection before assembly
	Severed connection between altimeter and Avionics bay			Shock/vibration proof connection
	Internal failure of Motor			Test/inspection before assembly

Table 3.2.7 : Raspberry Pi and Sense HAT Failure Chart

Hazard	Impact	Cause	Risk	Mitigation Strategy
Loss of power	Loss of actuation and failure to reach target altitude; Halt in data collection; Possible data corruption	Battery drain	2C	Ensure battery is fully charged before flight
		Improper battery voltage		Maintain good care of battery, care to prevent overuse
		UBEC failure		Test proper function before flight
		Wire failure (disconnection, short)		Ensure wired connection are secure and insulated
Total GPIO Failure	Loss of GPIO; Improper signal outputs and failure to reach target altitude; Possible backpowering of data connections	Short between GPIO pins	2E	Ensure care is taken when manually altering GPIO; Insulate GPIO connections
Output Failure	Loss of actuation and failure to reach target altitude	Faulty code (blocking, improper loop termination)	2D	Extensive software testing
		Output wire failure (disconnection, short)		Ensure stable, strong, insulated wire connections
Improper calculations	Failure to reach target altitude	Faulty code	2D	Extensive software testing

3.3. Launch Concerns and Operation Procedures/Checklists

Table 3.3.1: 2017-2018 Launch Checklist

Prepare Rocket Payload	
	Ensure all batteries are new/fully charged and connect to system electronics.
	Ensure vital electronics are all connected correctly to each other and running properly.
	Ensure recovery system is wired redundantly and correctly. Ensure again.
	Insert payload electronics into the avionics bay.
	Connect all external switches and motor control outputs.
	Arm altimeter and ensure that proper startup sequence follows.
	Disarm Altimeter.
	Arm apogee targeting system and verify that startup run as expected.
Prepare Rover	
	No rover for the subscale launch
Assemble Charges	
	Remove protective cover from e-match
	Place tape adhesive side up in fishtail shape >
	CAUTION: Black powder is highly flammable. Before measurement, make sure to keep away from all sources of flame and heat
	Measure amount of black powder decided in ejection charge testing using tared massing scale
	Place e-match on tape with adhesive side up at center of fishtail
	Pour black powder over e-match
	Seal tape in square pattern
Check Chute Connections	
	Ensure altimeters are disarmed
	Connect charges to ejection wells

	Turn on altimeters to verify continuity
	Disarm altimeters
Pack Parachutes	
	Connect ends of drogue shock cord to Booster and Avionics sections
	Attach drogue parachute to drogue shock cord using quick-link carabiner or bowline knot
	Fold parachute over itself until appropriate thickness is achieved
	Fold cord between carabiner and parachute over folded parachute
	Roll parachute tightly sleeping-bag style
	Insert rolled parachute into compartment between booster section and avionics bay
	Fold excess shock cord so it does not tangle
	Attach Nomex cloth to shock cord so it will enclose and shield the parachute while exposing only the Kevlar shock cord to ejection charge
	Ensure that parachute + cloth moves easily in/out of tube. If there is any undue resistance, remove parachute and repack tighter
	Insert cellulose wadding into drogue parachute bay between ejection charges and parachute
	Insert Avionics bay into Booster section, and secure with 4 shear pins
	Attach main parachute shock cord to eye-bolt on upper end of Avionics bay and U-bolt on bottom end of nose-cone
	Attach main parachute to main parachute shock cord via quick-link carabiner or bowline knot
	Fold parachute over itself until appropriate thickness is achieved
	Fold cord between carabiner and parachute over folded parachute
	Roll parachute tightly sleeping-bag style
	Ensure that parachute + cloth moves easily in/out of tube. If there is any undue resistance, remove parachute and repack tighter
	Insert cellulose wadding into main parachute bay between ejection charges and parachute
	Insert main parachute and shock cord into main parachute bay between avionics bay and nosecone section
	Fold excess shock cord so it does not tangle

	Attach Nomex cloth to shock cord so it will enclose and shield the parachute while exposing only the Kevlar shock cord to ejection charge
	Insert cellulose wadding into upper payload parachute bay between ejection charges and parachute
	Secure avionics bay and upper tube with 4 shear pins
Assemble motor	
	Note: Do not get grease on propellant grains or delay grain
	Note: Do not install igniter
	Follow manufacturer’s instructions
	Note: ensure the motor remains vertically oriented until launch
	Unscrew motor retention cap and, while the rocket is in the upright position, slide in the assembled motor.
	Screw in motor retention cap to keep motor secure in rocket
	Check screws securing baseplate to the Booster tube to ensure they are not loose. If loose, apply a small amount of blue loctite and retighten
Launch Vehicle Prep	
	Inspect launch vehicle, check CG and make sure it is within specified range
	Bring launch vehicle to Range Safety Officer(RSO) for inspection
	CAUTION: Keep igniter clips away from all flammable materials, as sparking will occur. Cover eyes, and skin to prevent burns.
	Touch igniter clips together to make sure they will not fire the igniter when connected
	Connect igniter clips to motor igniter
Launch	
	Watch flight so launch vehicle sections do not get lost
Post Launch Payload/Vehicle Recovery	
	Use GPS (eggfinder tx) to locate launch vehicle
	Recover Payload Section and tethered Body/Booster Section
	Disarm Altimeters if there are unfired charges
	Disassemble launch vehicle, clean motor case, other parts, and inspect for damage
	Record altimeter data

3.4. Design, Construction, and Assembly Safety

3.4.1. Machining Procedures

- -

Title: Machining Metal Components

Min Personnel Requirements: 2 people

Materials (ref 3.6. Material Handling)

- Metal (conglomerates and particulates)

Safety Equipment Required

- Safety glasses
- Safety gloves

Material Preparation

- Ensure clean material surface
- If surface finish is important, can sandwich workpiece in between to piece of wood, or place tape over surface for finer cutting procedures
- Pre-measure and mark up surface of material to designate cutting lines
- Have a dimension drawing for the part readily available for reference

Workspace Preparation & Precautions

- N/A

Power Sawing

1. Ensure metal piece is not too thick. Most bandsaws do not support cutting pieces of aluminum over .25”, and that number is even lower for steels

2. While tool is off, clean the area and tool of any dust or left over metal shavings
3. Ensure correct blade is being used (metal not wood)
4. Lower blade guard so the the bottom of it is as close to the top surface of the metal as possible
5. Turn on
6. Set correct speed for material being cut (slower for metals)
7. Ensure another person is supervising
8. Hold the metal firmly with two hands
9. Ensure hands are not positioned in a way that could cause them to run into blade if metal suddenly gives
10. Begin cut, be patient and precise

Water-jetting

1. Ask PI for supervision or help setting up the waterjet
2. Ensure workpiece is flat
3. Clamp workpiece to constrain x and y axis movement. This step is critical as the waterjet creates large forces and vibrations that have high tendencies to shake parts loose and ruin the operation.
4. Ensure that position of jet cutter is centered above piece
5. Ensure path of jet never leaves the workpiece
6. Ensure “kerf”, or jet diameter is on correct side of cutting line to achieve desired dimensions
7. Adjust offset height from workpiece
8. Raise water level between .25” and .5” above the workpiece
9. Make sure waterjet settings are set to cut the specific metal being used

Drilling

1. Measure location of hole

2. If needed, mark or create indentation at the center of the hole. An indentation will help prevent the bit from traveling. These are commonly done with a center punch
3. Align and clamp material in place to prevent workpiece from coming loose and spinning around drill bit during drilling
4. Find appropriate drill speed for type of metal being used
5. Avoid slow drilling speeds, as they tend to cause the drill bit to “bite” into the metal and create a screw-like effect
6. Blow off any metal shavings or dust as those can build up and not only damage the surface of the workpiece, but also cut flesh
7. Use a deburring tool to smooth the edges of the hole
8. To clean the inside walls of the hole, set the drill to a high speed and slowly move it through the center of the hole

Safety Officer Signature: ______________________________

- -

Title: Machining Wood Components

Min Personnel Requirements: 2 people

Materials (ref 3.6. Material Handling)

- Wood (conglomerates and particulates)

Safety Equipment Required

- Safety glasses
- Safety gloves

Material Preparation

- Ensure clean material surface

- If surface finish is important, can sandwich workpiece in between to piece of wood, or place tape over surface for finer cutting procedures
- Pre-measure and mark up surface of material to designate cutting lines
- Have a dimension drawing for the part readily available for reference

Workspace Preparation & Precautions

- N/A

Power Sawing

1. While tool is off, clean the area and tool of any dust or left over wood
2. Turn on ventilation system
3. Ensure correct blade is being used (wood not metal)
4. Lower blade guard so the the bottom of it is as close to the top surface of the wood as possible
5. Turn on
6. Set correct speed for material being cut
7. Ensure another person is supervising
8. Hold the wood firmly with two hands
9. Ensure hands are not positioned in a way that could cause them to run into blade if wood suddenly gives
10. Begin cut, be patient and precise

Water-jetting

1. Ask PI for supervision or help setting up the waterjet
2. Ensure workpiece is flat
3. Clamp workpiece to constrain x and y axis movement. This step is critical as the waterjet creates large forces and vibrations that have high tendencies to shake parts loose and ruin the operation.
4. Ensure that position of jet cutter is centered above piece

5. Ensure path of laser never leaves the workpiece
6. Ensure “kerf”, or jet diameter is on correct side of cutting line to achieve desired dimensions
7. Adjust offset height from workpiece
8. Ensure water level does not contact workpiece, or wood will become soggy and warp

Laser-cutting

1. Ask PI for supervision or help setting up the laser cutters
2. Ensure workpiece is flat
3. Place tape on surface of workpiece if surface finish is important
4. Ensure that position of laser cutter is centered above piece
5. Ensure path of laser never leaves the workpiece
6. Adjust laser offset height from workpiece to achieve optimal focal length

Drilling

1. Measure location of hole
2. If needed, mark or create indentation at the center of the hole. An indentation will help prevent the bit from traveling. These are commonly done with a center punch
3. Align and clamp material in place to prevent workpiece from coming loose and spinning around drill bit during drilling
4. Find appropriate drill speed for density of wood being used
5. Avoid slow drilling speeds, as they tend to cause the drill bit to “bite” into the wood and create a screw-like effect
6. Blow off any wood shavings or dust
7. Use a deburring tool to smooth the edges of the hole
8. To clean the inside walls of the hole, set the drill to a high speed and slowly move it through the center of the hole

Safety Officer Signature: ____________________________

- -

Title: Soldering

Min Personnel Requirements:1 person

Materials (ref 3.6. Material Handling)

- Unleaded Solder
- Soldering Iron
- Helping Hands

Safety Equipment Required

- Safety glasses
- Safety gloves

Material Preparation

- Inspect material for cracks or other structural defects
- Turn on the soldering iron and allow it to heat ensuring it kept in a safe orientation
- Tin the tip of the soldering iron with a small dot of solder
- Secure the workpiece in the helping hands soldering jig

Workspace Preparation & Precautions

- Ensure all flammable / combustible materials are clear of the soldering area
- Ensure solder tip is clean
- Make sure to wash your hands at the end of work

Soldering

1. Insert all electrical components to be connected into protoboard
2. Bend the ends of the components to ensure they do not move while soldering

3. Touch tip of soldering iron and solder to the component lead to be soldered from the back side of the board.
    a. Be careful to use only the amount of solder needed to secure the connection
4. Visually inspect your work to ensure the correct components are soldered together and no short circuits have been inadvertently created.

Safety Officer Signature: ______________________________

- -

<u>Title: LiPO Charging</u>

Min Personnel Requirements:1 person

Materials (ref 3.6. Material Handling)

- LiPO Battery
- Charging transformer

Safety Equipment Required

- Safety glasses
- Safety gloves

Material Preparation

- Inspect battery for bulges, punctures, and other forms of physical damage
- Take care to prevent the battery voltage from dropping below the allowable recharge threshold

Workspace Preparation & Precautions

- Ensure all flammable / combustible materials are clear of the charging area

- Ensure the charger is set to the correct recommended safe settings for the battery to be charged.

Charging

Special Care must be taken to ensure battery is never left unattended during a charge cycle, allowed to overheat, be punctured, or otherwise damaged else serious injury may occur.

1. Plug the charging transformer into the wall and double check the settings and the battery type to be charged.
2. Plug in the battery's charging lead to the appropriate receptacle on the charging transformer
3. Begin the charge cycle

Safety Officer Signature: ______________________________

- -

3.5. Material Handling

Table 3.6.1: Common Materials Used and their Properties

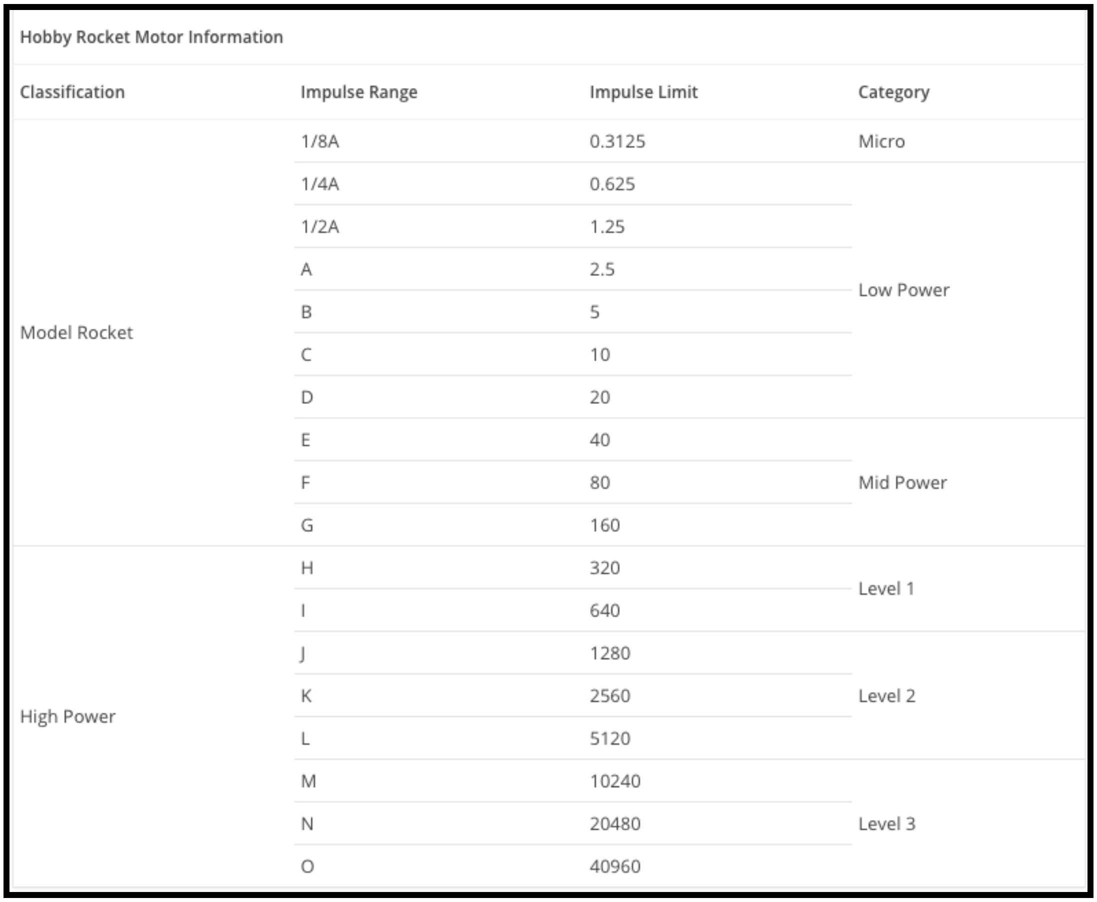
Material	Description	Density (kg/m^3)	Young's Modulus (GPa)	Shear Strength (MPa)	Compressive Strength (MPa)	Flammability
Balsa (longitudinal HD)	Tropical, light wood used in model building, packaging, and insulation	240 - 300	7.2 - 8.8	4.5 - 5.6	18 - 26	High
Balsa (transverse HD)	Tropical, light wood used in model building, packaging, and insulation	240 - 300	0.23 - 0.28	13.5 - 16.8	1 - 1.45	High
Balsa (longitudinal LD)	Tropical, light wood used in model building, packaging, and insulation	120 - 140	2.8 - 3.4	2.2 - 2.7	6.2 - 9.5	High
Balsa (transverse LD)	Tropical, light wood used in model building, packaging, and insulation	120 - 140	0.09 - 0.11	6.6 - 8.1	0.5 - 0.85	High
ABS	Thermoplastic commonly used in 3D printing/molding	1020 - 1080	2 - 2.9		35.9 - 69	High
ABS (15% carbon fiber)	Thermoplastic commonly used in 3D printing/molding	1100 - 1140	10.3	52 - 62.9	109 - 120	High
Basswood (longitudinal)	Hardwood	370 - 460	10 - 12.2	6.1 - 7.5	29.4 - 35.9	High
Basswood (transverse)	Hardwood	370 - 460	0.43 - 0.48	18.4 - 22.4	2.3 - 2.81	High
Carbon Fiber (PEEK)	Used as resin for aerospace app.	1420 - 1440	20.7 - 25		172 - 240	Self - Extinguishing
PC (30% glass fiber)		1400 - 1430	8.62	9.65	124 - 138	Self - Extinguishing
G12CR Fiberglass		1810	21 - 24	152	448	Low
G10/Fr-4 Fiberglass		1850	21 - 24	152	448	Flame - retardant
Polyurethane Foam	Used as impact pads, insulation, packaging	75 - 85	0.00033 - 0.0004	0.0125 - 0.015	0.025 - 0.03	Self - Extinguishing
Phenolic	Used in heat shields	62.7 - 65.3	0.000489 - 0.00123	1.05 - 1.16	3.87 - 4.27	Self - Extinguishing

3.6. Vehicle Safety

Refer to FMEA charts in section 3.2

3.7. Purchase, Shipping, and Transporting of Rocket Motors

Rocket motors are designated by their impulse limits, as shown below. Since we are using an L1390 motor, our motor is consider a Class 2 High Power Rocket Motor.



Hobby Rocket Motor Information

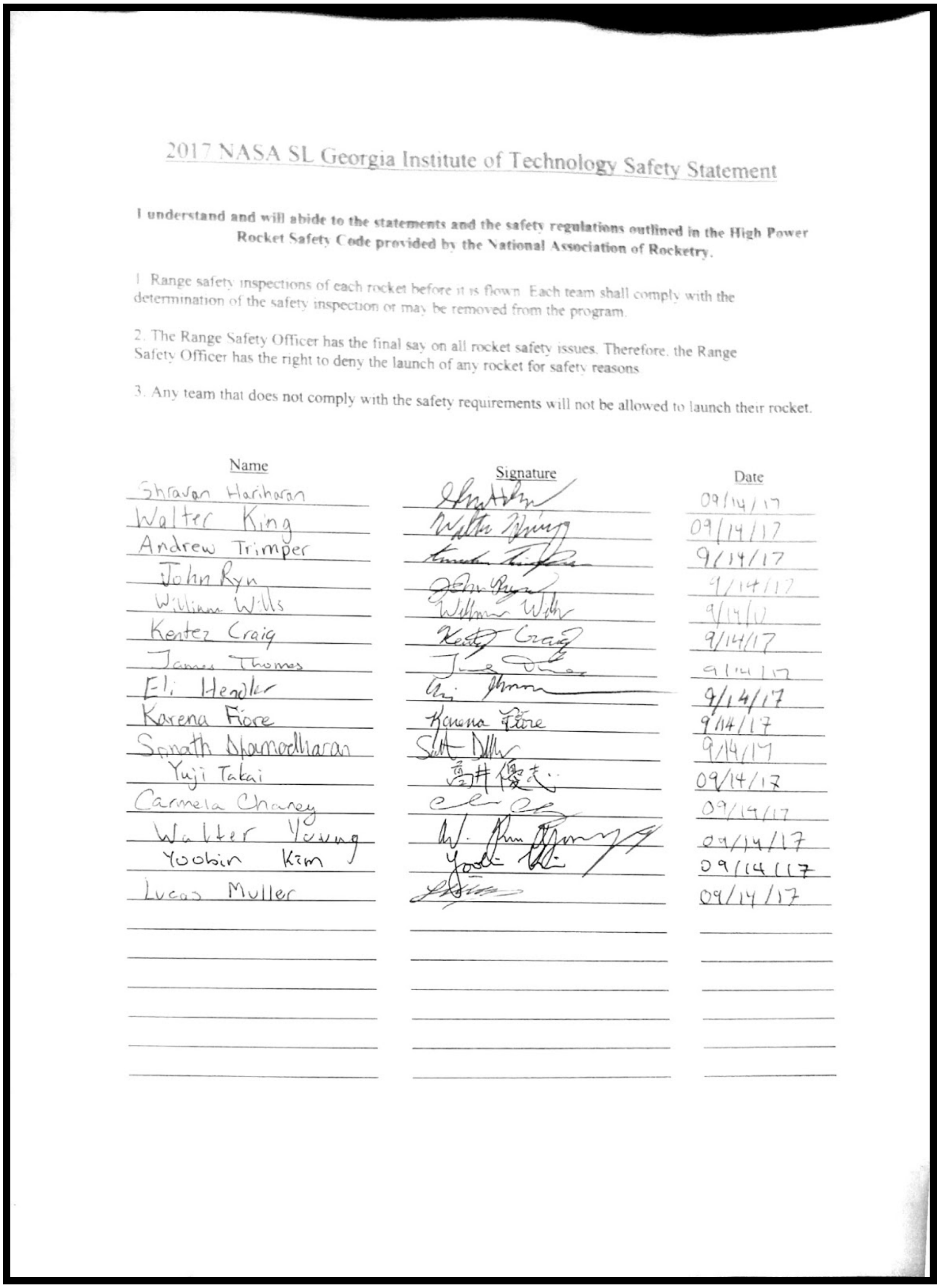
Classification	Impulse Range	Impulse Limit	Category
Model Rocket	1/8A	0.3125	Micro
	1/4A	0.625	Low Power
	1/2A	1.25	
	A	2.5	
	B	5	
	C	10	
	D	20	
	E	40	Mid Power
	F	80	
	G	160	
High Power	H	320	Level 1
	I	640	
	J	1280	Level 2
	K	2560	
	L	5120	
	M	10240	Level 3
	N	20480	
	O	40960	

Figure 3.8.1: Rocket Motor Classification (www.nar.org)

Our rocket motor will be purchased from an authorized, commercial retailer. Any motor purchases will be made by our Level 2 Certified mentor. Motors will not be tampered with in any way. Handling of these motors will be in compliance with Government regulation and NAR/Tripoli standards.

Rocket motors are composed of high-energy propellant and flammable materials, and are thus considered “hazardous materials”. Motors will be purchased in person from an authorized retailer, and transported back to the University in fire-resistant chests, well packed with dampening material to mitigate the possibilities of propellant damage. From there, motors will be unloaded and placed into fire-cabinets in a dry environment, where they will remain, untouched, until they are transported to the launch site in fire-resistant chests aboard our vehicles.

3.8. Team Safety Agreement



2017 NASA SL Georgia Institute of Technology Safety Statement

I understand and will abide to the statements and the safety regulations outlined in the High Power Rocket Safety Code provided by the National Association of Rocketry.

1. Range safety inspections of each rocket before it is flown. Each team shall comply with the determination of the safety inspection or may be removed from the program.

2. The Range Safety Officer has the final say on all rocket safety issues. Therefore, the Range Safety Officer has the right to deny the launch of any rocket for safety reasons.

3. Any team that does not comply with the safety requirements will not be allowed to launch their rocket.

Name	Signature	Date
Shravan Hariharan		09/14/17
Walter King		09/14/17
Andrew Trimper		9/14/17
John Ryn		9/14/17
William Wills		9/14/17
Kentez Craig		9/14/17
James Thomas		9/14/17
Eli Hendler		9/14/17
Karena Fiore	Karena Fiore	9/14/17
Sanath Dhamodharan		9/14/17
Yuji Takai	高井優志	09/14/17
Carmela Chaney		09/14/17
Walter Young		09/14/17
Yoobin Kim		09/14/17
Lucas Muller		09/14/17

Figure 3.9.1: Team Safety Agreement

4. Launch Vehicle

4.1. Final Vehicle Design

The bulk of the launch vehicle will be built from G12 and G10 fiberglass, aluminum 6061, plywood, and ABS plastic. In order to reach the target apogee of 5,280 ft by inducing drag with the Apogee Target System (ATS), the designs were chosen to minimize mass while retaining strength. The overall specification of the launch vehicle is summarized in the table below.

Table 4.1.1 Overall specification of the launch vehicle

Overall Specs	Value
Overall Length	107 in
Launch Vehicle Diameter	5.562 in
Overall Mass	37.38 lb
Center of Gravity (measured from nose cone)	71.336 in
Center of Pressure (measured from nose cone)	82.897 in

The launch vehicle consists of the five sections - nose cone section, rover housing section, avionics bay, drogue parachute section, and booster section. The two figures below depict the location of each section and of systems within the sections, and the table following describes the systems included in the sections, and the mass and the length of each section.

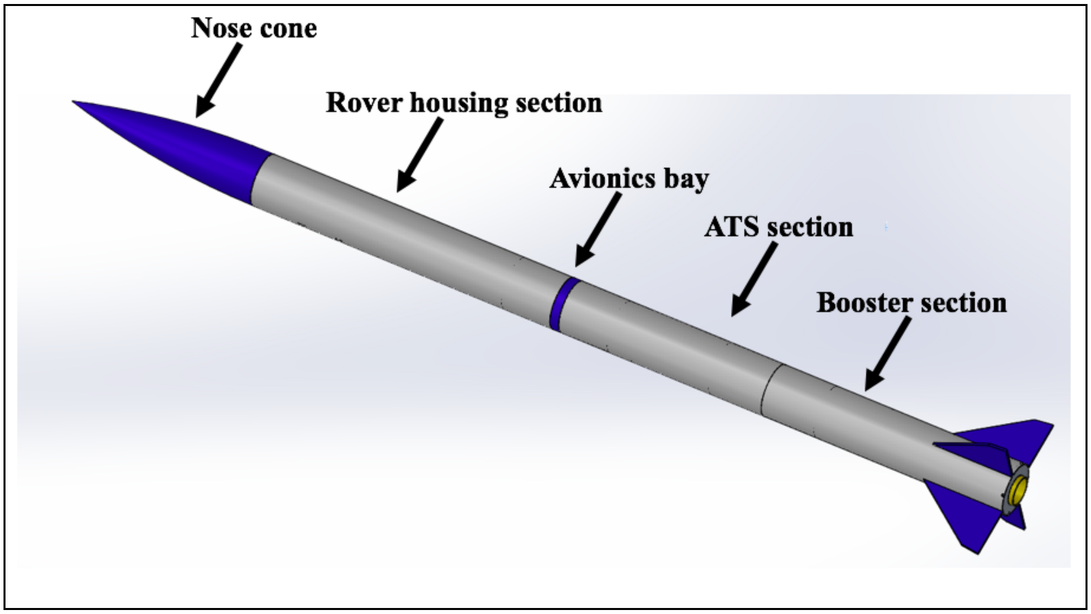


Figure 4.1.1 Five sections of the launch vehicle

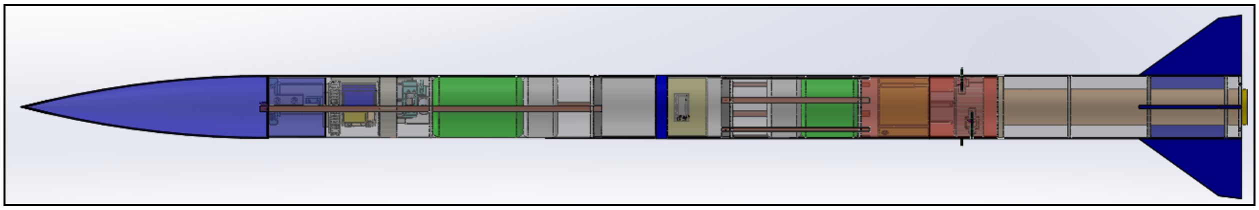


Figure 4.1.2 Systems within the sections

Each section of the rocket except for the nose cone is housed in a G12 5.5" fiberglass tube. The table below shows the different sections of the rocket, main specifications about each section, and the systems that they contain:

Table 4.1.2 Systems, mass and length of each section

Section	Systems	Mass (lb)	Length (in)
Nose cone	GPS	1.06	21.75
Rover housing section	Rover Rover deployment system Main recovery system	8.69	34.00
Avionics bay	Avionics	4.00	12.50
ATS section	Drogue recovery system Apogee Target System	7.13	23.00
Booster section	Propulsion system	16.50*	27.40

* mass with the propellant mass

The nose cone only houses the GPS system, and the purpose of the GPS system is to be able to find the rocket after flight. The rover housing section house the rover and deployment system, and the main recovery system. The rover will not deploy until landing, where it will drive out and deploy solar panels. The main recovery system deploys 800 ft in the air before landing, and slows the rocket down before landing. The avionics bay housing the control center for the electrical components of the rocket. The ATS section contains both the drogue recovery system which slows the rocket down directly after reaching apogee, and the Apogee Target system which adjusts the drag on the rocket to get as close to the target apogee as possible. Finally, the booster section houses the propulsion system which will provide thrust to the rocket. Additionally, the fins are housed on the exterior of the booster section.

During the flight of the launch vehicle, there will be two separation events. The first separation occurs between the between the ATS section and the avionics bay for the drogue parachute deployment. The avionics bay is secured to the ATS section with shear pins. After the altimeter detects that the rocket has ascended to apogee, the ejection charge will be ignited, breaking the shear pins and separating the two sections. The two sections will be tethered via 240 inch shock cord which has the drogue parachute attached.

The second separation occurs between the rover bay and the avionics bay for the main parachute deployment. The rover housing section will also be secured to the avionics bay via shear pins during the vertical ascent of the launch vehicle. After the altimeter within the avionics bay detects that the rocket has descended to 800 ft, the ejection charge on the front end of the avionics bay will be ignited, breaking the shear pins. The rover section with the nose cone will be secured to the avionics with another 240 inch shock cord.

The booster section and ATS section will not be separated during the flight of the launch vehicle. In case any fixture of the ATS is required, the two sections are locked to each other via rivets rather than epoxy, allowing easy separation on ground while securing tight connection during flight.

After the launch vehicle has successfully landed on the ground and receives the radio signal from our team, the nose cone will be separated from the rover housing section by the brackets on the steel rods of the rover deployment system. The design of the deployment system was chosen so that the nose cone will not separate from the rover housing section under any circumstance during the flight. The following figure shows the full assembly of the rocket exploded, illustrating the key sections and systems, and the following table summarizes the separation modes between the sections.

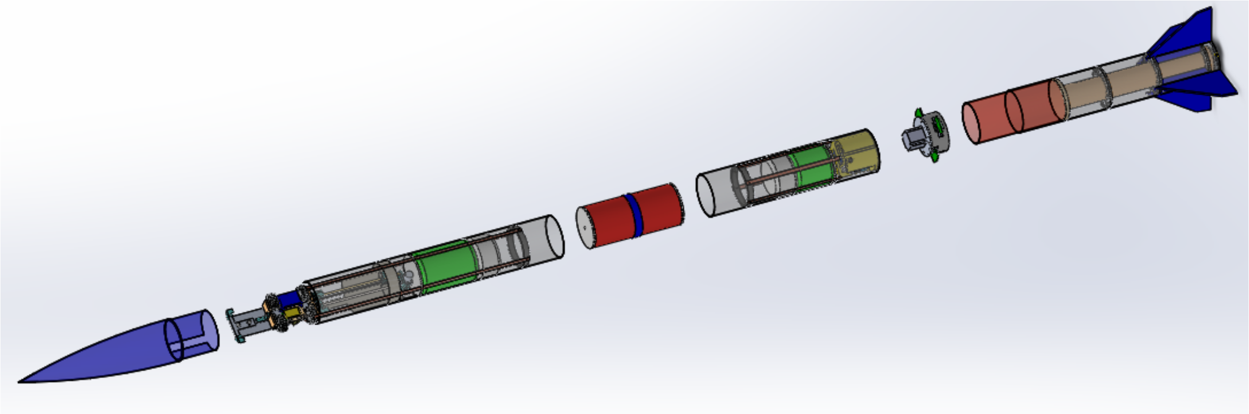


Figure 4.1.3 Exploded view of the launch vehicle

Table 4.1.3 Separation mode and events for each separation points

Location	Separation Mode	Separation Event
Nose Cone + Rover Tube	Supporting beams from rover tube	Rover deployment
Rover Tube - Avionics Bay	Shear Pins	Main parachute deployment
Avionics Bay - ATS Tube	Shear Pins	Drogue parachute deployment
ATS Tube + Booster Stage	Rivets	Not applicable

4.1.1. Mission Statement/Success Criteria

The missions of the launch vehicle are to deliver a payload to 5,280 ft above ground, to recover safely onto the ground, and to deploy the rover. The success of the mission will be determined based on the following criteria:

1. The launch vehicle ascents with a vertical trajectory
2. The launch vehicle with the payload reaches an apogee of 5,280 ± 50 ft
3. The drogue and main parachutes deploy at the programmed altitude
4. The launch vehicle safely recovers to ground, each section satisfying the kinetic energy requirements
5. The motor is retained throughout the flight
6. The rover is deployed from the launch vehicle with remote control
7. The rover autonomously drives away from the vehicle for more than 5 feet
8. The rover deploys its solar panel

4.1.2. Design integrity

Structural design of the launch vehicle

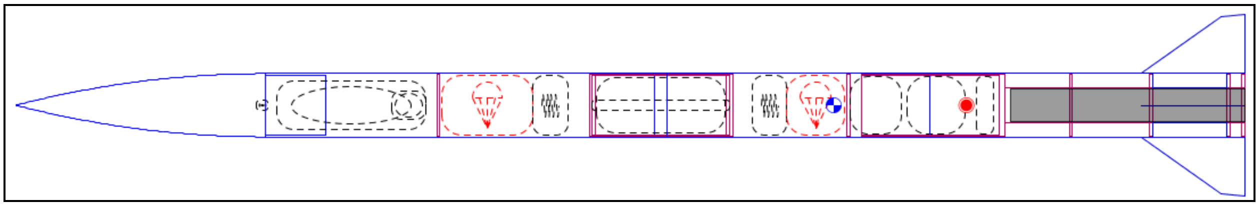


Figure 4.1.4 Layout of the launch vehicle

The figure above is the layout of the sections and their systems of the launch vehicle generated by OpenRocket. From the top to the bottom, there are the nose cone, rover and rover deployment system, the main parachute and the shock cord, the avionics bay, the drogue parachute and the shock cord, the ATS, and the booster section. While the positions of the nose cone, avionics bay and the booster section were fixed, our team had the freedom in locating the rover system, main parachute, drogue parachute, and the ATS system.

If the main recovery system were placed above the rover system, the rover housing tube would have to be cut into two tubes so that rover could deploy from the rocket. This will lose the structural integrity of the launch vehicle hence the rover system is placed above the main recovery system, separating the nose cone from the body tube for deployment. The rover system is a payload hence placing it towards the nose cone will also move the CG upwards, increasing the stability of the rocket.

Although the wires for actuating the ATS will be broken every time the drogue parachute is deployed, the ATS had to be placed below the drogue parachute because it is required to have any drag inducing system to be located below the CG. Moreover, in order to avoid any change in CP and thus the stability of the rocket, it was desirable to have the ATS at a position close to the CP which is at the lower point of the rocket. Hence, the ATS was determined to be placed between the drogue parachute compartment and the booster section.

The airframe of the rocket will be made from 5.5 inch diameter G12 filament wound fiberglass tube. Investigation on the effect of the diameter of the rocket, having the length of the rocket constant, was conducted as in the PDR. The team discovered that 6 inch diameter fiberglass tube will result in a higher mass with lower stability than the 5.5 inch and that 5 inch diameter tube will have a higher stability yet less space for packing the avionics in the avionics bay than the 5.5 inch. The assessment combined with the fact that the team already has a stock of 5.5 inch fiberglass tube led to the conclusion that such tube will be used as the core body of the rocket. Although cardboard tubes are lighter than the fiberglass tubes, they will not withstand the high pressure due to the high acceleration of the rocket, and hence fiberglass which has high strength was chosen as the material for the body tube.

The length of the rover housing body tube and the ATS body tube were increased from the PDR, making the overall length of the rocket to increase from 102 inches to 107 inches. The reason for this change was the team's underestimation of the packing volume of the parachutes. Before the subscale launch, the team underwent a difficulty of packing the drogue parachute since the estimation for the packing density was not sufficient that the drogue parachute could not be packed into its compartment. From this experience, the estimation of the packing densities of both main and drogue parachute were revised, resulting in an increase in the length of the body tubes. This increase in length caused a change in the mass and the stability of the rocket, resulting in the change of design of the fins as discussed later in this section.

Nose cone

The purpose of the nose cone is to reduce drag on the rocket and house the GPS for locating the rocket after landing. The team has decided to utilize the 5.5 inch Fiberglass ogive nose cone with a 4:1 length to diameter ratio, manufactured by Madcow Rocketry, which is shown below.

Figure 4.1.5 CAD drawing of the nose cone

The key properties of the nose cone is summarized in the table below.

Table 4.1.4 Key properties of the nose cone

Properties	Values
Gross Mass	20.96 oz (594.21 g)
Nose Length	21.75 in (55.25 cm)
Shoulder Length	5.25 in (13.34 cm)
Outside Diameter	5.50 in (13.97 cm)
Should Diameter	5.28 in (13.41 cm)

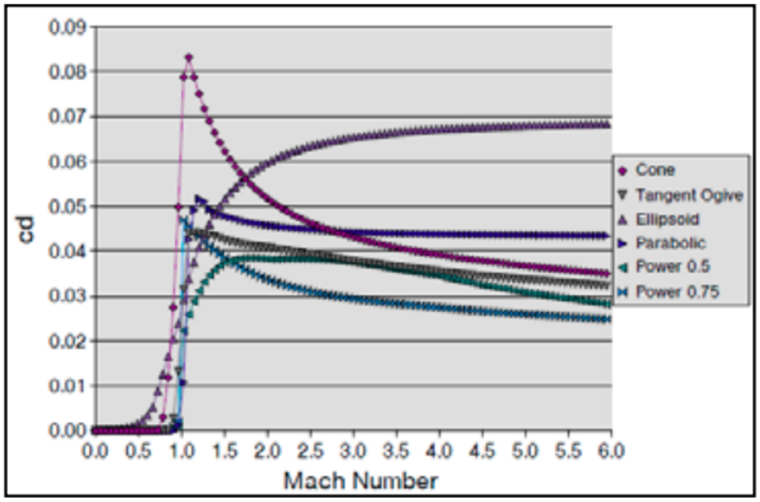


Figure 4.1.6 Drag coefficients for different nose cone shape

Figure above shows the experimentally determined coefficients of drag for different nose cone shapes. According to the diagram, the worst shapes for low velocities are the ellipsoid and conical shapes. The best performing shapes at all velocities are the Power .75 shapes and the Tangent Ogive shape. The Tangent Ogive is the last shape to ramp up in its drag coefficient. Additionally, the drag coefficient increases gradually compared to other shapes. Therefore, it was recommended to select the Tangent Ogive nose cone shape.

Commercial available G10 fiberglass nose cone was selected rather than 3D printing a nose cone because the melting point of ABS plastic is around 221 °F, which may be reached during the flight due to the air friction on the nose cone. G10 fiberglass, on the other hand, has a higher melting point, being capable of maintaining its structural integrity throughout the flight. Thus, G10 fiberglass was chosen as the material of the nose cone.

Bulkheads

The material that will be used for bulkheads is G10 fiberglass. The choice of the material was based on its strength to withstand the impulse caused by the ejection charge of the parachute deployments. When plywood and fiberglass were considered as potential materials, although plywood is less dense, it has too low strength that very thick bulkhead would be required to withstand the force applied by the parachute deployment. This will lead to an increase in the length of the body tube, corresponding to the increase in mass of the rocket and reduction in the apogee altitude. G10 fiberglass, on the other hand, has great strength that allows it to withstand the impulse of ejection charge with the thinner thickness. This will contribute to less body tube and thus less mass of the rocket.

The thickness of the bulkheads have been changed from 3/8 inch in the PDR to 1/4 inch since the bulkhead will still have a safety factor above two with this thickness. The bulkheads must be able to withstand the force of the ejection charge or a 155 pound force. The finite element analysis of the bulkhead subjected to the force due to ejection charge is shown below.

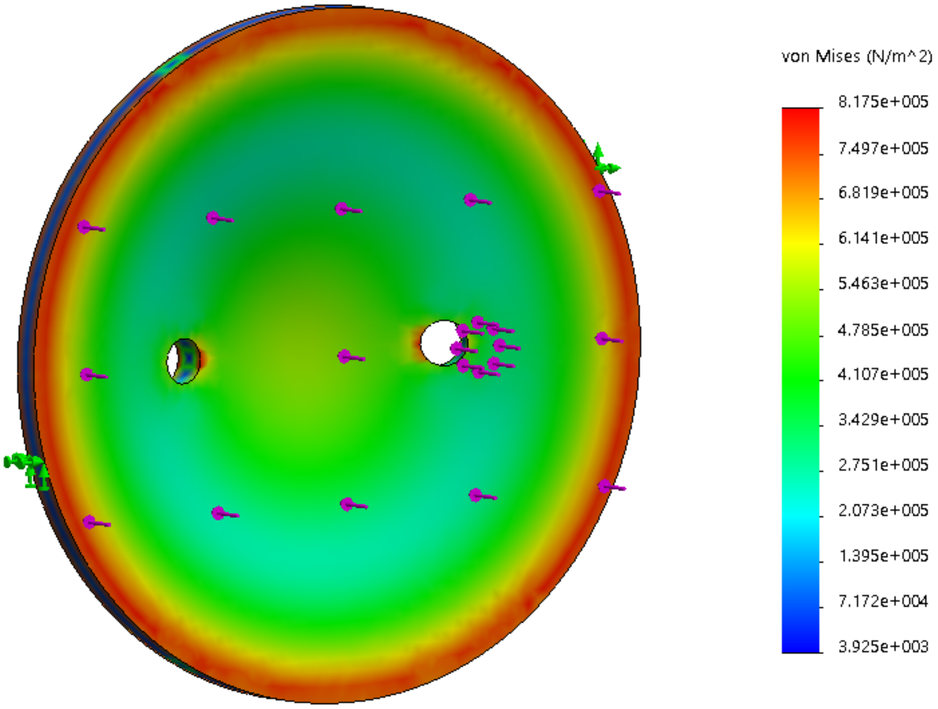


Figure 4.1.7 FEA Stress on Bulkhead

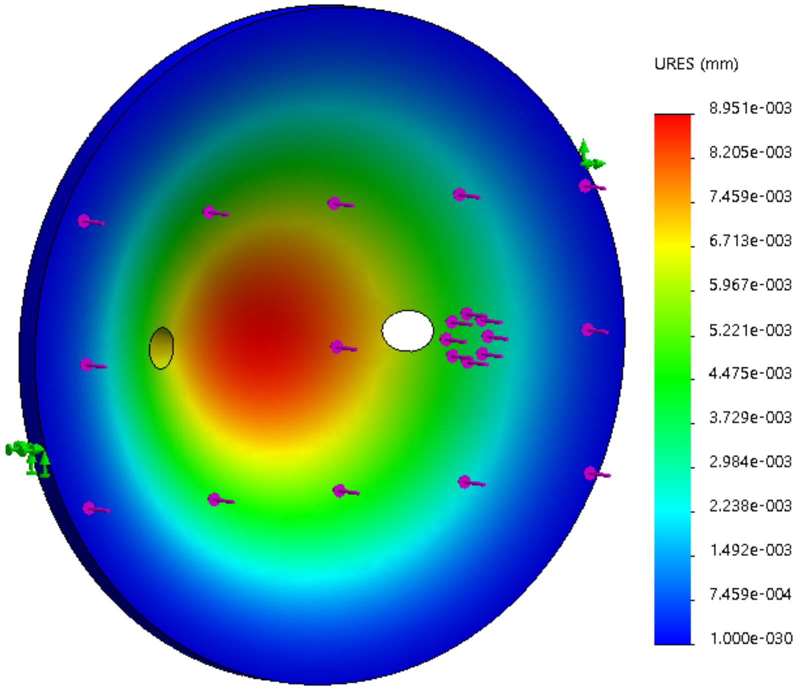


Figure 4.1.8 FEA Displacement of Bulkhead

As seen in the figures above, the maximum stress of the bulkhead was 8.175*10^5 N/m^2, which is below the yield strength of 1.38*10^7 N/m^2. The factor of safety for the bulkhead is therefore 16.8. The maximum deflection of the bulkhead will be 8.95*10^-3 mm, which is acceptable for our purposes.

Booster Section

Motor mount tube

The motor mount tube functions as the housing of the motor casing and the motor. It will be manufactured by cutting a 75mm brown kraft paper (LOC) tube into 21 inches, the length of the motor. Brown kraft paper rather than fiberglass was adapted as the material of the tube since brown kraft paper has light density and is strong enough to resist deformation by the impact of landing. The motor mount tube with the centering rings will assure the motor to be aligned properly with the entire launch vehicle.

Fin design

Although additional weight is added, the launch vehicle utilizes four fins in order to meet the minimum static stability margin requirement as well as to be consistent with the ATS system. Since the ATS system employs four flaps, the number of fins must be identically four in order to prevent any airflow to change the direction or stability of rocket during the actuation of the ATS. The fins will be machined from G10 fiberglass using OMAX Waterjet. As already written, the shape of the fin had to be modified from the version in PDR due to the change in stability associated with the change in the length of the launch vehicle. The figure below illustrates the detailed drawing of the fin.

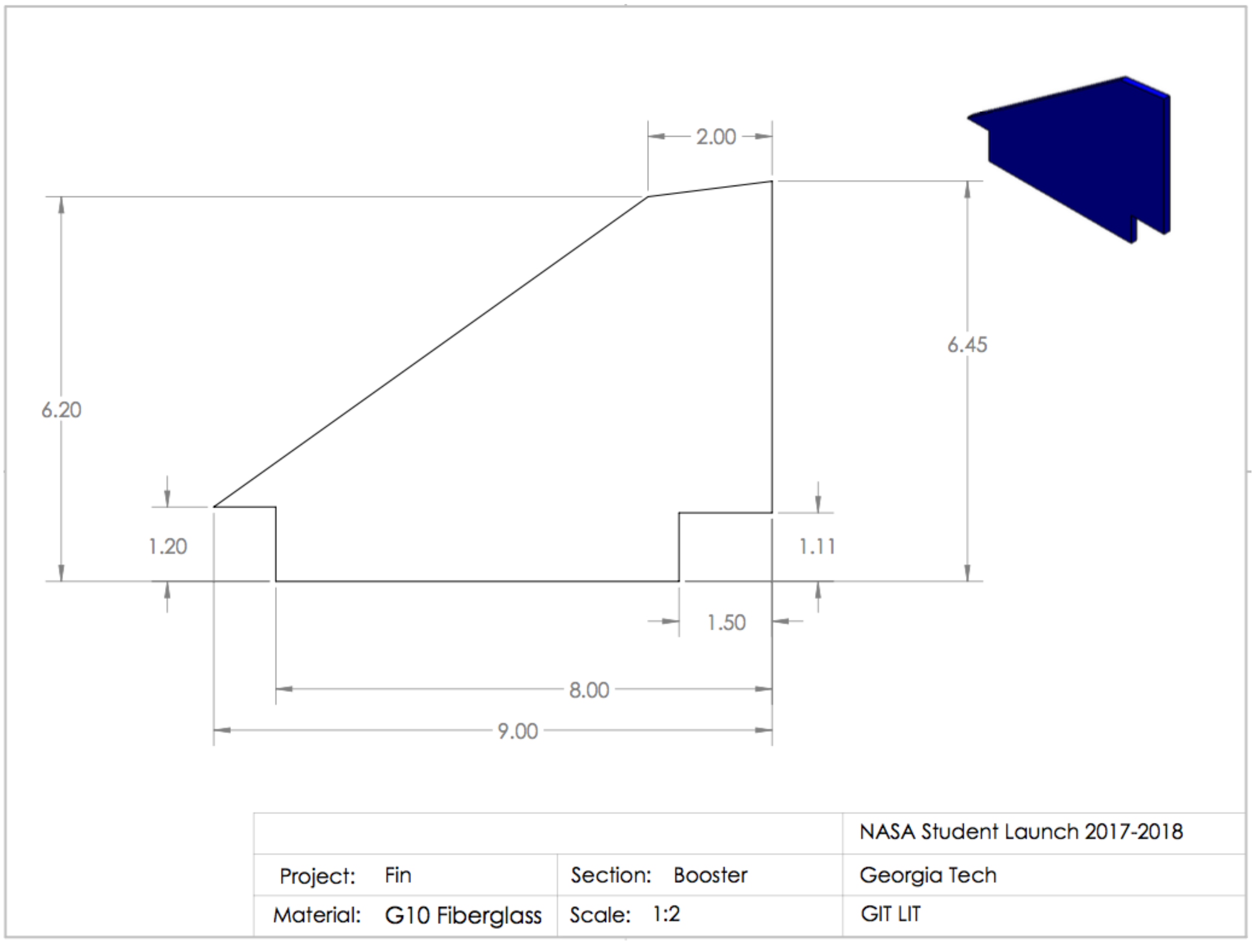


Figure 4.1.9 Fin detailed drawing

Although most of the dimensions are the same as the ones in the PDR, the length of a side of the fin was increased from 6.20 inches to 6.45 inches, in order to purposely produce more aerodynamic force and lower the CP, ultimately increasing the stability of the launch vehicle. The material used for the fins will be G10 fiberglass, due to its high strength to withstand the force applied at landing. The thickness of the fins is 1/4 inch, which is not too low to break at ground contact and not too high to increase the mass of the booster section unnecessarily and reduce stability. The general design of the fin was chosen by iterative alternation of the design until the stability margin of the launch vehicle became above 2.0 at rail exit as required. The design with some portion of the fins going below the bottom of the rocket was avoided since there was a possibility that such portion may chip off with the some landing orientation.

Thrust plate

The main two roles of the thrust plate are to prevent the motor from ejecting through the launch vehicle and to protect the ATS payload from the hot air ejected from the motor. The thrust plate will be manufactured from 1/2 inch plywood using Trotec laser cutter. The drawing of the part is shown below. The thrust plate has a diameter of 5.5 inches.

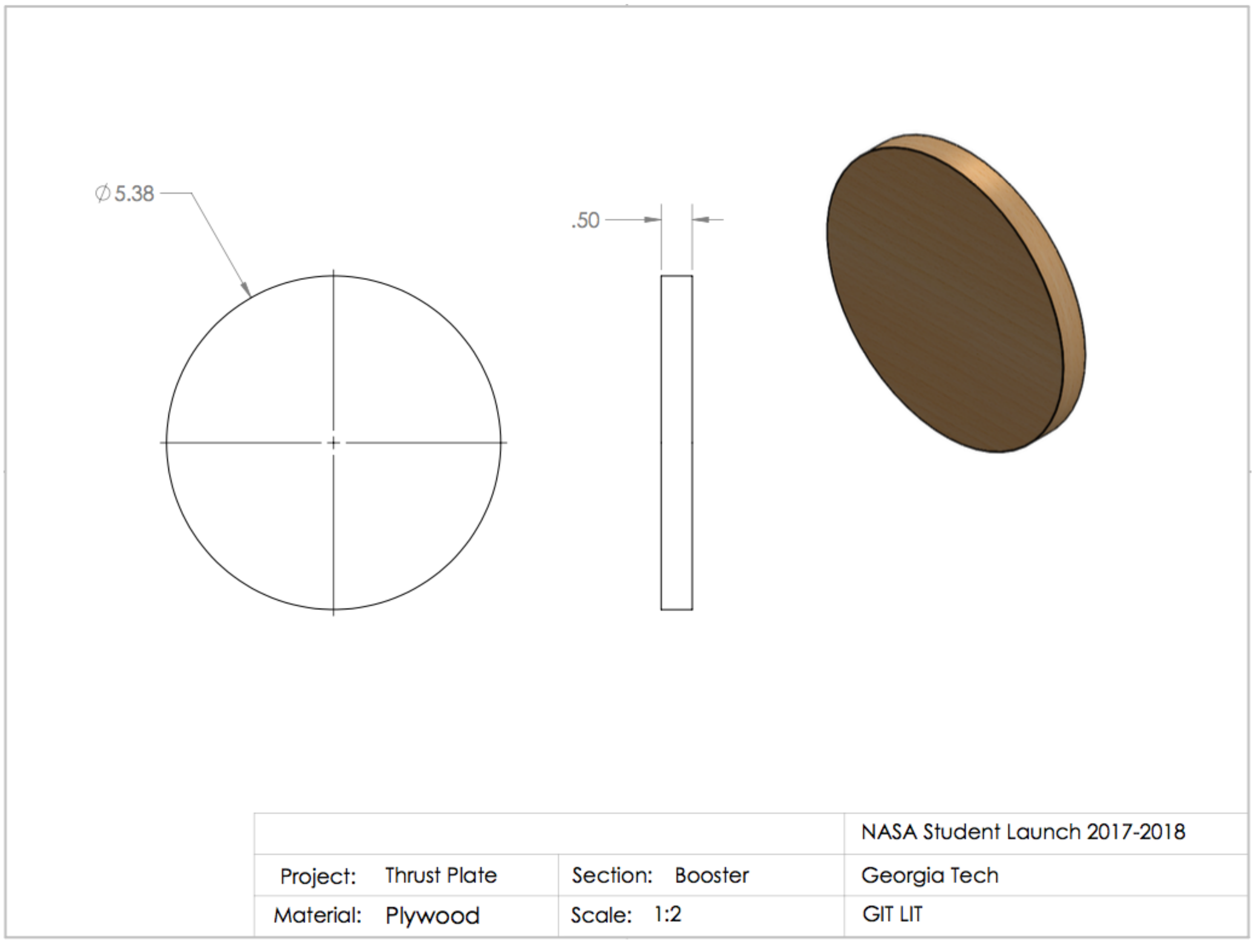


Figure 4.1.10 Thrust plate detailed drawing

Centering rings

The centering rings will be constructed from 6061-aluminum using OMAX Waterjet. The number of centering rings used is increased from two to three from PDR to CDR in order to ensure stable alignment of the motor to the launch vehicle. All the centering rings have a circular hole in the middle through which the motor mount tube goes through. The detailed drawing with essential dimensions of the centering rings is shown below:

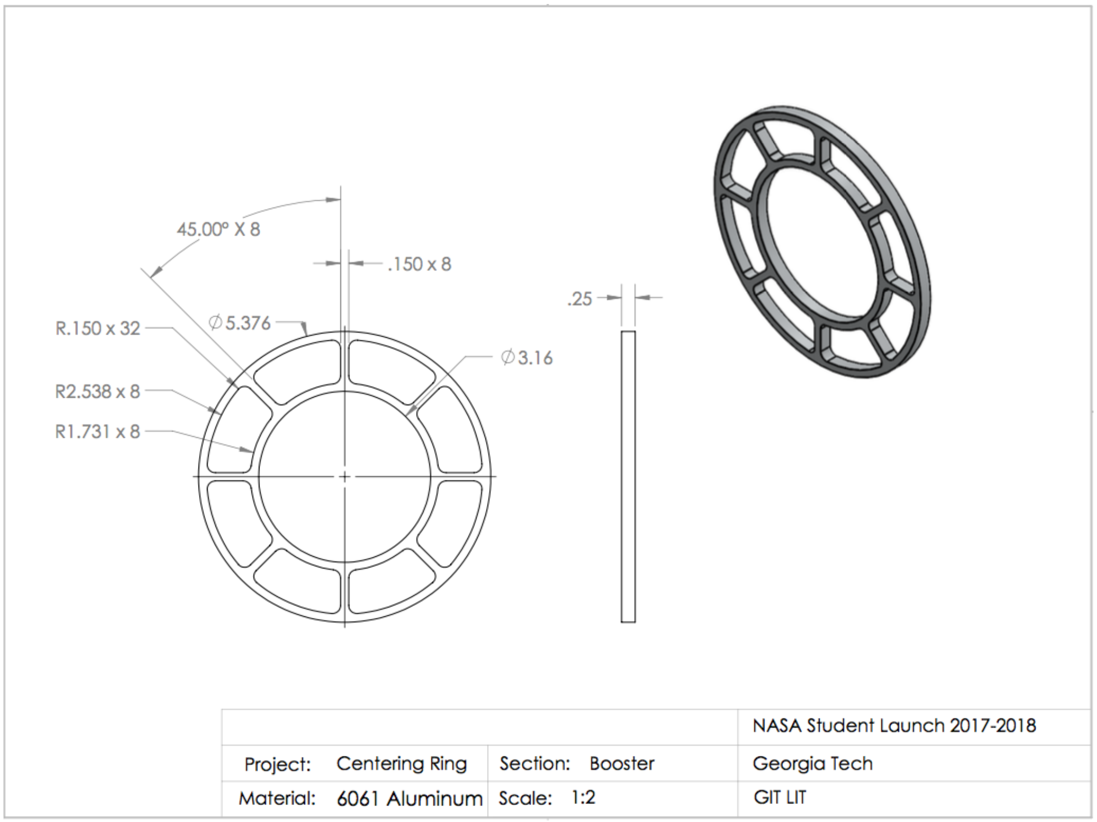


Figure 4.1.11 Centering ring detailed drawing

Retention ring

The retention ring ensures that the motor remains in its proper location within the launch vehicle throughout its mission. Identically to the centering rings, the retention ring will be machined from 6061-aluminum using OMAX Waterjet. After the motor is installed into the motor mount tube, the retention ring will be attached to the brackets inside the booster stage airframe by screws. The figure below shows the detailed drawing of the retention ring.

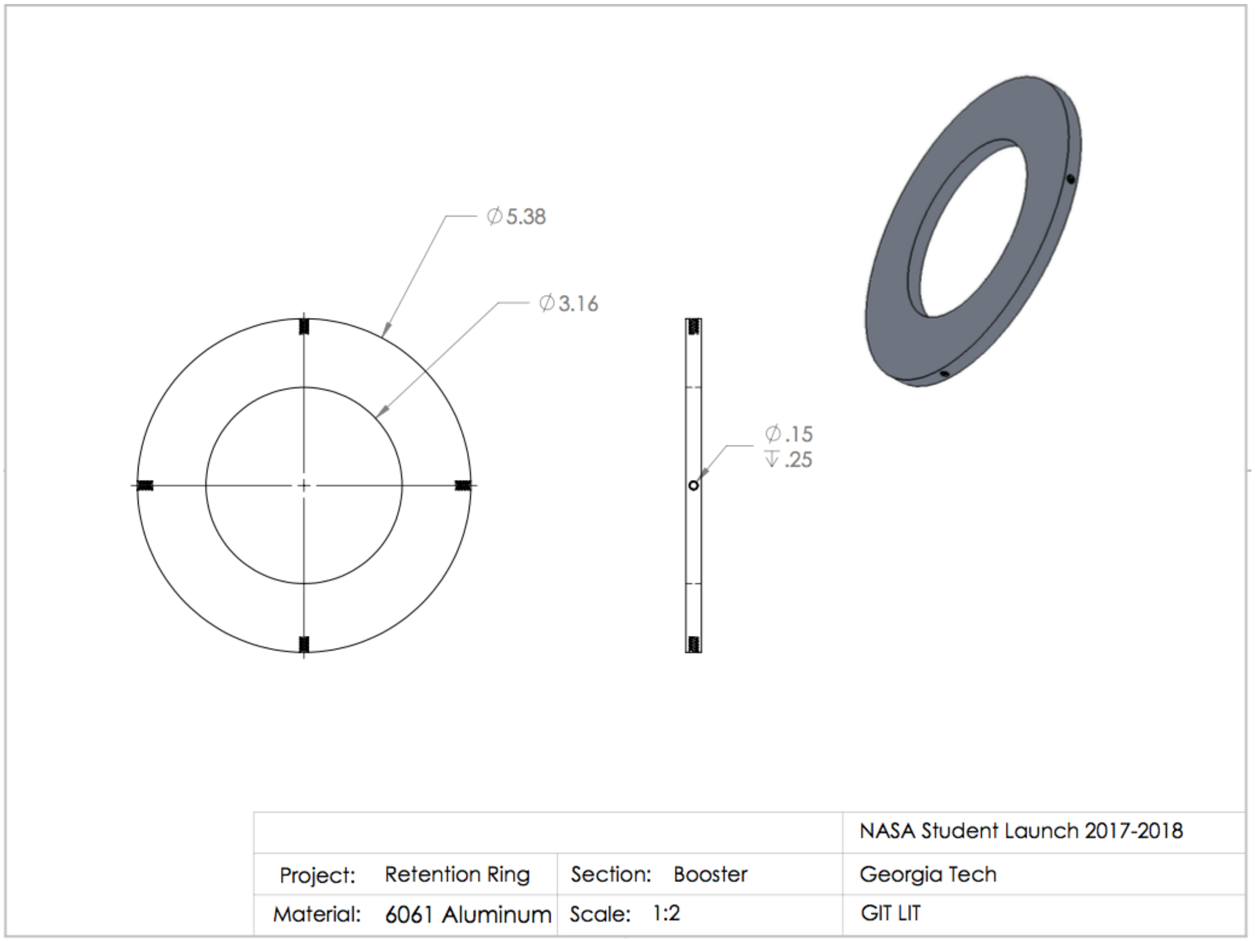


Figure 4.1.12 Retention Ring

Since the centering rings, the retention ring, and the thrust plate are subject to high stress produced by the motor providing thrust to the launch vehicle and by the ejection charge for the drogue parachute deployment, Finite Element Analysis (FEA) was conducted to prove that the each component are capable of enduring the stress. The following figures show the FEA stress and displacement plots for the thrust plate, centering rings and the retention ring.

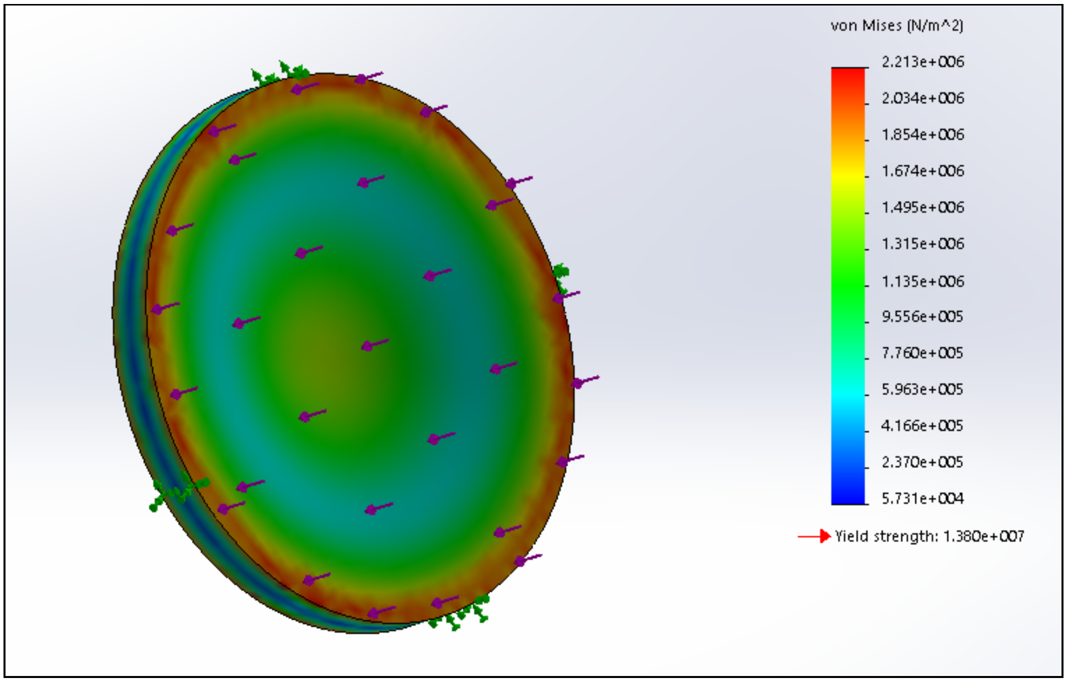


Figure 4.1.13: FEA stress plot for thrust plate

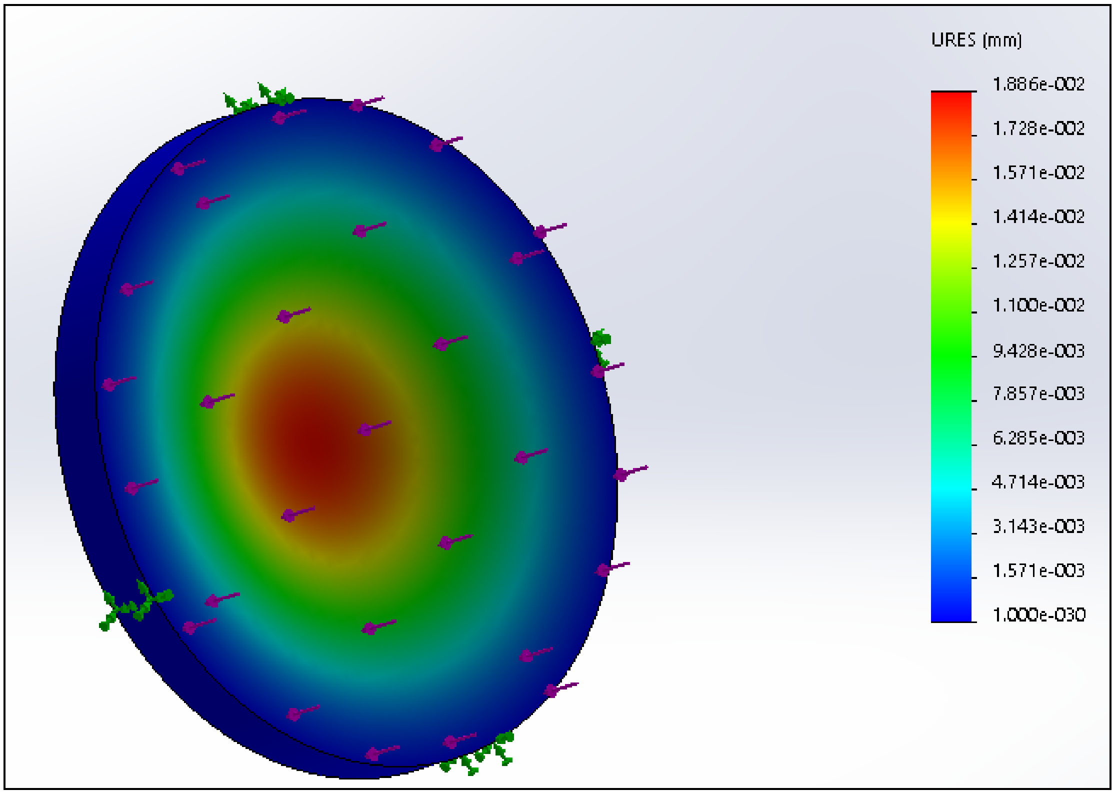


Figure 4.1.14: FEA displacement plot for thrust plate

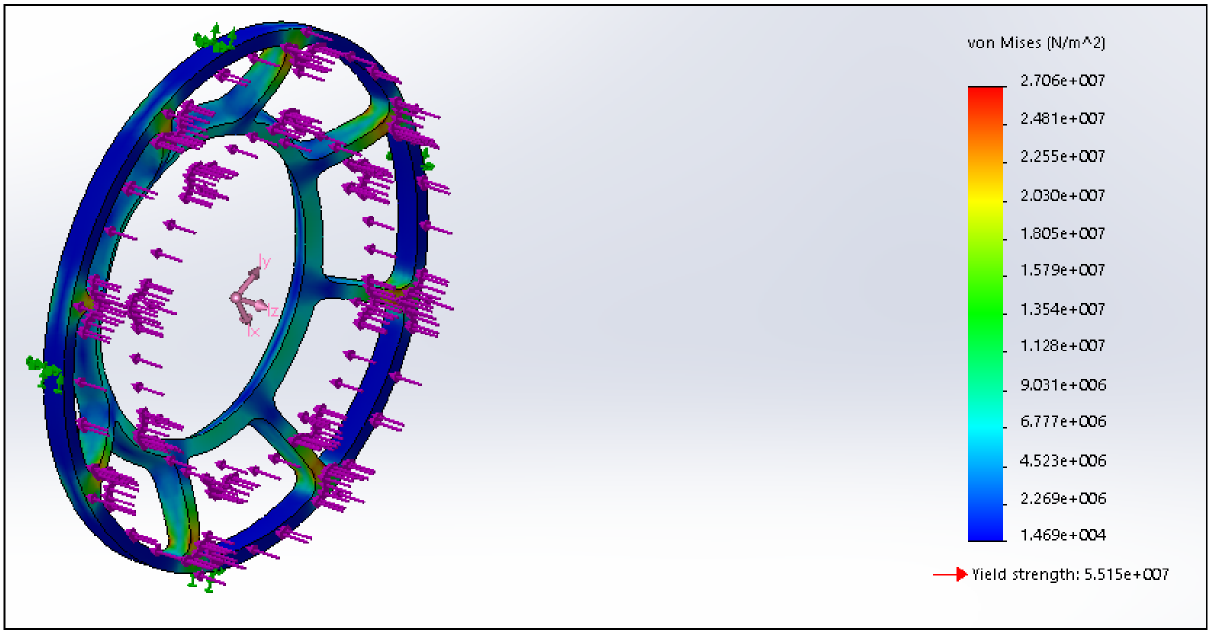


Figure 4.1.15: FEA stress plot for centering ring

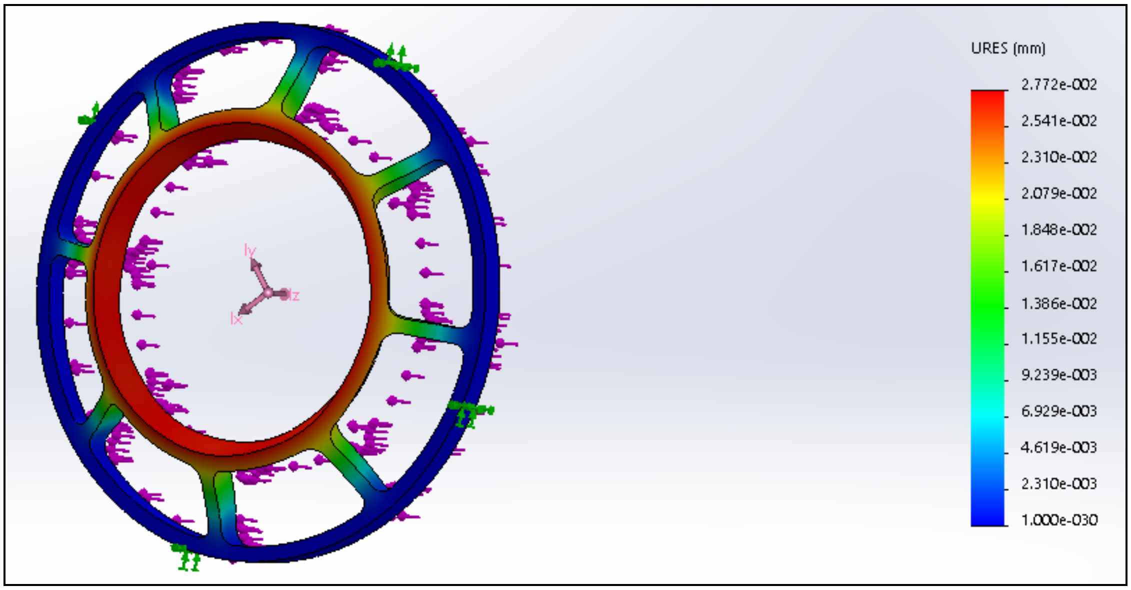


Figure 4.1.16: FEA displacement plot for centering ring

The minimum factor of safety as well the maximum displacement due to motor and ejection charge for each centering ring and the thrust plate are summarized below in Table 4.4.2.

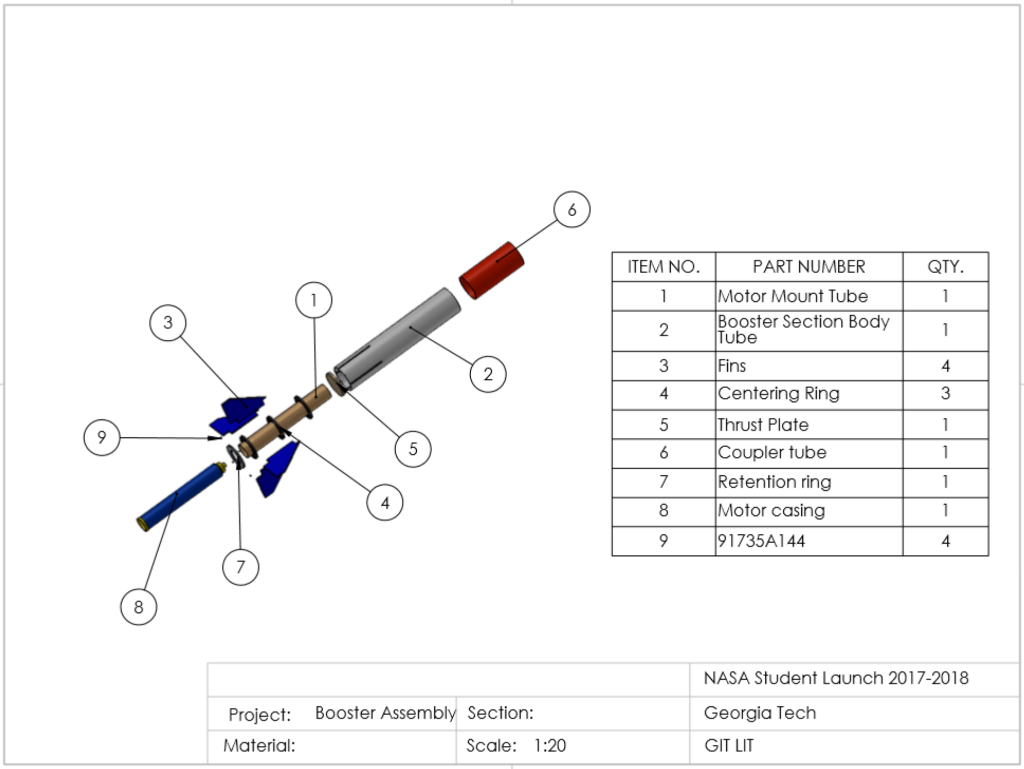
Table 4.1.5 Minimum factor of safety and maximum displacement due to motor

Component	Factor of safety	Max displacement (mm)
Thrust Plate	6.24	1.88×10^{-2}
Upper centering ring	2.04	2.77×10^{-2}
Lower centering ring	2.04	2.77×10^{-2}
Middle centering ring	2.04	2.77×10^{-2}

To get these values, a finite element analysis simulation was run in Solidworks. For the thrust plate simulation, the maximum thrust that the motor produces was applied uniformly across the thrust plate surface. The force was assumed to be normal to the surface, because the motor will be flush against the surface. The factor of safety was above 6 which will ensure safe retention of the motor.

The centering rings finite element analysis was run by applying half of the maximum thrust that the motor produces to the center edge and the outer edge of the centering rings. Both centering rings had a factor of safety of 2.04 which is an acceptable level of safety. Realistically, the thrust plate will be absorbing most of the forces produced by the motor, so it is more important for the thrust plate to have a high factor of safety than the centering rings. The centering rings were designed to minimize the weight while still being structurally sound enough to be safe.

4.1.3. Booster Section Manufacturing and Assembly



ITEM NO.	PART NUMBER	QTY.
1	Motor Mount Tube	1
2	Booster Section Body Tube	1
3	Fins	4
4	Centering Ring	3
5	Thrust Plate	1
6	Coupler tube	1
7	Retention ring	1
8	Motor casing	1
9	91735A144	4

		NASA Student Launch 2017-2018
Project: Booster Assembly	Section:	Georgia Tech
Material:	Scale: 1:20	GIT LIT

Figure 4.1.17 Booster Section Assembly

The figure above displays the assembly of the booster section. The section consists of the motor mount tube, the motor, three centering rings, a thrust plate, four fins, and a retention ring. The booster section connects to the ATS section and the fins for the entirety of the flight. The booster stage airframe will be constructed from 5.5 inch diameter G12 filament wound fiberglass tube. The centering rings, thrust plate, fins, and retention made will be made out of G10 fiberglass. They will be cut using a OMAX on campus waterjet. Any additional modifications that can not be achieved via waterjet will be created with a mill. The main purpose of the booster section is to hold the motor safely in place. The motor will be held securely inside the motor mount tube, which will be secured to the centering rings using epoxy. The centering rings will be attached to the motor mount tube also using epoxy. The thrust plate will be attached above the motor mount tube and will be epoxied to the body tube and to the motor mount tube. The retention ring will be attached below at the bottom of the booster stage airframe, and will be secured using four #6-32 screws. The screws will go through the body tube and into the retention ring.

In order to attach the fins straight and equally spaced out onto the booster body tube, a jig will be created as shown below. The jig will have a two plates having a round hole at the center that has the diameter of the body tube of the rocket, i.e. 5.562 inches, and four rectangular slots equally spaced out running out of the center round hole. These slots correspond to the location of the fins. By placing these two plates parallel to each other with eight supporting plates, the fins could be epoxied perfectly straight onto the motor mount tube. Moreover, by using the spacing between the supporting plates as guidelines, vertical slots on the body tube for the fins could be drawn perfectly straight, reassuring that the fins will be aligned straight when the booster is assembled.

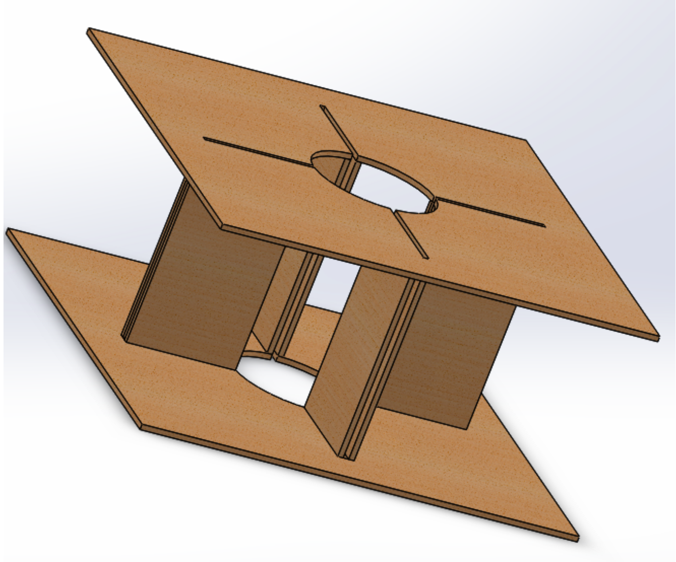


Figure 4.1.18 Fin Alignment Jig

4.2. Sub-Scale Flight Test Results

4.2.1. General Flight Data

The table below summarizes the flight data collected from the subscale launch, conducted on November 18th, 2017. The objectives of this launch were to test all critical rocket systems, as well as the Apogee Targeting System in flight. The subscale flight confirmed that all critical rocket systems, such as the recovery system, were functional and reliable.

Table 4.2.1 Major Flight Information

Apogee (ft)	3147
Ground Hit Velocity (ft/s)	25
Drogue Deployment Altitude (ft)	3147
Main Deployment Altitude (ft)	750
Time in Flight (s)	110

The images below show the team preparing the subscale vehicle for launch, as well as the rocket landing site after the launch had been completed.

Figure 4.2.1 Subscale Launch Images

4.2.2. ATS Data

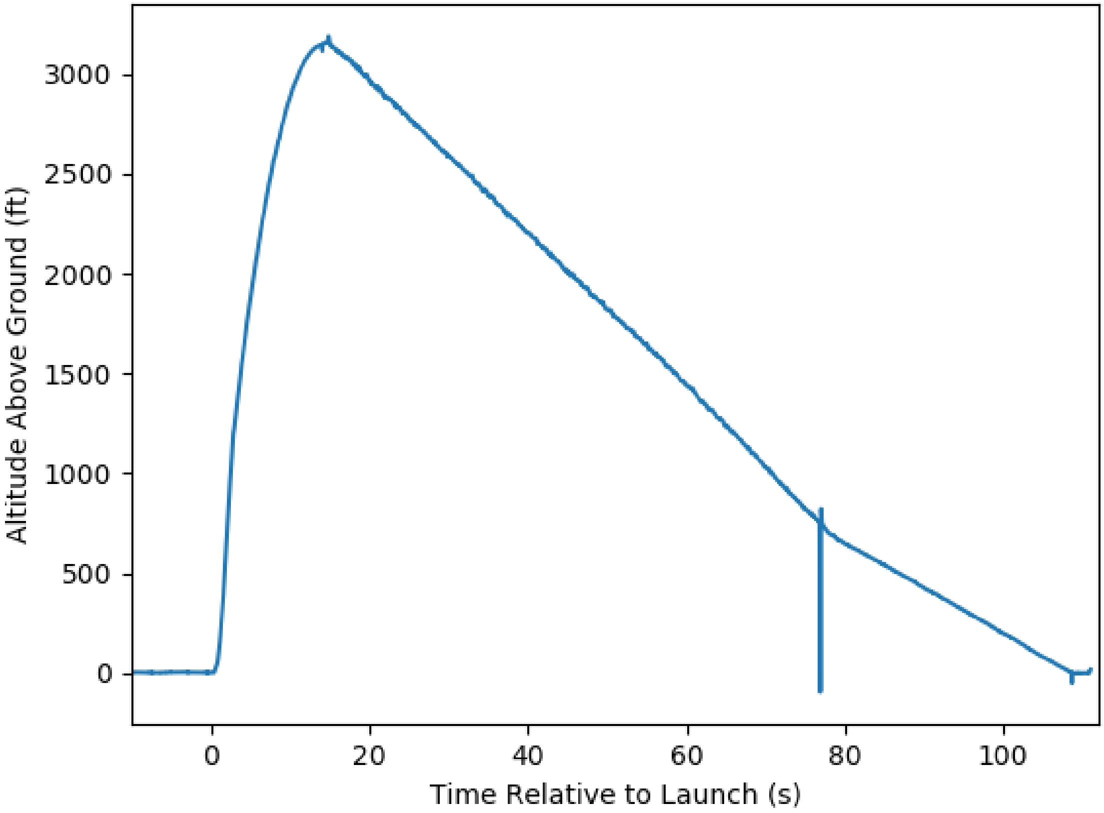


Figure 4.2.2 AGL plotted against time

Recorded altimeter output from the subscale flight is shown above. The noise seen at apogee is due to the pressure wave from separation charges, as is the noise at 750 ft (main deployment). This noise can be seen again when the rocket impacts the ground. This is verified in the acceleration graph below. Note that the max acceleration of the rocket exceeds the 8G limit of the Sense Hat, resulting in a plateau (this will be fixed in the full scale launch). Acceleration drops rapidly after burnout, before increasing again due to gravity. The noise seen in the altitude graph is visible at the same locations of deployment in the below acceleration graph.

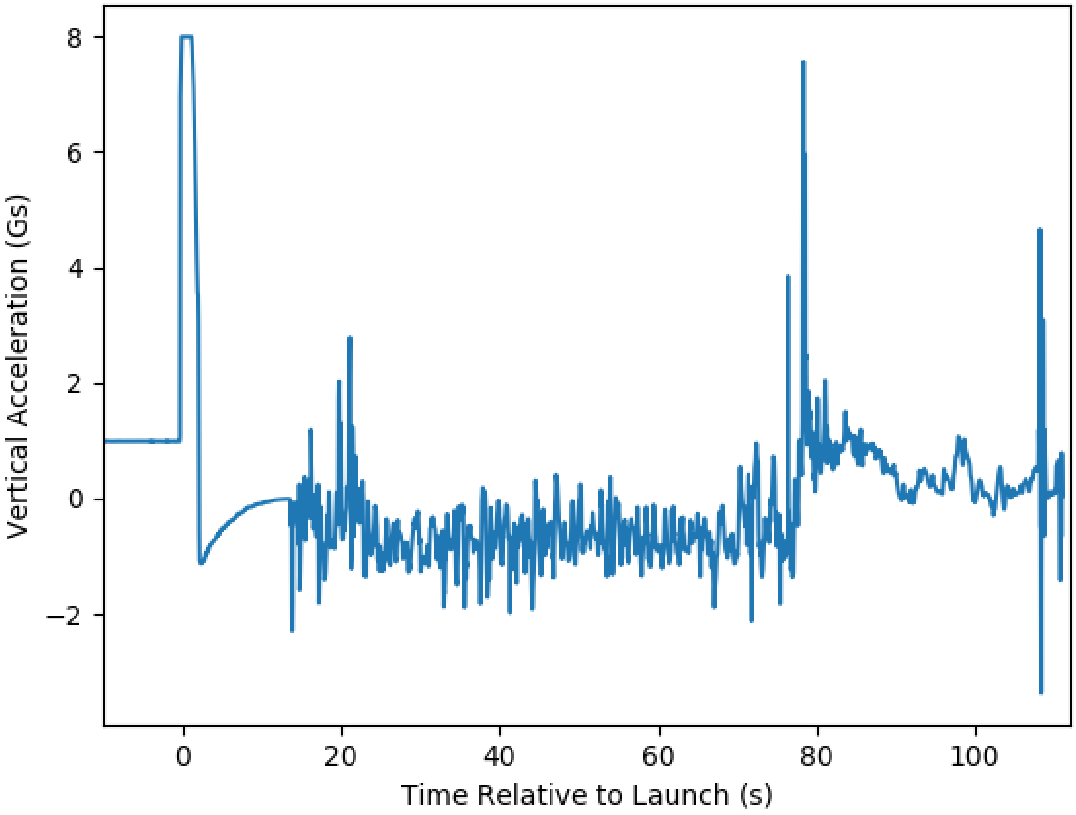


Figure 4.2.3 Acceleration plotted against Time

4.2.3. Rover Data

Due to concerns with the length of the rover body tube section, the rover system was not flown on the subscale flight. However, ground testing was conducted with the rover deployment system, to ensure that the system would function on rough terrain at long distances. To complete these tests, the deployment system was placed over 100 yards away from the team, in an area of the field with uneven ground. The transmitter was then triggered to open the deployment tube.

This test allowed the team to confirm that the deployment motor had enough torque to open the tube against rough terrain, and that the system would focus at long-ranges in addition to short-ranges. The figure belows show a prototype of the deployment section tube, which was used for these tests.

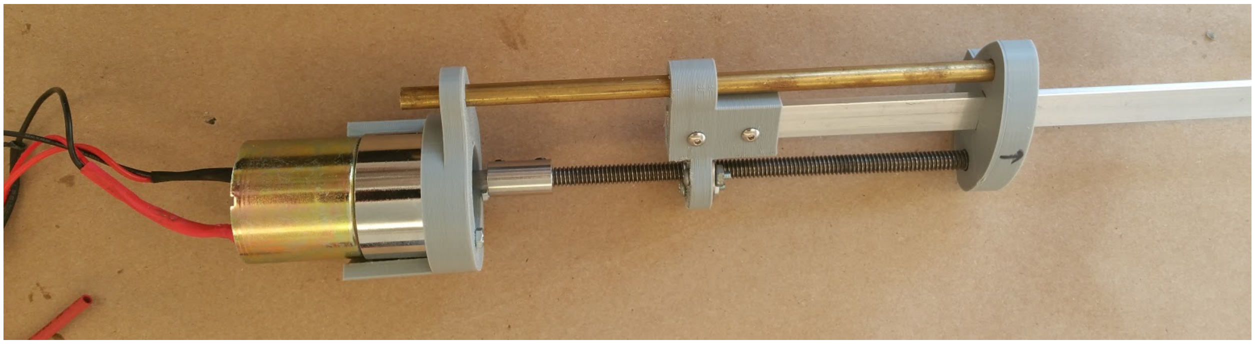


Figure 4.2.4 Deployment System Prototype

4.2.4. Rocket Scaling

The subscale flight was intended as a near ½ scale model (with a diameter 55% of the full-scale rocket diameter). The length was also scaled, as the subscale vehicle was approximately 58% of the length of the full scale vehicle. However, values such as the maximum velocity, maximum acceleration, and motor burnout time remained similar to that of a simulated full-scale launch, so these values were not scaled. The table below summarizes various properties of the subscale and full-scale launch vehicle, in order to convey which components were scaled and which were not.

Table 4.2.2 Rocket Scaling

Property	**Subscale Vehicle**	**Full-Scale Vehicle**
Length	62.2 in.	107 in.
Body Tube Outer Diameter	3.10 in.	5.562 in.
Apogee Altitude	3790 ft.	5434 ft.
Maximum Velocity	582 ft/s	669 ft/s
Maximum Acceleration	270 ft/s^2	270 ft/s^2

Motor Burnout Time	2.796 s	2.911 s
Stability Margin at Rail Exit	2.85	2.09
Velocity at Rail Exit	65.7 ft/s	71.7 ft/s

One major component of the rocket that was not scaled for the subscale launch was the rover deployment system, which retained a majority of its length for functionality purposes. Due to this, the deployment system was not flown on the subscale launch.

4.2.5. Launch Day Simulation

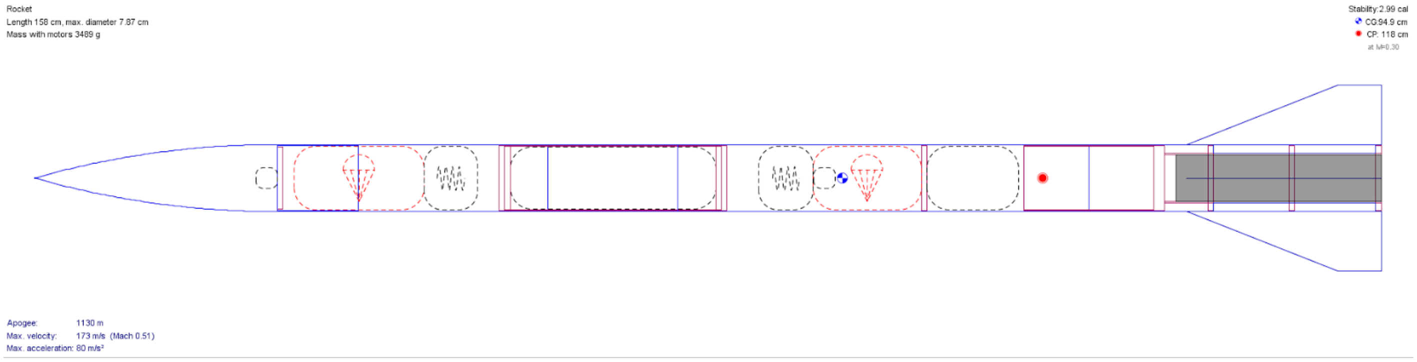


Figure 4.2.5 Subscale Rocket File used for Simulation Tests

Based on the measured conditions at the subscale launch, a simulation test was run. This test used the measured wind speed (5 mph) from the subscale launch, to best replicate the conditions. The figure and table below detail the results from the simulation, and how they compare to the measured flight data.

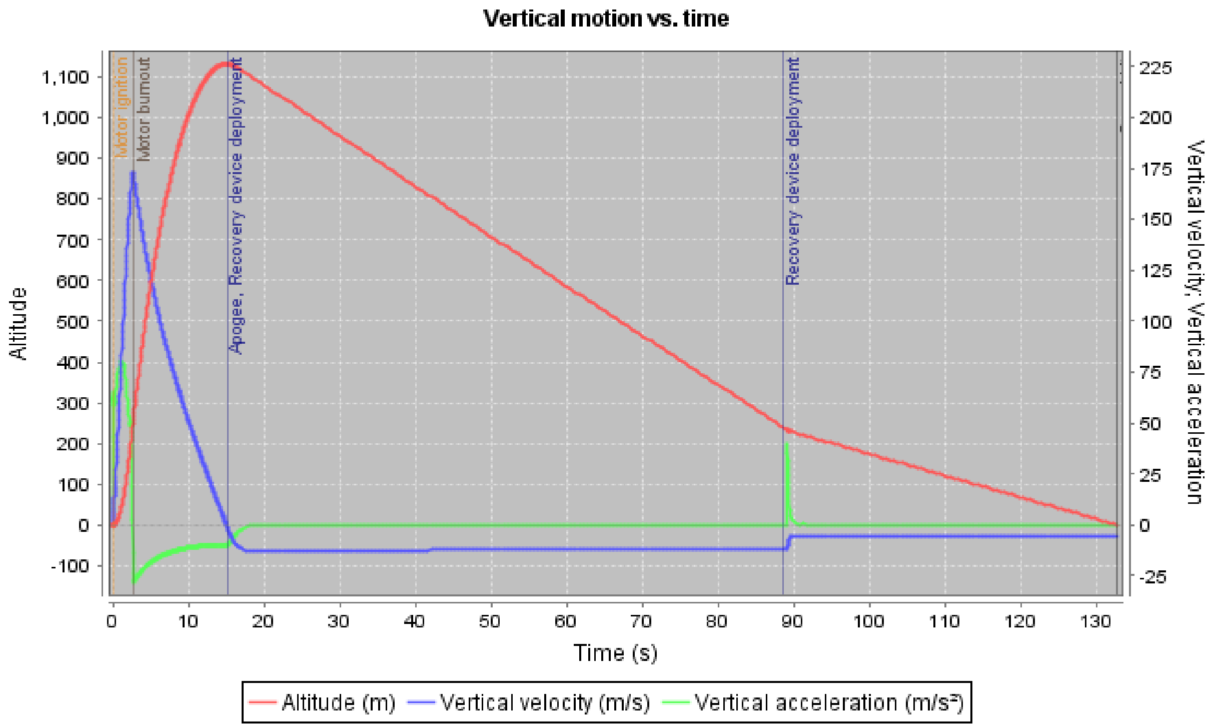


Figure 4.2.6 Graphical representation of a simulated flight

Table 4.2.2 Simulated Flight Data vs. True Data Collected

Property	Simulated Value	Measured Value
Altitude	3712 ft	3147 ft
CG	37.53 in	--
CP	46.6 in	--
Stability margin	2.99 cal	--
Thrust weight ratio	7.46	--
Max velocity	568 ft/s	678 ft/s
Descent velocity	17.4 ft/s	25 ft/s
Velocity at launch rail exit	63.9 ft/s	71.2 ft/s

As seen in the table above, the measured flight data is mostly similar to the simulated flight data. Changes include the altitude, as well as the maximum velocity, descent velocity, and velocity at rail exit. Possible sources of error include gusting or inconsistent wind speed, which would result in different measured values.

4.2.6. Effects on full-scale launch vehicle

The subscale launch confirmed the functionality of the recovery system as well as all flight-critical avionics systems. In addition, this launch confirmed that the rover deployment system was feasible and reliable. Due to this, these systems have been further developed for the full-scale launch vehicle.

However, the software error in the Apogee Targeting System resulted in revisions to the programming behind this system. The mechanics have been demonstrated as reliable through ground testing, so the team plans on proceeding with prototyping a full-scale ATS with revised software.

4.3. Final Recovery System Design

The recovery system will deploy once the rocket has reached the apogee. The signal will be given by two redundant and independent altimeters. Ejection charges made with black powder will break shear pins and deploy the parachutes. The parachutes will be protected from the explosion with a protective and fire resistant fabric. The drogue parachute will first deploy at apogee, followed by the main parachute at about 800 ft. The function of the recovery system design is to minimize the landing energy, and to minimize the drifting time so it will land within the 2,500 foot recovery radius. Hence, the use of a drogue and main parachute will be used.

Main Parachute

The final main parachute chosen is a 96” IRIS ULTRA PARACHUTE made with RipStop Nylon and is a Toroidal shape. The specifications for the parachute are shown in the table below.

Table 4.3.1 Main parachute specification

Material	RipStop Nylon
Weight	24.92 oz
Carrying Capacity	50 lbs
Parachute Shape	Toroidal
Coefficient of Drag	2.2 Cd
Shroud Line Length	110 in
Parachute Area	85.4 ft^2
Manufactured by	Fruity Chutes
Packing Volume	139.5 in^3
Number of Gores	12

The final parachute was decided because it has the highest drag coefficient with the lowest weight. With the drag coefficient, the rocket was slowed down to a low enough kinetic energy at landing. The main parachute will be attached to the bulkhead via I-bolt and shock cord.

Drogue Parachute

The drogue parachute is the 36 inch printed nylon parachute manufactured by Apogee. It was chosen because its price was low and the coefficient of drag was sufficient to reduce the kinetic energy of the rocket upon landing.

Table 4.3.2 Drogue parachute specification

Material	RipStop Nylon
Weight	1.82 oz
Parachute Shape	Octagon
Coefficient of Drag	0.8 Cd

Shock Cord

The shock cord is Tubular Nylon 9/16” that is 240” long. The minimum breaking strength is 1500 lbs. The shock cord must be capable of absorbing the kinetic energy difference between when the parachute is deployed and the velocity of the parachute. The following equations will prove safety of the shock cord length fo the final rocket. The following equations will assume the velocity of the parachute will start out at zero.

Assuming that the airframe and the nose cone will travel at approximately the same velocity:

$$E = \frac{1}{2}mv_a^2$$

Where m is the mass of the rocket and v_a is the velocity at apogee. The values will be taken off of the openrocket simulation. E is the total kinetic energy that the shock cords must be able to absorb. Using the mass of the rocket as 528.4 oz and velocity of deployment of 47.7 ft/s at the main and 19.7 ft/s for the drogue, the kinetic energy of the rocket is found to be:

$$E_m = 1282\frac{ft}{lbf}$$

$$E_d = 222.4\frac{ft}{lbf}$$

Next, the length of the shock cord for the needed kinetic energy will be calculated, where x is the total amount the cord will need to stretch to absorb the energy.

$$E = \frac{1}{2}kx^2$$

$$F_K = kx$$

$$x = \frac{2E}{F_K}$$

The minimum required length of the shock cord was therefore found to be 1.7 inches for the main parachute, and .3 inches for the drogue parachute. The factor of safety for the shock cord was then found to be 140 for the main parachute shock chord, and 800 for the drogue parachute shock cord. The factor of safety was increased substantially to allow a larger shock cord that will be able to absorb more energy from the seperation. This will put less stress on the I-bolt, and allow for a safer parachute ejection. Finally, the factor of safety for the shock cord is particularly important because if the shock cord breaks, part of the rocket could fall without any method of slowing down.

Ejection Charges

Three shear pins will hold together the rocket until it has reached apogee. The ejection charge will increase the pressure of the chamber and break three shear pins. Extra ejection charge will be used to deploy the parachutes and break the snap wire connections. Black powder will be used to create this process. The weight of the black powder can be calculated using this equation:

$$W = \Delta P * V / RT$$

The compartment will be held together by 3 Nylon shear pins of diameter 4-1/16'' and tensile yield strength of 12 ksi. A 155 pound force will be needed to separate each compartment from the equation below.

$$F = \sigma \pi d^2 / 4$$

Table 4.3.3 Nomenclature

Symbol	Description	Value
V	Volume of container	in^3
ΔP	Pressure differential	psi
R	Gas combustion constant for black powder	22.1 ft*lbf/lbm*R
T	Gas combustion temperature	3307 R

Table 4.3.4 Parachute Specs

	Main Parachute	Drogue Parachute
Volume	272.4	181.6
Total pressurization (psia)	24.7	23.7
Pressure at deployment altitude (psia)	14.43	13.9
Differential pressure	10.27	9.8
Amount of black powder (g)	1.45	0.92

4.4. Mission Performance Predictions

4.4.1. Apogee altitude formulaic calculation

The altitude at apogee can be calculated by following a sequence of equations.

For motor burning period

The average mass of the rocket while the motor is burning is calculated by:

$$M_{avg} = m_r + m_m - \frac{1}{2} m_p$$

Equation 4.4.1

where m_r, m_m, and m_p are mass of rocket, motor, and propellant respectively (kg). By using this average mass, the following calculations will assume that the mass is a constant i.e. rate of change of mass is zero. There are three forces acting on the rocket: weight, drag, and thrust. Based on these three forces, an equation of motion of the rocket can be set up:

$$\frac{dp}{dt} = M_{avg}\frac{dv}{dt} = -M_{avg}g - \beta v^2 + T$$

Equation 4.4.2

where T is the average thrust (N) provided by the motor and β is the aerodynamic coefficient (kg/m):

$$\beta = \frac{1}{2}\rho C_d A$$

Equation 4.4.3

where ρ is the density of air (kg/m^3), C_d is the drag coefficient, and A is the cross-sectional area of the rocket (m^2). Reorganizing and integrating Equation 4.5.2 provides the expressions for velocity and altitude at burnout, v_b and y_b:

$$v_b = \sqrt{\frac{\alpha}{\beta}}\tanh\left(\frac{\sqrt{\alpha\beta}}{M_{avg}}t_b\right)$$

Equation 4.4.4

$$y_b = \frac{\alpha}{M_{avg}}\ln\left|\cosh\left(\frac{\sqrt{\alpha\beta}}{M_{avg}}t_b\right)\right|$$

Equation 4.4.5

where t_b is the burnout time (s) and α is the constant difference between thrust and weight (N):

$$\alpha = T - M_{avg}g$$

Equation 4.4.6

For coasting period

During coasting, the mass of the vehicle is a constant M_C defined by:

$$M_C = m_r + m_m - m_p$$

Equation 4.4.7

Since the motor has burned out, thrust is zero and the equation of motion becomes:

$$M_C \frac{dv}{dt} = -M_C g - \beta v^2$$

Equation 4.4.8

Rearranging and integrating Equation 4.5.8 produces the t_{max}, the time when the rocket reaches apogee and y_{max}, the altitude of apogee of the rocked:

$$t_{max} = t_b + \sqrt{\frac{M_C}{\beta g}} arctan\left(\sqrt{\frac{\beta}{M_C g}} v_b\right)$$

Equation 4.4.9

$$y_{max} = y_b + \int_{t_b}^{t_{max}} \sqrt{\frac{M_C g}{\beta}} tan\left(\sqrt{\frac{\beta g}{M_C}}(t_b - t) + arctan\left(\sqrt{\frac{\beta}{M_C g}} v_b\right)\right) dt$$

Equation 4.4.10

4.4.2. Flight profile simulation and predicted altitude

As a primary tool for flight profile simulation, OpenRocket software is used. Based on the material densities of each component, the gross mass of each section and of the entire launch vehicle were estimated. Although certain masses such as the epoxy were not reflected with perfect accuracy in the OpenRocket model, the ATS system is designed such that the launch vehicle will still be able to attain the target apogee. The OpenRocket model of the full scale rocket was created to verify the equations 4.4.1 through 4.4.10 presented in the previous section.

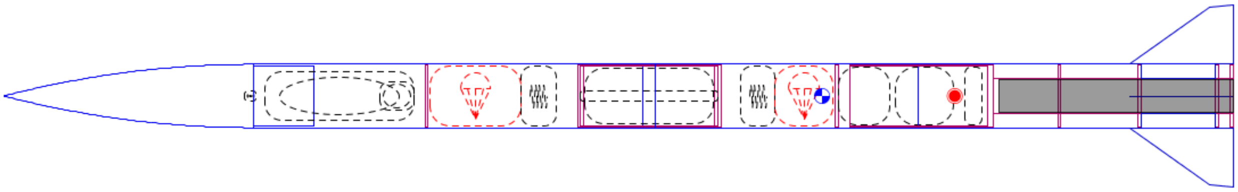


Figure 4.4.1 OpenRocket Layout of Full Scale Vehicle

The figure above depicts the overall layout of the full scale vehicle. The flight specifications obtained by the OpenRocket simulation of the full scale vehicle, using AeroTech L1390 G-P motor, are summarized below. The center of gravity and center of pressure are measured from the tip of the nose cone and the rail exit velocity was obtained by choosing the 12 ft rail rod.

Table 4.4.1 Flight specifications of the launch vehicle

Property	Value
Center of Gravity	71.336 in
Center of Pressure	82.897 in
Apogee altitude	5434 ft
Maximum velocity	669 ft/s
Maximum acceleration	294 ft/s^2
Rail exit velocity	71.7 ft/s
Thrust-to-weight ratio	8.26
Ground hit velocity	16.3 ft/s

The OpenRocket model is designed so that the apogee altitude of the launch vehicle without the ATS system activated would be approximately 5,400 ft under any wind conditions.

The following table summarizes the apogee altitude deviation under 0, 5, 10, 15, and 20 mph wind.

Table 4.4.2 Predicted apogee under different wind conditions

Wind condition (mph)	Predicted apogee altitude (ft)
0	5434
5	5424
10	5399
15	5368
20	5353

This overshooting of the target apogee of 5,280 ft accounts for various launch conditions and allows the ATS system to control drag and reach the target apogee. The following figures produced through the OpenRocket simulations prove that the motor selection was appropriate and that vehicle safety requirements are met.

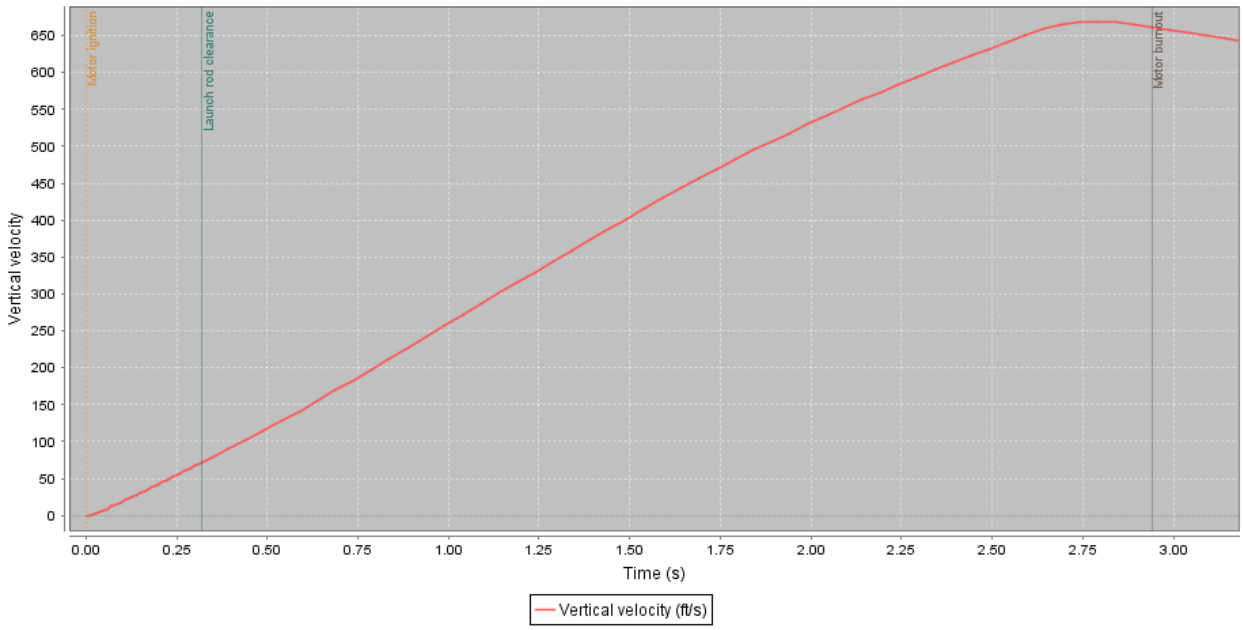


Figure 4.4.2 Vertical velocity vs time until motor burnout

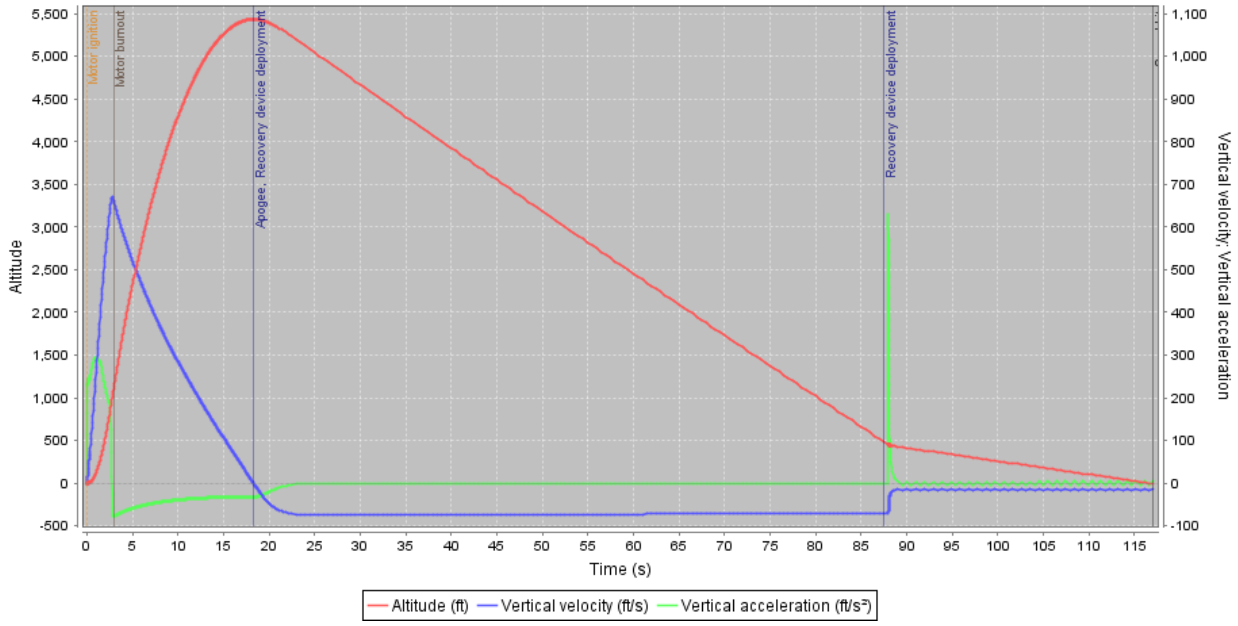


Figure 4.4.3 Altitude, vertical velocity, and vertical acceleration vs time

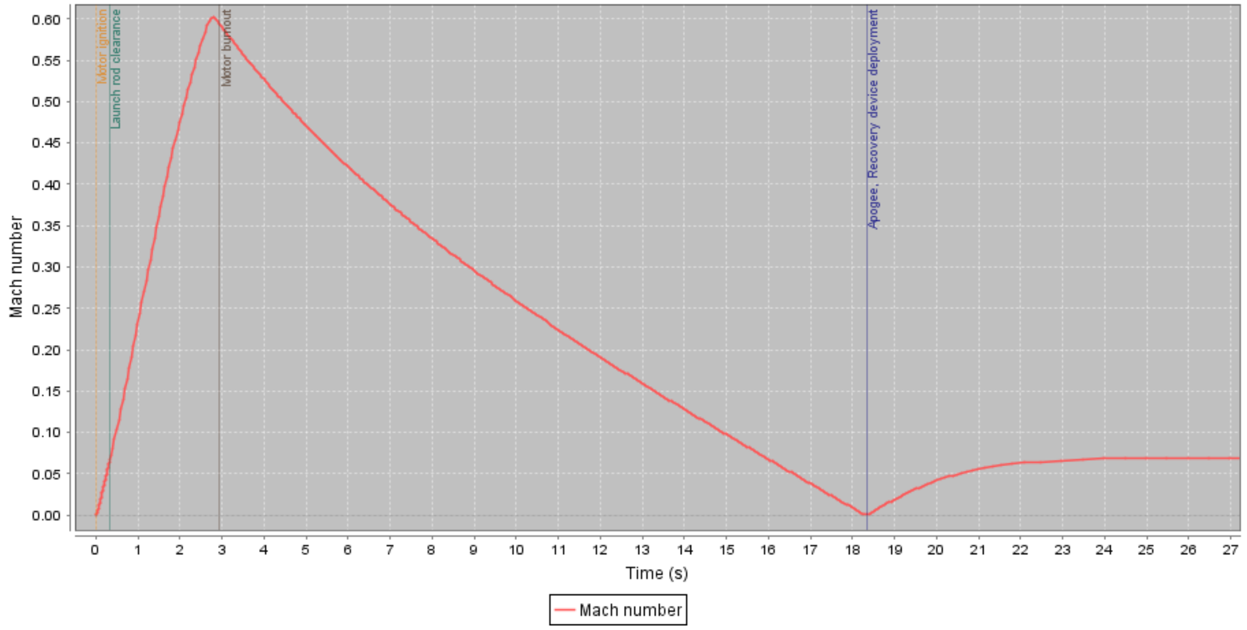


Figure 4.4.4 Mach number vs time until drogue parachute deployment

4.4.3. Section mass breakdown

In order to accurately predict the flight performance of the rocket, it is imperative to know the mass of each section of the launch vehicle. Based on material density used for each component and CAD, the mass of each section was estimated. The mass distribution of the launch vehicle among the sections are summarized in the figure below.

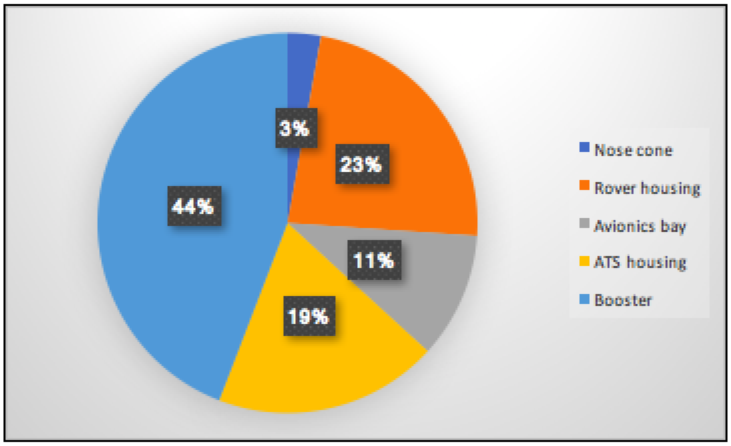


Figure 4.4.5 Mass Breakdown of the Launch Vehicle by Sections

The following tables summarize the material, mass, and locations of the components in each section of launch vehicle. "Location" is the relative position of the component from the top of the section in which it is housed. The materials of systems housed in each section will be summarized in the designated sections of this document.

Table 4.4.3 Nose cone section mass breakdown

Component	Material	Mass (oz)	Location (in)
Nose cone	G10 fiberglass	16.96	0
GPS	N/A	4.00	21

Table 4.4.4: Rover tube section mass breakdown

Component	Material	Mass (oz)	Location (in)
Body tube	G12 fiberglass	58.10	0
Rover deployment system	N/A	24.00	1
Rover	N/A	16.00	10
Bulkhead	G10 fiberglass	9.00	15
Main parachute	Ripstop nylon	24.92	15.375
Shock cord	Tubular nylon	3.44	23.375

Table 4.4.5: Avionics bay mass breakdown

Component	Material	Mass (oz)	Location (in)
Avionic bay coupler tube	G12 fiberglass	22.00	0.25
Avionic bay strip	White kraft paper	0.66	5.75
Body tube bulkhead	G10 fiberglass	8.00	0 and 12.25
Coupler tube bulkhead	G10 fiberglass	5.61	0.25 and 12
Electronics tray	N/A	4.00	0.5
Electronics	N/A	10.10	0.5

Table 4.4.6: ATS section mass breakdown

Component	Material	Mass (oz)	Location (in)
Body tube	G12 fiberglass	39.30	0.00
Drogue parachute	Ripstop nylon	1.67	10.5
Shock cord	Tubular nylon	3.44	7.5
Bulkhead	G10 fiberglass	9.00	15.75
Telemetry + Pi + LiPos	N/A	24.00	16
ATS mechanics	N/A	32.60	21

Table 4.4.7: Booster section mass breakdown

Component	Material	Mass (oz)	Location (in)
Coupler	G12 fiberglass	22.00	0.00
Body tube	G12 Fiberglass	46.80	6.00
Thrust plate	G10 Fiberglass	4.13	12.00
Motor mount tube	White kraft paper	6.76	12.50
Centering ring	6061-aluminum	1.35	12.15, 19.15, 25.9
Fin (x3)	G10 Fiberglass	9.55	31.90
Retention ring	6061-aluminum	5.79	27.15
Motor (with propellant)	N/A	136.83	6.5

4.4.4. Motor selection

During the process of selecting the motor for the rocket, several OpenRocket simulations were ran with different motors to obtain the maximum total vehicle mass for the launch vehicle to reach the target apogee of approximately 5,400 ft without ATS activation. Same configuration of the vehicle was used to maintain the same location of CP and the masses of the the ATS body tube was altered since the CG is within this tube so any change of its mass will not affect the location of the CG. The simulated motors have total impulse varying from 764 lbf·s to 1151 lbf·s (3,400 N·s to 5,120 N·s), which the maximum total impulse permitted by the competition. The result of the simulation are shown below.

Table 4.4.8: Motor Simulation Results

Motor name	Total impulse (lbf·s)	Max. vehicle mass (lbm)
AeroTech L1150	784	31.75
Cesaroni L890SS	831	34.69
AeroTech L1520TP	847	35.25
AeroTech L1390G	887	37.50
Cesaroni L1355SS	905	39.38

Cesaroni L1350	962	41.50
AeroTech L1420	1038	45.88
Animal Motor Works L1400SK	1066	47.50
Cesaroni L2375-WT	1103	49.88
AeroTech L2200G	1147	52.56

With the consideration of the burn time, maximum vehicle mass to reach approximately 5,400 ft, and the team's decision to reuse the RMS-75/3840 AeroTech motor casing from last year's competition for saving expenditure, three candidates for the motor of the full scale rocket were chosen: AeroTech L850W, AeroTech L1150P, and AeroTech L1390G-P. The following two tables compare the specifications of each motor and summarize the flight performances of the rocket (without the ATS activated) for each motor obtained by OpenRocket simulation.

Table 4.4.9: Specifications of each motor

Property	**L850 W**	**L1150 R**	**L1390 G-P**
Total impulse (lbf·s)	831	784	887
Average thrust (lbs)	176.85	247.40	305.63
Maximum thrust (lbs)	266.35	294.43	370.90
Burn time (s)	4.70	3.17	2.91
Gross mass (lbm)	8.10	8.10	8.54

Table 4.4.10: Flight performance of the launch vehicle with different motors

Property	**L850 W**	**L1150 P**	**L1390 G-P**
Apogee altitude (ft)	4989	4638	5434
Rail exit velocity (ft/s)	60.8	66.7	71.7
Maximum velocity (ft/s)	576	590	669
Maximum acceleration (ft/s^2)	205	232	294
Time to apogee (s)	18.2	17.3	18.3

According the OpenRocket simulation all the motors complied with the minimum rail exit velocity requirement of 52 fps. However, the only motor which surpassed the 5,280 ft requirement as well as reaching an apogee close to 5,400 ft without the ATS activated was L1390 G-P. Thus, the team decided to use this motor for the full scale launch vehicle. The FEA for the components in the motor retention system discussed in previous sections were based on the force applied by the L1390 G-P motor, proving that the retention system will be robust enough to withstand the high acceleration created by this motor. The thrust curve and specifications of L1390 G-P motor can be seen in the figure and table below, respectively.

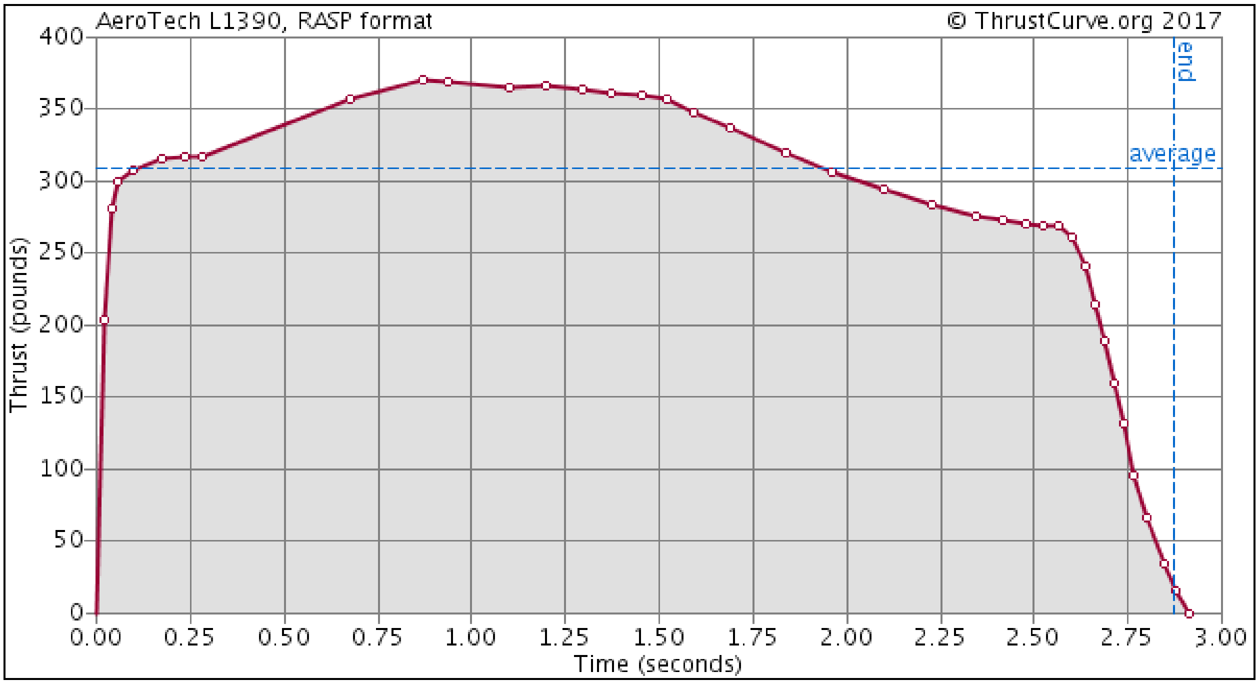


Figure 4.4.7: AeroTech L1390 G-P Thrust Curve

Table 4.4.11: AeroTech L1390 G-P specifications

Property	Value
Diameter (in)	2.95
Length (in)	20.87
Total mass (lbm)	8.54
Propellant mass (lbm)	4.35
Average Thrust (lbs)	305.63
Maximum Thrust (lbs)	370.90
Total Impulse (lbf·s)	887
Burn time (s)	2.91

4.4.5. Stability/CP/CG

The Center of Pressure (CP) is the point on the rocket where all the aerodynamic forces are said to be balanced. The relative positioning of the CG and CP changes the stability of the rocket. It is imperative that the CG is above CP, since the torque generated by the lift and drag forces about the CG will restore the nose's direction to the flight direction and maintain a stable flight. The static stability margin measures "how stable" the rocket is: it is a ratio of the distance between the CG and CP to the body tube diameter. The locations of the CG and CP are illustrated in the figure below and the distance of these points from the nose cone at mach 0.3 are shown in the table below. The blue circle indicates the CG and the red the CP.

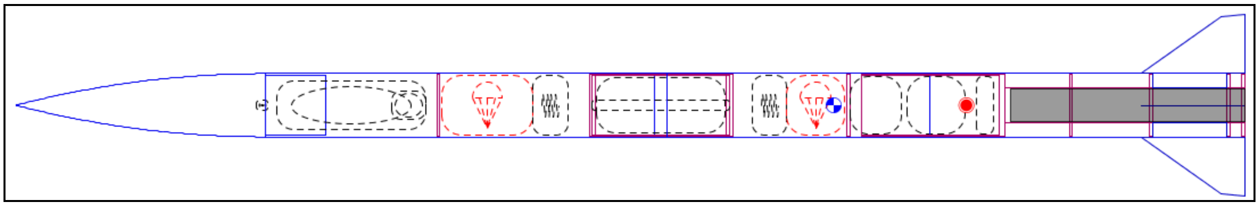


Figure 4.4.8 CG and CP of the Launch Vehicle

Table 4.4.12 Numerical values of CG and CP locations

Point	Distance from nose cone (in)
CG	71.336
CP	82.897

An OpenRocket simulation was confirming that, the static stability margin is above 2.0 at the point of rail exit. The figure below, generated by the software, shows the relationship between the CG, CP, and static stability margin, and time.

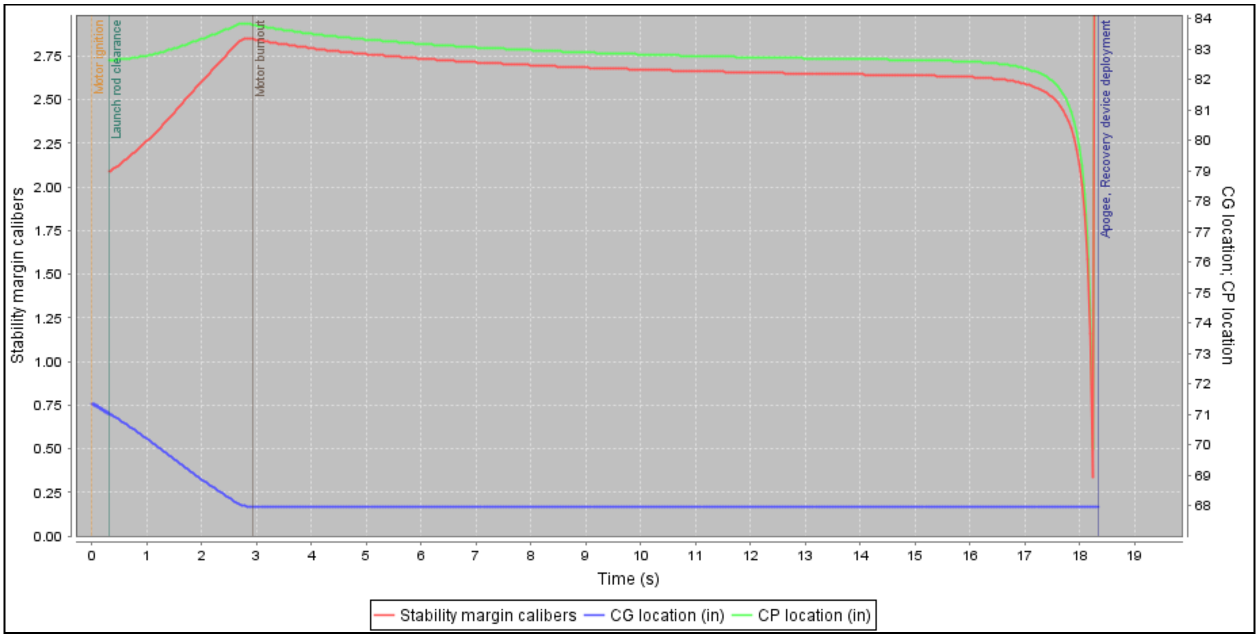


Figure 4.4.9 Stability Margin, CP and CG Location vs Time

4.4.6. Landing Energy

The landing energy was calculated by summing the kinetic energy of the Rover and nose cone section, the avionics bay, and the ATS and booster section. It is assumed that the parachutes will be landing at a much smaller velocity than the rocket, and therefore the contribution of the parachute to the total kinetic energy is negligible. From the OpenRocket simulation, the velocity at landing is projected to be 14.2 ft/s with no wind.

The following equation will be used to calculate the landing energy.

$$T = \frac{1}{2}mv^2$$

Where T is kinetic energy, v is velocity, and m is mass. The kinetic energy for each section of the rocket will be found, then added together to find the final kinetic energy. The results of the calculations are shown in the table below:

Table 4.4.13 Kinetic Energy for Rocket Modules

Module/Modules	Mass (oz)	Kinetic energy (ft*lbf)
Nose cone/Rover	131.54	29.51
ATS/Booster	266.48	59.8
Avionics bay	63.98	14.36

The total landing energy of the rocket is the sum of the three parts. Therefore, the total landing energy of the rocket is 90.48 ft*lbf, which is well within the allowed landing kinetic energy.

4.4.7. Drift Calculations

In order to examine the drift of the launch vehicle from the launch pad for different wind speeds, a simple hand calculation was done along with OpenRocket simulation to confirm the results. The calculation assumes the following conditions:

1. The launch vehicle ascents vertically without any wind
2. The launch vehicle experiences a constant wind from the apogee
3. The launch vehicle drifts at the same velocity as the wind

4. The terminal velocity is reached instantaneously after the deployment of each parachute

With these assumptions, the drift of the launch vehicle will simply be a product of the speed of the wind and the time difference between landing and apogee, since the launch vehicle does not experience acceleration in both vertical and horizontal direction during the recovery:

$$Drift\ distance\ =\ Wind\ speed\ \times\ (t_{landing} - t_{apogee})$$

Equation 4.4.11

Based on Equation 4.4.11, drift due to 0, 5, 10, 15, and 20 mph were calculated, and the results are summarized below.

Table 4.4.14 Drift distance of the launch vehicle due to different wind speeds

Wind speed (mph)	Drift time (s)	Drift distance (ft)
0	98.7	0
5	97.7	716.5
10	97.7	1432.9
15	98.7	2171.4
20	97.8	2868.8

To verify that the hand calculations are accurate, OpenRocket simulations with the various wind speeds were conducted. The following five figures depict the lateral displacement of the launch vehicle with the different wind speeds calculated by the OpenRocket software.

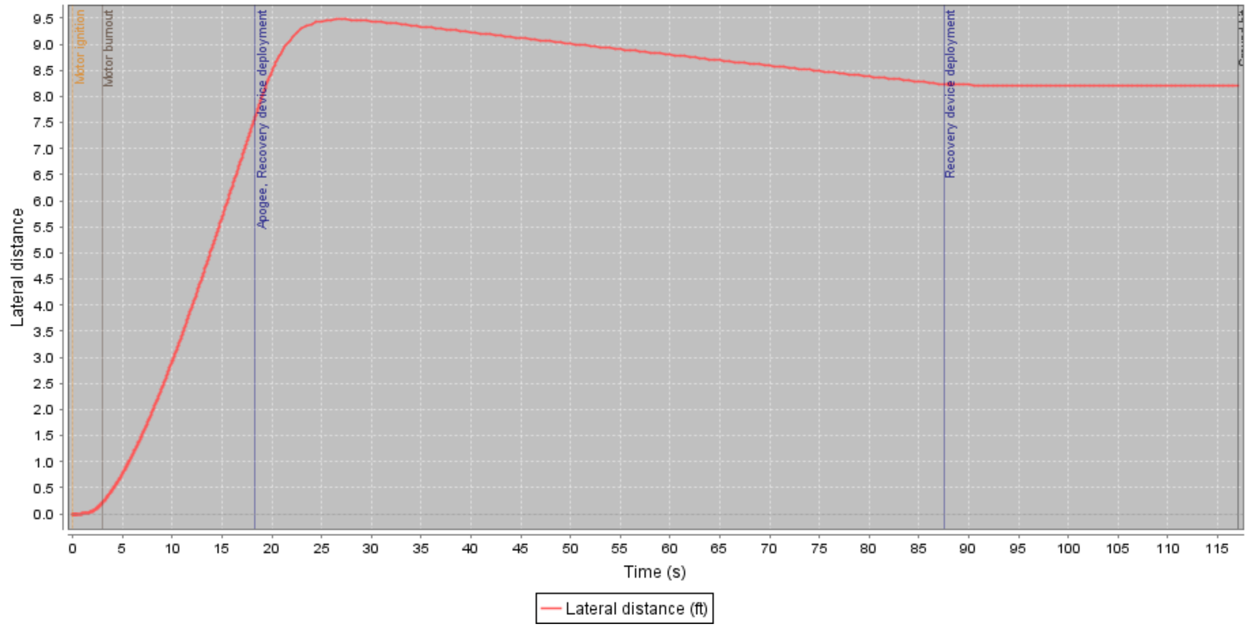


Figure 4.4.10 Drift due to 0 mph wind

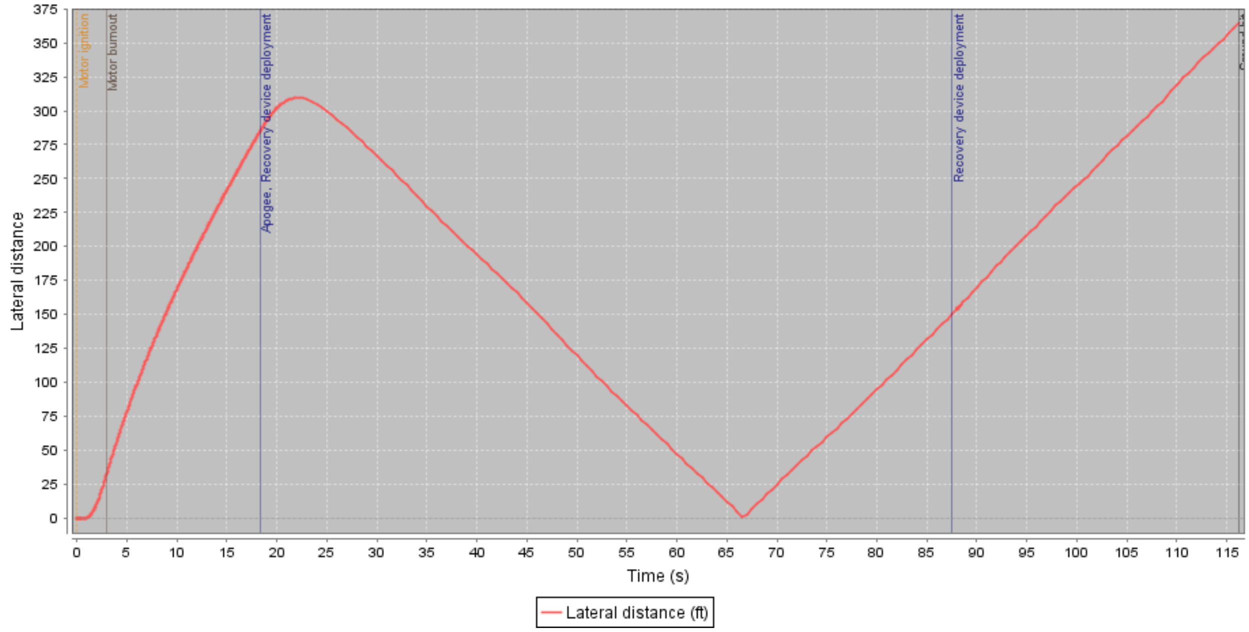


Figure 4.4.11 Drift due to 5 mph wind

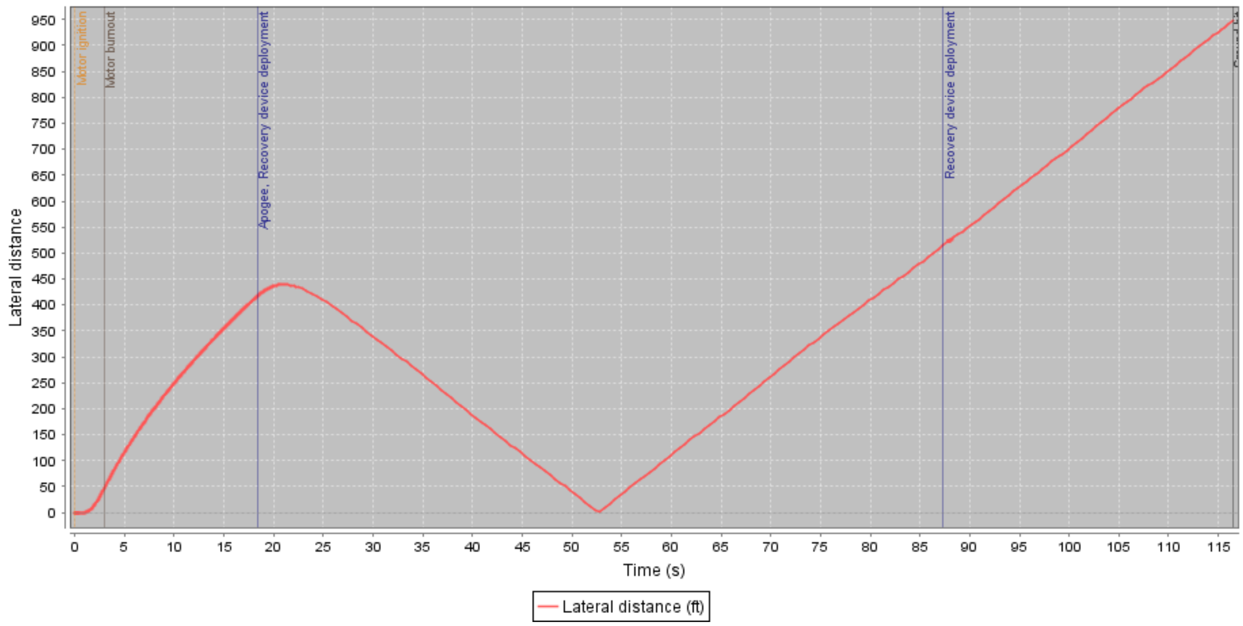


Figure 4.4.12 Drift due to 10 mph wind

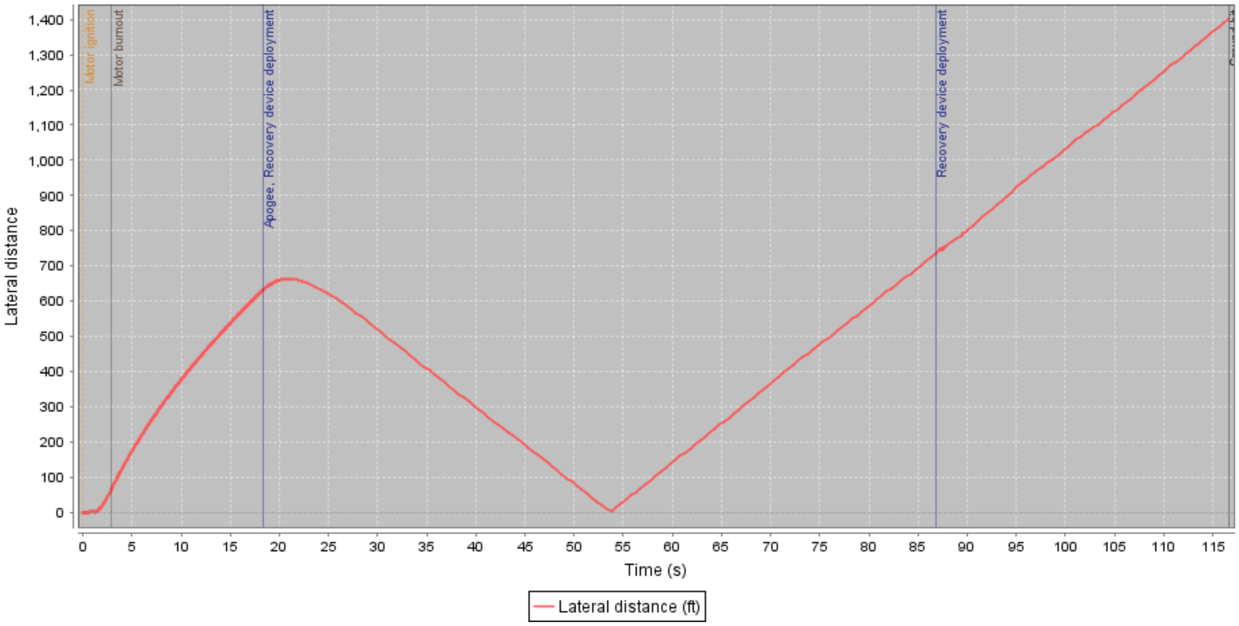


Figure 4.4.13 Drift due to 15 mph wind

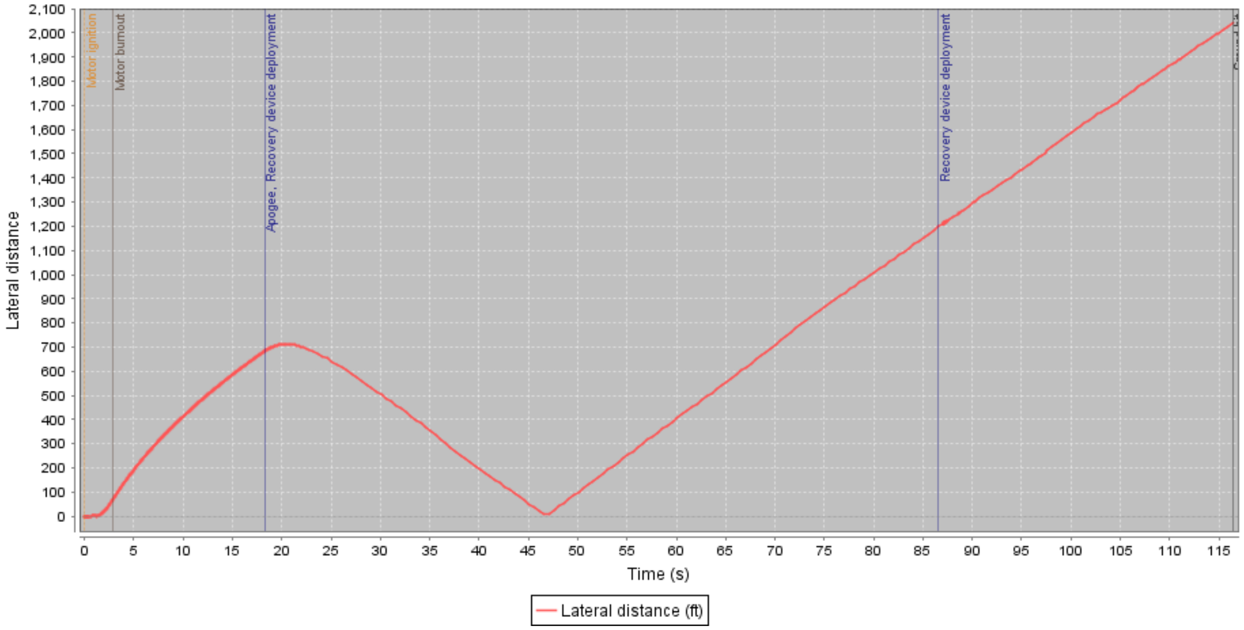


Figure 4.4.14 Drift due to 20 mph wind

Table 4.4.15 Drift distance prediction by hand calculation and OpenRocket simulation

Wind condition (mph)	Hand calculation predicted drift distance (ft)	OpenRocket predicted drift distance (ft)
0	0	8.2
5	716.5	364.3
10	1432.9	947.1
15	2171.4	1401.2
20	2868.8	2039.6

The values obtained from Equation 4.4.11 and the OpenRocket simulation were quite different as demonstrated in the table above. While the hand calculation suggested that the launch vehicle will recover within the required recovery area of 2,500 ft radius up until 17 mph, the OpenRocket simulation suggested that the launch vehicle can be recovered up until wind velocity close to 25 mph. The difference may have emerged due to the fact that the OpenRocket simulation considers the effect of the wind onto the launch vehicle during the ascent as well.

5. Apogee Targeting System (ATS)

5.1. ATS Overview

There was no major change in design of ATS; most components were scaled up to accommodate change in flight profile such as target apogee and maximum velocity of the rocket.

5.2. Chosen Design

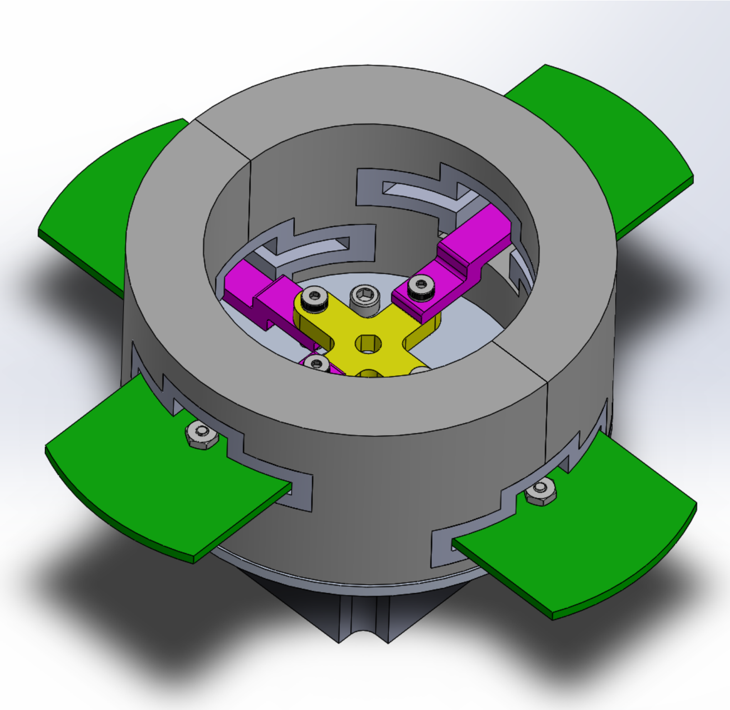


Figure 5.2.1 Isometric View of ATS From Top

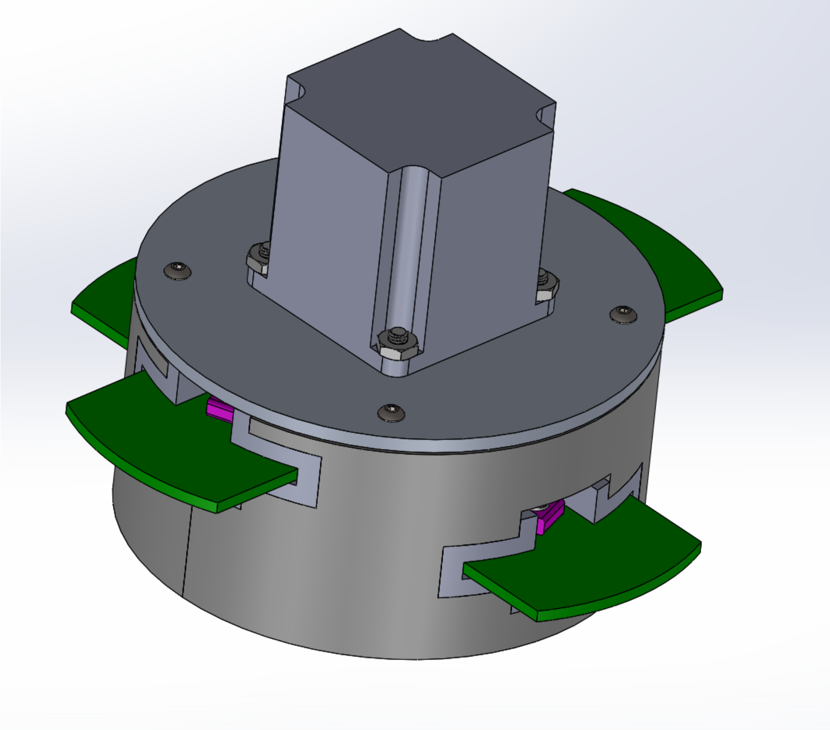


Figure 5.2.2 Isometric View of ATS From Bottom

All of preexisting components of ATS were scaled up for full scale flight. The only design change was the addition of nylon bracket. During the flight, it will have 3 configurations.

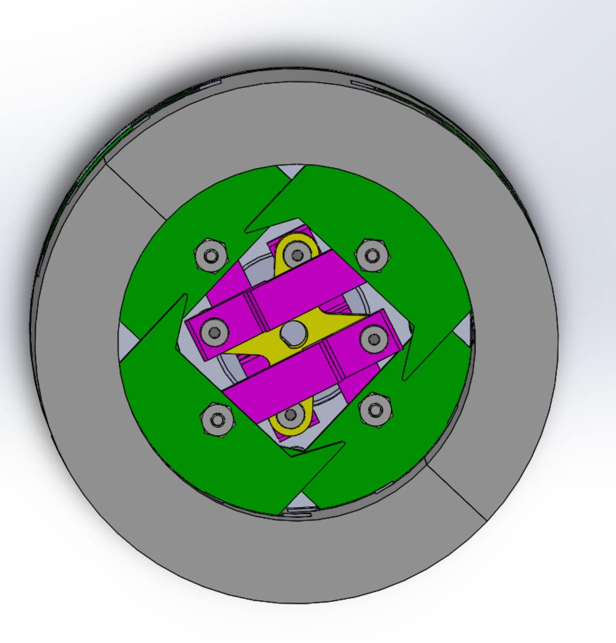


Figure 5.2.3 Configuration which all flaps are fully retracted.

ATS will be in this configuration before burnout and after the rocket slows down to appropriate velocity to reach a mile.

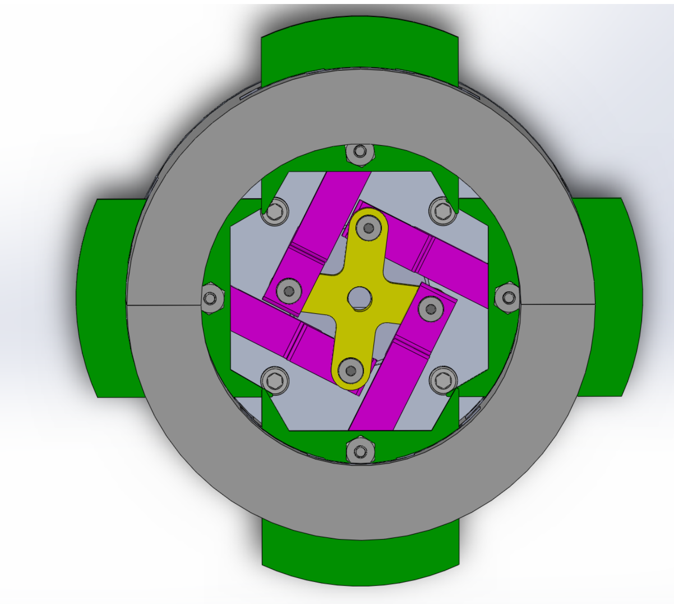


Figure 5.2.4 Configuration which all flaps are partially extended.

ATS will be in this configuration to provide controlled magnitude of drag, possibly near targeted apogee.

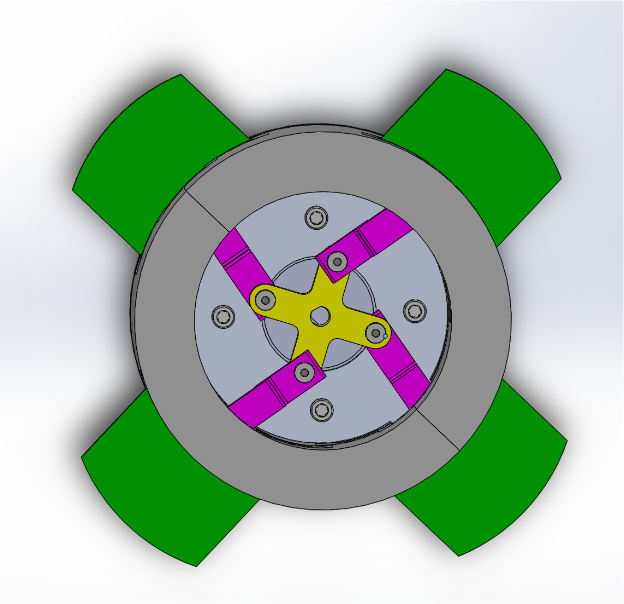


Figure 5.2.5 Configuration which all flaps are partially extended.

ATS will be in this configuration to provide maximum drag, possibly right after burnout when the rocket reaches maximum velocity.

5.2.1. Component Design/Specification

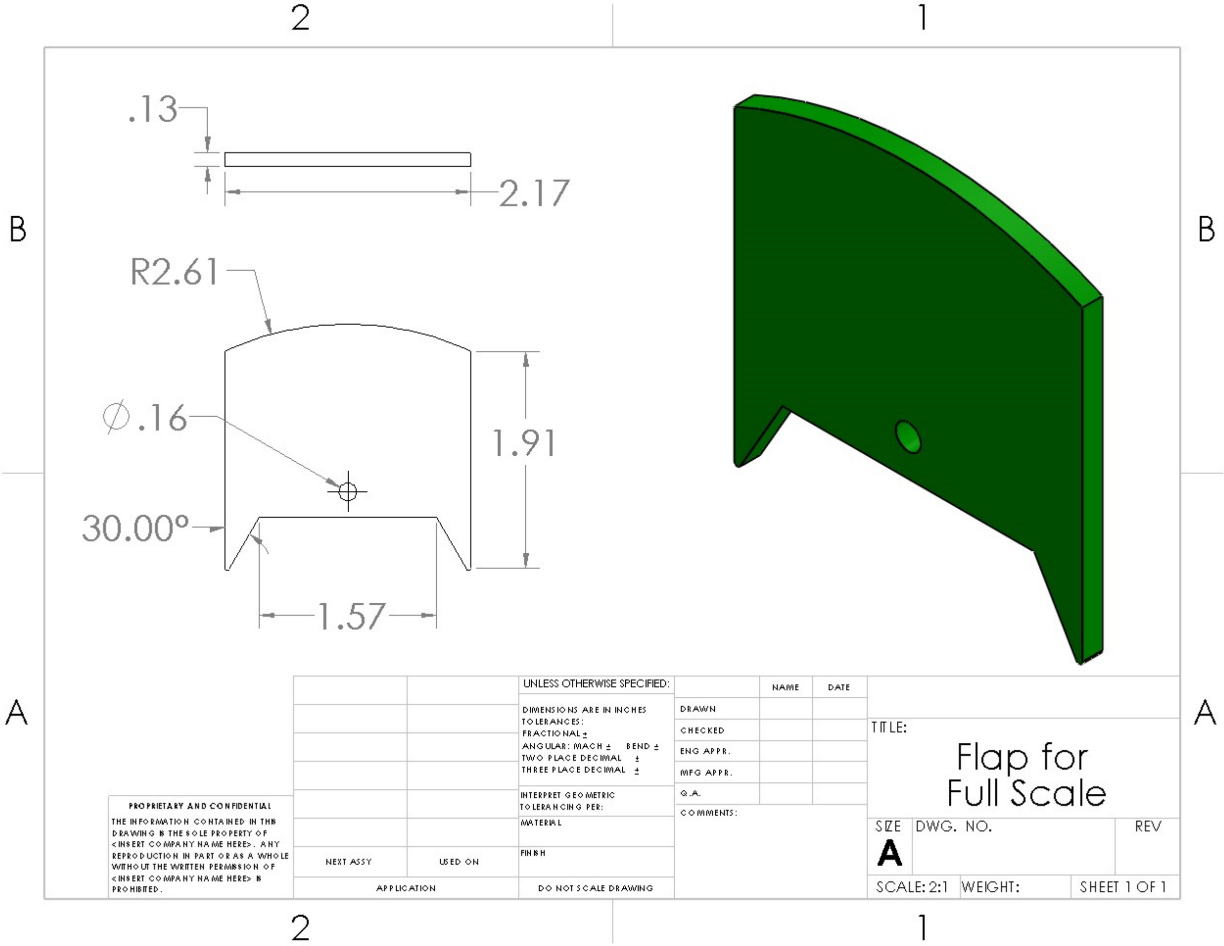


Figure 5.2.6 Drawing of Flap

The size of flap is increased to provide more drag as the full scale rocket flies faster than subscale rocket. Since the simulation from PDR showed that flap does not carry much of the load due to drag, the thickness of the flaps is same as the flap used for subscale flight which is 0.125 inches. The material of the flap will be 6061 aluminum alloy and it will be waterjetted.

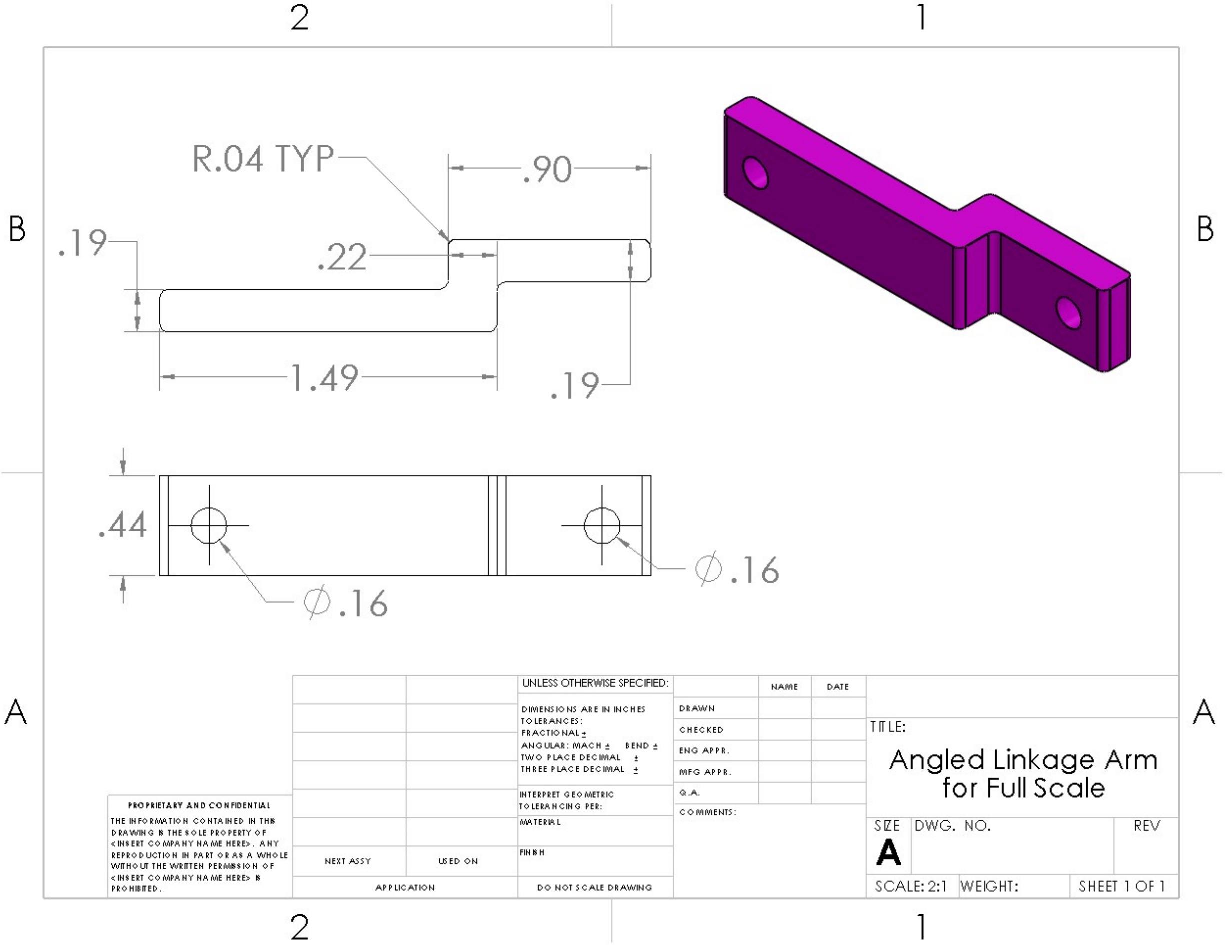


Figure 5.2.7 Drawing of Angled Linkage Arm

The purpose of angled linkage arm is to connect flaps to rotary disk.The simulation in PDR showed that the angled linkage arms will carry large load due to drag. To prevent material failure, the thickness of angled arms is increased to 0.1875 inches. 6061 aluminum will be waterjetted to make this part.

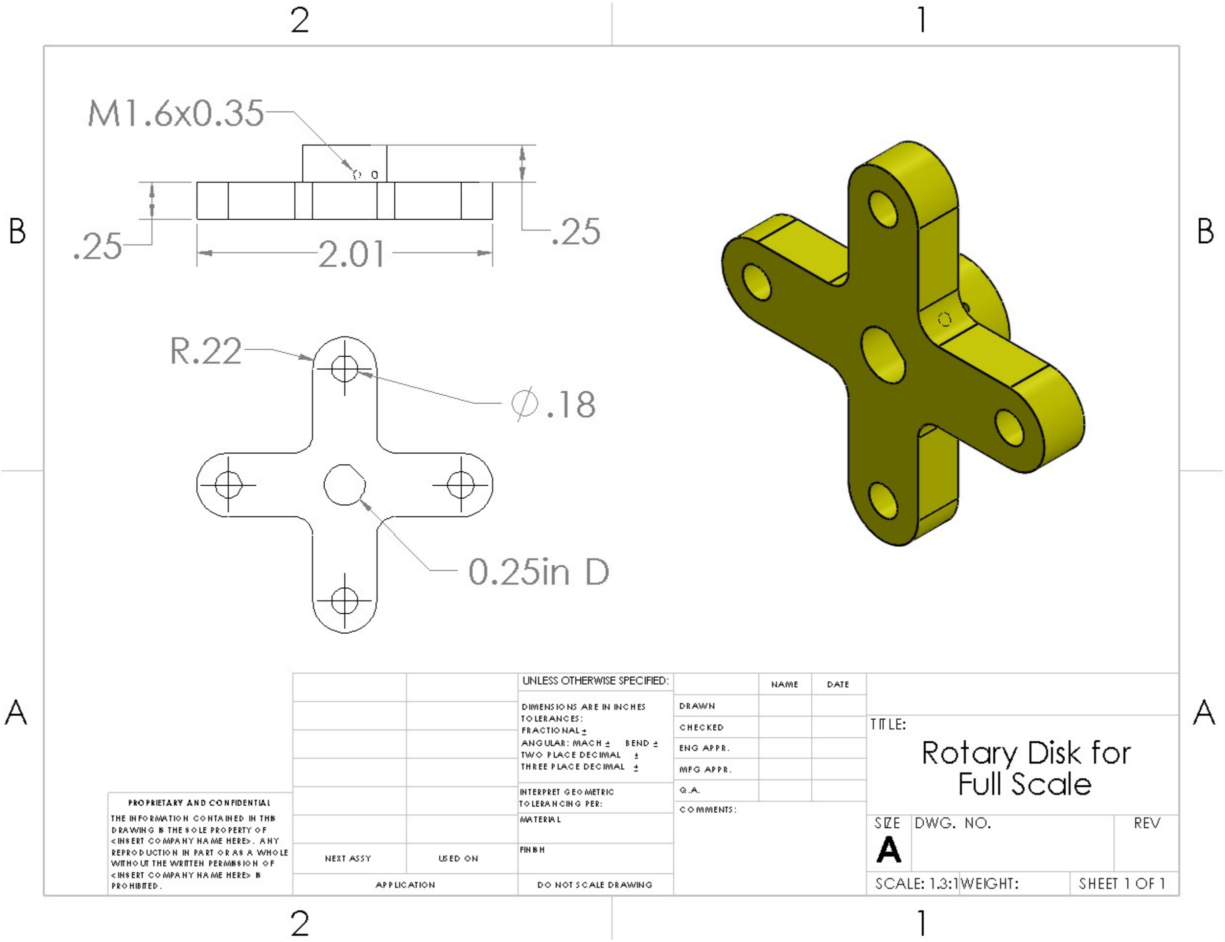


Figure 5.2.8 Drawing of Rotary Disk

The design of the rotary disk is changed due to shaft length. Since the shaft of the motor is short that flaps and bolts would collide with the motor holding plate, a cylinder on the rotary disk was extruded to hold the tip of shaft. Since the rotary disk also handles most of the load created by drag, the thickness was increased 0.25 inches. 6061 Aluminum alloy will be waterjetted to make this part.

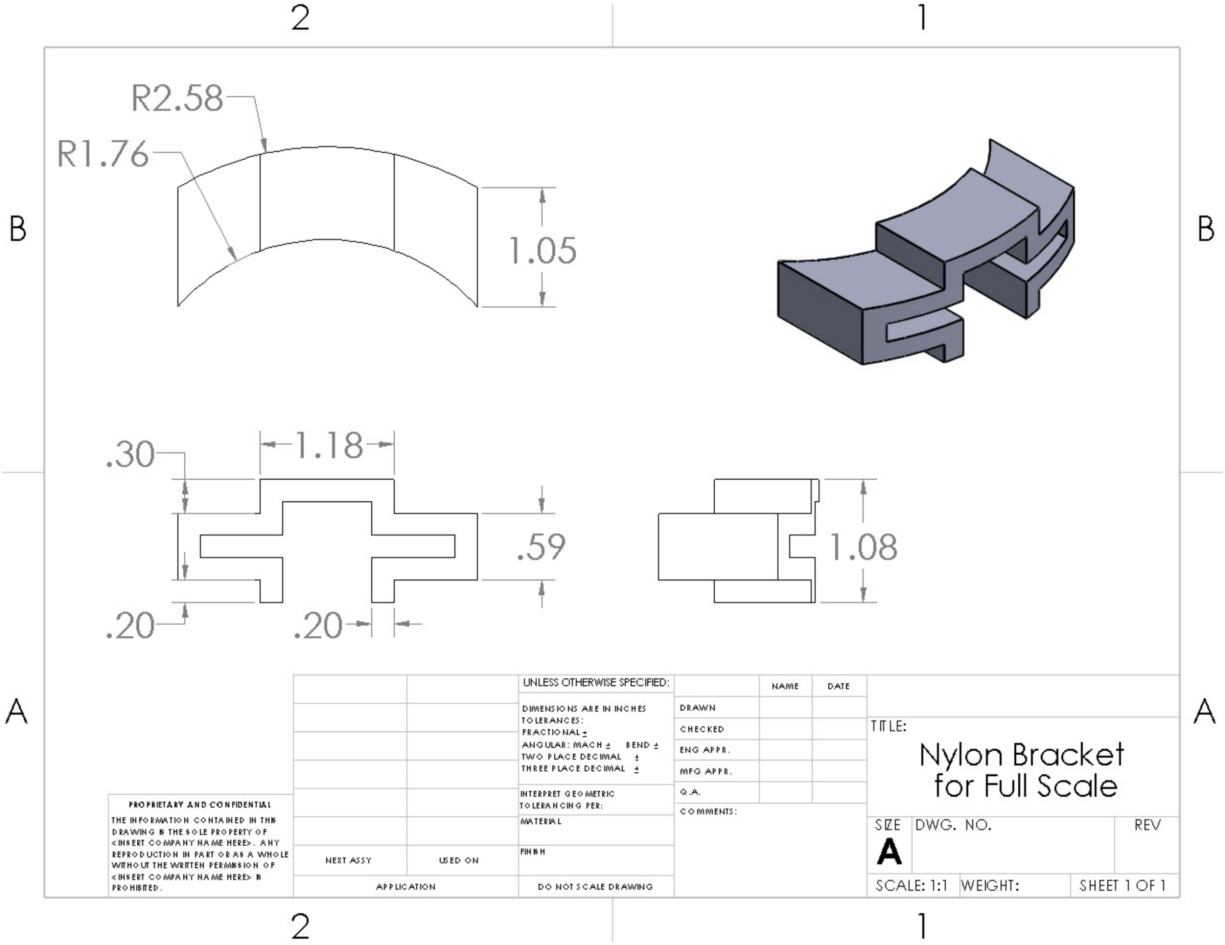


Figure 5.2.9 Drawing of Nylon Bracket

Nylon bracket is added for full scale flight to prevent flap support to be damaged and to provide smooth surface which flaps can move on. This part will be manufactured using 6/10 grade nylon and it will be waterjetted. This will be held onto the flap support using fast acting adhesive such as cyanoacrylate (Super Glue).

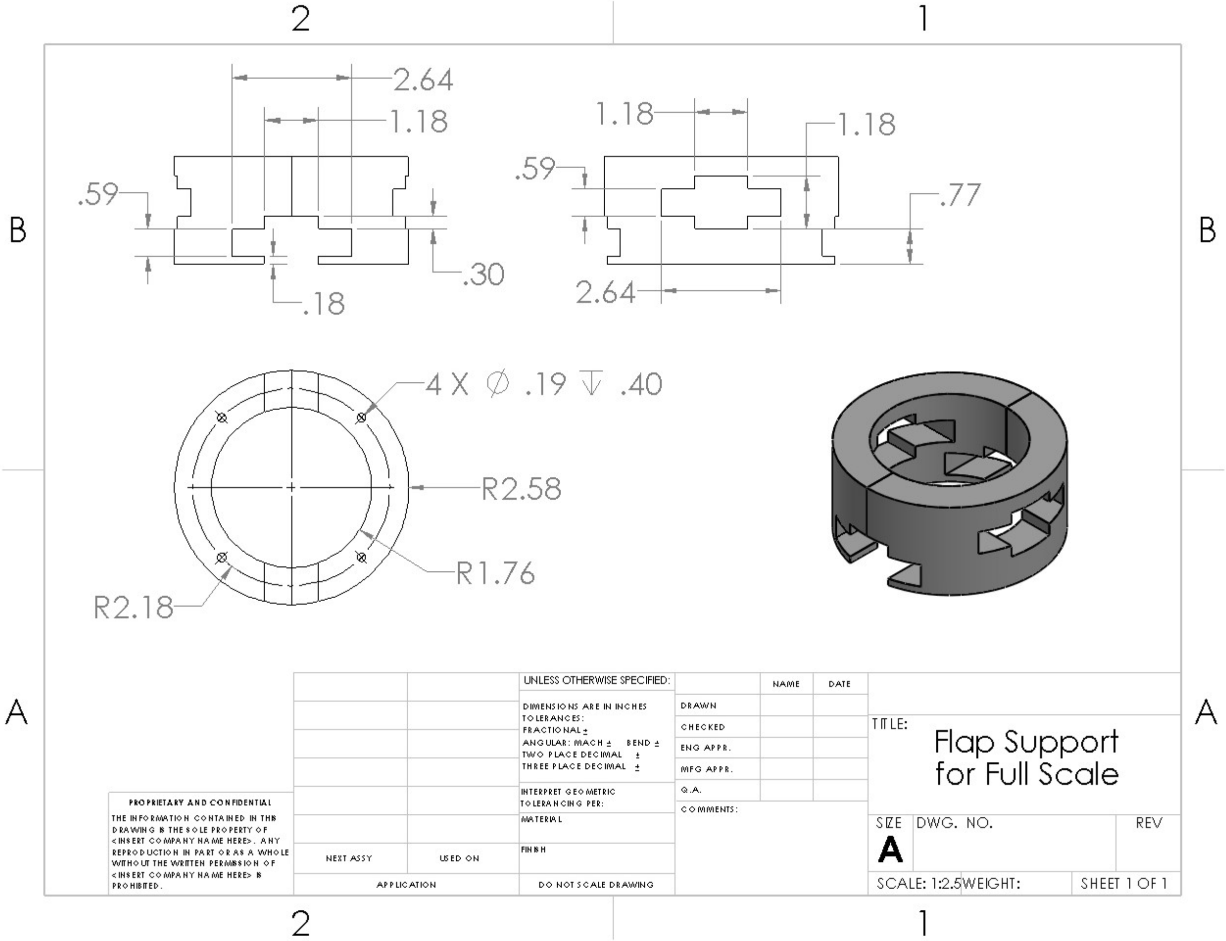


Figure 5.2.10 Drawing of Flap Support

The flap support was scaled up to fit into bigger coupler tube. The size of slit was increased significantly to hold nylon brackets. This part will be 3d printed with Acrylonitrile Butadiene Styrene (ABS).

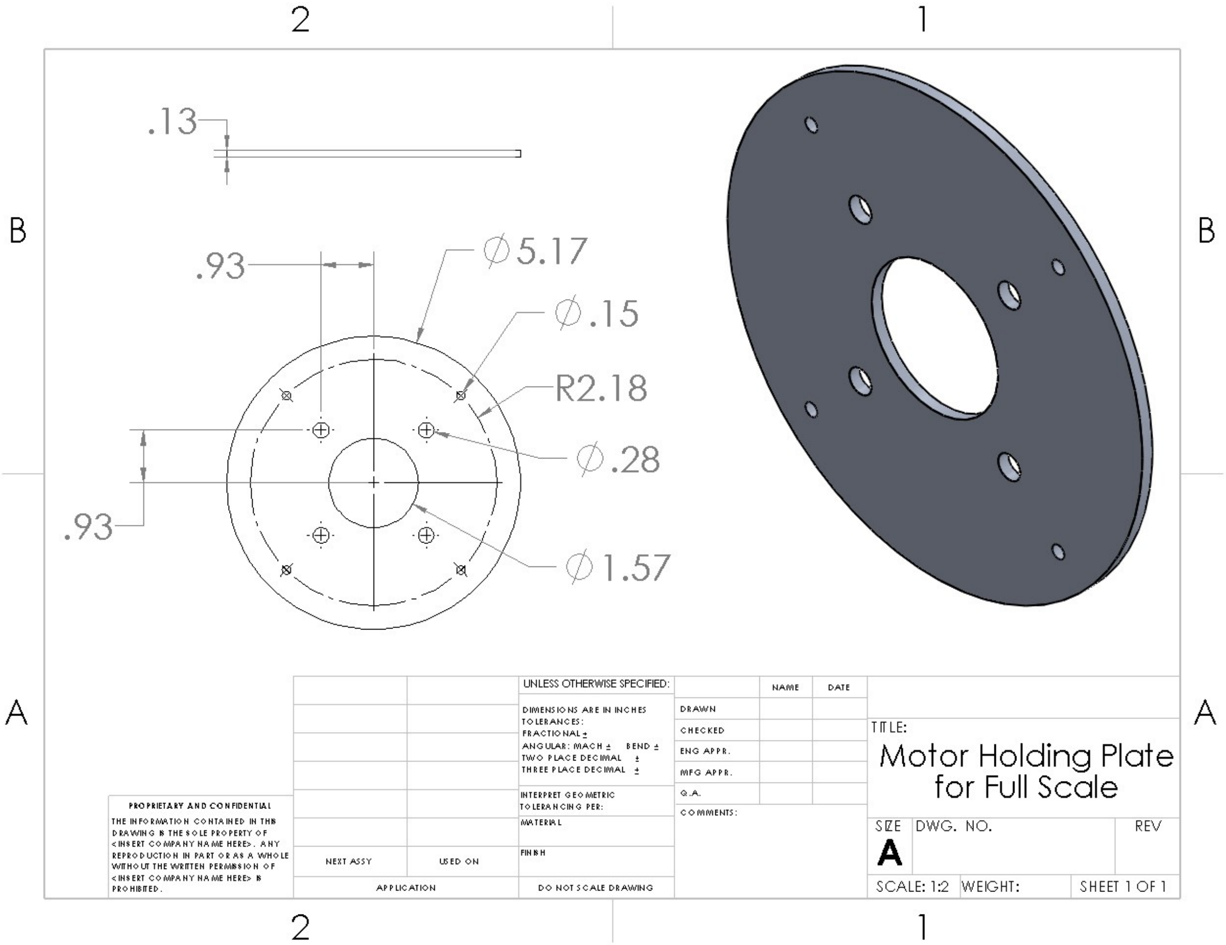


Figure 5.2.11 Drawing of Motor Holding Plate

The thickness of motor holding plate is same as that of motor holding plate used in subscale because simulation showed that it will not carry much load. The size was increased to hold larger flap support. 6061 aluminum alloy will be waterjetted to make this part.

Since the flaps produce more drag, the resistive torque will increase. Resistive torque was calculated by following steps. Variables used in calculations are defined as

d = vertical distance from the centroid of rotary disk to the outer perimeter of the slit

w = width of the flap

x = distance from the centroid of rotary disk to the connecting nut

θ = the angle between one of the arms of the rotary disk and angled linkage arm

a = length of the curved arm

b = length of one of the arms of rotary disk

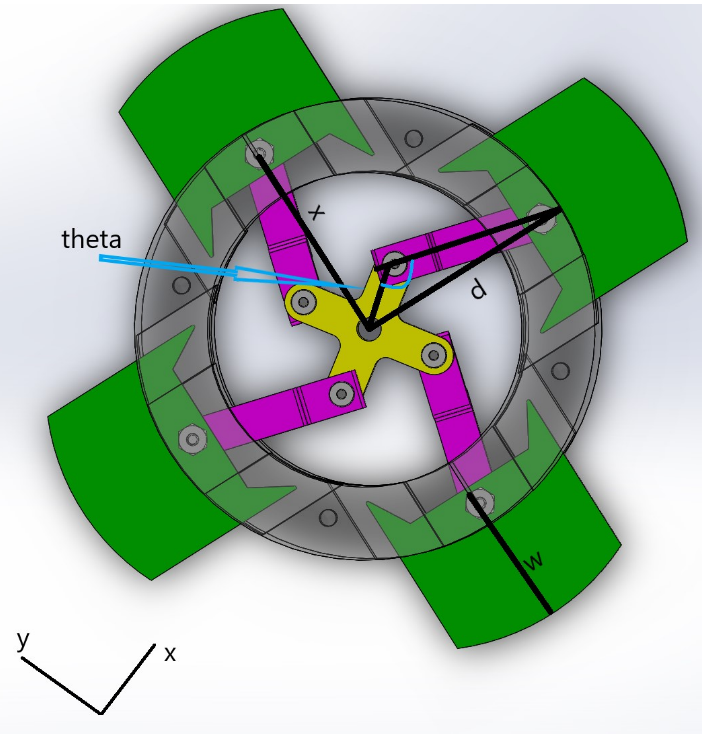


Figure. 5.2.12 Diagram of ATS

Area that generates drag, Aeff can be expressed

$$A_{eff} = \frac{A_{tot}}{w}(x(\theta) + \mathrm{w} - \mathrm{d})$$

Equation 5.2.1

x(θ) can be expressed

$$x(\theta) = \sqrt{a^2 + b^2 - 2abcos(\theta)}$$

Equation 5.2.2

Therefore, Aeff can be expressed

$$A_{eff} = \frac{A_{tot}}{w}\left(\sqrt{a^2 + b^2 - 2abcos(\theta)} + \mathrm{w} - \mathrm{d}\right)$$

Equation 5.2.3

The drag equation is

$$D = \frac{1}{2} C_d \rho A_{eff} {v_{max}}^2$$

Equation 5.2.4

where v_max is the maximum velocity of the rocket; ρ is the density of the air, Cd is the drag coefficient. Looking at the system in short frame of time, the drag will induce static friction which can be expressed as

$$F_D = \mu D$$

Equation 5.2.5

where μ is the coefficient of static friction. Based on friction, it is possible to calculate torque. The r for torque can be expressed in terms of ϕ, the angle between x- axis and one of the arms of the rotary disk. The torque due to friction on the flap is

$$\tau_D = bcos(\phi) * F_D$$

Equation 5.2.6

However, this can be expressed in terms of θ. The angle that the arm of the rotary coupler makes with the y-axis is $\pi/2+\phi$. Using sine law,

$$\frac{sin(\theta)}{x(\theta)} = \frac{\sin(\frac{\pi}{2} + \phi)}{b}$$

Equation 5.2.7

Therefore,

$$\sin(\frac{\pi}{2} + \phi) = \frac{bsin(\theta)}{x(\theta)}$$

Equation 5.2.8

$$\phi = \arcsin\left(\frac{bsin(\theta)}{x(\theta)}\right) - \frac{\pi}{2}$$

Equation 5.2.9

Therefore, the full equation for torque due to friction induced by the drag is

$$\tau_D = bcos\left(\arcsin\left(\frac{bsin(\theta)}{\sqrt{a^2+b^2-2abcos(\theta)}}\right)-\frac{\pi}{2}\right) * \mu * \frac{1}{2}C_d\rho {v_{max}}^2 * \frac{A_{tot}}{w}\left(\sqrt{a^2+b^2-2abcos(\theta)}+\mathrm{w}-\mathrm{d}\right)$$

Equation 5.2.10

The friction created on the joint between the rotary coupler and the angled arm can be calculated with the same equation stated previously. Therefore the net torque produced in this region is

$$\tau_D = 4 * \left(\left(bcos\left(\arcsin\left(\frac{bsin(\theta)}{\sqrt{a^2+b^2-2abcos(\theta)}}\right)-\frac{\pi}{2}\right)\right) * \mu + (2r_{bolt} * \mu')\right) * \frac{1}{2}C_d\rho {v_{max}}^2 * \frac{A_{tot}}{w}\left(\sqrt{a^2+b^2-2abcos(\theta)}+\mathrm{w}-\mathrm{d}\right)$$

Equation 5.2.11

where r_bolt is the radius of bolt; μ' is the coefficient of friction between aluminum and steel. 4 is multiplied because there are four flaps that causes torque and 2 is multiplied because there are two bolts on one side. Then the graph of torque vs. angle was plotted to find the maximum value. The maximum resistive torque was approximately 70.5 oz-in. Since the only options for the stepper motor were one that can generate 55 or 125 oz-in, the motor that produces 125 oz-in was chosen for the final design.

ATS also has some parts that are The list of parts are shown in the table below.

Table 5.2.1 Table of Parts

Parts Name	Manufacturer	Material	Weight (lb)
Motor Holding Plate	Custom	6061 Aluminum Alloy	0.228
Rotary Disk	Custom	6061 Aluminum Alloy	0.0373
Angled Linkage Arm	Custom	6061 Aluminum Alloy	0.0069
Flap	Custom	6061 Aluminum Alloy	0.0445
Flap Support	Custom	6061 Aluminum Alloy	0.687*
Nylon Bracket	Custom	6/10 Grade Nylon	0.04
#1473 Stepper Motor	Pololu	N/A	1.54
91251A356, Black-Oxide Alloy Steel Socket Head Cap Screw	McMaster-Carr	Alloy Steel	0.0009
92949A149, 18-8 SS Button-head Socket Cap Screw	McMaster-Carr	Alloy Steel	0.0025
91259A162, Alloy Steel Shoulder Screw	McMaster-Carr	Alloy Steel	0.0006
91259A161, Alloy Steel Shoulder Screw	McMaster-Carr	Alloy Steel	0.0005
90480A007, Low Strength Steel Hex Nut	McMaster-Carr	Zinc-Plated Steel	0.0003
90480A195, Low Strength Steel Hex Nut	McMaster-Carr	Zinc-Plated Steel	0.0004
90363A044, Brass Press-Fit Insert for Composite	McMaster-Carr	Brass	0.0017
92313A003, Type 316 SS Cup Point Set Screw	McMaster-Carr	Alloy Steel	0.0003

*The result was retrieved from CAD analysis. Since 3D printed part is non homogeneous, the real mass is lighter.

5.2.2. Assembly Design/Specification

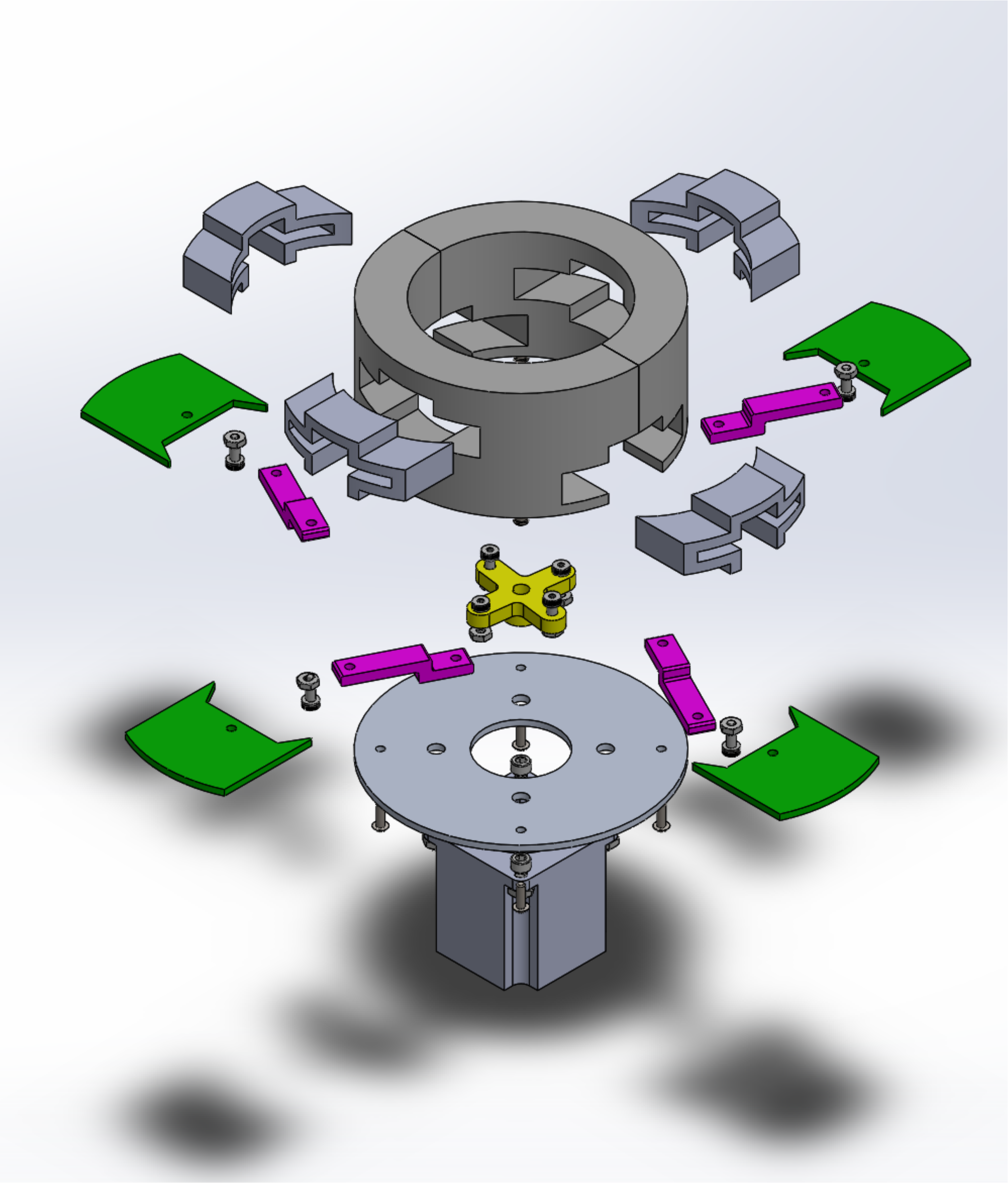


Figure 5.2.13 Exploded View of ATS Assembly

The goal of the assembly is that each part serves its function. To guarantee that ATS will function properly, each components, as one interacts with each other, should not go through any failure under expected circumstance. Such condition was simulated using Solidworks. Following figures are the result of the simulation. The force on each flap which is drag is calculated using drag equation. The speed was assumed to be 0.8 Mach as this rocket was not intended to travel at supersonic speed.

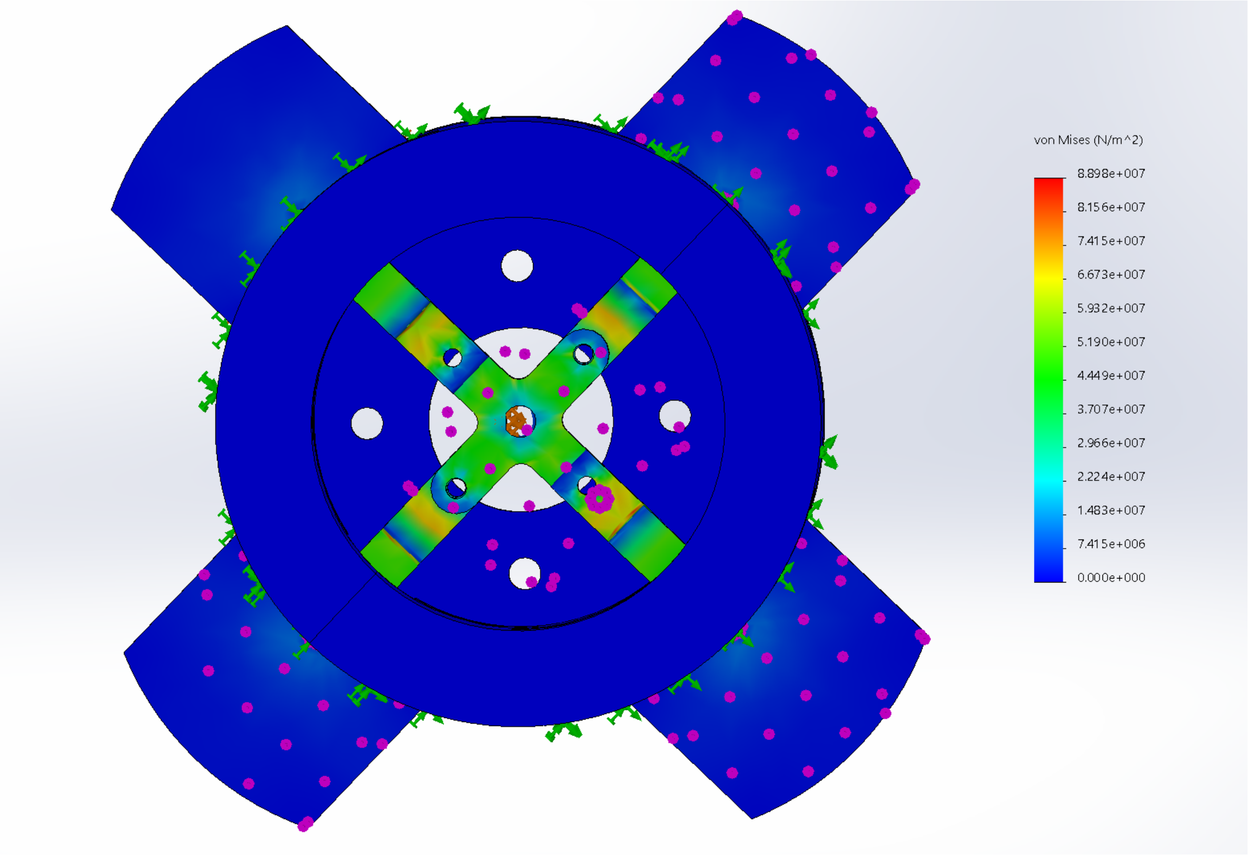


Figure 5.2.14 Simulation Result

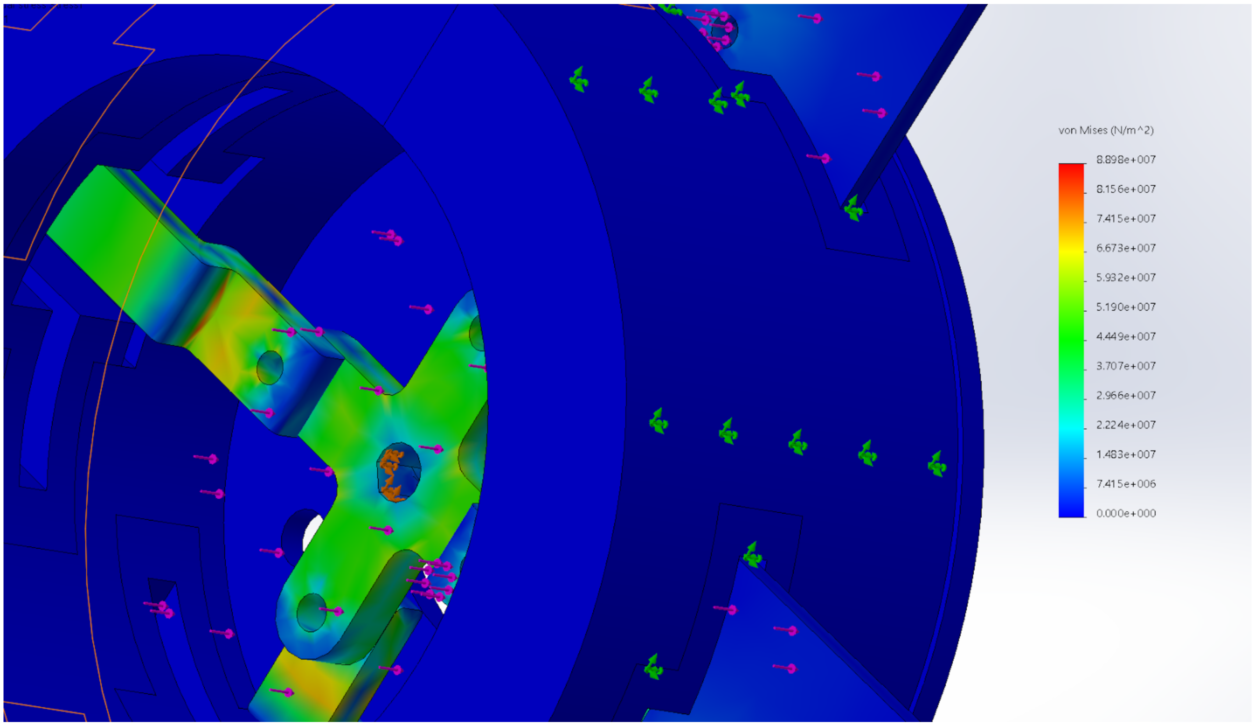


Figure 5.2.15 Simulation Result (Zoom into Angled Linkage Arm)

The simulation shows that angled linkage arm will go through 8.9e7 Nm^-2, which is 12,910 psi. Since the yield strength of 6061 Aluminum is 40,000psi, the factor of safety is 3.1 which satisfies the requirement that the factor of safety should be bigger than 2.

5.2.3. Component Interactions

The ATS mechanism is, for the most part, held together with mechanical fasteners. Screws hold the two halve of the bracket together, and secure the stepper motor to the plate and brackets. The linkage bar assembly is attached to the stepper motor via a set screw that clamps on the motor shaft to lock rotation. In order to fasten to the 3D-printed plastic, gnarled inserts will be sunken into the material through the application of enough heat to cause significant deformation.

The flaps that act as the aerodynamic surfaces will rub against the nylon guides in which they rest. Synthetic teflon grease will be applied to this surface to further decrease the static and low-velocity dynamic friction coefficients.

To ensure that vibrations do not cause fasteners to loosen, temporary loctite will be applied to each screw in the assembly during final assembly.

5.2.4. Launch Vehicle Integration

Flap support will be glued to coupler tube. After the coupler tube with ATS is mounted on the body, it will be wired to the avionics bay.

5.3. Payload Electronics

5.3.1. Drawings and Schematics

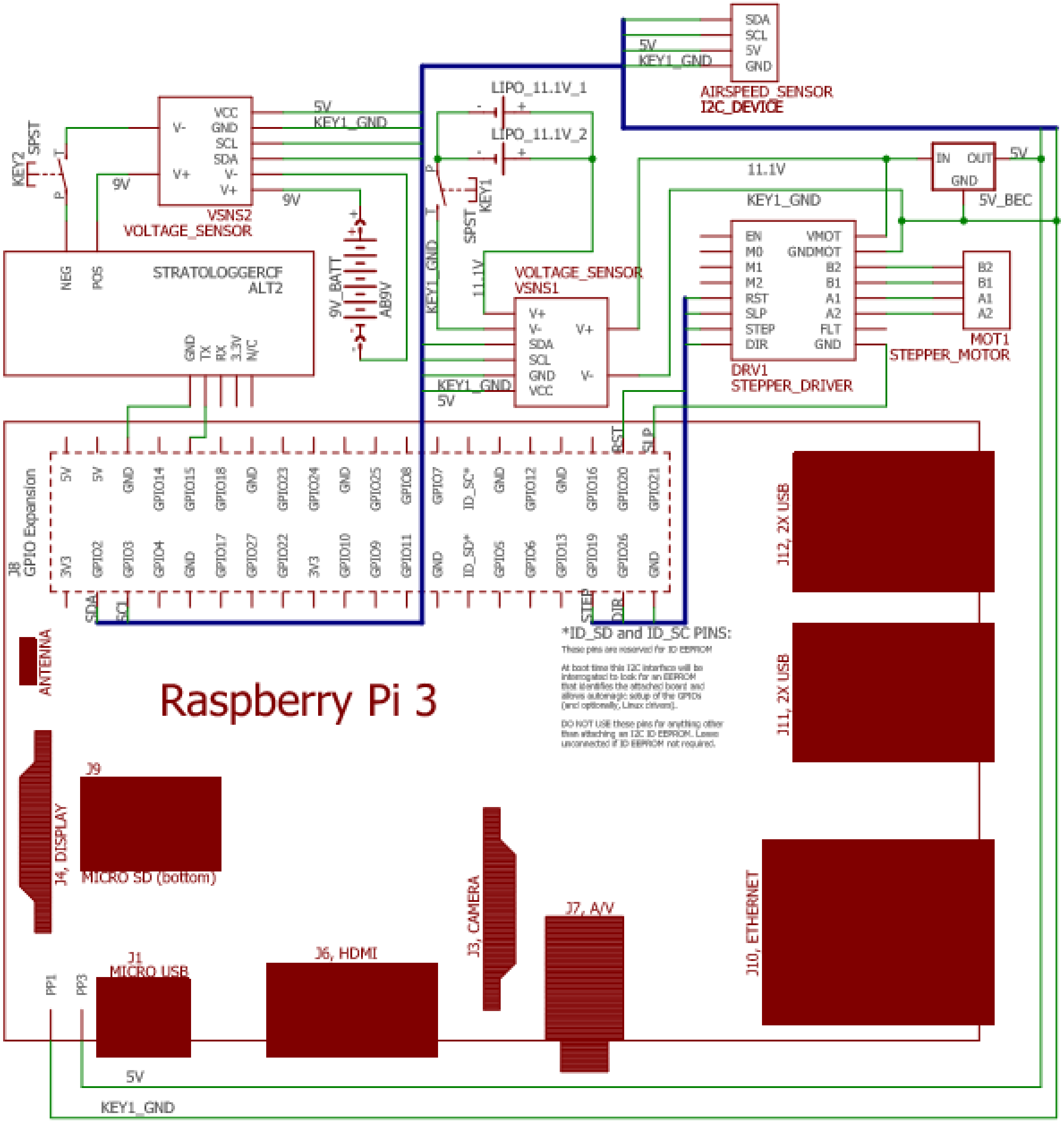
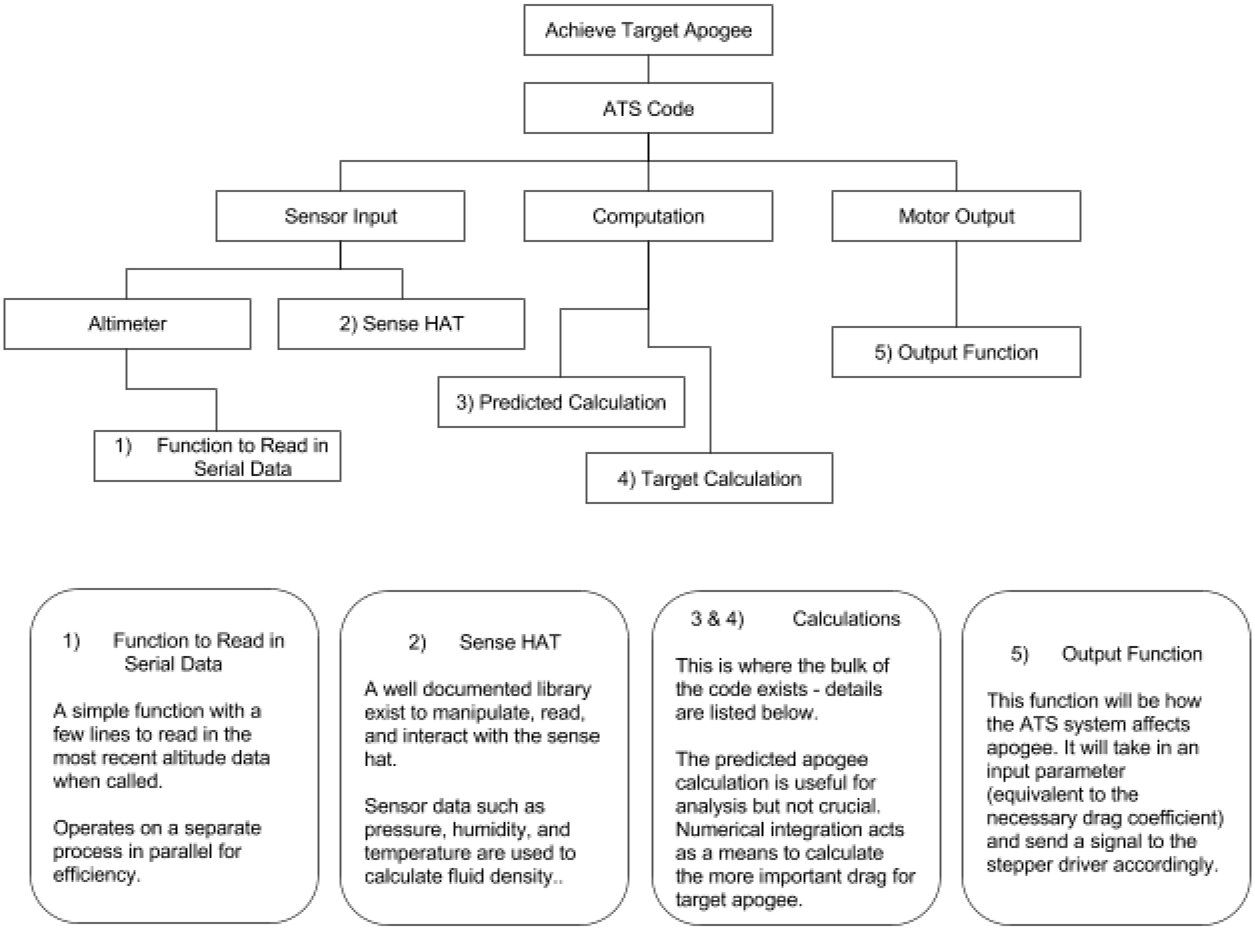


Figure 5.3.1 ATS Circuit Schematic

The above figure details the circuitry immediately relevant for the ATS. Voltage sensors are used to monitor the two LiPO batteries that power the Raspberry Pi and Motor in addition to the 9 volt battery powering the altimeter (specifically used for ATS only for redundancy). A 5 volt regulator is used to power the Pi and voltage sensors from the 11.1 volt output of the LiPo batteries. Because the Pi only has one of each I2C pin, all other I2C devices (the voltage monitors and the airspeed sensor) are wired in parallel on an I2C bus consisting of 4 wires: SDA, SCL, 5V BEC output, and the corresponding ground. To accomplish this, each device must be given a different address.

The switch for the altimeter is placed after the voltage monitor so that if the Raspberry Pi is powered before the altimeter, the Pi may still record voltage data from the relevant battery. The 5V and ground outputs are used directly from the BEC rather than from the Pi to prevent exceeding the maximum current draw on the Pi pins.

5.3.2. Software



1) Function to Read in Serial Data

A simple function with a few lines to read in the most recent altitude data when called.

Operates on a separate process in parallel for efficiency.

2) Sense HAT

A well documented library exist to manipulate, read, and interact with the sense hat.

Sensor data such as pressure, humidity, and temperature are used to calculate fluid density..

3 & 4) Calculations

This is where the bulk of the code exists - details are listed below.

The predicted apogee calculation is useful for analysis but not crucial. Numerical integration acts as a means to calculate the more important drag for target apogee.

5) Output Function

This function will be how the ATS system affects apogee. It will take in an input parameter (equivalent to the necessary drag coefficient) and send a signal to the stepper driver accordingly.

Figure 5.3.2 ATS Software Function Tree

Sensory data will be sent to the microcontroller from the altimeter and Sense HAT. While the altimeter data is most important for apogee calculations, gyroscopic and accelerometer data from the Sense HAT may also be used to predict apogee, in addition to climate data used to determine air density. All sensory data input will be logged during flight for post-flight analysis by the team. This will be done in parallel on the quad-core CPU on the Raspberry Pi 3 to prevent negative impact on the apogee calculations.

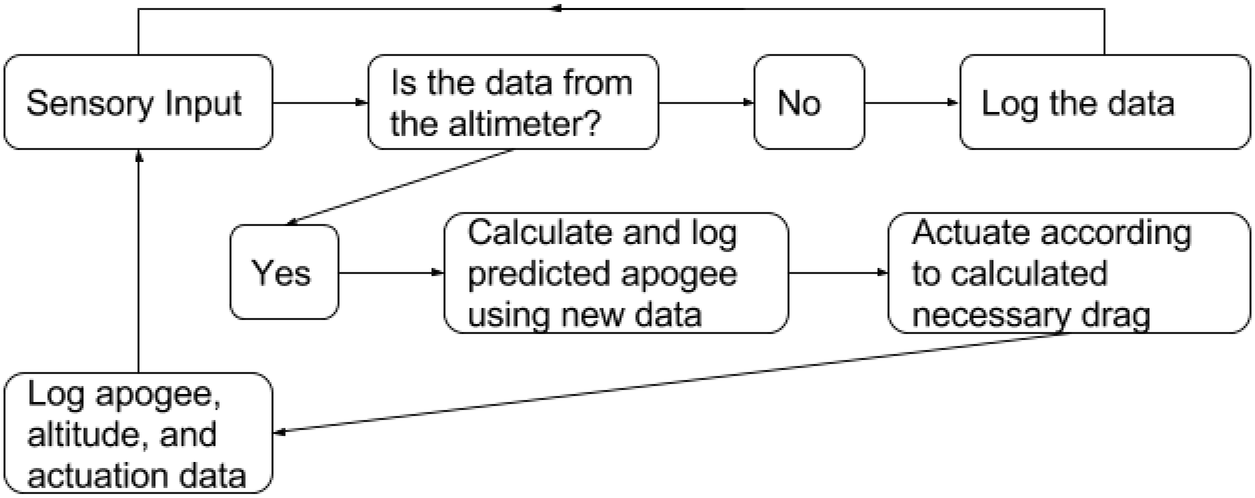


Figure 5.3.3 ATS Software Flowchart

The ATS software runs in a parallelized python script that makes full use of each of the four cores on the Raspberry Pi 3. The individual processes each perform a core task of the ATS. They are as follows: a process dedicated to receiving and time-stamping altimeter data 20 times a second before sending it to the logging process, a process solely focused on collecting and arranging data before it is logged and sent to other processes, a process that transmits incoming data via telemetry to a ground-based receiver, and the core calculation and actuation process of the ATS.

While recording data, the rest of the ATS software is directed at processing altimeter output to predict an apogee and actuate accordingly in a loop. The code will use a method of numerically solving a second order nonlinear differential equation (Euler's method) to iteratively calculate the altitude of the rocket based on the equation for acceleration. This can be done by solving for a the time derivative of altitude using the normal Euler's method and then numerically integrating to get height. Using Euler's method, the predictions will become increasingly accurate given smaller and smaller time steps between adjacent points. It is a goal to integrate the full altitude function of the rocket up to apogee in a time equivalent to one time step; thus if the software can iterate faster, smaller time steps can be used and the predictions will be more accurate. For this reason performance is vital to the ATS and the software needs to be aptly optimized to generate useful predictions. The quad-core CPU of the Pi is especially appealing for this reason as it is more than sufficient for this purpose.

Actuation will occur in an iterative manner based on the comparison between the predicted apogee and target apogee. This is necessary because we may not be directly calculating the drag coefficient needed to reach target apogee, and ideally this ideal drag coefficient will be reached after a few iterations. This problem is significant because there is no way to generate additional upwards force on the rocket since we do not have variable thrust; thus if the apogee is decreased too far below the target, nothing can be done to raise it. The flight time will also be short so there will be little time to correct these errors.

5.3.3. Batteries and Power

One of the hindrances during preparation for the subscale flight included not providing the correct power to the ATS. The motor requires a substantial voltage and current to run properly, which quickly drains batteries during testing. The RPi with all of the wired devices also can draw up to 2.5 amps of current as well. To remedy this, two LiPo batteries are wired in parallel to increase the capacity of the circuit without affecting the output voltage.

6. Rover System

6.1. Rover System Overview

The rover system is composed of two main subsystems: the rover body, and the rover deployment system. The following sections detail the mechanics and avionics behind each of these subsystems, as well as their integration into the launch vehicle.

6.2. Deployment System Design

6.2.1. Deployment System Overview

The deployment system uses a threaded rod mechanism to open the rocket. Within the body of the rocket, the rover is suspended on a rail with the direction of its wheels perpendicular to the body of the rocket. As the rocket opens, the rover is pushed along the rail. Once the rover reaches the end of the rail, it falls either to the ground or onto the support plate, depending on the roll orientation of the rocket. When the rocket is fully open, the rover will activate and drive away.

6.2.2. Component Design/Specifications

The motor turns the threaded rod, which causes the carriage to move and the deployment system to open. It is a small DC motor attached to a worm gear box.

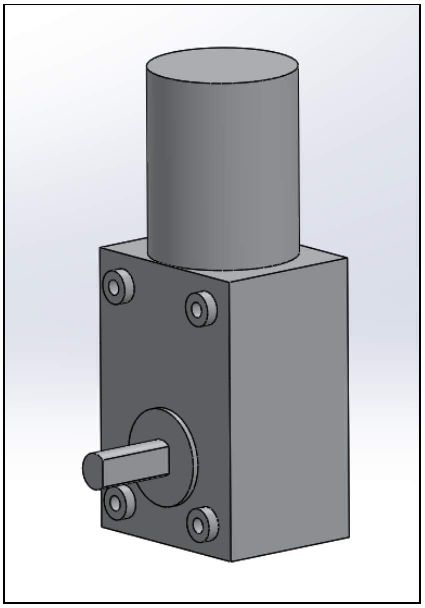


Figure 6.2.1 Rover Deployment Motor

This configuration has several advantages. The worm gear provides high torque, which will allow the system to open despite any resistance the terrain might provide. In addition, the fact that the body of the motor is perpendicular to its output shaft saves space. The system was designed to take up as little of the rocket's length as possible while still opening wide enough to deploy the rover. The threaded rod will be attached to the motor with a small coupler.

The motor bracket is a 3D printed part that holds the rover deployment motor and supports the guide rails. The front face has holes that line up with the screw holes on the motor. This is how the motor will be mounted. The bottom of the bracket has a large surface area so it can easily be epoxied into place. The indentations in the sides prevent interference with the carriage when the system is closed. The guide rails prevent the carriage from rotating and provide support.

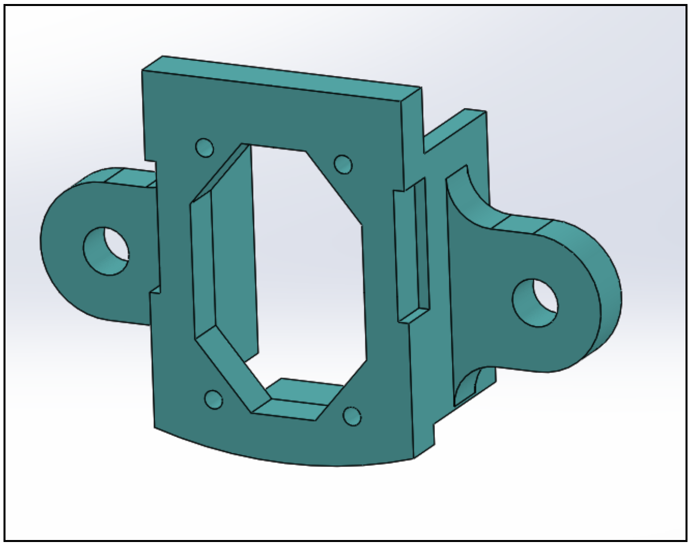


Figure 6.2.2 Motor Bracket

The front support bracket supports the ends of the threaded rod and guide rails as well as the Support Plate. There is an gap on top because the entire Support Plate must slide through the Front Support Bracket as the rocket opens. The notch below the gap prevents the bracket from interfering with the screws that fasten the Support Plate to the Nose Cone Bracket.

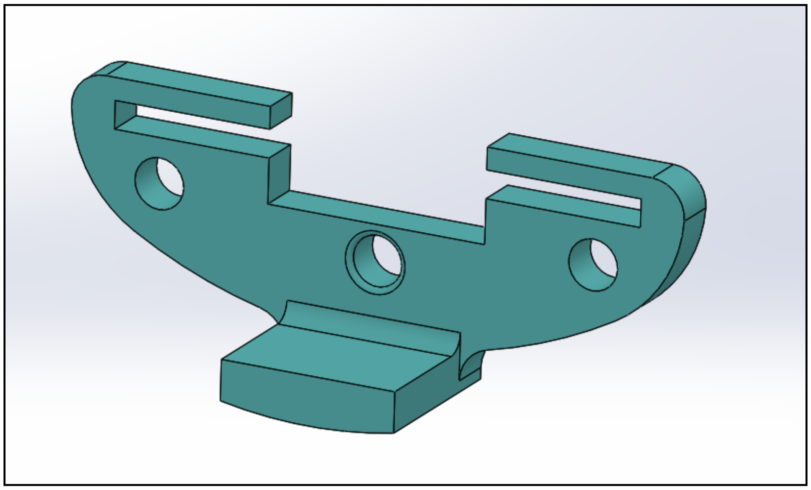


Figure 6.2.3 Front Support Bracket

The Carriage has multiple purposes. The lead nut is screwed into the hole in the center, preventing it from rotating as the threaded rod turns. This causes the carriage to move along the threaded rod. The Support Plate fits into the large slot and is screwed in place. The holes on the sides of the bottom portion are for the guide rails. The pusher, which is not shown in the image below, is mounted to the top portion of the carriage. It pushes the rover along the rover rail as the rocket opens, and is padded to protect the rover from vibrations and other loads.

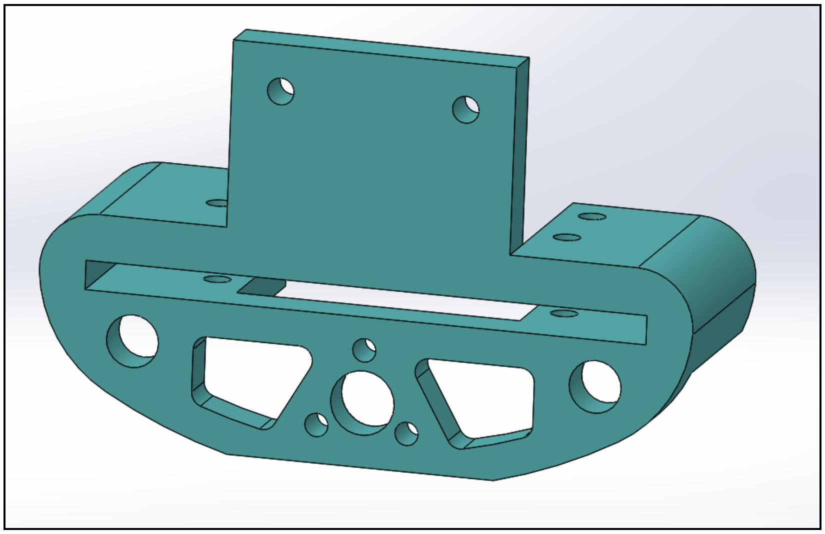


Figure 6.2.4 Carriage

The Nose Cone Bracket connects the Support Plate to the Nose Cone. It consists of 3D printed components on either side that will be epoxied to the inside of the Nose Cone's shoulder. They curved bottom surface of these parts fits the curvature of the shoulder. The center portion has two aluminum T Brackets with spacers between them. These parts are aluminum because they must be thin enough to avoid interfering with the Front Support Bracket, but strong enough to safely secure the Nose Cone. The assembly is designed so that, if need be, the nose cone can be unscrewed from the Support Plate, allowing access to the deployment system for maintenance purposes.

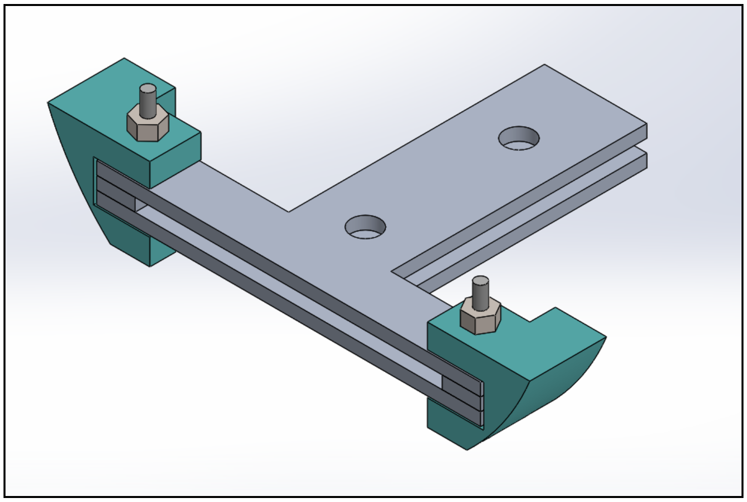


Figure 6.2.5 Nose Cone Bracket Assembly

The Support Plate is what connects the body of the rocket to the Nose Cone. Within the body, it is screwed into the Carriage. In the Nose Cone, it is screwed into the Nose Cone Bracket, shown above. The Support Plate is made from aluminum because of its strength. It is a single plate rather than two beams so that the rover can easily roll over it without getting stuck. Mounted to the support plate is the Nose Cone Pusher. This component, like the other Pusher, helps to prevent the Rover from moving along the rail during flight. It is also padded to protect the Rover. The Pushers are spaced far apart enough that they can’t both touch the opposite sides of the Rover at the same time. They do not prevent the Rover from driving out of the system by holding it too tightly. The notch in the end prevents interference with the motor when the system is closed.

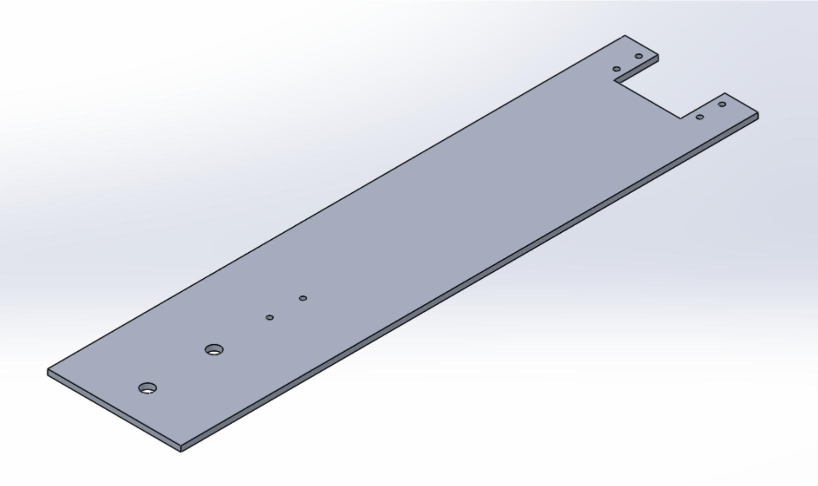


Figure 6.2.6 Support Plate.

The Rover Rail Bracket is what holds the Rover Rail in place. Due to its complex geometry, it will be 3D printed. The rectangular holes in the bottom are where the Rover Rail is held. The bracket is mounted on the top surface of the rocket body, opposite the Deployment Motor and Front Support Bracket.

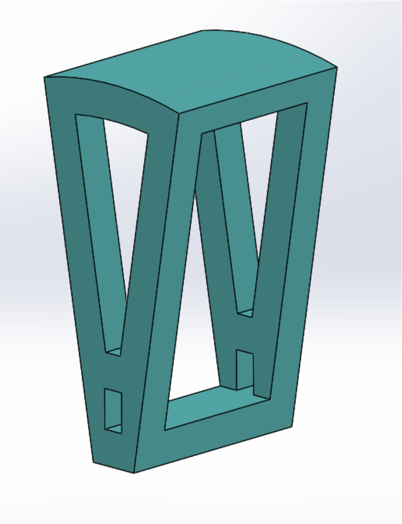


Figure 6.2.7 Rover Rail Bracket

6.2.3. Assembly Design/Specifications

The Rover Deployment assembly is designed to open the rocket and deploy the Rover consistently regardless of the orientation in which it lands.

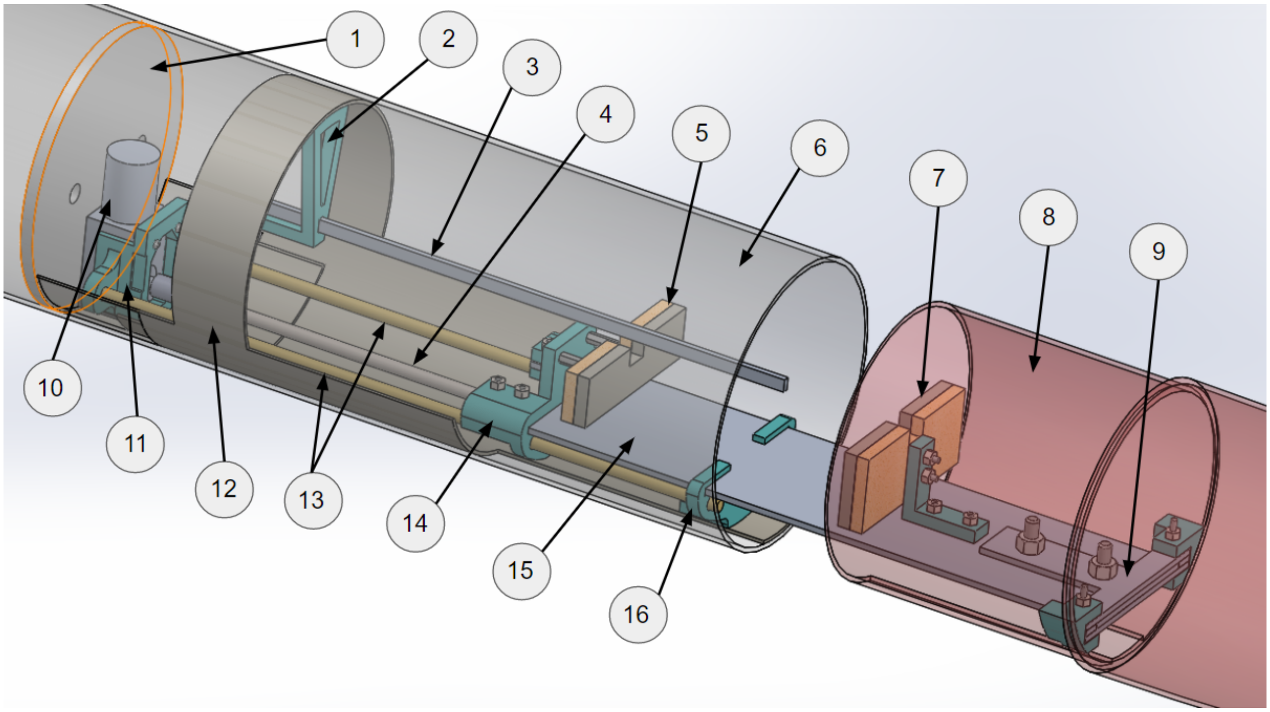


Figure 6.2.8 Labeled Rover Deployment Assembly

Table 6.2.1 Rover Deployment Assembly Key

Number	Component
1	Bulkhead
2	Rover Rail Bracket
3	Rover Rail
4	Threaded Rod
5	Pusher
6	Rover Bay Tube
7	Pusher

Number	Component
9	Nose Cone Bracket
10	Deployment Motor
11	Motor Bracket
12	Tray
13	Guide Rails
14	Carriage
15	Support Plate

8	Nose Cone	16	Front Support Bracket

The Deployment Motor is held in place by the Motor Bracket, and is attached to the Threaded Rod with a shaft coupler. There is a lead nut on the Threaded Rod which is screwed into the Carriage. The rotation of the threaded rod pushes the Carriage forward. The Carriage is also supported by the two Guide Rails that run through it from the Motor Bracket to the Front Support Bracket. The Carriage also holds the Support Plate, the other end of which is attached to the Nose Cone by the Nose Cone Bracket. As the carriage advances, it pushes the Nose Cone off of the Rover Bay Tube, opening the body of the rocket.

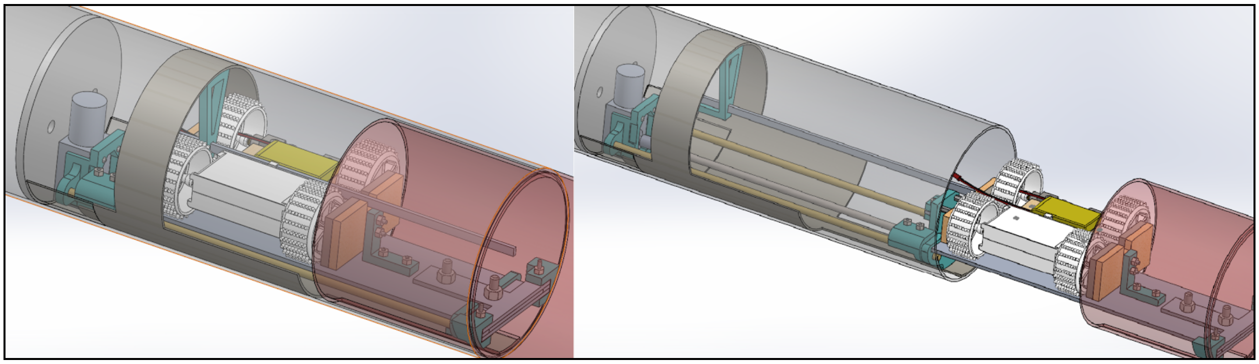


Figure 6.2.9 The Rover Deployment System With the Rover in Open and Closed Configurations

The Rover has a loop attachment that sits on the Rover Rail with the Rover between the two Pushers. The opening of the rocket causes the Pushers to push the Rover along the Rover Rail. Once it reaches the end of the Rover Rail, the Rover will fall off either onto the support plate or the ground depending on the roll orientation in which the section lands. The Rover is designed to function right-side up or upside down. When the rocket is full open, the Pushers will have guided the Rover into a position from which it can easily drive away from the rocket.

6.2.4. Launch Vehicle Integration

The rover deployment system will be constructed on a Tray outside of the rocket body. The Tray will be made from a cardboard coupler tube that fits snugly into the rocket body tube. The coupler will be cut open, making it much easier to epoxy the Motor Bracket, Rover Rail Bract, and Front Support Bracket into place and assemble the system. Since the different brackets must be carefully aligned, mounting them to the Tray instead of the inside of the closed Rover Bay Tube will make assembly much easier.

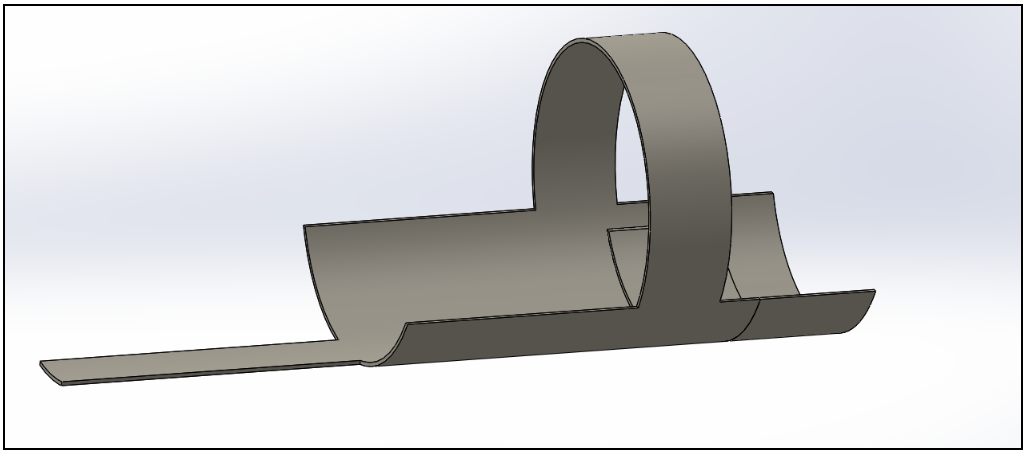


Figure 6.2.10 Tray

The coupler, as purchased online, is only 12” long, so it will need to be extended to 14” using a piece of the scrap left over from cutting it open. The Front Support Bracket will be mounted at the end of the thin strip. It is cut this way to avoid interfering with the Nose Cone when the rocket is closed. The Nose Cone has a slot in the shoulder to accommodate this strip. The “ring” portion of the Tray is where the Rover Rail Bracket will be mounted. The Motor Bracket will be in the center of the extended portion. Once each bracket is epoxied in place, other components can be added. Once the system is fully assembled and briefly on the Tray, it can be inserted into the Rover Bay Tube of the rocket and epoxied into place. The electronics of the deployment system are isolated from the rest of the rocket.

6.3. Deployment System Electronics

6.3.1. Drawings and Schematics

The rover deployment system has a primary purpose of moving the rover to a point where it can easily exit the rocket's fuselage. The specific details of the deployment system hardware are discussed in the hardware section of the rover subsystem description, but a brief overview of the system is necessary for a complete understanding of the electronics that drive the system. Essentially, the rover deployment system is just a motor that drives a lead screw. This lead screw pushes the nose cone off of the top of the rocket and moves the rover, which is attached to the lead screw, out of the rocket so that it can drive forward and complete its ultimate goal. The electronics that drive this system are relatively simple, and consist of a radio transmitter, receiver, battery, motor, 2 receiver-controlled-switches, and limit switch. A block diagram of the deployment system's function is outlined in 6.3.2 below. The battery is connected through the receiver controlled switch which is then connected through the motor, a limit switch and finally back to the battery. When a switch is flipped on the transmitter, the receiver controlled switch closes (by means of a signal from the receiver), thus allowing current to flow through the motor. This drives the lead screw. When the motor drives nose cone off of the rocket, the carriage that holds the rover makes contact with the limit switch, which opens the circuit. This stops current flow to the motor and prevents the motor from damaging rocket hardware. There is an additional mesh that consists of the battery connected in reverse to a receiver controlled switch that then connects to the motor. This circuit is not used in launch, and is merely to close the rover deployment system, as the motor is relatively inaccessible after installation in the rocket. A circuit diagram of the system can be found on Figure 6.3.1.

The avionics and rover subteams took precaution in selecting ideal components for each task necessary for successful deployment of the rover. The transmitter and receiver pair used for triggering the rover subsystem has multiple free channels, allowing multiple signals to be sent to the rover after landing. The avionics subteam discussed using a transistor to control current flow with the transmitter, but eventually chose the receiver controlled switch due to its ability to allow large amounts of current flow through the circuit. The receiver controlled switch is also less fragile than a transistor, as it is a system packaged onto a PCB. This type of robustness would have been difficult to achieve with a transistor; solder joints are liable to break, while the connections on a PCB are permanent. The motor was selected by the rover subteam, and met the necessary torque requirement to drive the rover and nose cone out of the rocket. It was the job of the avionics subteam to ensure that the rest of the rover deployment system could support the motor choice. The primary dependency of the motor is the battery, which must have enough capacity to drive the motor until the rover and nose cone are successfully separated from the rocket. Rover and avionics subteams met to perform these calculations, and due to the small current draw of the motor, a standard 9V battery was deemed to be sufficient for successful operation of the system.

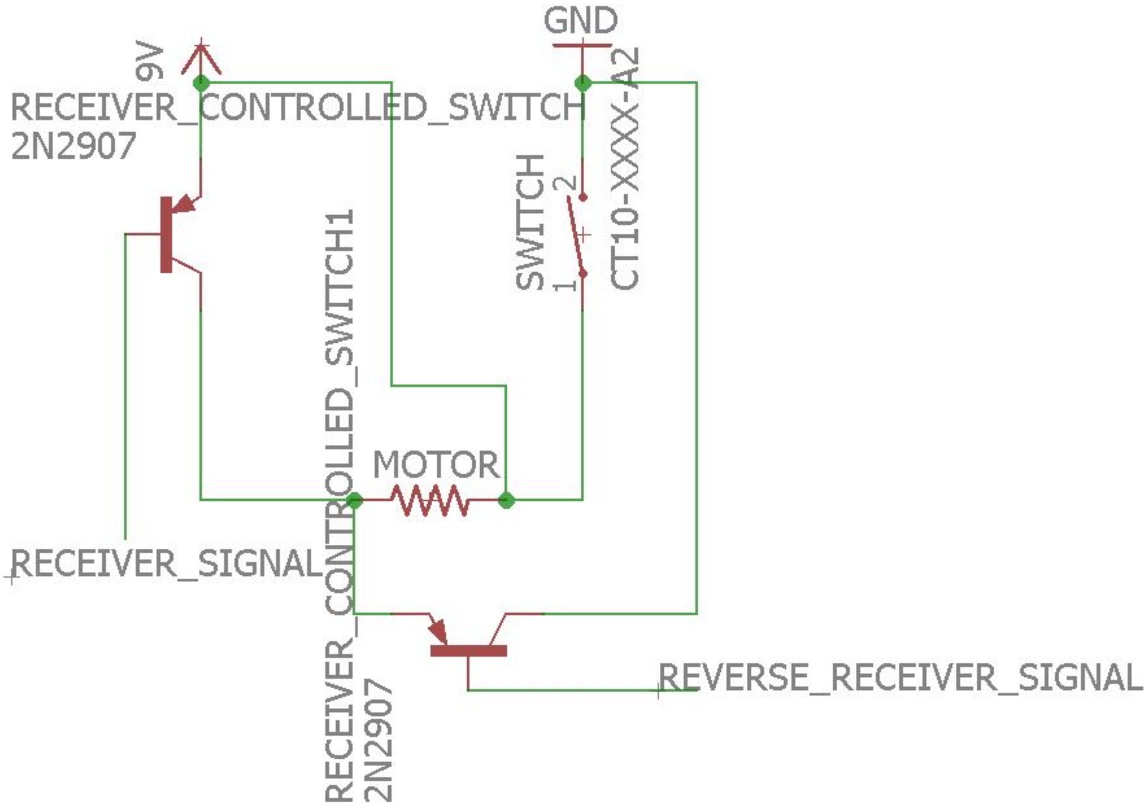


Figure 6.3.1 Rover Deployment Circuit Diagram

6.3.2. Software

It is worthwhile to note in this section that the rover deployment electronics require no software to function normally. Instead of some software logic loop determining the point at which the rover deployment system starts and stops, the points at which the system starts and stops are determined by limit switches and receiver controlled switches that create either a closed or open circuit: digital logic in its simplest form. The decision to create this system without any microprocessor or software was made early on in the design process of the system and allowed the mechanical design to be slightly less space-conscious. In addition, wiring complexity for the system decreases significantly with the removal of the microprocessor. This increases ease of manufacturing for the full-scale rocket and decreases the likelihood of wires becoming caught in the mechanical deployment system.

6.3.3. Block Diagrams

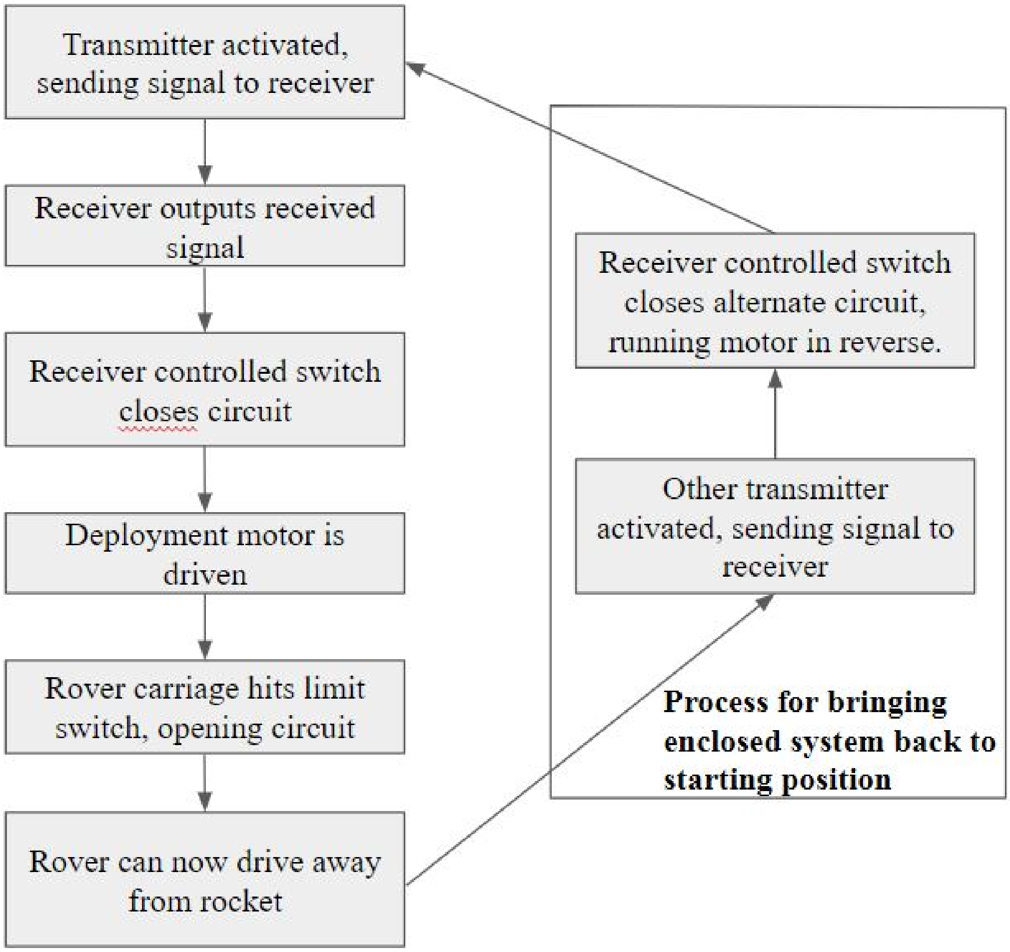


Figure 6.3.2 Rover Deployment Electronics Block Diagram

6.3.4. Batteries/power

Due to the low current draw of the rover deployment motor, it was possible to go with a battery with a very low current supply rating and a low capacity. The low capacity requirement is a direct result of the motor’s current draw statistics and the short time which the motor must run for to deploy the rover. For these reasons, and to satisfy the 9V required voltage supply to the motor, a standard 9V battery was selected for use in the rover deployment system. This type of battery is extremely reliable and has many pre-built mounting brackets that are available for use in the rover deployment system. The main issue with using a non-rechargeable 9V battery is the constant need to monitor battery voltage and, if necessary, replace the battery. The avionics and rover teams have committed to verifying that the battery voltage is optimal, as we will with every other battery on the rocket, before launch.

6.4. Rover Design

6.4.1. Rover Design Overview

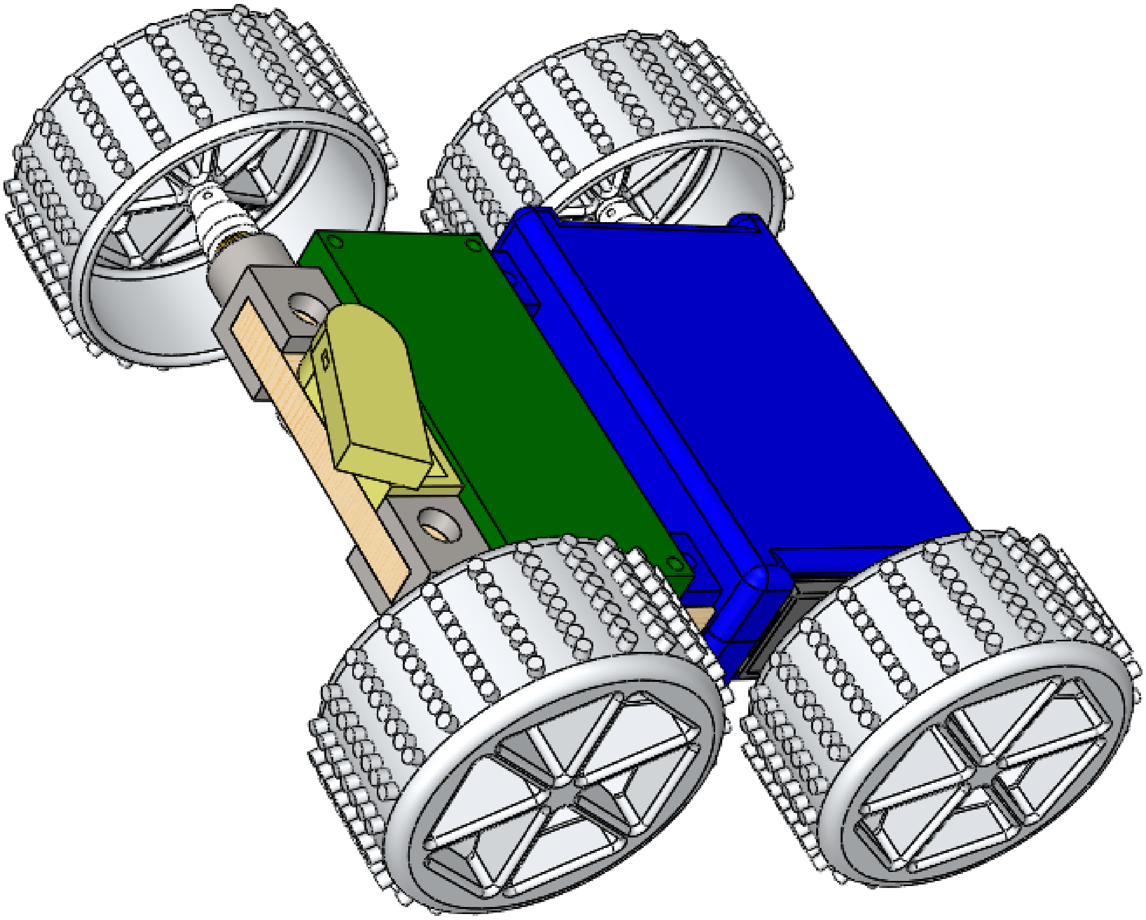


Figure 6.4.1 Complete Rover Assembly

The design requirements of the rover consisted of: The ability to deploy from the launch vehicle, The ability to complete the challenge with only the push of a button, The ability to navigate to a point at least five feet away from the launch vehicle, and The ability to deploy a set of folding solar cell panels as the final task. After careful thought and deliberation our team found an advantageous addition to the aforementioned requirements would be the ability to drive no matter the deployment orientation.

6.4.2. Component Design/Specifications

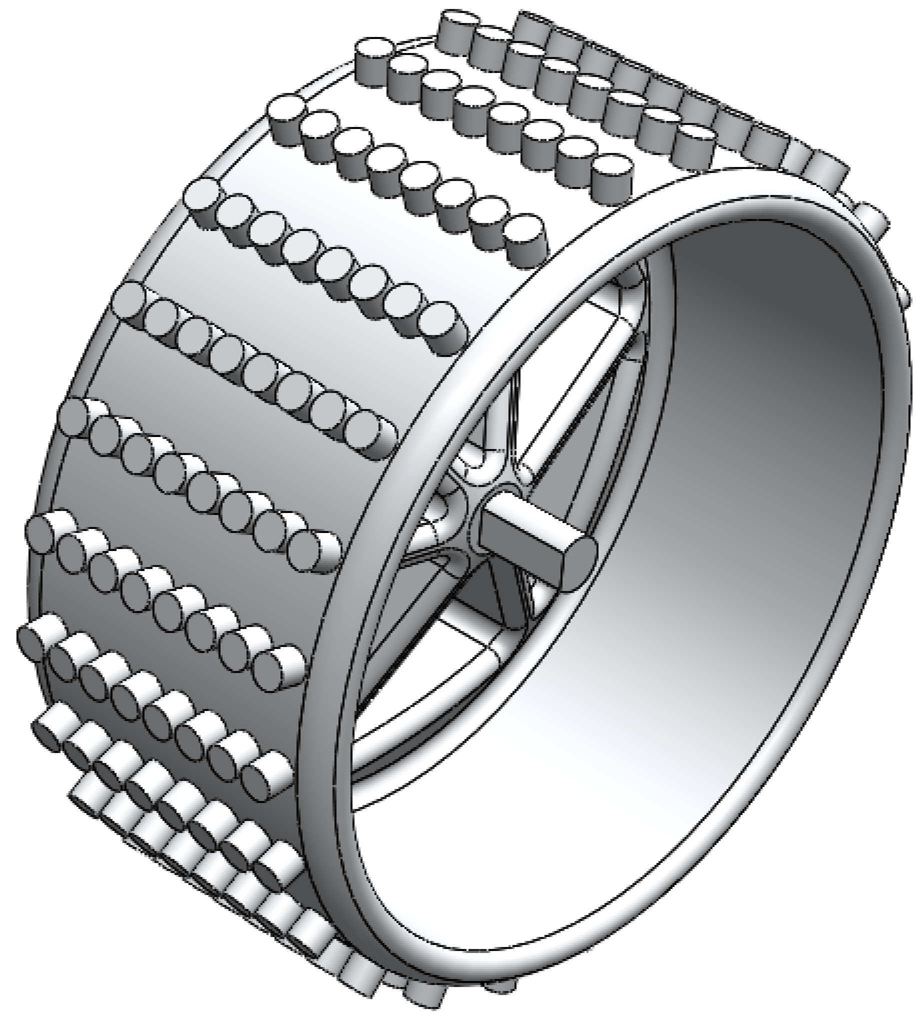


Figure 6.4.2 Rover Wheel

The wheels were designed to have a diameter larger than the thickness of both the servos and the base with all other required components attached. This larger diameter ensures both adequate ground clearance and the ability to drive no matter the orientation of the rover. The flat d-shaped shaft functions as the axle for the wheel and connects the wheel to the servo horn. The spikes are essential to the design as they provide substantially more traction than a slick version of the same wheel. Additionally, due to the fact that the wheels will be 3D printed there is a wide range of freedom for incorporating different design features. 3D printing is being investigated due to the fact that it is a easy way to create custom parts and multiple iterations of said parts quickly to match highly customized applications.

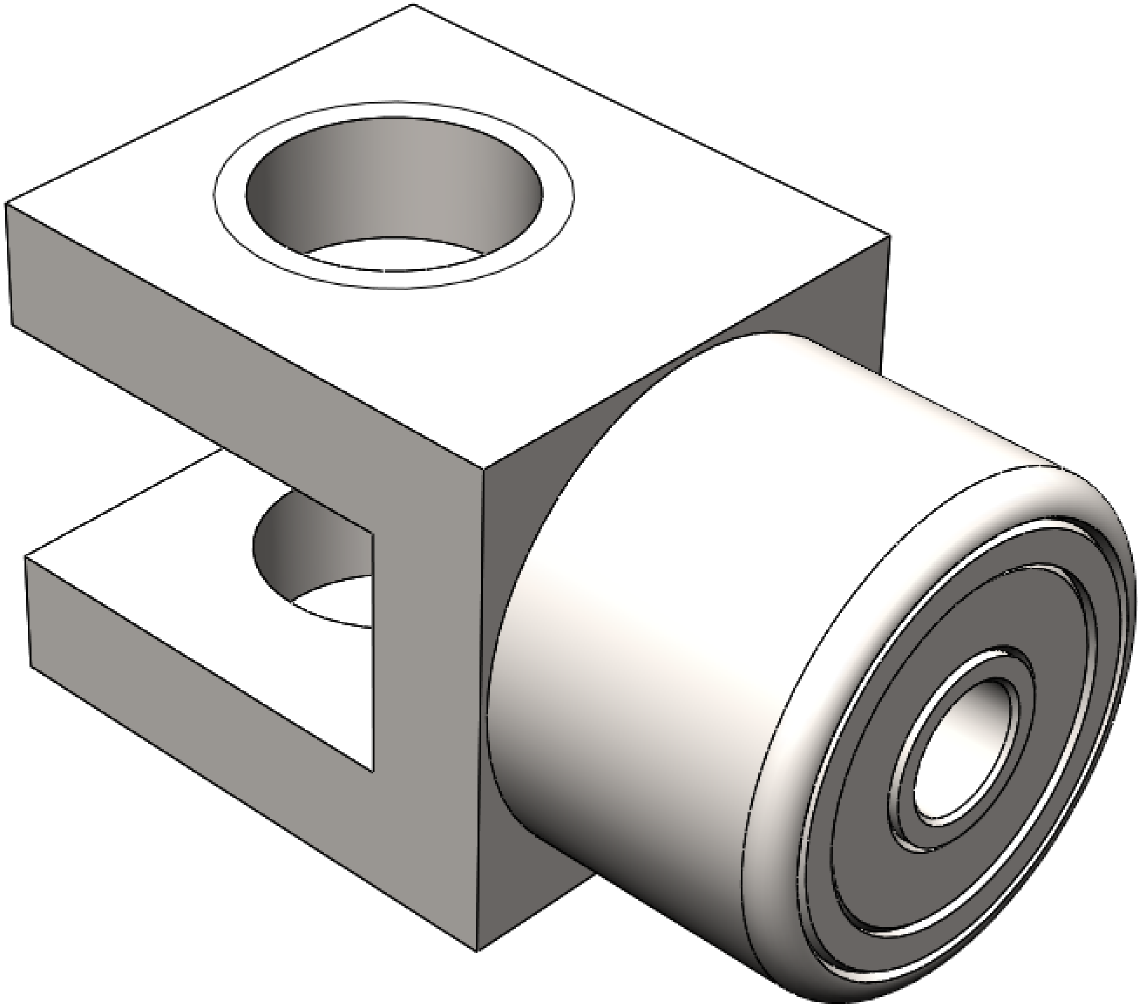


Figure 6.4.3 Front wheel mount

The bearing mounts on the front wheels are designed to allow the wheels to roll freely as the rover progresses over terrain. The mount consists of a commercially available ball bearing mated to a rectangular bracket. The front face of the bearing accepts the wheel's axle and will allow said wheel to freely rotate. The rear of the bearing mount has holes that interface with the holes in the base and by a nut and bolt assembly method will secure the assembly in place.

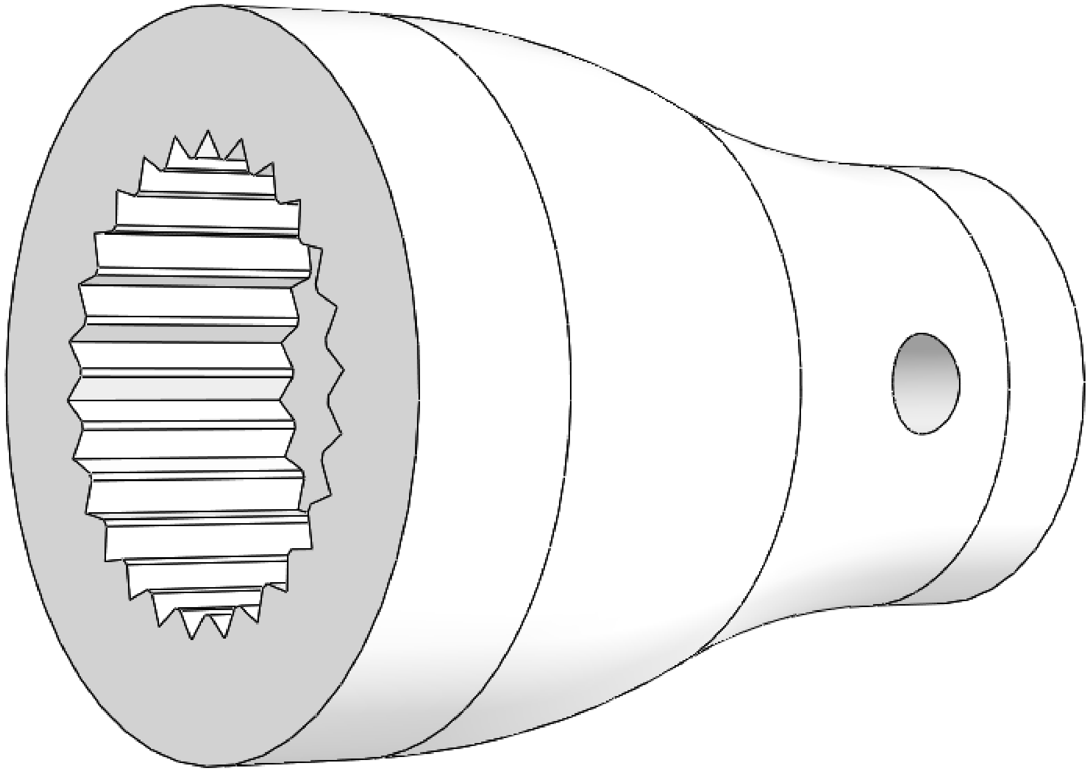


Figure 6.4.4 Servo Horn

The servo horn is designed to act as a custom interface between the wheels and the main drive shaft of the servo. It incorporates the negative impression of the gear teeth from the servo drive shaft with the d-shaft profile of the axle emanating from the wheel. The horn will be held to the wheels by the use of a set screw. By resin printing this component the gear teeth interface and the d-shaped axle can be produced with a high degree of detail enabling the horns functionality.

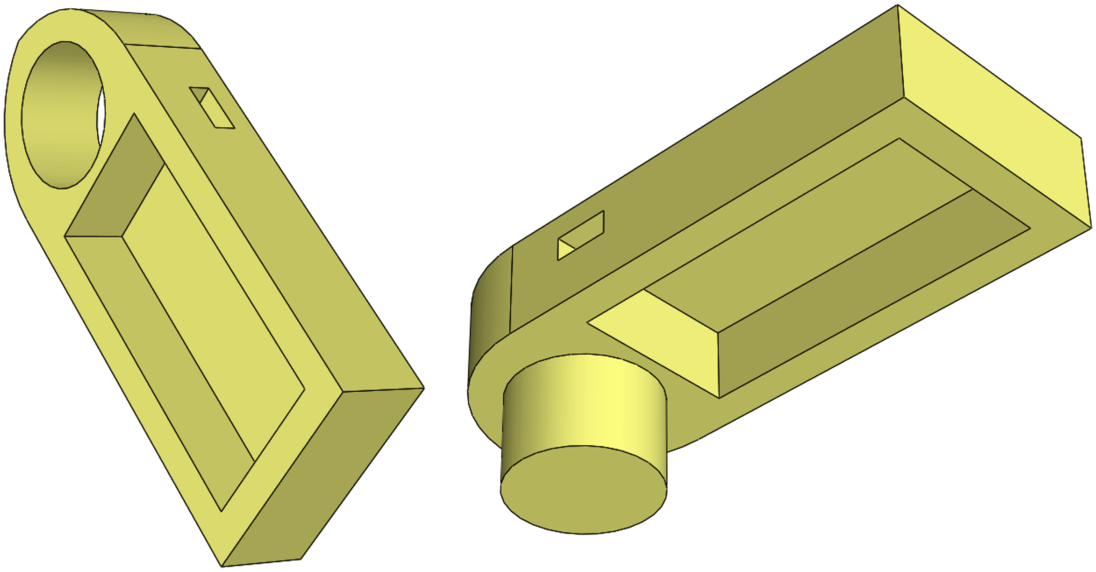
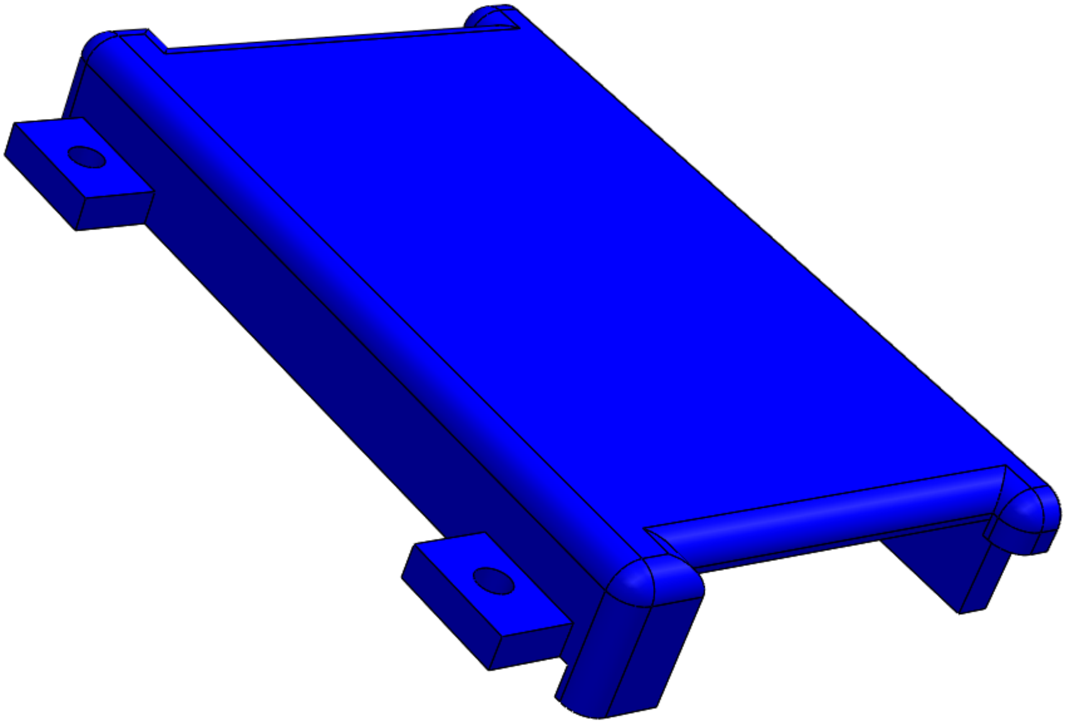
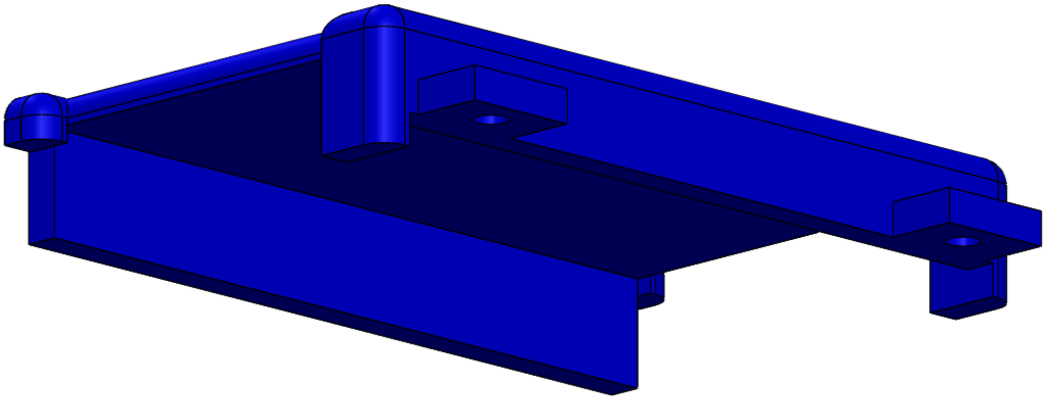


Figure 6.4.5 Solar panel top and bottom housing

The solar panel housing is designed to hold both an upward and downward facing panel set with an interface for a stepper motor. The assembly sits between the front two wheels and the base of the housing is epoxied to the rover base. The two part housing will be responsible for opening to allow the panels to capture light and complete the final portion of the challenge. Two key design aspects are the fillets around the point of rotation to prevent the corners from striking the control board and preventing the mechanisms successful actuation, and the housings open opposite directions in order to ensure the panels are exposed to light no matter the orientation in which the rover drives.



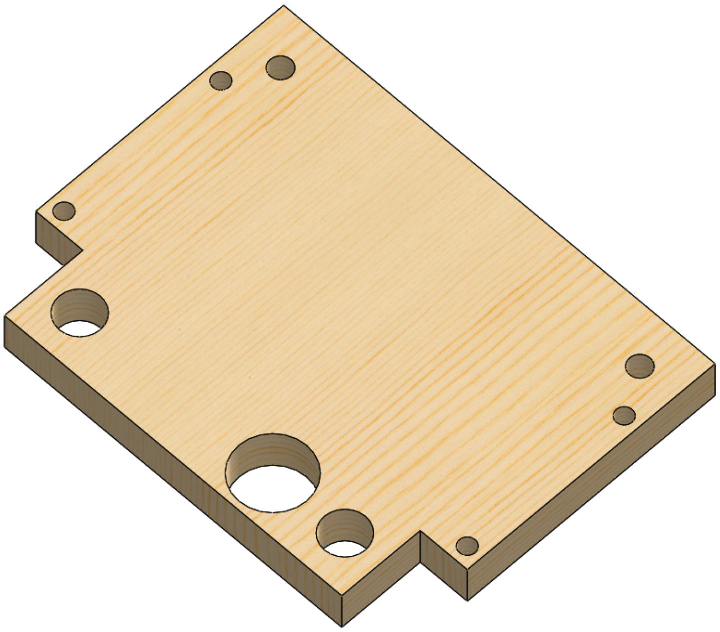
A.



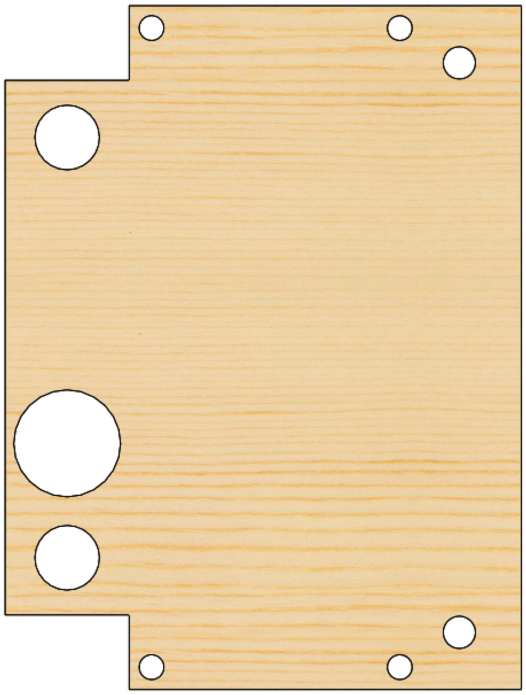
B.

Figure 6.4.6 Servo mounting brackets

The servo mounting cases are custom fit to the Tower Pro MG-995 to ensure both servos stay flush together and are unable to move relative to the rest of the rover. The rear of the mounts will come together and be epoxied so they function as one piece. The front of the mounts have holes to interface with corresponding holes on the base. By using a nut and bolt assembly the rear wheel drive system will be securely attached to the rest of the system while still having the ability to be removed for servicing or replacement of parts that fail during testing.



A.



B.

Figure 6.4.7 Rover base

The base is to be made out of solid wood in the effort to reduce weight and maintain a strong level of machinability. Each hole is put in place to perfectly interface with other components and thereby assemble solely by bolting together all the components. An added benefit in the use of wood over another material such as metal is the fact that there is little need to be concerned with accidentally shorting out control boards since wood is a non conductive material. Additionally, the ability to laser cut the base and holes means that it is possible to achieve a high level of both precision and repeatability.

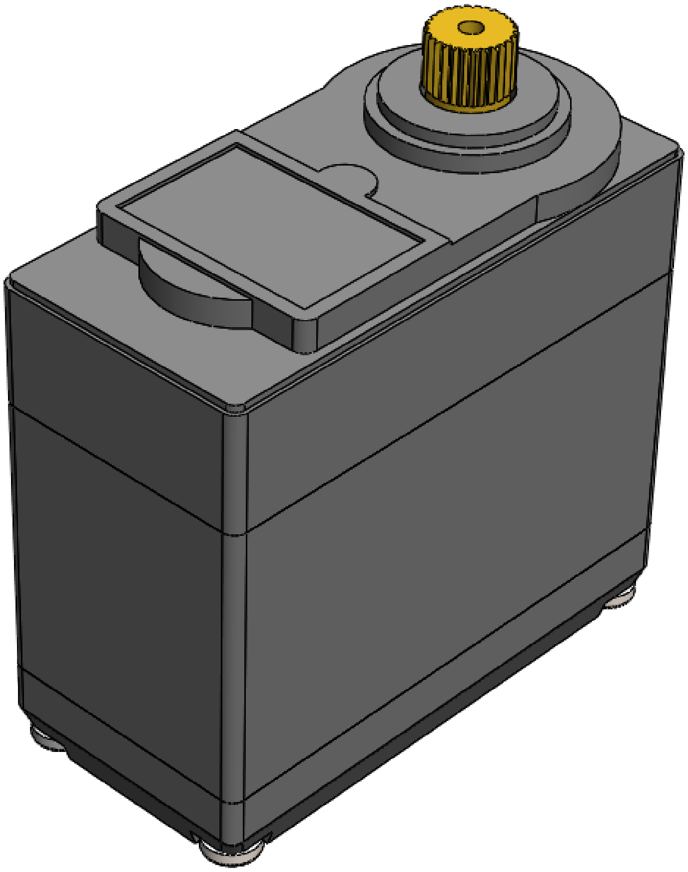


Figure 6.4.8 Servos

The servos were chosen to be able to provide adequate torque to move the rover over uneven terrain and give the vehicle the ability to extricate itself from collisions with obstacles. Two servos are placed back to back to allow them to operate independently and perform turns to go around obstacles. They are then held together with the aforementioned servo mounting brackets to be incorporated into the rest of the rover body.

6.4.3. Assembly View

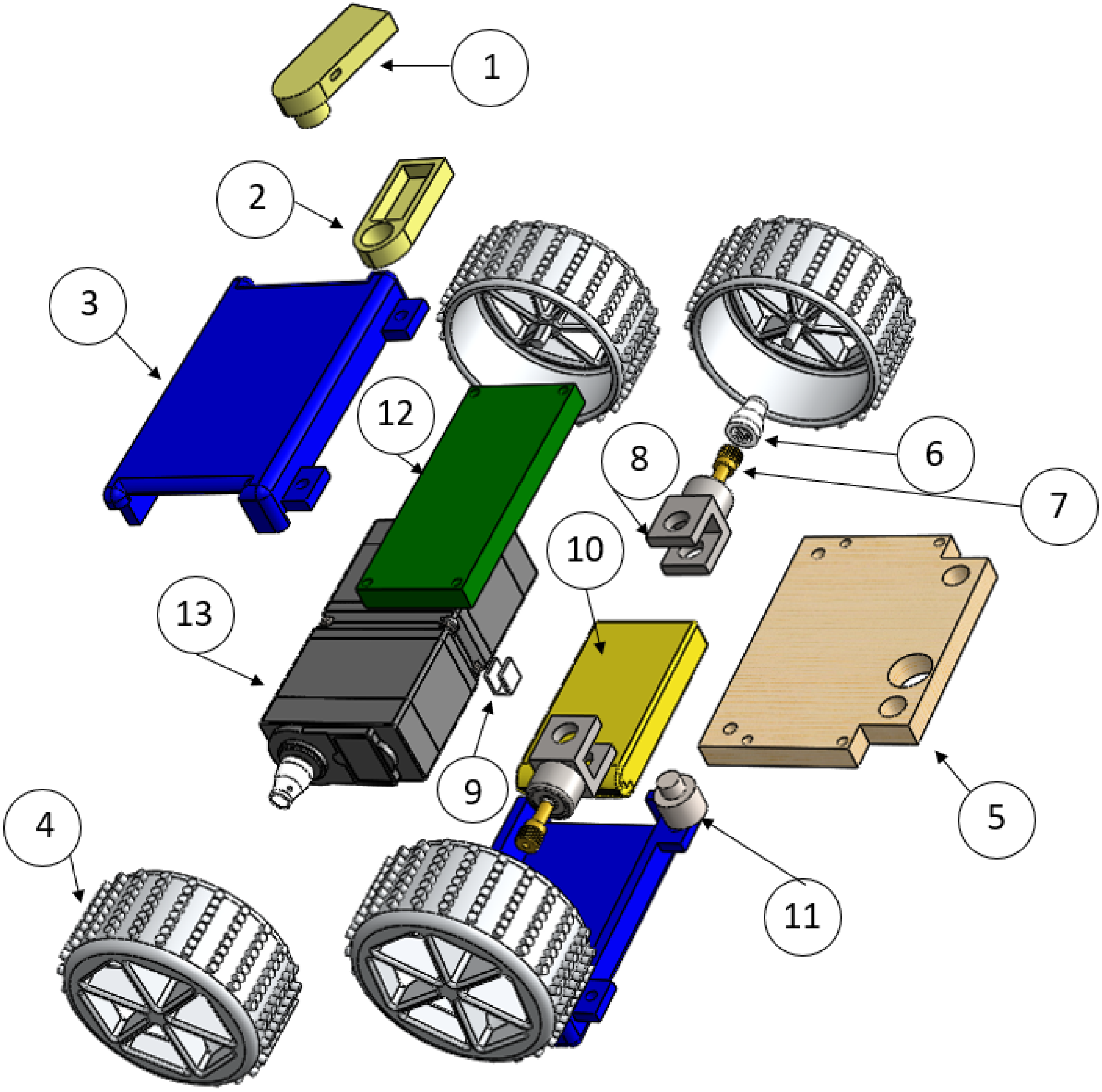


Figure 6.4.9 Exploded Assembly View

Table 6.4.1 Exploded View Key

1	Solar Panel Housing Top
2	Solar Panel Housing Bottom
3	Servo Mount
4	Wheel
5	Base Plate
6	Servo Horn / Wheel Adapter
7	Front Wheel Axle
8	Bearing Mount
9	Rover Detachment Bracket
10	Battery
11	Solar Panel Stepper Motor
12	Control Board
13	Servos

6.4.4. Launch Vehicle Integration

The Rover system has an integrated hanging bracket that is part of the servo mount. That mount rides along the rover rail in the deployment mechanism. Upon full extension of the aforementioned mechanism the rover will be free to egress from the body of the rocket and proceed to accomplish its mission.

6.5. Rover Electronics

6.5.1. Overview

The rover control system hardware provides a platform for control software to run on. The system must also interfaces the microprocessor that controls rover function with the servos that drive the rover and the stepper motor that deploys the solar panels. At the center of the system is the ATMEGA8 microprocessor unit. This unit is the same as the unit used in the arduino UNO, which was a large factor in the choice of the unit; its widespread use has given the avionics team an ample amount of resources to use while designing a board around the microprocessor. There are many components on the control board that are used only by the microprocessor to achieve normal function. A few of the key components in this area are the 16 MHz oscillator, the 5V regulator, and the reset circuit. The 16 MHz oscillator functions as a clock for the microprocessor, which is needed to function. The 5V regulator brings the 7.4V input voltage from the battery down to 5V, which is the value required by the ATMEGA8. The reset circuit allows for a hard reset of the microprocessor by the touch of a button. This will be important if anything goes awry during testing of the rover control board. Outside of the microprocessor, there are a few other components that interface the control board with rover hardware. First, the bootloading board attached to the top of the control board is used for programming the ATMEGA8 after it has been installed on the board. This programming is done through a simple serial connection. Second, there is a stepper motor driver attached to the top of the control board that will take signals from the microprocessor and drive the stepper motor to deploy the solar panels accordingly. The connection between the stepper driver and the stepper motor is facilitated through male headers on the control board. Third, there are two sets of three pin holes for connecting the female servo connection to the male pin headers that will be inserted in the board. The specific board layout and wire connections for all components are located in figure 6.5.1 and 6.5.2. One additional provision that is worthy of note is the connection between the rover control subsystem and the rover deployment subsystem. In order to release the rover without hitting the rocket fuselage, it is vital that the rover receive a signal when it is clear of the fuselage. The solution to this problem is simple: there will be a single wire connected from GND to a digital port on the microprocessor. This wire will also be attached within the rover deployment system in such a way that the wire is pulled loose from the rover when it clears the fuselage. When the wire is pulled loose, the rover control board will receive that signal and a logic loop will alert the next step of the process: moving the rover forward.

6.5.2. Drawings and Schematics

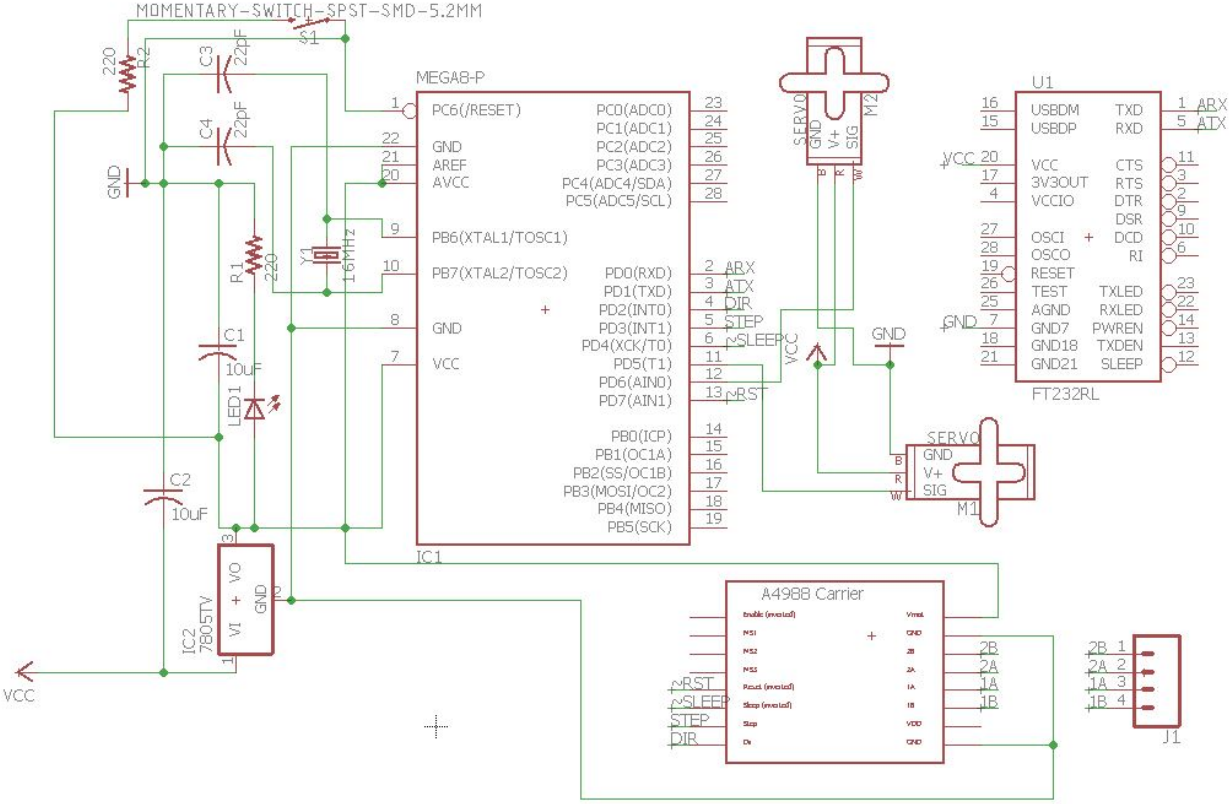


Figure 6.5.1 Rover Control Board Schematic

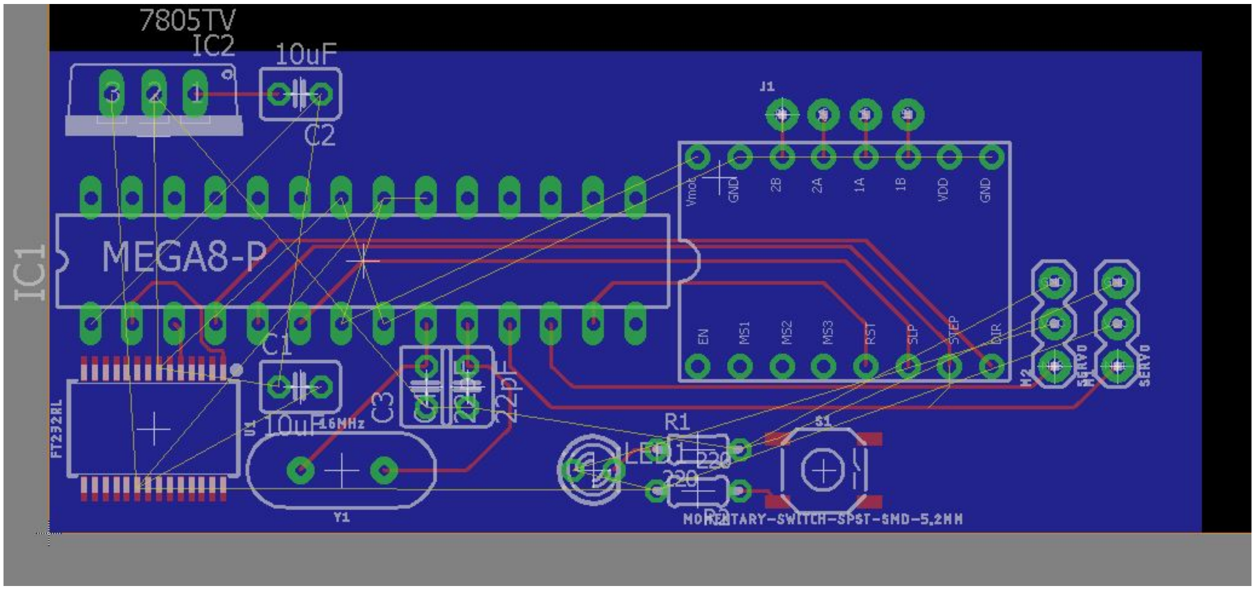


Figure 6.5.2 Rover Control Board Layout

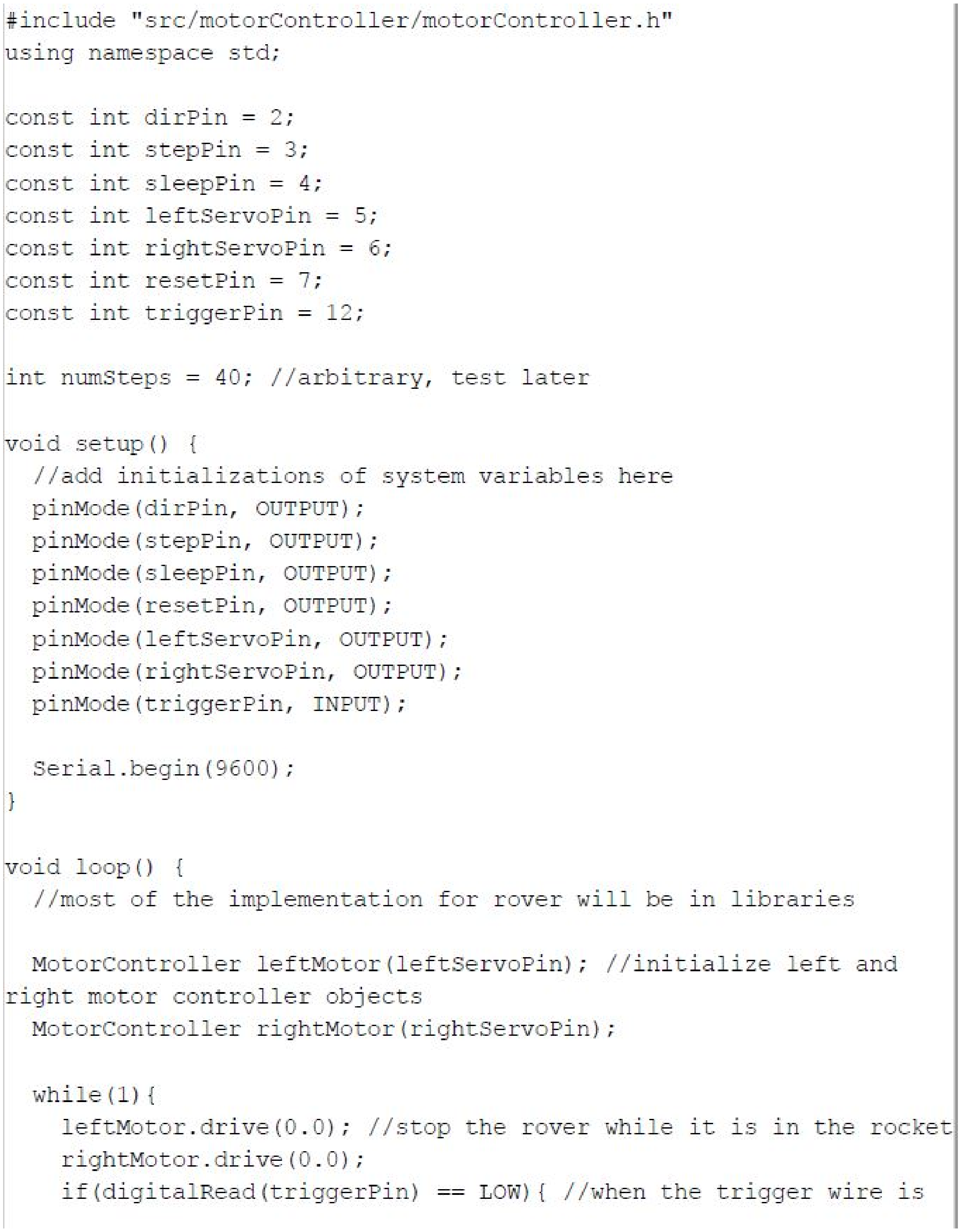
6.5.3. Software

Because the rover control system consists of an ATMEGA8 microcontroller for processing data, the final choice of programming language is arduino, which is built specifically to run on this microcontroller. The avionics team chose this language after discussing a few options, namely, C++ and C. The choice became simple when we searched for libraries available for each of these languages. While libraries exist for C and C++, these languages are more commonly used in industrial settings, which results in many libraries closed-source. Arduino is a language built on open-source principles, and is not widely used in industrial settings, so it was easy to find and implement libraries for servo control and ultrasonic sensor usage.

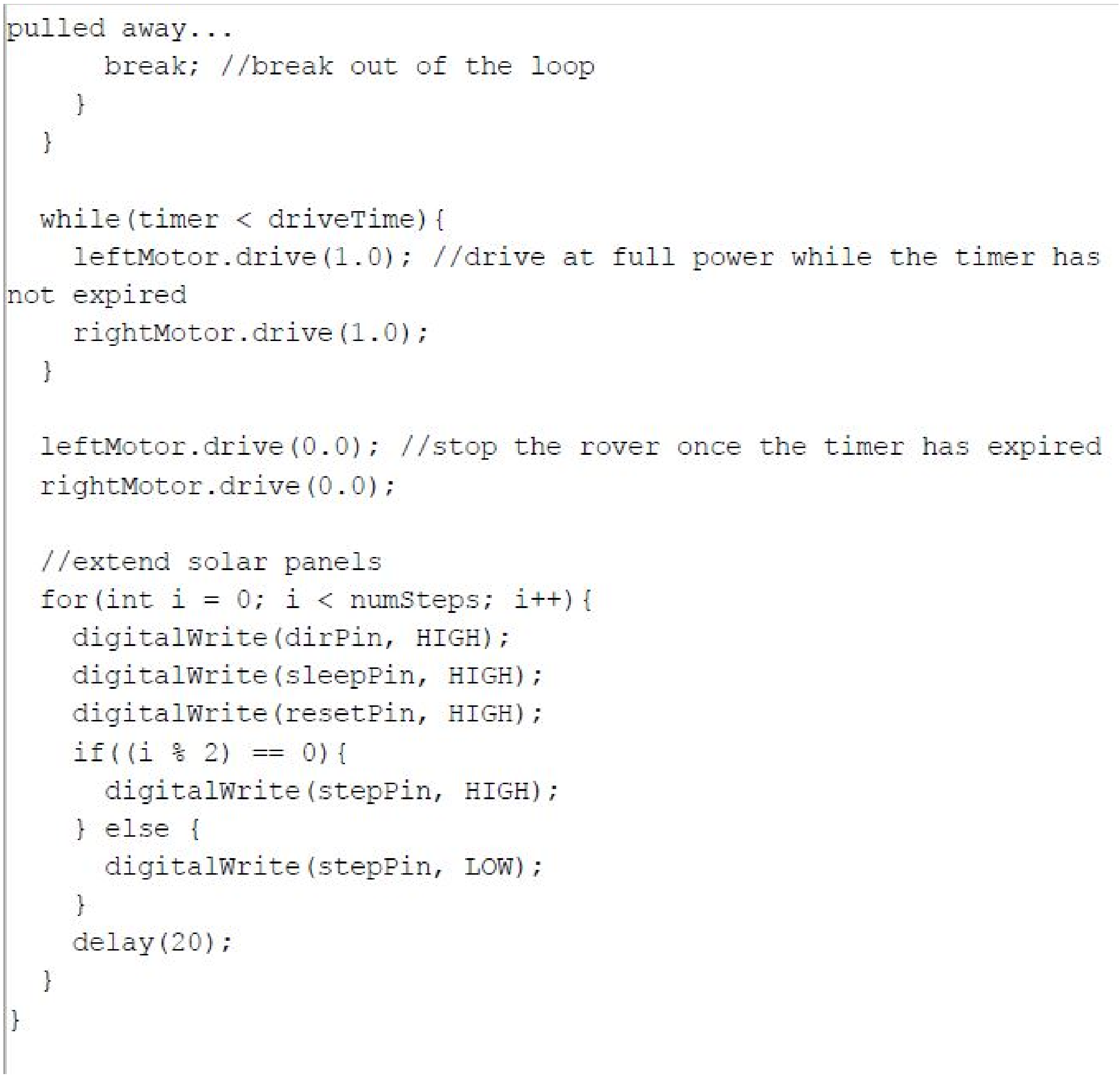
Given the small size of the avionics subteam, it is extremely important that we eliminate some of the low-level programming so that we can focus on the big picture: controlling the rover's function. The rover has the primary functions of driving forward at least 6 feet and subsequently deploying solar panels. The servos are controlled by a simple PWM square wave sent through a single signal wire. The ATMEGA8 is capable of sending this type of signal. The distance traveled will be controlled by a stoppage of the drive servos after a given time has passed. The time will be calculated based off of preliminary testing of the rover. After the time threshold is reached, the solar panel will deploy as a result of the stepper motor turning. This turning motion will be a result of short digital pulses sent to the stepper motor driver from the ATMEGA8 microcontroller. At this time, the solar panels will begin charging the battery that drives the rover. Much of the source code is shown in snapshots below, and can also be found at the following github link: https://github.com/atrimper/roverControl.

Table 6.5.3 Language Pro/Con Table

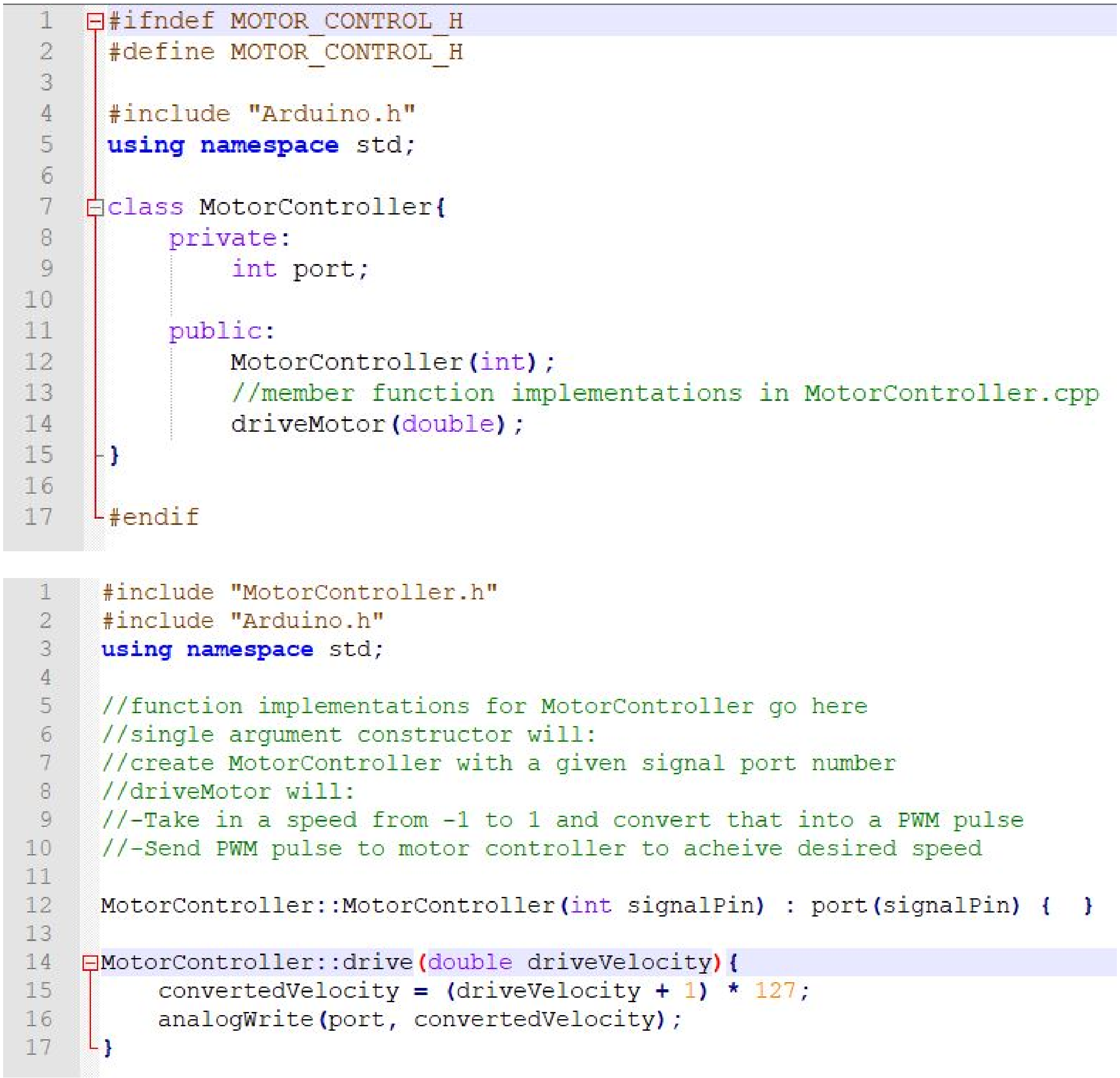
Arduino		**C**		**C++**	
Pros	**Cons**	**Pros**	**Cons**	**Pros**	**Cons**
Servo libraries	Lacks complex object orientation of C++	Almost universally understood	Lacks complex object orientation of C++	Most widely used programming language for embedded systems	Less efficient than C or Arduino
Gyro libraries	Less universally used than C/C++	Industry standard	Fewer libraries than Arduino	Complex object orientation without using structs	Not optimized for ATMEGA8
Encoder libraries	Limited to specific set of microcontrollers	Works with large variety of microcontrollers	Not optimized for ATMEGA8	Works with large variety of microcontrollers	Fewer libraries than Arduino
Naturally built for use with ATMEGA8				Industry standard	
More efficient than C++					



```
#include "src/motorController/motorController.h"
using namespace std;

const int dirPin = 2;
const int stepPin = 3;
const int sleepPin = 4;
const int leftServoPin = 5;
const int rightServoPin = 6;
const int resetPin = 7;
const int triggerPin = 12;

int numSteps = 40; //arbitrary, test later

void setup() {
  //add initializations of system variables here
  pinMode(dirPin, OUTPUT);
  pinMode(stepPin, OUTPUT);
  pinMode(sleepPin, OUTPUT);
  pinMode(resetPin, OUTPUT);
  pinMode(leftServoPin, OUTPUT);
  pinMode(rightServoPin, OUTPUT);
  pinMode(triggerPin, INPUT);

  Serial.begin(9600);
}

void loop() {
  //most of the implementation for rover will be in libraries

  MotorController leftMotor(leftServoPin); //initialize left and
right motor controller objects
  MotorController rightMotor(rightServoPin);

  while(1){
    leftMotor.drive(0.0); //stop the rover while it is in the rocket
    rightMotor.drive(0.0);
    if(digitalRead(triggerPin) == LOW){ //when the trigger wire is
```



```
pulled away...
      break; //break out of the loop
    }
  }

  while(timer < driveTime){
    leftMotor.drive(1.0); //drive at full power while the timer has
not expired
    rightMotor.drive(1.0);
  }

  leftMotor.drive(0.0); //stop the rover once the timer has expired
  rightMotor.drive(0.0);

  //extend solar panels
  for(int i = 0; i < numSteps; i++){
    digitalWrite(dirPin, HIGH);
    digitalWrite(sleepPin, HIGH);
    digitalWrite(resetPin, HIGH);
    if((i % 2) == 0){
      digitalWrite(stepPin, HIGH);
    } else {
      digitalWrite(stepPin, LOW);
    }
    delay(20);
  }
}
```



```
#ifndef MOTOR_CONTROL_H
#define MOTOR_CONTROL_H

#include "Arduino.h"
using namespace std;

class MotorController{
    private:
        int port;

    public:
        MotorController(int);
        //member function implementations in MotorController.cpp
        driveMotor(double);
}

#endif
```

```
#include "MotorController.h"
#include "Arduino.h"
using namespace std;

//function implementations for MotorController go here
//single argument constructor will:
//create MotorController with a given signal port number
//driveMotor will:
//-Take in a speed from -1 to 1 and convert that into a PWM pulse
//-Send PWM pulse to motor controller to acheive desired speed

MotorController::MotorController(int signalPin) : port(signalPin) {   }

MotorController::drive(double driveVelocity){
    convertedVelocity = (driveVelocity + 1) * 127;
    analogWrite(port, convertedVelocity);
}
```

Figure 6.5.4 Code Snapshots

6.5.4. Block Diagrams

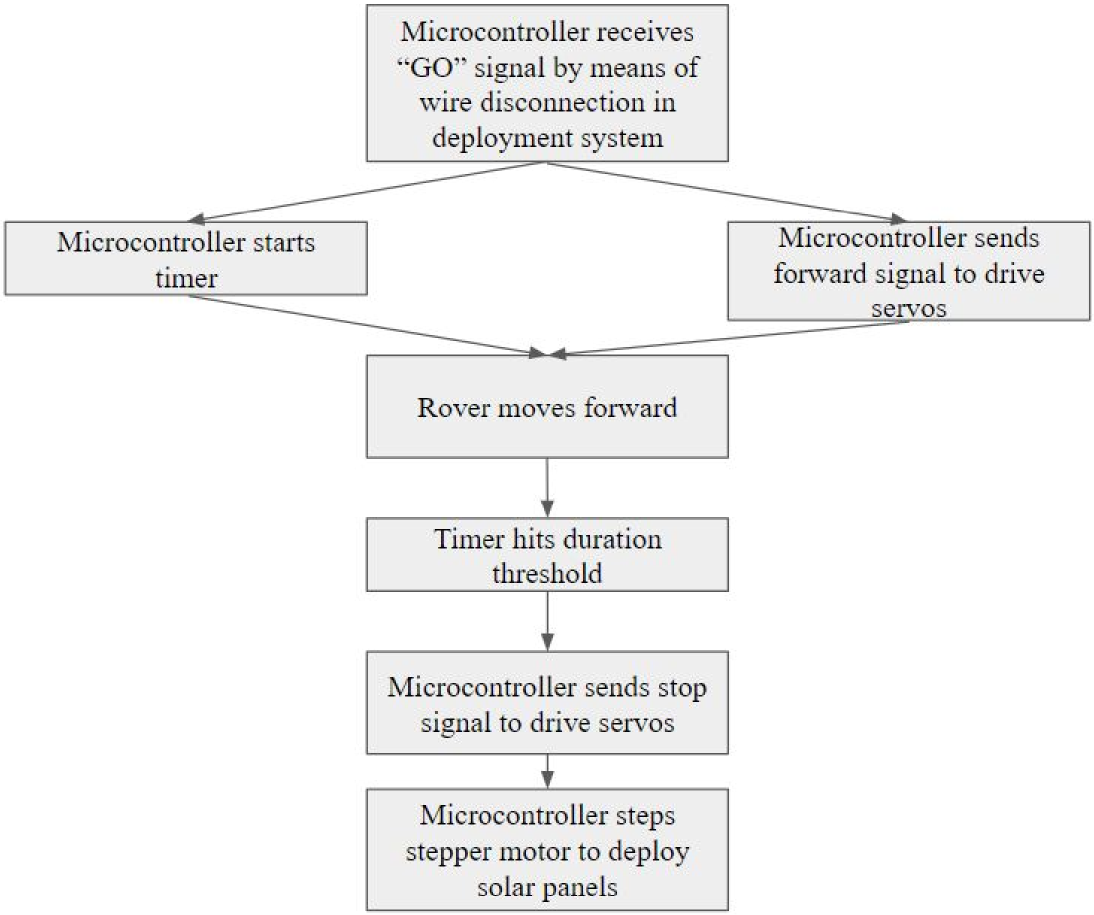


Figure 6.5.5 Rover Control Block Diagram

6.5.5. Batteries/power

There were a few key components in the Rover subsystem to consider when choosing the correct battery. Because the team chose servos for the drive system of the rover and a small stepper motor for the solar panel deployment, the spike in current draw while these systems are operating is not a major concern, given that all LiPo batteries in consideration by the team had greater than 30A peak current discharge rating. The main points of consideration for the battery, then, were capacity, voltage, and size. Given that both the servos and stepper motor run off of a 5V source, the team decided to go with a commonly available 7.4V battery (2 cells). A 5V regulator will be used to drop the voltage to 5V for all components on the rover. To determine minimum capacity requirements, it was necessary to find/calculate current draw for all rover components and estimate the total time that each component will be active for. These values can be found in the table below. The overall capacity required turned out to be relatively low at a value of 251 mAh, so a 430 mAh battery was chosen to add a safety threshold. The size constraint of the battery was determined by the rover cad, and the Venom Fly 30C 2S 430mAh 7.4V LiPo Battery fit this and all other constraints, and was therefore the best choice of battery.

Table 6.5.6 Capacity Draw Matrix

Component Name	Current Draw	Total Time Active	Capacity Draw
Left Drive Servo	500 mA	0.008 Hours	4 mAh
Right Drive Servo	500 mA	0.008 Hours	4 mAh
Rover Control Board	120 mA	2 Hours	240 mAh
Stepper Motor	1000 mA	.003 Hours	3 mAh
			Total: 251 mAh

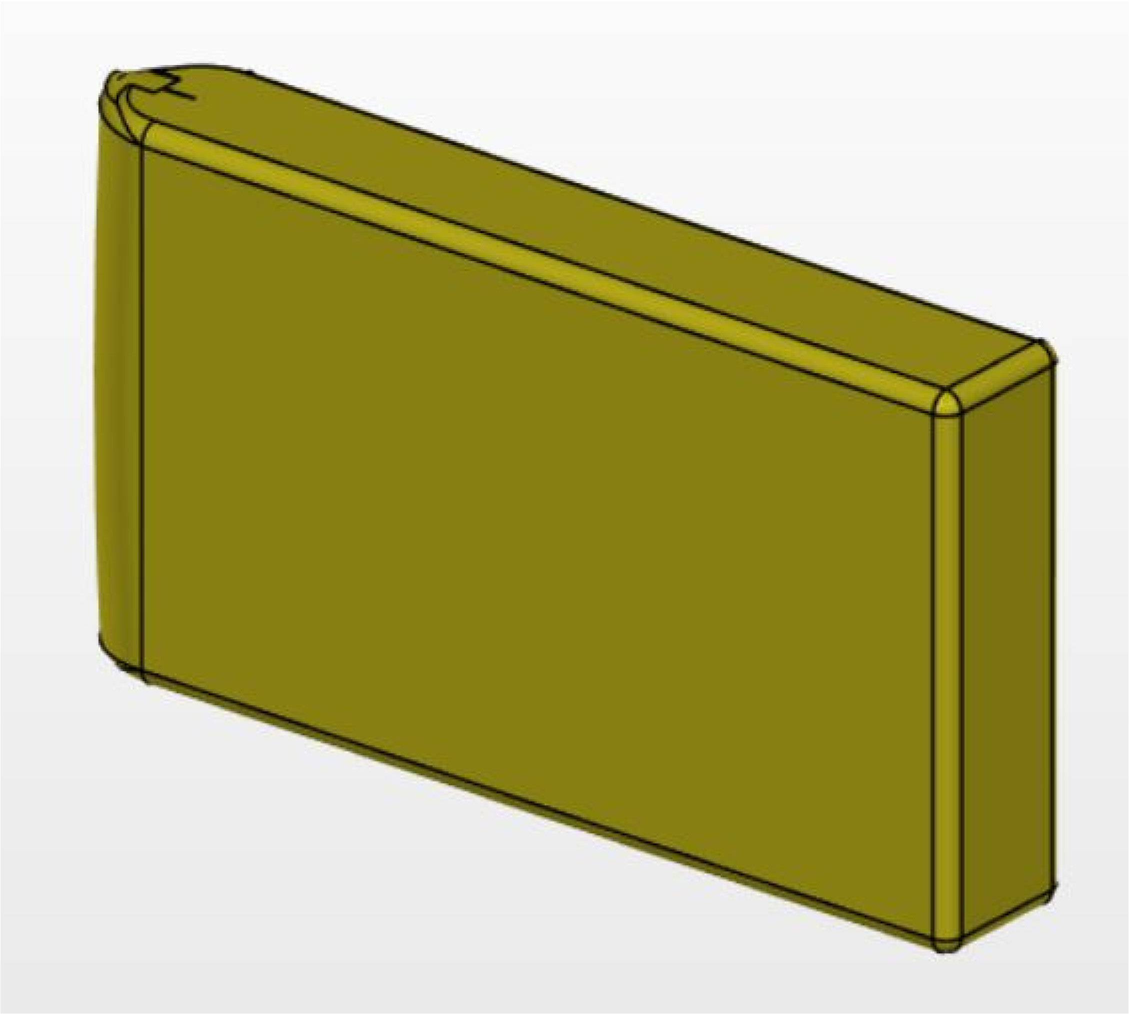


Figure 6.5.7 Battery CAD

7. Flight Systems

7.1. Overview

The flight systems of the rocket can be categorized into two different subsystems: the recovery system and the telemetry system. The recovery system is responsible for ensuring the vehicle returns to the ground safely and for providing coordinates for the location of the vehicle throughout the flight and after touchdown. The telemetry system is responsible for relaying flight data to a ground station in real time throughout the launch. The electronics and software of the ATS system and challenge system are discussed in the Apogee Targeting System Section and the Rover System Section respectively. The block diagram below shows the dependencies associated with components of the flight systems.

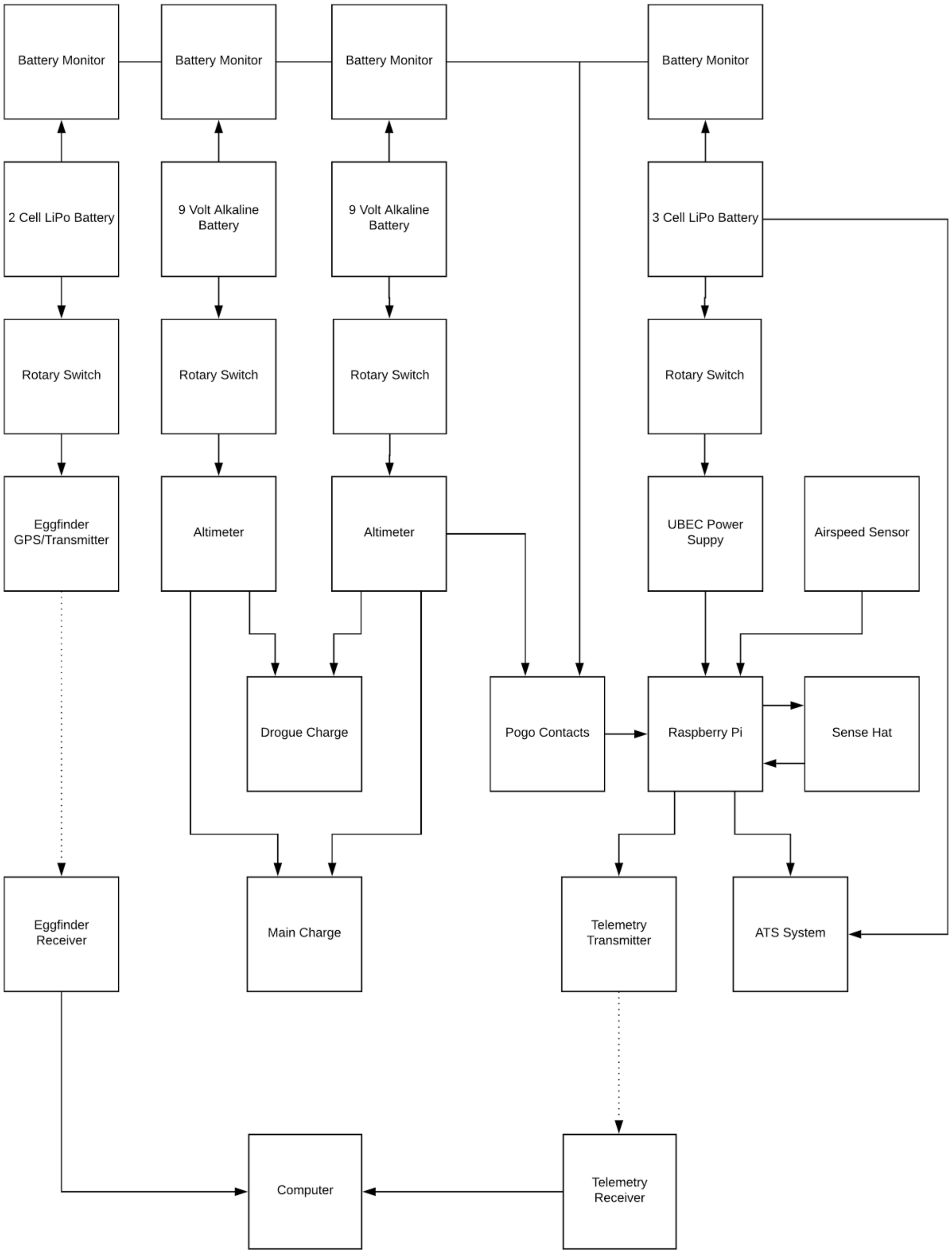


Figure 7.1.1 Flight System Block Diagrams

7.2. Recovery System

7.2.1. Overview

The recovery system is broken down into two main functions: GPS Tracking and Parachute Deployment. A function tree of the recovery system is shown in figure below.

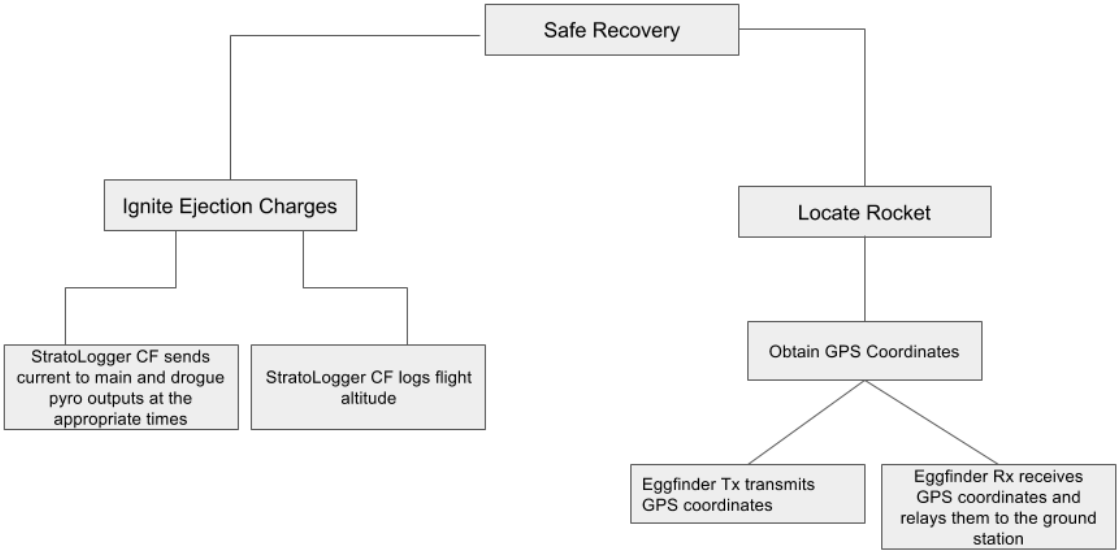


Figure 7.2.1 Recovery System Function Tree

We will be using the Stratologger CF altimeter and an Eggfinder GPS system to track the position (altitude) and control our parachute deployment system on the rocket. To ensure the reliability of the recovery system, we have decided to install a backup recovery system in the Avionics bay in case the main system fails to deploy the parachutes. This system is a duplicate copy of the main recovery system with a second 9V battery powering a second Stratologger CF, which is connected to the Raspberry Pi 3, drogue and main chutes. A wiring schematic of the main recovery system is shown in the figure below.

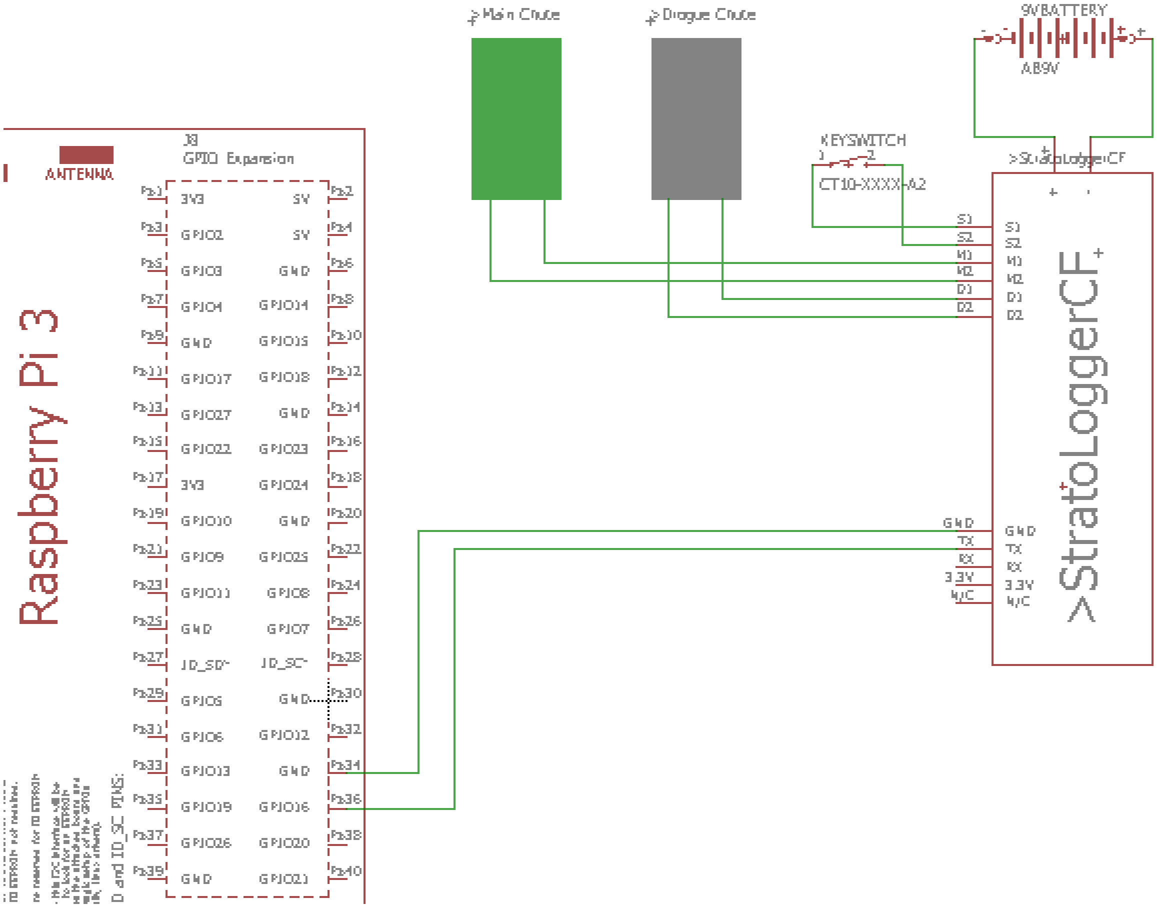


Figure 7.2.2 Recovery System Wiring

7.2.2. Altimeters

The StratoLogger CF altimeter records flight data at a rate of 20 samples per second and is able to do so for flights of up to 18 minutes in duration that can be stored for later use. The altimeter reports the rocket's peak altitude and maximum velocity after flight via a sequence of beeps. It draws a current of 1.5 mA to function and can output up to 5 A for up to 1 second (although this will vary slightly depending on the voltage of the battery connected to it). During launch, two outputs are provided for deploying a small chute at apogee to minimize drift and a larger chute closer to the ground to slow down the rocket. Main chute deployment altitude is adjustable between 100 feet and 9,999 feet. The altimeter also includes a Data I/O connector which allows real-time altimeter data to be sent to the onboard Raspberry Pi 3. Table 7.2.1 lists the different ports of StratoLogger CF and briefly describes the functionality of each. Figures below show a more detailed view of the StratoLogger CF schematic.

Table 7.2.1 StratoLogger CF Port Description

Port	*Name*	*Description*
+ -	Power input and output	Connects to 9V Battery
S1,S2	Port to Key Switch	Connects to Key Switch, which turns on the altimeter
M1,M2	Main Ejection Output	Connects to main chute ejection charges
D1,D2	Drogue Ejection Output	Connects to drogue chute ejection charges
GND	Ground	Connects to the GND port on the Raspberry Pi 3
TX	Transmitting Signal	Sends live data to the Raspberry Pi 3
RX	Receiving Signal	Not used. Purpose is to receive commands/signals from a microcontroller
3.3V	High Voltage Port	Not used.
N/C	N/C	Not used.

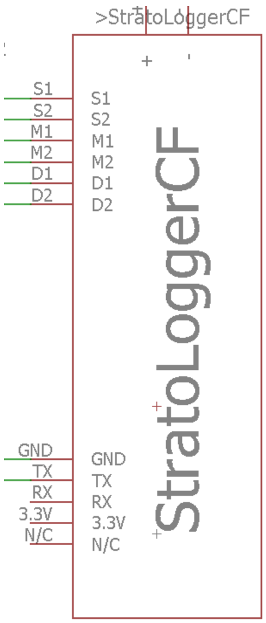


Figure 7.2.3 StratoLogger CF Schematic

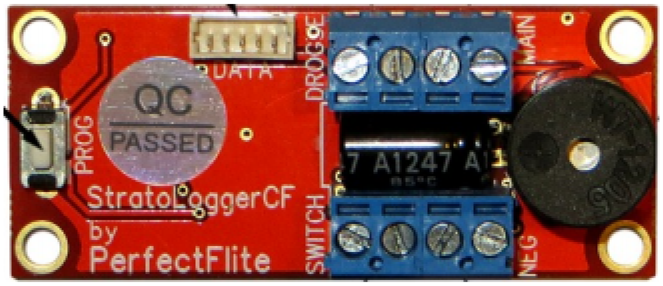


Figure 7.2.4 StratoLogger CF Altimeter

The StratoLogger CF's power requirements are listed below as well as its precision. As stated before, a 9V Duracell battery will be used to power the Stratologger CF.

Table 7.2.2 Altimeter Specifications

Component	Voltage Rating	Current Consumption	Precision
StratoLoggerCF altimeter	4V-16V	1.5mA	< 38,000 ft MSL (±1 ft.) Additional for calibration (±0.05%)

7.2.3. GPS

We will use an Eggfinder GPS Tracking system to send NMEA data to stream the rocket's position as it launches and lands. The module transmits data in the 900 MHz license-free ISM band at 100mW. The module sends packets in 9600 baud, 8 bits, and no parity. The Eggfinder GPS Tracking System comes with a RX(receiver) and TX(GPS) module, both of which are surface mount. The GPS module weighs approximately 20 grams and draws 70-100 mA while operating and 10-20 mA while on standby. We will use a 2s 7.4V Lipo to power the GPS module. For the receiver module, a USB connector will be used to connect the module to either a laptop or another Raspberry Pi 3 to read the received data from the GPS module. An image of an assembled GPS and receiver Eggfinder modules is shown in the figure below.

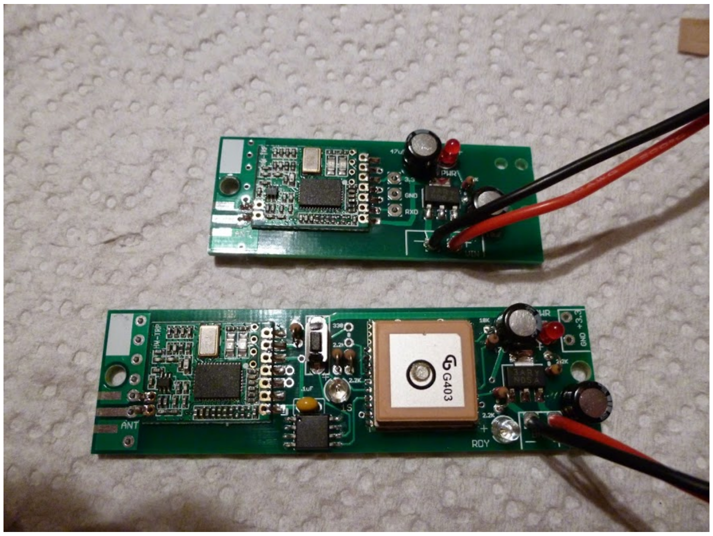


Figure 7.2.5 Assembled Eggfinder GPS Tracking System

The GPS module will be installed inside the nose cone along with a 7.4 V 2s Lipo, which will power the GPS module. The receiver module will be connected to an external antenna and a microcontroller/laptop, which will read the transmitted data from the GPS module.

7.2.4. Possible Challenges and Solutions

One possible challenge could be the assembly of the GPS module and receiver modules. Because they are surface mount, each component on the GPS and receiver modules will have to be soldered. This could be a challenge since soldering each of those components will carry great risk (if one component is not soldered incorrectly, the entire module could become unusable). A possible solution is to have multiple people solder the GPS modules together. For example, one or two people can observe while the rest do the actual soldering. This way the observer or observers can catch mistakes and the properly guide the people doing the soldering.

7.3. Telemetry

7.3.1. Overview

The telemetry system will relay data about the vehicle in real time throughout the launch. It will transmit battery voltages, sensor data, and ATS system events. A laptop will be used to display and record the received data. In the unlikely event that the vehicle is unable to be recovered, the data logged at the ground station will be invaluable in the analysis of the launch and investigation of possible failures.

7.3.2. Hardware

Data will be transmitted using the HKPilot Transceiver Telemetry Radio Set V2 shown below.

Figure 7.3.1 Telemetry Radio

This radio transmits on 433 MHz at 100 mW and will not interfere with the 2.4 GHz and 900 MHz systems used by the rover system and the GPS system. Battery voltages will be measured for the two 9 volt altimeter batteries, the ATS battery, and the GPS battery. The Texas instruments INA219B chip will be used to make these measurements with an accuracy of 1%. These chips communicate over I2C and four will be wired in parallel. A breakout board for this chip made by sparkfun will be used. This breakout board is shown below.

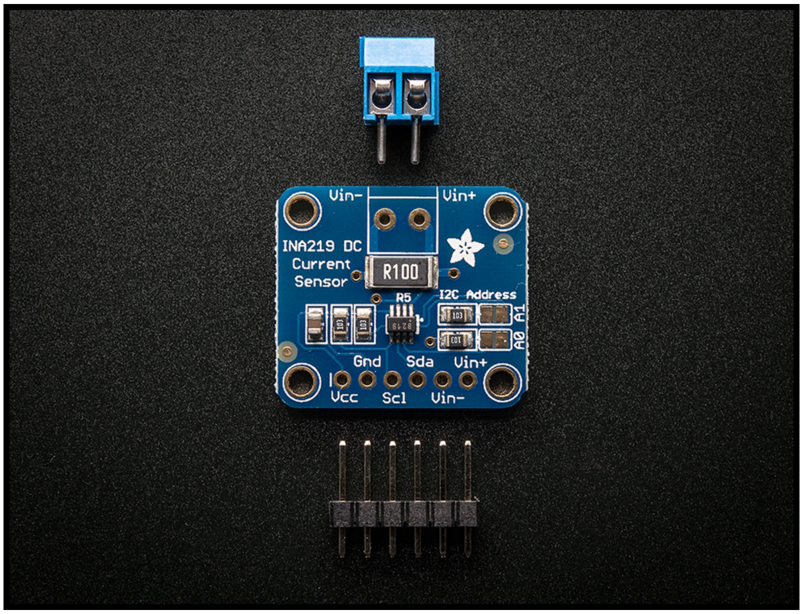


Figure 7.3.2 INA219B Breakout Board

Accelerometer, gyroscope, magnetometer, and barometer data will be collected by a Raspberry Pi Sense hat. An I2C airspeed sensor will also be used to gain velocity data. All of the data will be processed by the onboard Raspberry Pi 3 and sent to the telemetry radio to be relayed to the ground station.

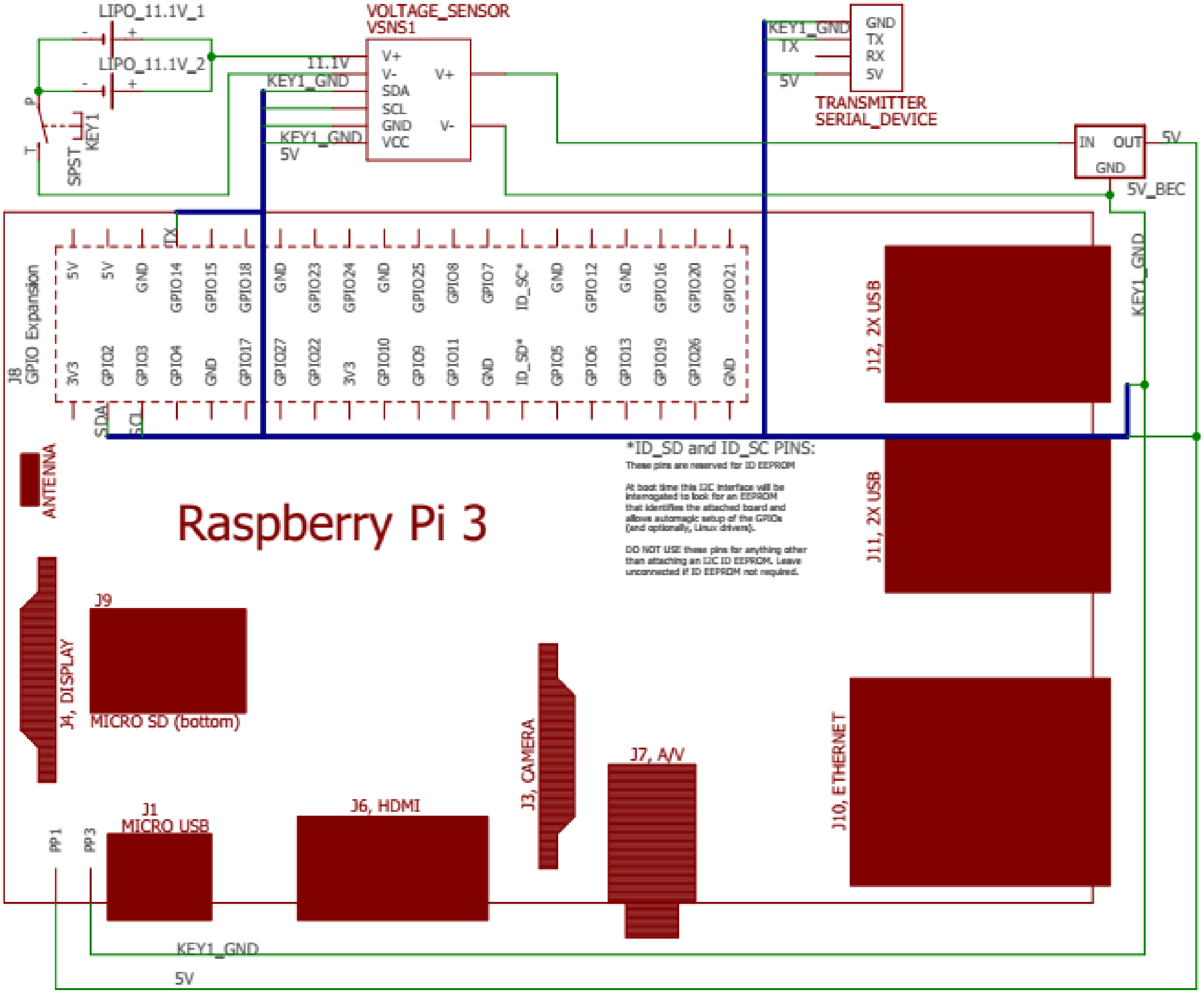


Figure 7.3.3 Telemetry Circuit Schematic

7.3.3. Software

The telemetry system is comprised of a serial data stream from the Raspberry Pi from the ATS system and a transmitter which forms an uplink to the ground station. The ground station receives the data as a serial string of characters and delimiters, which are fed into a Graphical User Interface (GUI) in the program running on the ground station computer. This GUI displays real time critical data about the health of several major subsystems such as ATS, and GPS battery voltages to name a few. Another key feature of the GUI is the real time altitude reporting and declaration of major staging events (i.e. Drogue and Main Parachute Deployment).

7.4. Structures

7.4.1. Overview

In previous years, the design and manufacture of the avionics bay has been handled by the Vehicle Subteam. This competition season both the avionics and the avionics bay were designated the responsibility of the Avionics Subteam. During the design and construction of the subscale vehicle, this redistribution of tasks proved to simplify and streamline the design process and the integration of the avionics with the launch vehicle. This increase in efficiency is a result of the Avionics Team’s familiarity with the avionics systems and understanding of how best to arrange and constrain them within the vehicle. Avionics components are primarily housed in two locations on the vehicle: in the ATS section and in the avionics section.

7.4.2. Design Considerations

The primary design considerations for housing the avionics components were limited space in the ATS bay and organization. The location of each component was chosen carefully to allow all electrical connections between components to be as short and easy to create as possible. The avionics housings, and their associated components, were modeled in Solidworks to ensure that all components would fit within their respective sections without complication.

7.4.3. ATS Section

There are ten primary components housed within the ATS section: one rotary switch, one UBEC power supply, one Raspberry Pi, one raspberry pi sensor hat, one radio transceiver, one airspeed sensor, one stepper motor driver, two lithium polymer batteries, and one battery voltage monitor. Mounting these components on a wooden tray within the ATS section, as was done in the avionics section for the subscale flight, was impractical. The threaded rods needed to hold a tray within the section would add an unacceptable amount of weight aft of the center of gravity, and mounting all components within a single plane would result in components being packed very close together, making components difficult to assemble and access. Alternatively, a housing will be 3D printed from either ABS or PLA plastic (depending on the availability of printers on campus). The CAD assembly of the ATS section housing is shown below.

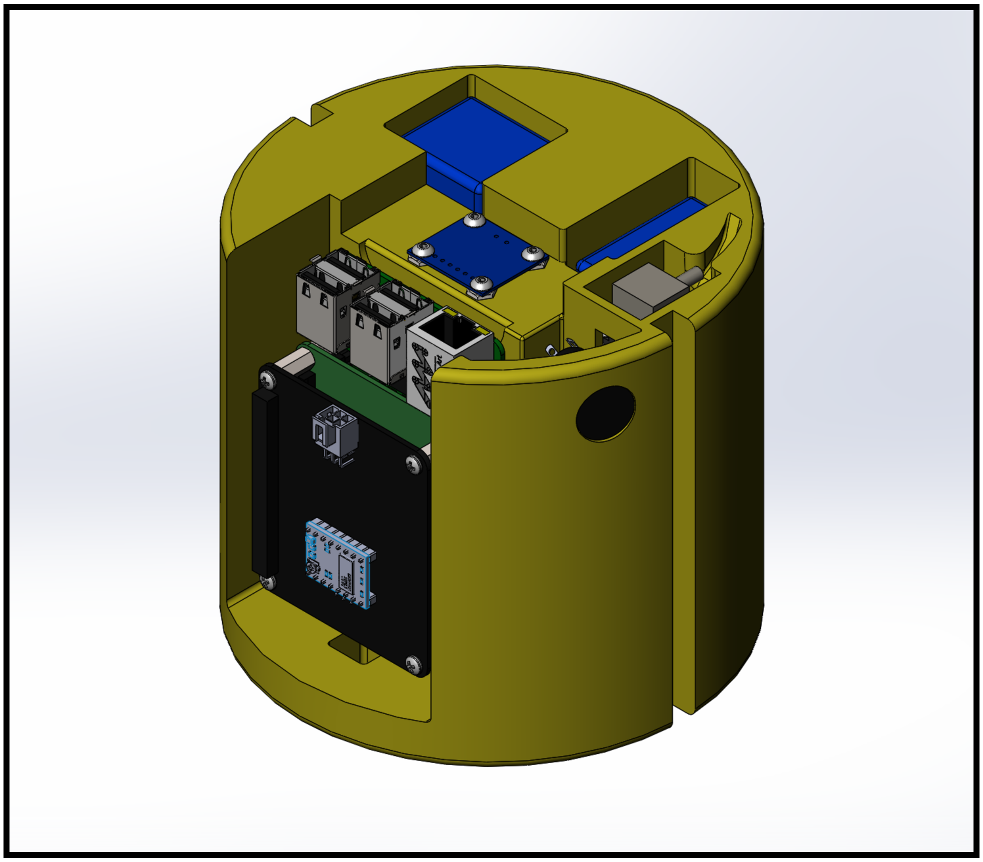


Figure 7.4.1 ATS Section Avionics Assembly Isometric View

The above assembly will rest atop the ATS assembly and will be prevented from rotating by two 4-40 screws driven through the body tube on each side of the rocket. Four 4-40 lock nuts will be used to secure the screws on the inside of the body tube. These nuts will interface with the rails the channels cut from each side of the housing, preventing rotation.

7.4.4. Avionics Section

There are eight primary components housed within the Avionics section: two rotary switches, two battery voltage monitors, two nine volt batteries, and two altimeters. There is ample space within in the avionics section to mount components on a tray, and as the section is well forward of the center of gravity, low mass is not as crucial for the avionics section housing. However, a housing very similar to the housing in the ATS section will be 3D printed to enclose the components housed within the avionics section. This decision was made to streamline the design and manufacture of the avionics structures. The avionics section housing and the components it houses are shown below. Two views are shown to display all components.

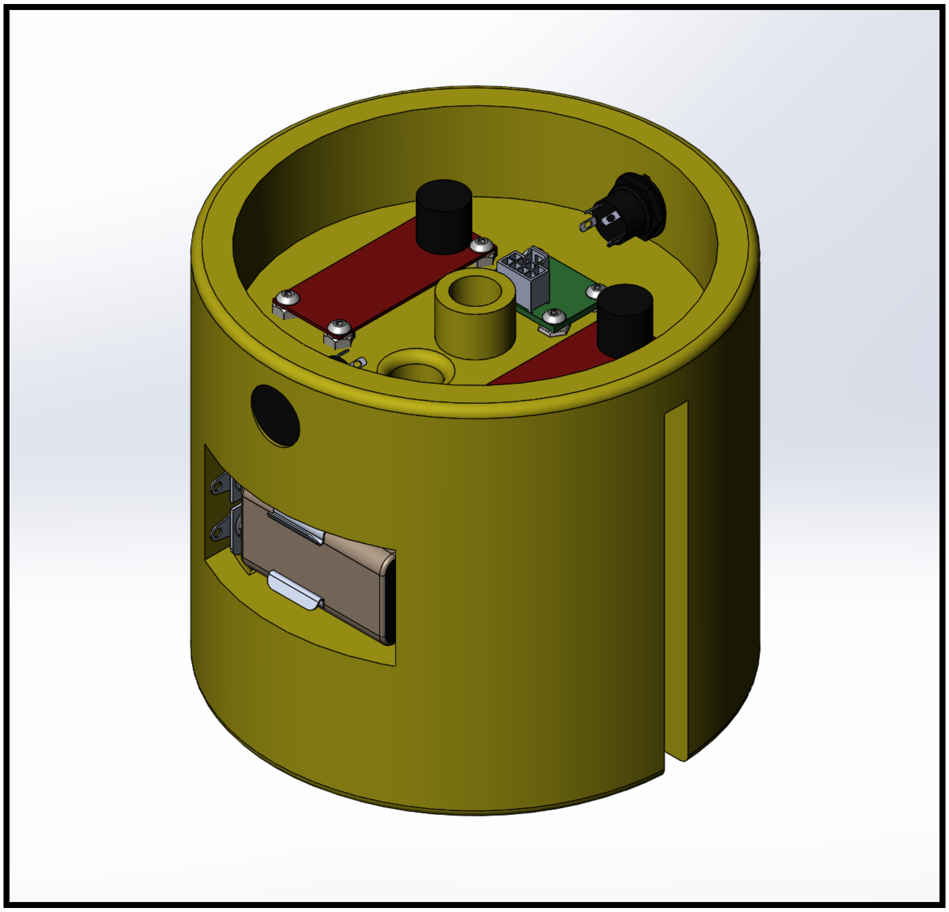


Figure 7.4.2 Avionics Section Avionics Assembly Isometric Top View

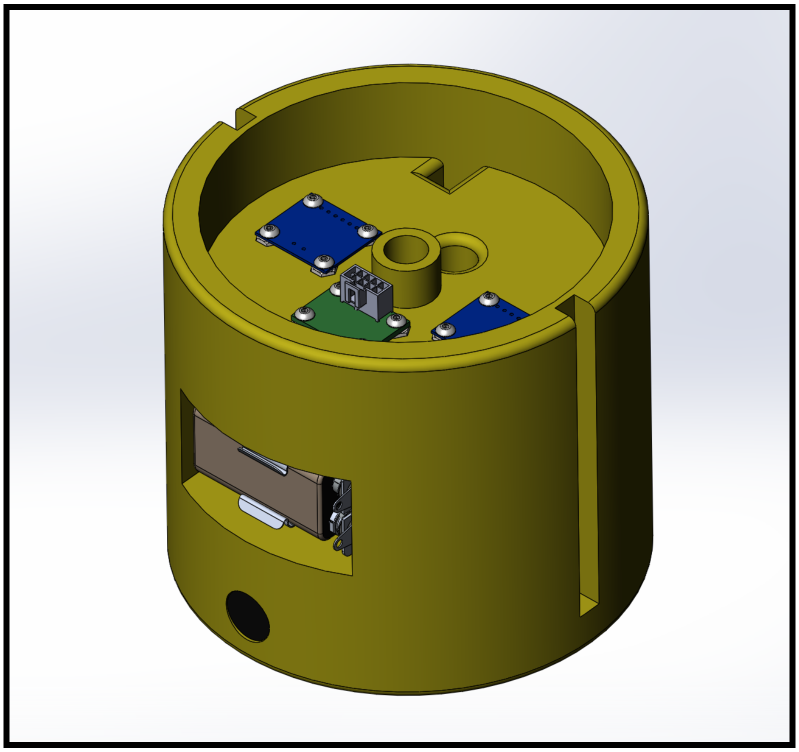


Figure 7.4.3 Avionics Section Avionics Assembly Isometric Bottom View

A single ⅜ inch threaded rod will run through the center of the housing, anchoring the bulkheads at either end of the 13 inch long avionics section. The avionics section housing will sit in the center of the avionics section. It will be prevented from rotating using the same method as the ATS section housing. It will be supported in three places: on the bottom face of housing by a washer and nut threaded onto the central rod, and by two of the four nuts that prevent the housing from rotating within the body tube.

7.4.5. Electrical Separation and Pyrotechnic Events

The largest challenge faced in housing and linking together the various electrical components is allowing for the separation of connections at chute deployment. Disconnections must occur between the nose cone and the rover section, the rover section and the avionics section, and the avionics section and the ATS section. In the subscale flight, this was accomplished using simple hobby grade bullet connectors and free floating wires between sections. However, this method risked tangling the chute or preventing it from deploying all together. For the full scale vehicle, a new approach will be implemented. Spring loaded contacts, often referred to as “pogo” contacts, will be used in combination with strips of 0.005 inch thick copper foil to create electrical connections that span the length of the rocket and separate cleanly during pyro events. The Mil-Max pogo contact pictured below will be used to make all connections that separate in flight.

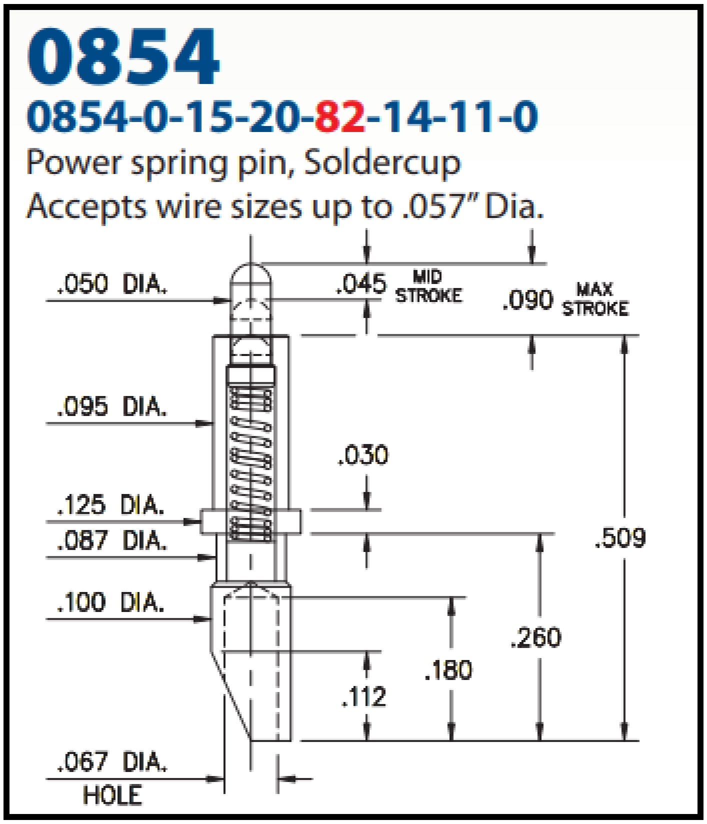


Figure 7.4.4 Mil-Max Spring Loaded Contacts

These contacts were chosen as they have a sufficiently large stroke length and have solder cups that will allow for easy soldering.

The pogo contacts will be distributed radially around the inside of the body tube, held in place by a 3D printed mount. Two mounts with installed contacts, one with 4 contacts and one with 6 contacts are shown below. A contact assembly is also shown interfacing with the copper strips that run along the inside of the body tube.

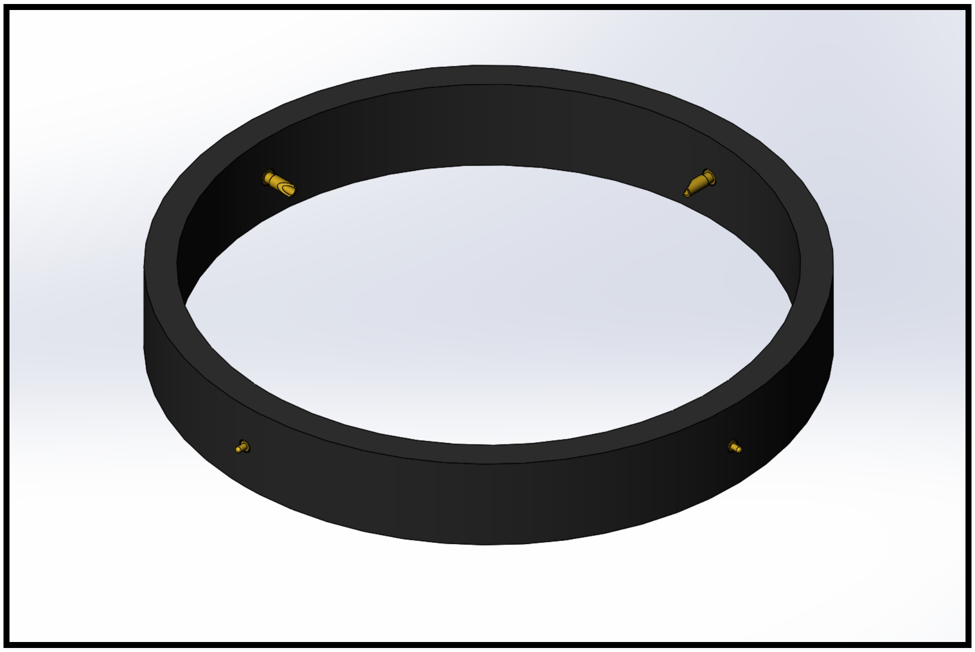


Figure 7.4.5 Pogo Contact Assembly with Four Contacts

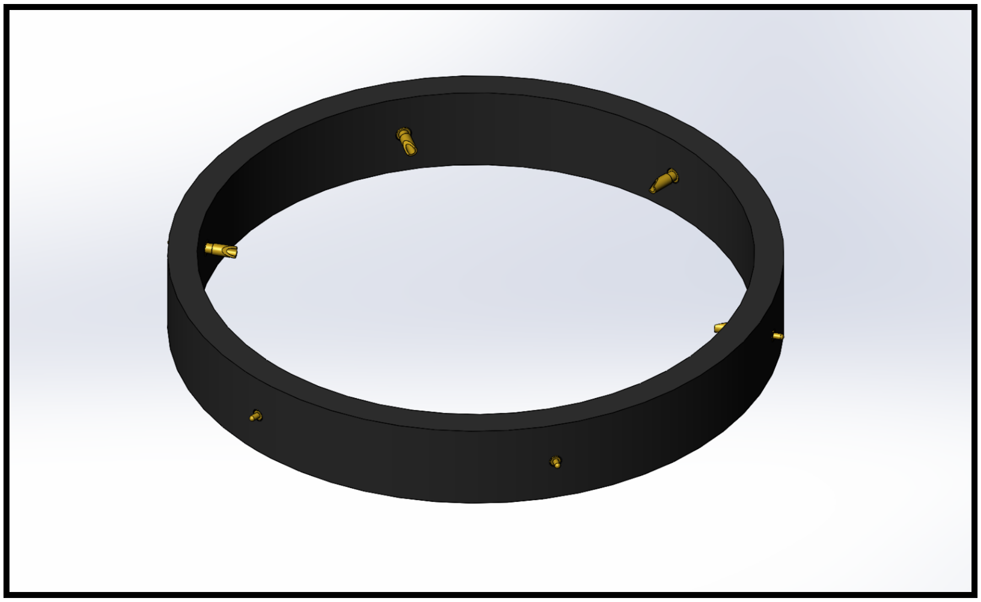


Figure 7.4.6 Pogo Contact Assembly with Six Contacts

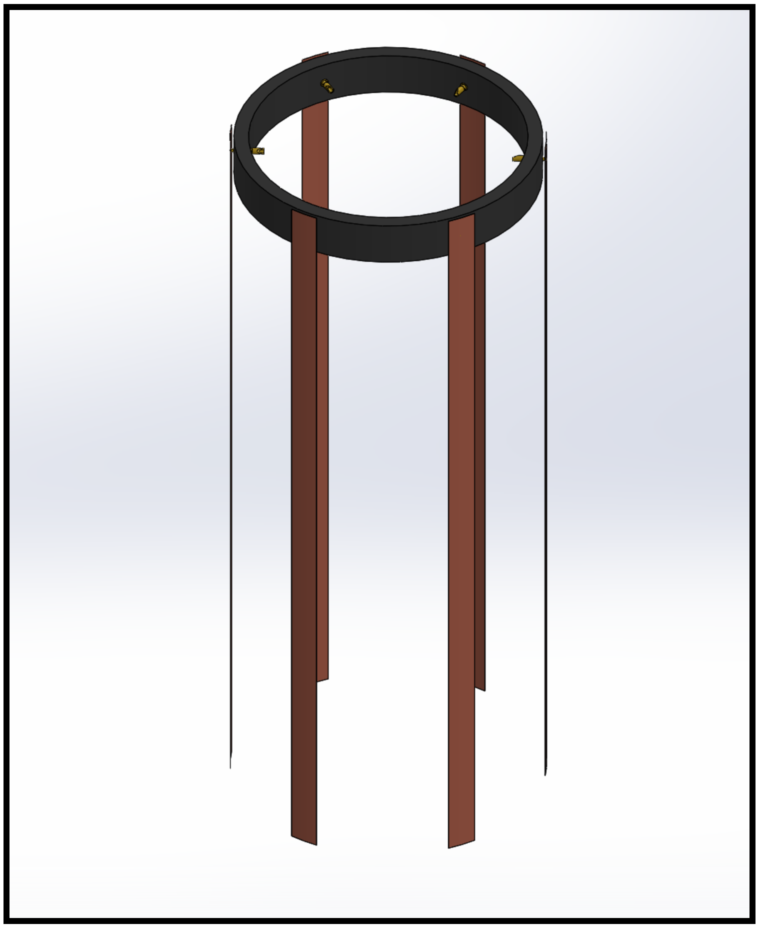


Figure 7.4.7 Pogo Contact to Copper Strip Interface

7.4.6. Assembly

Once the housings have have been 3D printed, standoffs and nuts will epoxied within predesignated recesses. Then components will be placed within the housing and screwed down with either 4-40 or M2.5 screws, depending on the component. Copper strips will be fixed to the inside of the body tube with epoxy. Soldered connections will be used wherever possible to decrease the chance of accidental disconnection or disconnection in flight due to vibration. Molex Nano-Fit locking connectors will be used to connect any components that cannot be soldered together.

8. Project Plan

8.1. Testing Plan

8.1.1. Airframe Testing

Table 8.1.1 Airframe Testing

A subscale model must be launched and recovered and report the models apogee	Two altimeters will be mounted on a subscale rocket, which will be launched. The apogee values from each altimeter will then be compared.	The altimeter reads altitude values within %1 difference	Success, completed on November 18th, 2017
The rocket should have a capability to reach 5,500 ft safely without the ATS system activated	Several test flights without the ATS fully activated will be done to measure the apogee	The rocket reaches an apogee of 5,500ft within 2% difference without ATS activated	Incomplete
The rocket lands within a circle centered at the launch pad with a 2500 ft. radius	The launch vehicle will undergo several test flights to validate that it lands within 2500 ft radius from the launch pad	The rocket lands in the area less than 2,500 ft away from the launch pad	Incomplete

8.1.2. ATS Testing

Table 8.1.2 ATS Testing

Motor must be able to fully retract and extend all flaps without any hindrance	The motor will be actuated multiple times to ensure that the flaps	The flaps are able to move without any collisions or hindrances.	Completed on November 18th, 2017

	do not encounter resistance		
All flaps must have synchronized motion	The motor will be actuated multiple times while being filmed by a high speed camera, to ensure that the flaps are synchronized	All flaps actuate at the same time	Completed on November 11th, 2017

8.1.3. Altimeter Testing

Table 8.1.3 Recovery Testing Chart

Requirement Tested	Test Description	Pass/Fail Criteria	Status
Check Continuity	Use continuity setting on multimeter and power up altimeters to check for continuity beep	Multimeter and altimeter buzzer both confirm continuity.	Incomplete
Check Altimeter for error codes	Power up altimeter and listen to any sequences of beeps	No sequences of beeps correspond to an error code	Incomplete
Check drogue and main deployment altitudes/ delays	Listen for altitudes and delays as indicated by altimeter buzzer and verify correct altitudes via the PerfectFlite DataCap GUI	Beep sequences and GUI match expected for given deployment altitudes and delays	Incomplete

8.1.4. GPS Testing

Table 8.1.4 GPS Testing Chart

Requirement Tested	Test Description	Pass/Fail Criteria	Status
Data Transmission Test	Transmitter and receiver will be powered up and	GPS data will be received and be accurate	Incomplete

	connected to the computer		
Visual Inspection	Inspect the assembled GPS module for solder bridges and misplaced components	No soldering faults are identified	Incomplete
Range Test	Transport GPS system and ground station to local park. Move GPS transmitter 2500 ft from the ground station	Connection remains stable with a 2500 ft line of sight distance between transmitter and receiver	Incomplete

8.1.5. Telemetry Testing

Table 8.1.5 Telemetry Testing Chart

Requirement Tested	Test Description	Pass/Fail Criteria	Status
Data Transmission Test	Transmitter and receiver will be powered up and connected to the computer	Telemetry data will be received and be accurate	Incomplete
Visual Inspection	Inspect the assembled Telemetry modules for solder bridges and misplaced components	No soldering faults are identified	Incomplete
Range Test	Transport Telemetry system and ground station to local park. Move Telemetry transmitter 2500 ft from the ground station	Connection remains stable with a 2500 ft line of sight distance between transmitter and receiver	Incomplete

8.1.6. Rover Testing

In order to verify the rover requirements, multiple tests have been devised for various aspects of the rover system.

Table 8.1.6 Rover Testing Chart

Requirement Tested	Test Description	Pass/Fail Criteria	Status
Rover is not damaged by vibrations/landing	Rover will be enclosed in bay, and dropped from heights of 1 and 2 stories	Critical rover systems will remain intact after test	Incomplete
The rover must deploy in the proper orientation	The deployment system will be triggered in several different orientations, three times each.	The rover will deploy in the proper orientation for all tests	Incomplete
The rover can deploy regardless of rocket orientation	The rocket will be placed in several roll orientations. Each test will be conducted three times.	The rover will be successfully deployed at least 7/9 times, with no more than 1 unsuccessful deployment per orientation	Incomplete
Deployment system functions at long range	The rocket will be placed at 1,000, 2,000, 3,000, and 4,000 ft away from the transmitter, and deployment will be triggered.	The deployment system will function at all ranges	Incomplete
Rover has enough torque for uneven terrain	The rover drivetrain will be tested on smooth dirt, uneven	The rover will be able to move forward at least 5 ft on all	Incomplete

	dirt, short grass, and long grass.	terrains.	

8.2. NASA Requirement Verification

8.2.1. Vehicle Requirements

Table 8.2.1 NASA Vehicle Requirements

Requirement	*Approach*	*Requirement Verification*	*Success Criteria*
The vehicle will safely deliver the payload (deployable rover) to an apogee altitude of 5,280 feet AGL and return to ground	The motor will overshoot the rocket beyond target apogee of 5,280 ft and the ATS system will retract in response to the altimeter reading to reduce the apogee	Gathering data from flight altimeter after test launch	The vehicle reaches the apogee within 2%
The vehicle will carry altimeters to record data of the rockets ascent	The avionic bay will be housing two altimeters for recording the ascent	Inspection	Altimeter records data during flight
Each altimeter will be armed by a dedicated switch accessible from the outside of the rocket	Three key holes are made on the avionics bay which make the switch accessible from the exterior	Inspection	The altimeters are turned on by the key rotation
Each altimeter must be locked on during flight	Screws are used to lock each altimeter onto the avionics tray	Inspection after the launch of the vehicle	Altimeter still locked onto the avionics tray after the landing
The vehicle will be recoverable and reusable.	The vehicle will house two parachutes that will lower the kinetic energy at landing to minimize the damage onto the rocket	Inspection after the flight if the vehicle could have a new motor installed and is capable of flying again immediately	Vehicle can fly again with a replacement of the motor

The vehicle will have a maximum of four independent sections.	The rocket consists of the 3 independent sections after deployment of the parachutes: 1. Nose cone with rover tube 2. Avionics bay 3. ATS tube with Booster section	Inspection that the vehicle has 3 sections after the parachutes are	The vehicle does not split into 4 sections during its flight
The vehicle will contain a single motor, which will provide total impulse that will not exceed 5,120 Newtons - seconds	The rocket will use a commercial L-class motor, AeroTech L850W which has a total impulse of 3840 Ns	Inspection that there is only one motor installed in the rocket	Only one motor is used during the flight
The launch vehicle can be prepared within 3 hours of the FAA flight waiver opening	The rocket will be designed so that only the installation of motor will be need on the launch site	Inspection that at the launch site, only the motor is installed and no other change is made to the rocket	Only the motor is installed at launch site
The launch vehicle can be launched by the 12 volt firing system	The rocket will utilize a commercial L class motor that can be ignited with 12 volt firing system	Will check manufacturer's specifications	Meets requirement
The launch vehicle will use a commercially available APCP motor certified by the NAR, TRA, and/or CAR	Will purchase a APCP motor	Will check manufacturer’s details	Meets requirement
The pressure vessel will have a factor of safety of 4:1	No pressure vessel is used on the launch vehicle	Inspection	Meets requirement
Pressure vessel will have a pressure relief valve that can withstand the maximum pressure and flow rate of the tank	No pressure vessel is used on the launch vehicle	Inspection	Meets requirement

The launch vehicle will have a stability margin greater than 2.0 at the point of rail exit	The launch vehicle is designed to have a stability margin greater than 2.0 at the point of rail exit	Analysis: Simulation based on OpenRocket and hand calculations	Meets requirement
A subscale model must be launched and recovered and report the models apogee	The subscale rocket has altimeter like in the full scale that would record the altitude of the rocket	Test: After the subscale launch, the recordings of the altimeter will be read	The altimeter reads altitude values within %1 difference

8.2.2. Rover Requirements

Table 8.2.2 Rover System NASA Requirements

Requirement	*Approach*	*Requirement Verification*	*Success Criteria*
Teams will design a custom rover that will deploy from the internal structure of the launch vehicle	The rover will be housed within a separate bay in the rocket body	Inspection	The rover will successfully be placed in the launch vehicle
At landing, the team will remotely activate a trigger to deploy the rover from the rocket	The rover deployment system will be controlled by an RC receiver controlled switch. The receiver will be triggered by an RC transmitter.	Inspection	The rover will be remotely deployed from the rocket
After deployment, the rover will autonomously move at least 5 ft. from the launch vehicle	The rover wheels will be hard-coded to travel a distance of greater than 5 ft	Inspection	The rover will move at least 5 ft. from the launch vehicle
Once the rover has reached its final destination, it will deploy a set of foldable solar cell	Solar panels will be mounted on servos, which deploy the panels from the body	Inspection	Solar panels are deployed intact in the proper orientation

panels	of the rover		

8.2.3. Recovery Requirements

Table 8.2.3 Recovery System NASA Requirements

Requirement	*Approach*	*Requirement Verification*	*Success Criteria*
The recovery system shall operate such that a drogue parachute is deployed at apogee and a main parachute is deployed at a lower altitude	StratologgerCF altimeters will be programmed with PerfectFlight DataCap such that the drogue charge is ignited at apogee and the main charge is ignited at *altitude*	Altimeter settings will be verified prior to launch. Visual observation of full-scale test flight will confirm the requirement is met	Both pyro events are triggered at the proper location in the flight and the chutes are ejected properly by the pyro events
A successful ground ejection test for both the drogue and main parachutes must be performed prior to flight	Ejection charge tests will be performed prior to all flights	Visual observation will confirm the tests are successful	The sections separate cleanly above and below the avionics bay and the vehicle is undamaged.
At landing, each independent sections of the launch vehicle will have a maximum kinetic energy of 75 ft-lbf	The main and drogue parachutes will be sized to slow down the rocket to reduce the total kinetic energy at landing	"Analysis: the size and shapes of the parachutes will be modeled in OpenRocket to simulate the landing velocity, and kinetic energy can be calculated from there Test: The launch vehicle will undergo test flights to validate the landing speed will have a kinetic energy below the requirement "	The kinetic energy is below 75 ft-lbf
The recovery system	StratologgerCF	Altimeter settings will	Both pyro events are

shall operate such that a drogue parachute is deployed at apogee and a main parachute is deployed at a lower altitude	altimeters will be programmed with PerfectFlight DataCap such that the drogue charge is ignited at apogee and the main charge is ignited at 800 feet above ground level	be verified prior to launch.	triggered at the proper location in the flight and the chutes are ejected properly by the pyro events
The recovery system electrical circuits will be completely independent of any payload electrical circuits	The recovery and payload systems will be designed such that they are electrically independent.	Design reviews will confirm that the recovery and payload systems will be electrically independent.	The recovery system is electrically isolated from the payload.
All recovery electronics will be powered by commercially available batteries	Altimeters have been chosen that can use commercially available 9 volt batteries	Ground testing will be performed to ensure the chosen altimeters function properly using commercially available 9 volt batteries	The recovery system is powered only by commercially available batteries
The recovery system will contain redundant, commercially available altimeters	The system was designed to use two StratologgerCF altimeters, one primary and one backup	Ground testing will ensure that both altimeters are fully functional	Two commercially available altimeters are used to trigger the pyro events
Motor ejection shall not be used	Motor ejection will not be used	Inspection	Motor ejection is not used
Removable shear pins will be used for both the main parachute compartment and the drogue parachute compartment	The parachute deployment will be controlled by removable shear pins	Inspection	The parachute deployment will be controlled by shear pins
Recovery area will be limited to a 2500 ft. radius from the launch pads	The altitude of the deployment of the parachutes are determined so that the ratio of time of drogue	Test: The launch vehicle will undergo several test flights to validate that it lands within 2500 ft radius	The rocket lands in the area less than 2,500 ft away from the launch pad

	parachute and that of main parachute is maximized while meeting the requirement of maximum kinetic energy at landing	from the launch pad	
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	A GPS tracking device will be incorporated to transmit the real-time location of the launch vehicle. All sections of the vehicle will be tethered together	The GPS system shall undergo ground testing prior to launch.	The GPS system allows for safe location and recovery of the launch vehicle.
The recovery system altimeters will be physically located in a separate compartment within the vehicle from any other radio frequency transmitting device or magnetic wave producing device	The system shall be designed such that no RF emitting devices are present in the avionics bay	Design reviews confirm that no RF emitting devices will be housed in the avionics bay	No RF emitting devices are housed in the avionics bay
The recovery system electronics will be shielded from any other onboard devices which may adversely affect the proper operation of the recovery system electronics	The recovery system is housed in a separate section from any RF emitting devices	It has been determined that physical distance is sufficient to shield the recovery system from onboard transmitting devices.	The recovery system is not adversely affected by other systems on the launch vehicle.

8.2.4. Safety Requirements

Table 8.2.4 NASA Safety Requirements

Requirement	*Approach*	*Requirement Verification*	*Success Criteria*
Each team will use a launch and safety checklist	The safety officer will be responsible to enforcing the safety checklist	The team will check that the safety officer has a safety checklist before launches	The safety checklist is used before every launch
Teams will abide by rules and guidance of the local rocketry club's RSO	The safety officer will communicate with the local rocketry club to ensure everybody is following the rocketry clubs rules	The local rocketry club will be contacted before launch to ensure Georgia Tech's rocket follows protocol	All rocketry club's rules are followed
Teams will abide by FAA rules	The safety officer will ensure the team is abiding by all FAA rules	Inspection	All FAA rules are followed

8.3. Team Derived Requirement Verification

8.3.1. Vehicle Requirements

The functions of our vehicle are divided into three different buckets: Vehicle Ascent, Vehicle Recovery, and Payload Delivery. This division displays that there are three different overarching goals that this rocket is to accomplish. It must ascent to 5,280 feet, recover safely from that apogee, and deploy its payload.

Vehicle Ascent:

Shown in the figure below is the first subset of functions that the rocket is to complete. It is to reach an apogee of 150- 400 feet above 1 mile. If the vehicle aims for one mile, the ATS is able to slow down the rocket to reach the exact 1 mile apogee. This main function can be broken down into three sub functions that enable this main function to proceed. It must produce minimal drag, fly the rocket safely, and fly true (in that it flies directly upward).

Producing minimal drag allows makes it much easier to reach the one mile apogee because it takes less force total to reach this target. If the rocket produced too much drag, the other sub functions would not matter given that the rocket could not reach the targeted apogee to begin with.

In order to fly safely the rocket must control the dangers that can put the rocket in an unsafe condition. If the rocket rotates during flight it is at risk of flexing, breaking, or drifting, all of which can lead to an unsuccessful mission where the rocket crashes into the ground. This means that the rocket must not twist around the X,Y,or Z axis. This also means that the motor must propel the rocket directly upward so it does not put any moment on the rocket body or frame as a whole. Lastly, the rocket must also ensure that motor remains stationary in regard to the Z axis. If the motor is free to move along the Z axis within the rocket, it is likely to shoot through the entire rocket and damage every single subsystem, which is obviously catastrophic failure.

The rocket must also fly true in order to reach the apogee. It must propel itself directly upward to ensure that the 1 mile apogee is reached. Aside from that, it must also maximize the ratio of burning time to drift time. During drift time, the rocket will be exposed to winds at upper altitudes that will take the rocket off course and out of the 2500 foot recovery radius. The further the rocket travels while the motor is burning the less time during the total ascent that the rocket will be exposed to winds that could take it off course.

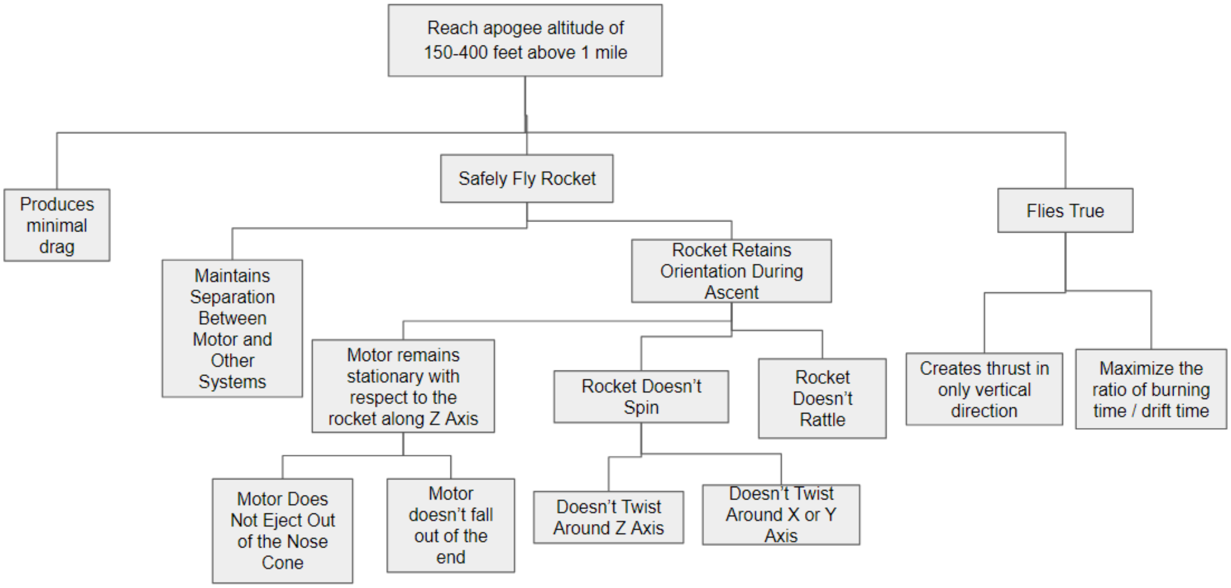


Figure 8.3.1 Vehicle Ascent Function Tree

Vehicle Recovery:

Once the rocket has reached its targeted 1 mile apogee, it must then deploy a recovery system that will allow it to return safely to the ground. The figure below shows the function tree associated with this recovery process.

The primary function of the recovery process is to return the rocket safely to the ground. Therefore, the most important sub function under this category is that the final landing impulse is minimized. Thus the rocket will be safely returned to the ground.

Next, the recovery system must also minimize the drifting time in order for the vehicle to remain within the 2500 foot recovery radius. In order to do so the decent time must be minimized to allow less time for drift to take place. A sub function of that is maximizing the time between when drogue parachute is deployed and when the main parachute is deployed; the rocket will fall for longer without drifting. Another aspect of minimizing drift is ensuring that the rocket is maintains a straight path downward by having symmetrical geometry.

Lastly, the recovery system must be able to safely deploy the parachutes, meaning they come out of the rocket untangled and undamaged. WIthout this the recovery system completely fails as the parachutes are the primary means of recovery.

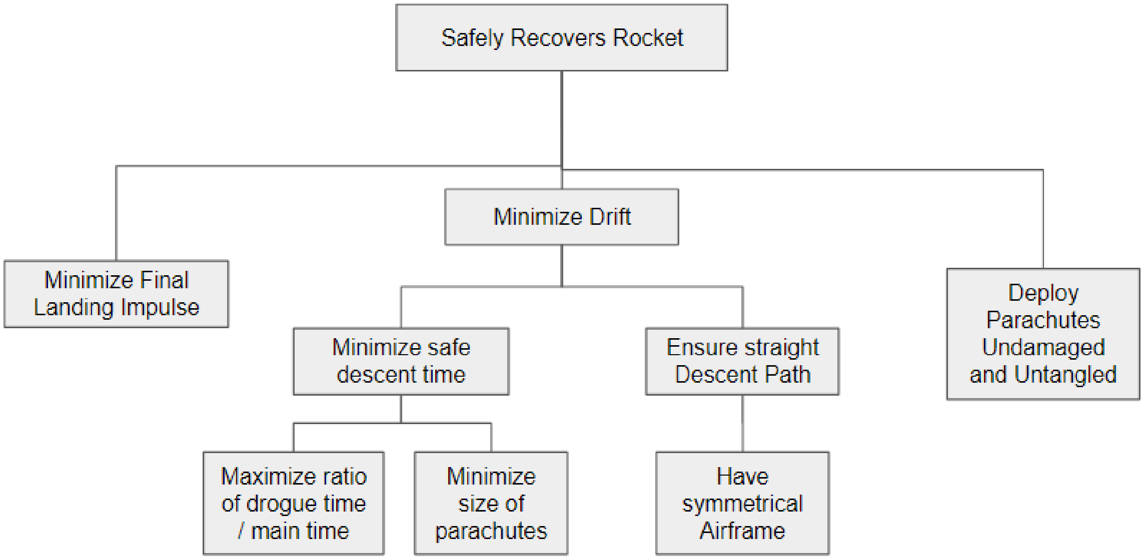


Figure 8.3.2 Vehicle Recovery System Function Tree

Payload Delivery:

The final subsystem of functions is the successful delivery of the payload. Shown in the figure below is the short function tree in which this system is entailed.

In order for the rover to successfully place solar panels it must be brought to apogee, recover with the rocket, and deploy from the rocket without damage. Since the rover is effectively a mass pinned between bulkheads in the rocket, it is a fairly simple process. The rover must be stationary relative to the rocket during the ascent and descent. After it returns to the ground the rocket then must incorporate some system that allows for the rover to leave the rocket unharmed.

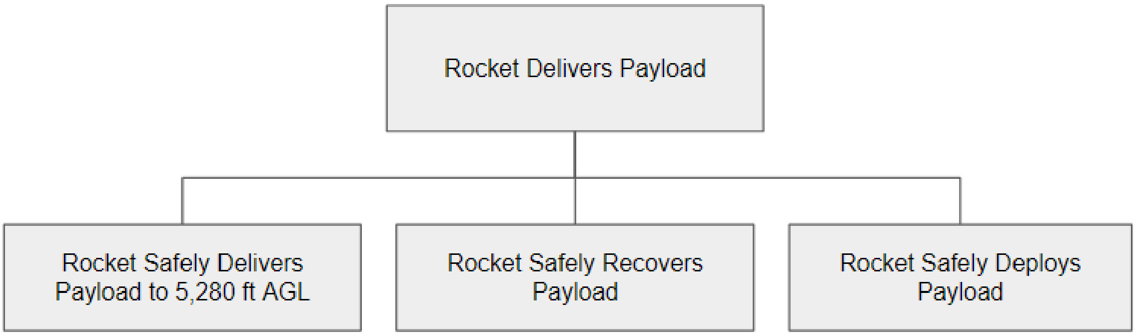


Figure 8.3.3 Payload Delivery Function Tree

These team-derived requirements are summarized in the table below.

Table 8.3.1 Airframe Team Derived Requirements

Requirement	*Approach*	*Requirement Verification*	*Success Criteria*
The rocket should have a capability to reach 5,500 ft safely without the ATS system activated	The materials of each component as well as the dimensions are chosen so that the total mass of the vehicle is minimized	1.Analysis: Simulation based on OpenRocket and hand calculation will conducted so that the rocket will theoretically ascent 5,500 ft 2. Test: Several test flights without the ATS activated will be done to measure the apogee	The rocket reaches an apogee of 5,500ft within 2% difference without ATS activated

		altitude without ATS activated	
The thrust-to-weight will not below 7	The motor is chosen such that its average thrust will be more than 7 times the weight of the rocket	Analysis: Compare the weight of the rocket with the average thrust of the motor	The thrust-to-weight ratio is above 7
The rocket weight will not exceed 40 lb	The materials of each component as well as the dimensions are chosen so that the total mass of the vehicle is minimized while still securing strength of each component	Inspection: Weight of the rocket predicted based on component material density and weight measurement of the actual weight of the rocket	The weight of the rocket is below 40 lb
The launch vehicle will have a stability margin greater than 2.2 at the point of rail exit	The vehicle equips four fins that produces enough aerodynamic forces to keep the stability margin high	Anaylsis: Simulation using OpenRocket will be conducted to predict the static stability margin at the point of rail exit	The launch vehicle's stability margin at point of rail exit is above 2.2
The centerring rings and the retention ring must have safety factor greater than 2 with applied force 950 N (in case one of the them breaks, the half of the maximum force will be applied to each ring)	The materials as well as the designs of these components are chosen to minimize mass while maintaining safety factor above 2 and below 10 with the applied force of 210 lbf	Analysis: FEA using SolidWork's will be conducted for each component	The factor of safety is in between 2 and 10
The thrust plate must have safety factor greater than 2 with applied force 300 pounds (maximum thrust provided by the motor)	The thrust plate uses 1/4 inch, dense plywood	Anaylsis: FEA using SolidWork's will be conducted with 300 pounds applied	The factor of safety is above 2

8.3.2. ATS Requirements

Table 8.3.2 ATS System Team Derived Requirements

All components in ATS must not deform as a result of drag force	ATS components subject to drag will be made of materials able to withstand drag forces	Analysis Using FEA, the factor of safety will be calculated	Factor of safety calculated by FEA must be over 2
ATS must be able to generate sufficient drag to decrease the apogee of the rocket by at least 300ft	ATS flaps will be sufficiently sized and actuated to induce sufficient drag	Analysis Using FEA, the maximum possible work done by the ATS will be calculated	The maximum work done by drag force should be equal to change in potential energy
ATS must be secured to the body tube in such a way that prevents motion/vibration	ATS will be secured using a combination of epoxy and mechanical constraints	Demonstration The body tube mounted with ATS will be shaken and held at different angles	ATS should not vibrate or move when it is shaken
All components in ATS must be secured using threadlocker	All components in ATS will be secured using threadlocker	Inspection All the screws that connects components will be inspected before installation on the body tube	Threadlocker on bolts/nuts must be visible
The motor driver must be connected to the Avionics bay	The motor driver will be connected to the Avionics bay using secure wire connections	Inspection Connection between Avionics bay and the motor board must be checked using multimeter	The board and the circuit should be wired without any break
ATS must be located below CG of burnout to	ATS must be located below CG of burnout to prevent instabilities	Analysis	The location of ATS on Open

prevent instabilities		The model of the rocket will be generated using open rocket	Rocket Model must be below CG
Motor must be able to fully retract and extend all flaps without any hindrance	Slits will be cut in the body tube to allow the flaps to move without any hindrance	Test The motor will be actuated multiple times	The flaps should be able to fully extend and retract smoothly
All flaps must have synchronized motion	The ATS flaps will be linked to a single motor driver using a linkage mechanism	Test The motor will be actuated multiple times	The flaps should retract and extend at the same speed
ATS must not generate any moment on the vehicle when actuated	The flaps will be positioned opposite each other, so that the moments cancel	Analysis Using CFD, the pressure/ force on each flap will be calculated	Sum of moment generated by the flaps respect to center of gravity should be zero
ATS must have mechanical restraint to prevent flap misalignment	ATS will have at least one mechanical restraint to prevent flap misalignment	Inspection Existence of a mechanical restraint will be checked	There is one or more mechanical restraint that will prevent flap misalignment
ATS will not actuate before burn-out is reached	The ATS will be programmed to begin actuation after the microcontroller detects the end of burnout,which must be equal to or after the rated burn time of the motor	Inspection Programmed function to induce a wait equivalent to the rated burn time of the motor	Mechanism will remain dormant during burn time due to complex nature of motion-profile under large accelerations
ATS flaps will not create drag on launch vehicle when retracted	The ATS mechanism will have a mechanical hard stop, which holds the retracted flaps flush with the outer surface of the body tube	Analysis Mechanical hard stop implemented to prevent flaps from retracting too much	When retracted, the edges of the ATS flaps must be flush with the outer surface of the body tube

8.3.3. Rover Requirements

The rover system must perform three different functions to complete our task successfully as illustrated in the figure below. This task is most easily simplified into a few base functions: Deployment, Drivetrain, and Solar Panels. Each function category is further split into team-derived requirements.

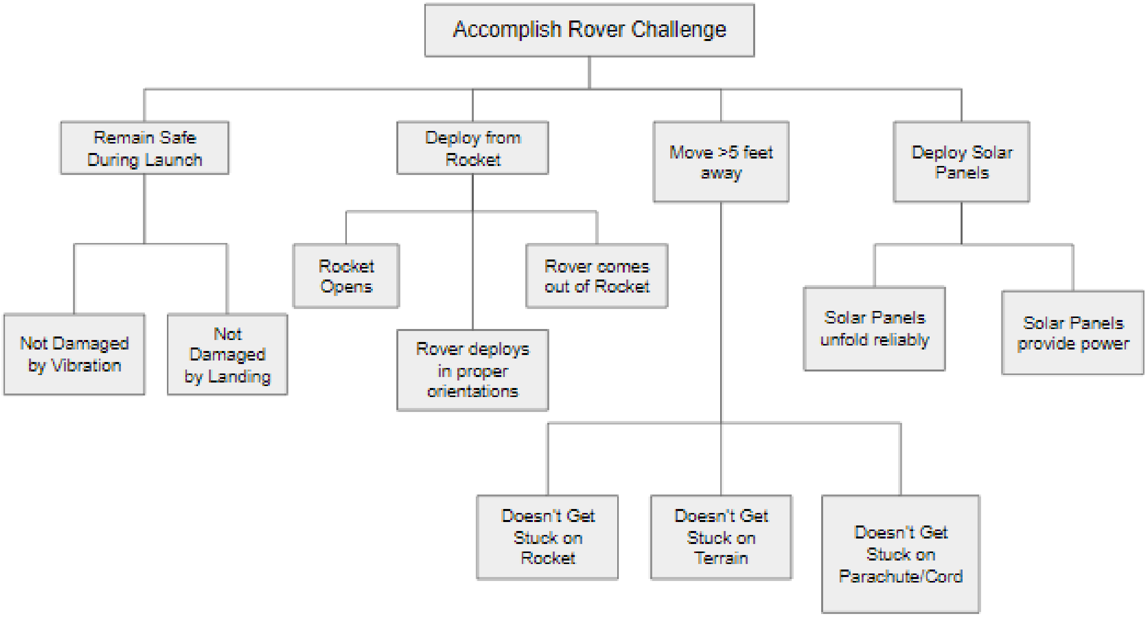


Figure 8.3.4 Rover Challenge Function Tree

Deployment

For the rover to accomplish any of the required tasks it, must first successfully deploy from the rocket after landing. This task can only be accomplished after taking into consideration the rocket orientation, terrain, and the potential of parachutes covering the deployment area as seen in the figure below.

The orientation of the rocket will be an unknown factor. The rover must be able to account for this and be able to exit the rocket regardless of its orientation. The terrain might be sloped in such a way that inhibits the separation of the nose cone and results in the rover being unable to deploy. There might also be a parachute or other obstructions the deployment system will have to push out of the way to allow the rover to deploy safely. The system should be designed to produce enough torque to move the entire rocket in order to ensure the rover is able to separate from the recovered vehicle.

.

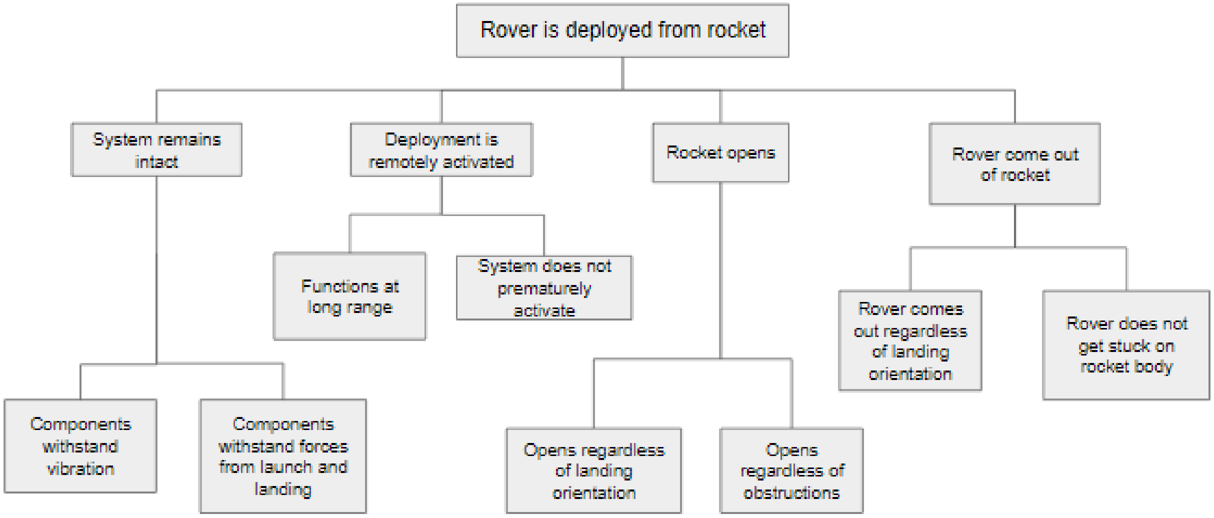


Figure 8.3.5 Rover Deployment Function Tree

Drivetrain

After a successful deployment, the rover must move a minimum of 5 feet away from the rocket. The figure below illustrates the challenges of remaining intact during flight, being able to overcome any terrain, and have the ability to not interfere with other components.

In order to move out of the rocket, the drivetrain must be intact upon landing. The best way to ensure the drivetrain system remains unharmed is to make the components unable to slip and fall off in the case of treads, and make them unable to interfere with other mechanical components. Interference with other components could cause component failure not exclusive to just the drivetrain. Such interference may result in deployment failure if the rover became entangled in its own deployment system resulting in component damage.

If the drivetrain remains intact, the rover must successfully exit the rocket. In order to do so the rover must be capable of exiting the rocket regardless of orientation without getting stuck on any deployment components, parachutes, or the rocket nose cone.

Next, the rover must drive more than 5 feet away from the rocket. For this task to reach successful completion, the rover must be capable of driving in its deployed orientation, and must be able to overcome getting stuck on any terrain such as the parachute, shock cords, or uneven terrain.

Lastly, the drivetrain mechanism will be relatively large and cannot interfere with other systems on the rover. Therefore they must be designed in such a way to keep compact, self contained, and out of the way of other systems such as the solar panels.

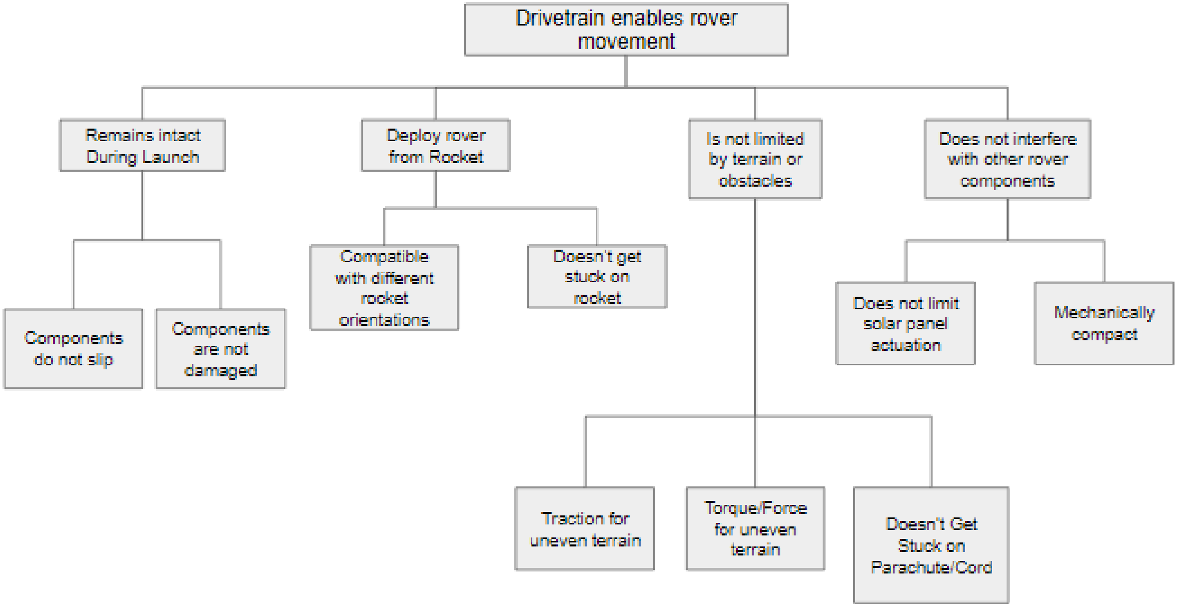


Figure 8.3.6 Drivetrain Function Tree

Solar Panels

Once the rover has reached a distance of five feet away from the rocket, the rover will stop and deploy its solar panels. The steps to accomplish this task are well illustrated in the figure below. For this to occur successfully, the solar panels must remain safe from vibrations and landing as well as keeping closed for the duration of the mission until instructed to open.

Assuming the solar panels remain safe and closed, they will need to be deployed per competition guidelines, and in an orientation that will receive sunlight. The deployment method as the competition states, requires the panels to fly in a folded configuration which requires the panels to endure not only flight forces but also the constant concentrated force of the unfolding mechanism throughout the flight. There is a risk that the deployment mechanism could crack or damage the panels during flight or recovery. Essentially, minimizing the impact and long duration loads that the solar panels must endure is paramount to keeping them in operating condition.

Lastly, for the final task to be completed the rover panels must generate power. For the power generation to be detected it is required that the connections must also remain safe during flight. Solid connections will allow the panels to transmit their generated power in order to light an LED as the final signal of mission accomplished.

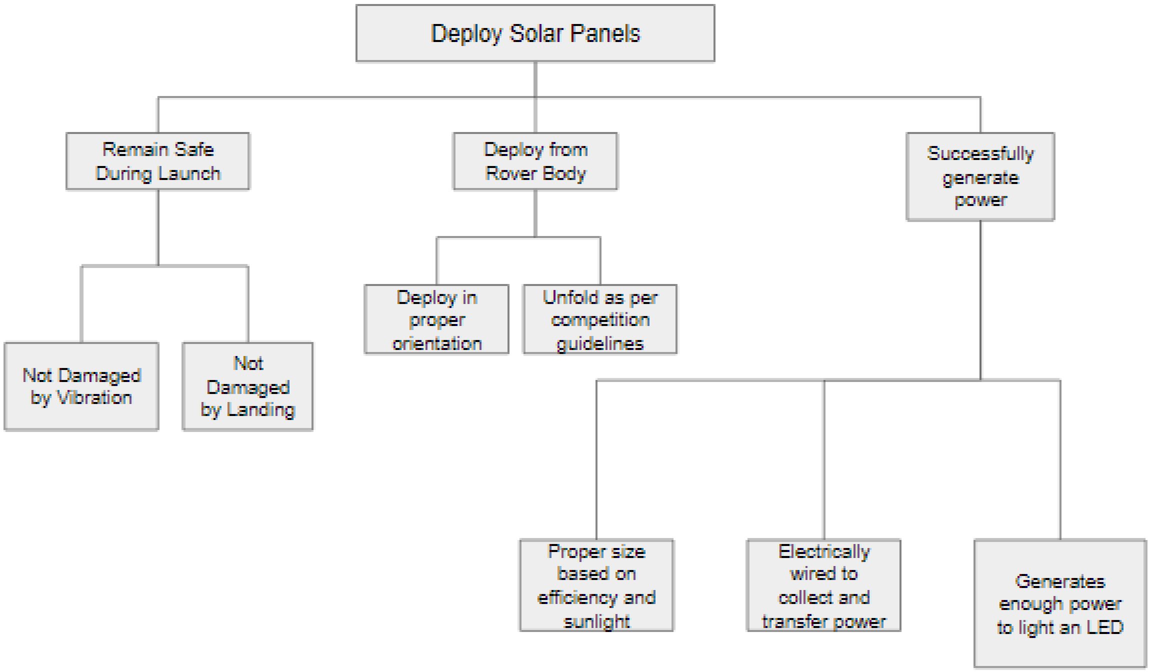


Figure 8.3.7 Solar Panels Function Tree

The requirements derived above are summarized in a table below, detailing the specific requirement, team approach, verification method, and success criteria.

Table 8.3.2 Rover System Team Derived Requirements

Requirement	***Design Feature***	***Verification***	***Success Criteria***
Rover is not damaged by vibrations/landing	The rover will be secured by foam pads to damp motion within the rover bay	Test: Rover will be placed in bay and dropped from two stories to ensure that it can withstand the impact	Criticial rover components remain intact and functional after landing
The rocket must open	A motor will turn a lead screw, which separates the body tube. This in turn opens the rover bay	Inspection	The rocket body opens wide enough for the rover to exit
The rover must deploy in the proper orientation	The rover can rotate inside of the rocket, so it will always land right side up	Test: The deployment system will be triggered in different orientations to ensure that the rover exits in the proper orientation	The rover will exit the rocket in a proper driving orientation
The rover must come out of the rocket	The rover drivetrain will carry it out of the rocket body	Inspection	The rover entirely exits the rocket body
Rover must not get stuck on rocket/parachute/cord	Rover will have obstacle detection	Inspection	Rover successfully navigates away from rocket body
The rover can deploy regardless of rocket orientation	The rover is mounted on a rail within the bay, allowing it to rotate with the launch vehicle	Test: The deployment system will be triggered in multiple orientations	The rover can deploy regardless of the launch vehicle orientation
Deployment system functions at long range	Deployment system will utilize long-range transmitter	Test: Rocket will be placed at various distances and deployment system will be triggered	Deployment system is functional up to 4,000 ft away from the team transmitter

Deployment system does not deploy prematurely	Deployment will be controlled by an RC receiver controlled switch, which is only operated by the team-controlled transmitter	Demonstration	Deployment system is only triggered by the team at the intended time, not prematurely
Rover has enough torque for uneven terrain	Wheels have studs, and are operated by powerful motors to cross over uneven terrain	Test: Rover will be operated on different types of uneven terrain to ensure functionality	Rover can drive on all possible conditions expected at launch site

8.3.4. Recovery Requirements

Table 8.3.4 Recovery System Team Derived Requirements

Requirement	*Approach*	*Requirement Verification*	*Success Criteria*
The launch vehicle return will to earth in a safe and controlled manner	Parachutes are sized appropriately and the pyro events are triggered at appropriate locations in the flightpath	Full Scale Test flight and simulations.	Altimeters deploy charges at the proper altitudes and the vehicle is safely recovered
The rocket will be recovered quickly and efficiently	Parachute size is minimized and a GPS tracker is implemented.	Full scale test flight and drift calculations	The coordinates of the landing location are received from launch vehicle and the vehicle is retrieved in a timely manner
Ejection charges will be properly sized	Ejection charges will be sized to deploy the drogue parachute at apogee, and the main parachute 750 ft above ground	Ejection charge testing will be completed prior to all launches Analysis: the charges will be sized to separate the rocket at atmosphere conditions at apogee and 750 ft above ground	The ejection charge successfully separates the rocket at apogee, and again at 750 ft above ground

All pyrotechnic charges shall be isolated from the parachutes	The pyrotechnic charges shall be located in separate area of the recovery bay The parachutes will be packed with a thermal barrier between itself and the ejection charge	Inspection	The parachute is undamaged at deployment
The bulkheads must have safety factor of 2 with respect to all applied forces	The bulkheads are manufactured from G10 fiberglass which has high yield strength	Analysis: FEA on the bulkheads are conducted using SolidWorks	The safety of factor of the bulkheads are above 2
The shockcord must have a length to absorve 1500 ft/lb (1.5 times the kinetic energy at the deployment of the main parachute)	The length of shockcord is chosen based on its elastic module to satisfy the requirement	Analysis: Hand calculation is made to confirm the shockcord is capable to absorb the required kinetic energy Test: After each test flight, inspection will be made to confirm that the shockcord is not damaged by the deployment of the parachutes	The shockcord has a length that absorves 1,500 ft/lb

8.4. Project Timeline

In order to meet all NASA deadlines as well as team-derived deadlines, GIT LIT has implemented a task management and timeline system, hosted on Zoho. This system allows the team to track high level milestones, such as NASA deadlines, as well as low level milestones, such as weekly team assignments and outreach activities. Status indicators attached to each milestone show the percentage of completion, so that the team can track the specific status of each milestone. This information is also displayed on a GANTT chart, which allows the team to easily visualize deadlines. The project timeline and list of tasks are found below in Appendix A.

8.5. Budget

The projected budget for GIT LIT for the 2017-2018 competition cycle is $7,394.36, with Table 8.5.1 showing the breakdown between eight categories: ATS, Airframe, Avionics, Rover, Travel, Prototyping, Subscale Vehicle, and Outreach/Misc. This breakdown is shown further as a percentage distribution in Figure 8.5.1.

Table 8.5.1 Team Budget Breakdown

Category	**Cost**
ATS	$113.10
Airframe	$632.19
Avionics	$479.95
Rover	$115.00
Travel	$3,268.00
Prototyping	$69.74
Subscale Vehicle	563.67
Outreach/Misc.	$2,152.71
Total	**$7,394.36**

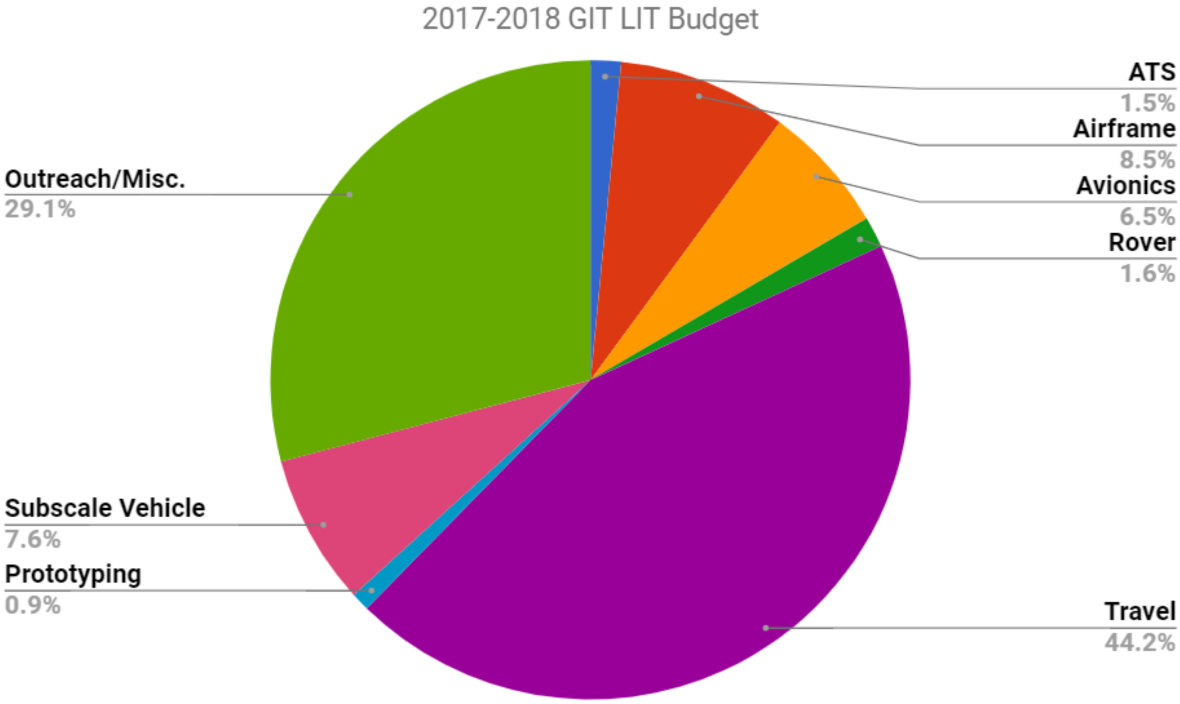


Figure 8.5.1 Team Budget Distribution

Tables 8.5.2 and 8.5.3 are comprehensive breakdowns of the subscale rocket costs and full year budget respectively. The components are sorted by the rocket system that they are a part of. This budget does not include leftover components from previous competition cycles, which the team does not have to purchase for the 2017-2018 competition cycle.

Table 8.5.2 Subscale Vehicle Costs

	Description	**Unit Cost**	**Qty**	**Total Cost**
Airframe	Nosecone	$20.79	1	$20.79
	Shear Pins	$3.10	1	$3.10
	Motor	0	0	$0.00
	Couplers	$4.13	2	$8.26
	Motor Mount Tube	$8.09	1	$8.09
	Black Powder	0	0	$0.00
	Ejection caps	$3.15	2	$6.30
	Rail Buttons	$3.22	2	$6.44
	Shock Cord (9/16 tubular nylon)	$8.75	1	$8.75
	Main Chute (58" TFR Std)	$31.95	1	$31.95
Rover	Screw-mount nuts	$10.74	1	$10.74
	4-40 1" screws	$4.43	1	$4.43
	4-40 lock nuts	$2.67	1	$2.67
	Motor	$12.99	1	$12.99
	Shaft Couplers (6mm to 1/4")	$4.99	1	$4.99
	1/8" thick x 1/2" x 12" 6061 Aluminum	$0.99	4	$3.96
	9V Batteries	$6.61	1	$6.61
	Receiver Controlled Switch	$13.91	1	$13.91
ATS	.125 x 4 x 12" 6061 Al Sheet	$14.59	1	$14.59
	Stepper Motor - NEMA 17	$16.95	1	$16.95
	.25 x 3 x 12" 6061 Al Bar	$7.32	1	$7.32
	2-56 .25" set screw 316 SS (5-pck)	$5.38	1	$5.38

	1/8" Diameter 1/4" Long Shoulder, 4-40 Thread	$1.64	5	$8.20
	M3, 8m long, low profile SHC screw	$5.71	1	$5.71
	1/8" Diameter 3/8" Long Shoulder, 4-40 Thread	$1.62	5	$8.10
	0.1875 x 4 x 12" 6061 Al Sheet	$6.83	1	$6.83
	Stepper Motor Driver	$8.95	2	$17.90
	DuPont Teflon Multi-Use Lubricant 11oz (add-on)	$6.69	1	$6.69
Avionics	RPI Sense Hat, includes several sensors (main appeal is IMU)	$37.99	1	$37.99
	Micro SD (8GB)	$6.99	1	$6.99
	RPI/ATS Battery	$10.80	1	$10.80
	Terminal Blocks, 5 pcs of 2 rows of 12 ports	$10.99	1	$10.99
	RPi/ATS battery 2	$14.61	1	$14.61
	Protoboards	$13.99	1	$13.99
	Silicone wire black/red	$1.98	1	$1.98
	bullet connectors	$2.30	1	$2.30
	heat shrink tubing	$6.99	1	$6.99
	arming switch	$5.95	3	$17.85
	4-40 standoffs	$8.32	1	$8.32
	M2.5 standoffs	$0.96	4	$3.84
	4-40 screws	$10.43	1	$10.43
	M2.5 screws	$11.90	1	$11.90
Motor	Complete 54mm Aerotech Motor Hardware (used)	$79.75	1	$79.75
	J250FJ Motor	$72.99	1	$72.99
			Total:	**$563.37**

Table 8.5.3 Comprehensive Team Budget

	Category	**Description**	**Unit Cost**	**Qty**	**Total Cost**
Rocket Materials	ATS	1/8" Al sheet (1x2ft)	$50.98	1	$50.98
		1/4" Al sheet (1x1ft)	$34.73	1	$34.73
		2-56 .25" set screw 316 SS (5-pck)	$5.38	1	$5.38
		1/8" Diameter 1/4" Long Shoulder, 4-40 Thread	$1.64	5	$8.20
		M3, 8m long, low profile SHC screw	$5.71	1	$5.71
		1/8" Diameter 3/8" Long Shoulder, 4-40 Thread	$1.62	5	$8.10
	Avionics				
		PerfectFlite stratologgerCF	$54.95	1	$54.95
		FS(fullscale) Battery	$25.00	1	$25.00
		FS Stepper Driver	$20.00	1	$20.00
		Stepper Motor	$40.00	1	$40.00
		Misc. Parts(wire, connectors, etc)	$50.00	1	$50.00
		Eggfinder GPS	$90.00	1	$90.00
		Weller Soldering Iron	$200.00	1	$200.00
	Rover				
		Rover electronics	$80.00	1	$80.00
		Motor	$15.00	1	$15.00
		Rover solar panel	$20.00	1	$20.00
	Airframe				
		75mm LOC tube	$14.95	1	$14.95
		3/8" Tubular Kevlar Shock Cord (per yard)	$2.50	12	$30.00
		Ejection Igniters (10 pack)	$15.79	2	$31.58
		5.5" G12 Coupler (12" length)	$54.11	1	$54.11
		2-56 Nylon Screws (Shear Pins) (#??)	$2.95	3	$8.85
		Parachute Protector	$10.95	1	$10.95

		Nosecone	$84.95	1	$84.95
		Complete 54mm Aerotech Hardware	$79.75	1	$79.75
		J250FJ Motor	$72.99	1	$72.99
		Aluminum for Ctr Rings	$51.58	1	$51.58
	Misc				
		Hardware	$150.00	1	$150.00
		Taps	$30.83	1	$30.83
		Electronics Box	$11.65	1	$11.65
Competition Expenses	Hotel	Hotel Rooms	$80.00	16	$1,280.00
	Rocket Fair	Poster (cost per foot, 36 inches)	$2.75	12	$33.00
		Display Stand	$30.00	1	$30.00
	Food		$100.00	16	$1,600.00
	Transportation	Gas for competition	$2.50	90	$225.00
		Trailer Rental	$20.00	5	$100.00
Prototyping	ATS				
		Nylon Bar	$35.36	1	$35.36
		2-56 .25" set screw 316 SS (5-pck)	$5.38	1	$5.38
		1/8" Diameter 1/4" Long Shoulder, 4-40 Thread	$1.64	5	$8.20
		M3, 8m long, low profile SHC screw	$5.71	1	$5.71
		1/8" Diameter 3/8" Long Shoulder, 4-40 Thread	$1.62	5	$8.10
	Avionics				
		Breadboard	$6.99	1	$6.99
Misc					
Mask	Safety		$22.49	1	$22.49
P100 Filter	Safety		$6.48	2	$12.96
Fire Extinguisher	Safety	FS	$19.29	1	$19.29

Fire Cabinet	Safety		$342.00	1	$342.00
Pens	Outreach		$0.62	250	$155.00
Stickers	Outreach	300 Stickers	$111.00	1	$111.00
T shirts			$18.00	20	$360.00
Whiteboard		6'x4'	$150.00	1	$150.00
Polo Shirts			$20.00	20	$400.00
Launch Transportation	Launch	Gas for launches	$60.00	9	$540.00
Drawer Safe			$39.97	1	$39.97
				Total:	**$6,830.69**

8.6. Funding Plan

We are working closely with the Georgia Space Grant Consortium to receive most of the rocket materials budget as we have done in the past, and they have estimated they can allocate us $4000 as they have done in prior years. We plan for Orbital ATK to cover our travel budget for up to $400, as this was also granted in previous competition cycles. In addition, we are estimating a grant of $2500 in funding from the Georgia Institute of Technology Daniel Guggenheim School of Aerospace Engineering, as this amount was granted last year. We hope to extend relations with other companies for further sponsorship. More specifically, we intend to reach out to companies GIT LIT members have interned with, local Atlanta companies, and established invested aerospace companies such as Orbital ATK, SpaceX, Lockheed Martin, etc.; we also plan on reaching out to Georgia Tech Aerospace alumni who could connect us more directly to companies. The Georgia Space Grant Consortium has offered to assist in connecting us with corporate sponsors. Table 8.6.1 shows our projected funding, which exceeds our cost estimates by over 25%, giving appropriate room for unanticipated costs. The Georgia Tech Ramblin' Rocket Club has generously offered the use of some of their tools, storage space, and facilitating the purchase of rocket motors. Georgia Tech has also offered us a room in the Engineering Science and Materials Building to use for construction, storage, and meeting space.

Table 8.6.1 Projected Funding

Sponsor	***Contribution***	***Date***
2016-2017 Unused Funds	$1,775.23	--
Georgia Space Grant Consortium	$4,000	November 2017
Alumni Donations	$200 (est.)	December 2017
Georgia Tech School of Aerospace Engineering	$2,500 (est.)	January 2018
Corporate Donations	$1,000 (est.)	January 2018
Orbital ATK Travel Stipend	$400 (est.)	April 2018
Total	**$9,875.23 (est.)**	

Table 8.6.2 shows a preliminary list of companies and organizations that the team plans on contacting for advice, funding, and components. By dividing these categories amongst team leadership, our team will be able to contact a wider range of companies, with better likelihood of success. In addition, by asking specific companies for specific components, we are reducing the risk of ambiguity and confusion on the part of the sponsoring company.

Table 8.6.2 Preliminary Sponsorship Targets

Company	Component	Person Responsible
McMaster Carr	Scrap Aluminum	Kentez
Turnigy	3S Lipos	Lucas
	Transmitter/Receiver	Lucas
	LiPo Charger	Lucas
Mobius	Camera	Lucas
GoPro	Camera	Lucas
RedBull	Funding	Shravan
Northrop Grumman	Funding	Shravan
SpaceX	Funding/Experience/Advice	Shravan
Blue Origin	Funding	Shravan
Weller	Soldering Iron	Kentez
Formlabs	SL Printer	Walter
Carbon	SL Printer	Walter
Ultimaker	3D Printer	Walter
Polymaker	3D Printer Filament	Walter
Eagle Mfg	Flammable Cabinet	Daniel
Grainer	Flammable Cabinet	Daniel
Home Depot	Dremel	Kentez
	Drill Press	Kentez

Ace	Power Tools	Kentez
Loewes	Power Tools	Kentez
Flash Forge	3D Printer	Walter
Makerbot	3D Printer	Walter
Quartet	Whiteboard	Daniel
Epson	Mini Projector	Lucas
Microsoft	Monitors/Surfaces	Lucas
Craftsmen/Sears/Loewes	Tools	Kentez
	Toolbox	Kentez
	Tool Chest	Kentez
GTRI	Funding	Shravan
Advanced Circuits	Funding/Circuit Boards	Shravan/Lucas
Generation Orbit	Funding	Shravan
Trotec	Laser Cutter	Kentez
Canon/Nikon/Sony	Camera (DSLR)	Lucas
DJI	Quadcopter	Daniel
Cardibe 3D	Desktop CNC Mill	Kentez
Invention Studio/ME 2110	Mini Mills	Kentez

8.7. Sustainability Plan

Recognizing the experience and hands on practice that the NASA SL competition offers, GIT LIT has worked with the institute to offer Student Launch as a vertically integrated project within the VIP program (see 9. Educational Engagement). The VIP program provides an infrastructure that allows for a highly integrated design through utilizing resources from undergraduate students, graduate students, and professors from various engineering disciplines. Additionally, the VIP program adds further incentive by offering technical and elective course credits for team participation. These attributes establish the Student Launch program as a lasting and beneficial experience for students, preparing new students to become the future leaders of the team. In addition, through continuous marketing to all undergraduate students regardless of class level, the team is able to maintain a high level of diversity in terms of majors, class standing, and interests.

9. Education Engagement

9.1. Vertically Integrated Projects Program

One of the most valuable aspects of the GIT LIT is the pursuit of engagement in the Georgia Tech community. The Student Launch competition has been made into a highly integrated, class- based team project through Georgia Tech's Vertically Integrated Projects (VIP) Program. The VIP Program unites undergraduate education and faculty research in a team- based context. VIP extends the academic design experience beyond a single semester, allowing students to participate for up to three years. It provides the time and context to learn and practice professional skills, to make substantial contributions, and experience different roles on large multidisciplinary design/recovery teams. As a part of this experience, the Student Launch team takes on the responsibility to contribute in turn to the community and to promote scientific and engineering knowledge to over 200 students, age levels ranging from kindergarten to high school, through educational outreach.

As a part of the VIP program, students are taught how to maintain detailed research notebooks, which are then passed on to new students as an introduction to the team and project. In addition, the VIP team has a non-traditional class structure, with student-led general meetings as well as independently organized subteam meetings. The general meetings are designed to educate inexperienced members, through weekly assignments, technology demonstrations, and updates from each of the subteams; the subteam meetings, on the other hand, are where most of the rocket design and fabrication take place. Through presentations from the VIP teams to groups across campus, GIT LIT is able to continually educate both the members of the team as well as the Georgia Tech community.

9.2. Boy Scout Merit Badge

Last year, GIT LIT started a Boy Scout merit badge program, which consisted of inviting a local troop (Troop #433) to Georgia Tech, where the scouts were introduced to Aerospace Engineering facilities as well as different careers and opportunities in engineering. The badge program also included a presentation that introduced numerous examples of engineers' methods and mindsets, to give the scouts a window into the mind of an engineer. The team then took the troop on a tour of campus and the aerospace labs located in multiple buildings. This has created a large amount of interest in teaching more Engineering Merit Badge classes, as well as beginning programs with different merit badges, such as Astronomy, Aviation, and Robotics badges. By continuing the merit badge program, GIT LIT is striving to create the next leaders in STEM fields, particularly in Aerospace Engineering.

This year, the team is leading a Robotics merit badge, working alongside both the Boy Scout troop as well as local middle and high school robotics teams to provide a comprehensive educational experience. The program is expected to begin in February.

9.3. On-Campus Collaboration

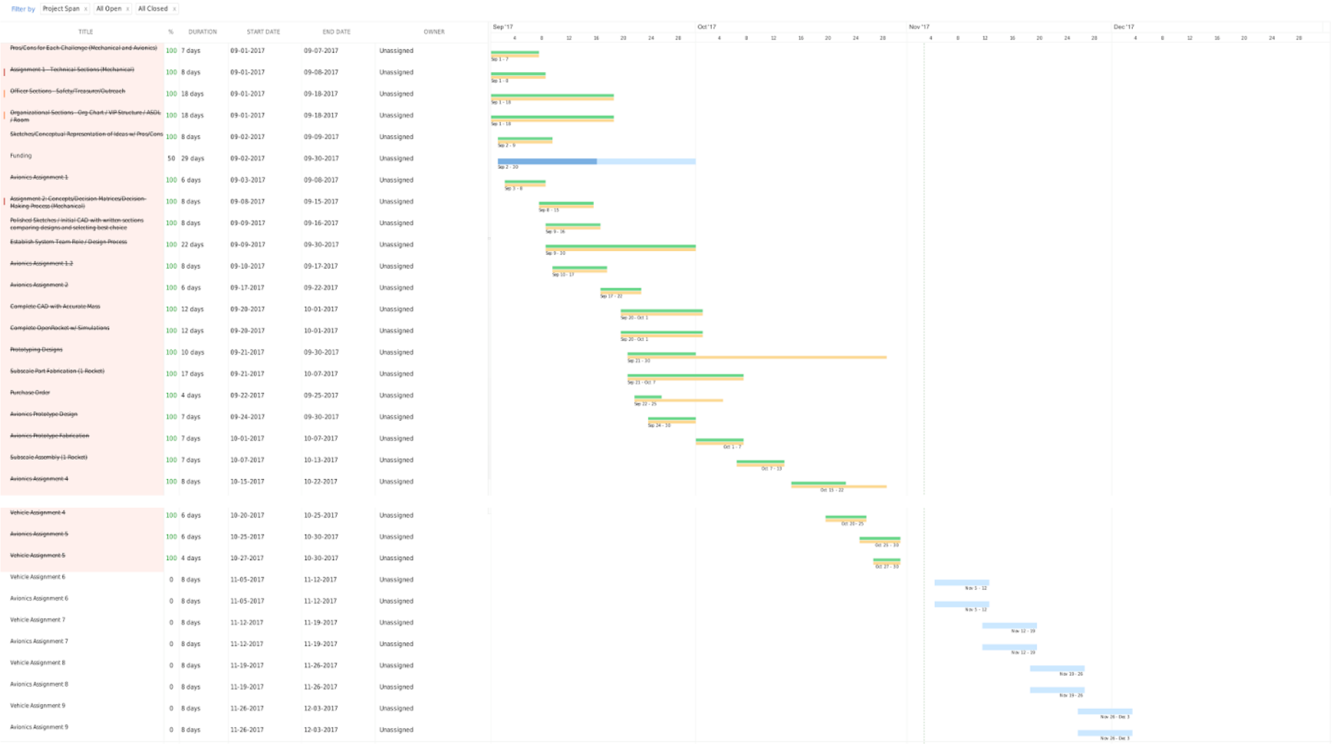
Many other Georgia Tech student organizations organize and support community outreach events, so one of GIT LIT's major new initiatives is to increase collaboration with such groups to expand STEM outreach. Possible groups to collaborate with include SWE, the Society of Women Engineers, and NSBE, the National Society of Black Engineers. Both of these groups conduct events with groups that are underrepresented in STEM fields, and hold a large presence both on campus and in the Atlanta community. As GIT LIT shares many of the same outreach goals as these organizations, a collaboration would allow all parties involved to increase their impact on the community.

9.4. Peachtree Charter Middle School

GIT LIT has run an after school program at Frederick Douglass High School and Peachtree Charter Middle School for the past three years, teaching students the basics of rocketry and allowing them to design and build their own rockets. By working closely with the engineering instructor at both schools, our team has been able to expand our outreach to local Atlanta middle and high schools, where STEM is underrepresented. Our team has been in communication with Aaron Campbell, our liaison at Peachtree Charter Middle School, and the program is currently being organized for the 2017-2018 school year.

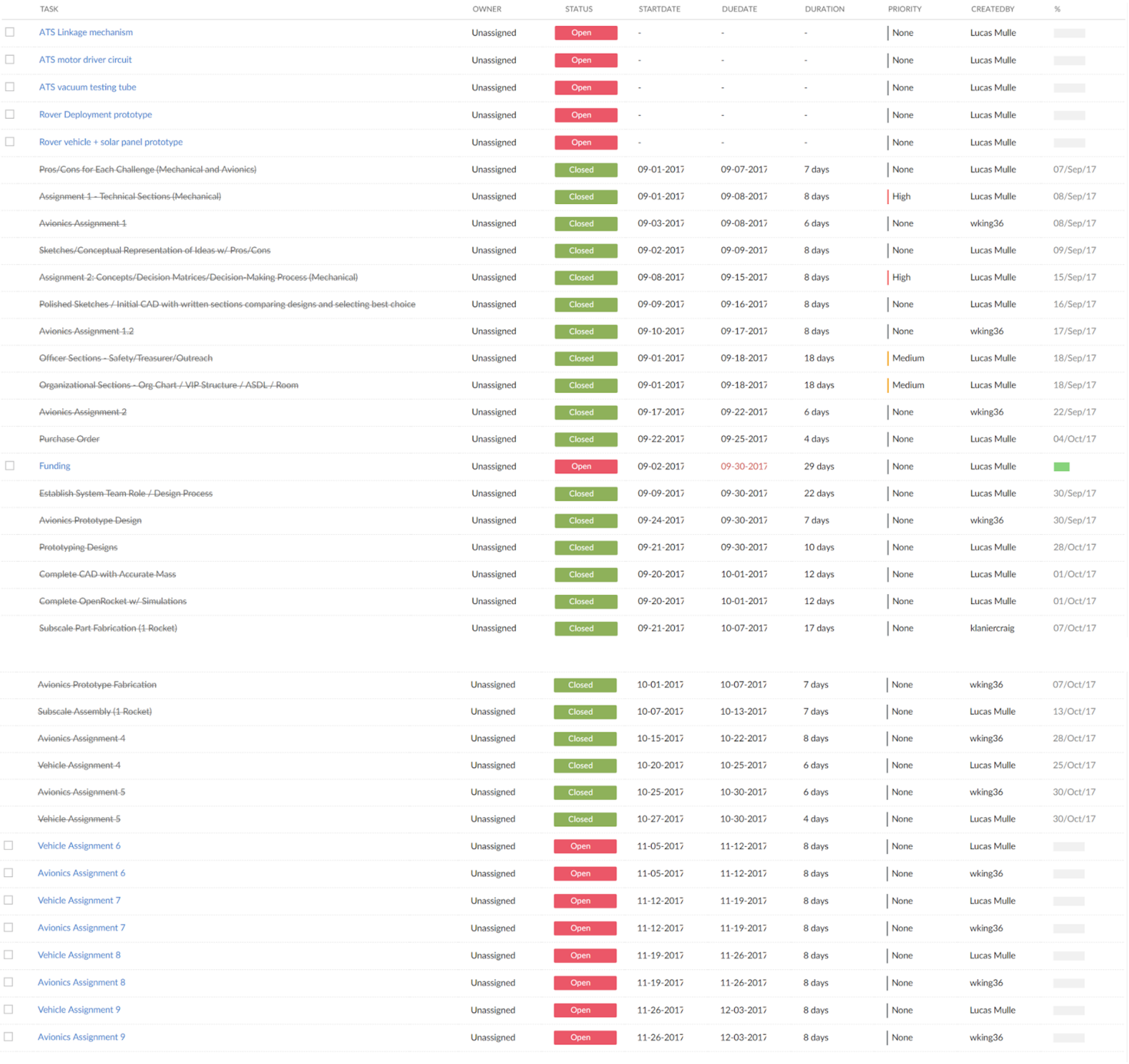
Appendix

A. Gantt Chart and Timeline



TITLE	%	DURATION	START DATE	END DATE	OWNER
~~Pros/Cons for Each Challenge (Mechanical and Avionics)~~	100	7 days	09-01-2017	09-07-2017	Unassigned
~~Assignment 1 - Technical Sections (Mechanical)~~	100	8 days	09-01-2017	09-08-2017	Unassigned
~~Officer Sections - Safety/Treasurer/Outreach~~	100	18 days	09-01-2017	09-18-2017	Unassigned
~~Organizational Sections - Org Chart / VIP Structure / ASDL / Room~~	100	18 days	09-01-2017	09-18-2017	Unassigned
~~Sketches/Conceptual Representation of Ideas w/ Pros/Cons~~	100	8 days	09-02-2017	09-09-2017	Unassigned
Funding	50	29 days	09-02-2017	09-30-2017	Unassigned
~~Avionics Assignment 1~~	100	6 days	09-03-2017	09-08-2017	Unassigned
~~Assignment 2: Concepts/Decision Matrices/Decision-Making Process (Mechanical)~~	100	8 days	09-08-2017	09-15-2017	Unassigned
~~Polished Sketches / Initial CAD with written sections comparing designs and selecting best choice~~	100	8 days	09-09-2017	09-16-2017	Unassigned
~~Establish System Team Role / Design Process~~	100	22 days	09-09-2017	09-30-2017	Unassigned
~~Avionics Assignment 1.2~~	100	8 days	09-10-2017	09-17-2017	Unassigned
~~Avionics Assignment 2~~	100	6 days	09-17-2017	09-22-2017	Unassigned
~~Complete CAD with Accurate Mass~~	100	12 days	09-20-2017	10-01-2017	Unassigned
~~Complete OpenRocket w/ Simulations~~	100	12 days	09-20-2017	10-01-2017	Unassigned
~~Prototyping Designs~~	100	10 days	09-21-2017	09-30-2017	Unassigned
~~Subscale Part Fabrication (1 Rocket)~~	100	17 days	09-21-2017	10-07-2017	Unassigned
~~Purchase Order~~	100	4 days	09-22-2017	09-25-2017	Unassigned
~~Avionics Prototype Design~~	100	7 days	09-24-2017	09-30-2017	Unassigned
~~Avionics Prototype Fabrication~~	100	7 days	10-01-2017	10-07-2017	Unassigned
~~Subscale Assembly (1 Rocket)~~	100	7 days	10-07-2017	10-13-2017	Unassigned
~~Avionics Assignment 4~~	100	8 days	10-15-2017	10-22-2017	Unassigned
~~Vehicle Assignment 4~~	100	6 days	10-20-2017	10-25-2017	Unassigned
~~Avionics Assignment 5~~	100	6 days	10-25-2017	10-30-2017	Unassigned
~~Vehicle Assignment 5~~	100	4 days	10-27-2017	10-30-2017	Unassigned
Vehicle Assignment 6	0	8 days	11-05-2017	11-12-2017	Unassigned
Avionics Assignment 6	0	8 days	11-05-2017	11-12-2017	Unassigned
Vehicle Assignment 7	0	8 days	11-12-2017	11-19-2017	Unassigned
Avionics Assignment 7	0	8 days	11-12-2017	11-19-2017	Unassigned
Vehicle Assignment 8	0	8 days	11-19-2017	11-26-2017	Unassigned
Avionics Assignment 8	0	8 days	11-19-2017	11-26-2017	Unassigned
Vehicle Assignment 9	0	8 days	11-26-2017	12-03-2017	Unassigned
Avionics Assignment 9	0	8 days	11-26-2017	12-03-2017	Unassigned

Figure A.1 Gantt Chart



	TASK	OWNER	STATUS	STARTDATE	DUEDATE	DURATION	PRIORITY	CREATEDBY	%
☐	ATS Linkage mechanism	Unassigned	Open	-	-	-	None	Lucas Mulle	
☐	ATS motor driver circuit	Unassigned	Open	-	-	-	None	Lucas Mulle	
☐	ATS vacuum testing tube	Unassigned	Open	-	-	-	None	Lucas Mulle	
☐	Rover Deployment prototype	Unassigned	Open	-	-	-	None	Lucas Mulle	
☐	Rover vehicle + solar panel prototype	Unassigned	Open	-	-	-	None	Lucas Mulle	
	~~Pros/Cons for Each Challenge (Mechanical and Avionics)~~	Unassigned	Closed	09-01-2017	09-07-2017	7 days	None	Lucas Mulle	07/Sep/17
	~~Assignment 1 - Technical Sections (Mechanical)~~	Unassigned	Closed	09-01-2017	09-08-2017	8 days	High	Lucas Mulle	08/Sep/17
	~~Avionics Assignment 1~~	Unassigned	Closed	09-03-2017	09-08-2017	6 days	None	wking36	08/Sep/17
	~~Sketches/Conceptual Representation of Ideas w/ Pros/Cons~~	Unassigned	Closed	09-02-2017	09-09-2017	8 days	None	Lucas Mulle	09/Sep/17
	~~Assignment 2: Concepts/Decision Matrices/Decision-Making Process (Mechanical)~~	Unassigned	Closed	09-08-2017	09-15-2017	8 days	High	Lucas Mulle	15/Sep/17
	~~Polished Sketches / Initial CAD with written sections comparing designs and selecting best choice~~	Unassigned	Closed	09-09-2017	09-16-2017	8 days	None	Lucas Mulle	16/Sep/17
	~~Avionics Assignment 1.2~~	Unassigned	Closed	09-10-2017	09-17-2017	8 days	None	wking36	17/Sep/17
	~~Officer Sections - Safety/Treasurer/Outreach~~	Unassigned	Closed	09-01-2017	09-18-2017	18 days	Medium	Lucas Mulle	18/Sep/17
	~~Organizational Sections - Org Chart / VIP Structure / ASDL / Room~~	Unassigned	Closed	09-01-2017	09-18-2017	18 days	Medium	Lucas Mulle	18/Sep/17
	~~Avionics Assignment 2~~	Unassigned	Closed	09-17-2017	09-22-2017	6 days	None	wking36	22/Sep/17
	~~Purchase Order~~	Unassigned	Closed	09-22-2017	09-25-2017	4 days	None	Lucas Mulle	04/Oct/17
☐	Funding	Unassigned	Open	09-02-2017	09-30-2017	29 days	None	Lucas Mulle	🟩
	~~Establish System Team Role / Design Process~~	Unassigned	Closed	09-09-2017	09-30-2017	22 days	None	Lucas Mulle	30/Sep/17
	~~Avionics Prototype Design~~	Unassigned	Closed	09-24-2017	09-30-2017	7 days	None	wking36	30/Sep/17
	~~Prototyping Designs~~	Unassigned	Closed	09-21-2017	09-30-2017	10 days	None	Lucas Mulle	28/Oct/17
	~~Complete CAD with Accurate Mass~~	Unassigned	Closed	09-20-2017	10-01-2017	12 days	None	Lucas Mulle	01/Oct/17
	~~Complete OpenRocket w/ Simulations~~	Unassigned	Closed	09-20-2017	10-01-2017	12 days	None	Lucas Mulle	01/Oct/17
	~~Subscale Part Fabrication (1 Rocket)~~	Unassigned	Closed	09-21-2017	10-07-2017	17 days	None	klaniercraig	07/Oct/17
	~~Avionics Prototype Fabrication~~	Unassigned	Closed	10-01-2017	10-07-2017	7 days	None	wking36	07/Oct/17
	~~Subscale Assembly (1 Rocket)~~	Unassigned	Closed	10-07-2017	10-13-2017	7 days	None	Lucas Mulle	13/Oct/17
	~~Avionics Assignment 4~~	Unassigned	Closed	10-15-2017	10-22-2017	8 days	None	wking36	28/Oct/17
	~~Vehicle Assignment 4~~	Unassigned	Closed	10-20-2017	10-25-2017	6 days	None	Lucas Mulle	25/Oct/17
	~~Avionics Assignment 5~~	Unassigned	Closed	10-25-2017	10-30-2017	6 days	None	wking36	30/Oct/17
	~~Vehicle Assignment 5~~	Unassigned	Closed	10-27-2017	10-30-2017	4 days	None	Lucas Mulle	30/Oct/17
☐	Vehicle Assignment 6	Unassigned	Open	11-05-2017	11-12-2017	8 days	None	Lucas Mulle	
☐	Avionics Assignment 6	Unassigned	Open	11-05-2017	11-12-2017	8 days	None	wking36	
☐	Vehicle Assignment 7	Unassigned	Open	11-12-2017	11-19-2017	8 days	None	Lucas Mulle	
☐	Avionics Assignment 7	Unassigned	Open	11-12-2017	11-19-2017	8 days	None	wking36	
☐	Vehicle Assignment 8	Unassigned	Open	11-19-2017	11-26-2017	8 days	None	Lucas Mulle	
☐	Avionics Assignment 8	Unassigned	Open	11-19-2017	11-26-2017	8 days	None	wking36	
☐	Vehicle Assignment 9	Unassigned	Open	11-26-2017	12-03-2017	8 days	None	Lucas Mulle	
☐	Avionics Assignment 9	Unassigned	Open	11-26-2017	12-03-2017	8 days	None	wking36	

Figure A.2 Task List

B. Planned Fabrication Tasks

#	Task Description	DONE?	Material Handled	Fabrication Techniques	Est. Time	Fabrication Locations	Safety Precautions
1	3D Print Servo Brackets	NO	PLA/ABS	3D Printer	< 1hr	Inv Studio / AE MakerSpace	N/A
2	Cut Motor Tube to Length	NO	Cardboard	Chop Saw	< 1hr	Inv Studio / SCC	N/A
3	Cut Tubing to Length	NO	Fiberglass	Chop Saw	< 1hr	Inv Studio	2 ppl, shop vac, N95/P95 mask
4	Drill Shear Pin Holes (8)	NO	Fiberglass	Drill	< 1hr	RR room / Inv Studio	2 ppl, shop vac
5	Drill Rivet Holes (4)	NO	Fiberglass	Drill	< 1hr	RR room / Inv Studio	2 ppl, shop vac
6	Drill wire routing holes into bulkheads/centering rings	NO	Fiberglass	Drill	< 1hr	RR room / Inv Studio	2 ppl, shop vac
7	Drill Holes for Bottom Plate	NO	6061 Aluminum	Drill	< 1hr	RR room / Inv Studio	
8	Slots into Body Tubing	NO	Fiberglass	Jigsaw/Bandsaw /Chop Saw	2 hrs	Inv Studio / SCC	2 ppl, shop vac, N95/P95 mask
9	Cut out Thrust Plate	NO	Plywood	Laser Cutter	< 1hr	Inv Studio / AE MakerSpace	N/A
10	Fin Features for Brackets	NO	Fiberglass	Mill	1-2 hrs	BME Shop	2 ppl, shop vac, N95/P95 mask
11	Features for Brackets	NO	Fiberglass	Mill	1-2 hrs	BME Shop	2 ppl, shop vac, N95/P95 mask
12	Flats into Shafts	NO	1024 Steel	Mill/Grinder	1-2 hrs	Montgomery MM	N/A
13	Fin Brackets	NO	6013 Aluminum	Waterjet	1-2 hrs	Inv Studio / SCC	N/A
14	Avionics Bay Tray Brackets	NO	6013 Aluminum	Waterjet	1-2 hrs	Inv Studio / SCC	N/A
15	Fins Cut Out	NO	Fiberglass	Waterjet	2 hrs	Inv Studio	N/A
16	Avionics Bay bulkheads (2 coupler, 2 body)	NO	Fiberglass	Waterjet	1-2 hrs	Inv Studio	N/A
17	Cut Out Bottom Plate	NO	6061 Aluminum	Waterjet	1-2 hrs	Inv Studio / SCC	N/A
18	Cut Out Rover Plates	NO	6061 Aluminum	Waterjet	1-2 hrs	Inv Studio	N/A

19	Cut Out Flaps	NO	6061 Aluminum	Waterjet	1-2 hrs	Inv Studio	N/A
20	Set Screws for gears / servo hub attachments	NO	Brass / Aluminum	Drill, Saws, etc...	2 hrs	Anywhere you can	N/A
21	Cut servo hub to length	NO	Aluminum		<1hr	Inv Studio	N/A
22	Drill gears bore diameter	NO	Brass	Drill	<1hr	Inv Studio	N/A
		NO					
21	Epoxy Fins + Centering rings to Motor Tube	NO		Booster			
22	Epoxy Thrust Plate Inside Body Tube	NO		Fins			
23	Assemble Avionics Bay (Tray, brackets, threaded rods, nuts)	NO		Avionics Bay			
24	Nosecone Weight	NO		Recovery			
25	GPS Bay Epoxy	NO		Rover Mechanism			
26	Bottom Plate Brackets Installed	NO					
28	Motor Measured Out + Dimensional Sketch of Booster ASSY	NO					
29	GPS Bat ASSY (PVC fitting + Ubolt)	NO					
30	GPS Bay Epoxied	NO					
31	Fins Epoxied to Tubing (Nice, LARGE Fillets)	NO					
32	Shock Cord Cut to Length	NO					
33	Parachute Attached to Shock Cord & Quick Links	NO					
34	Ejection Charges Created	NO					
35	ATS System ASSY	NO					
36	Ground Ejection Test (main)	NO					
37	Ground Ejection Test (drogue)						

Figure B.1 Fabrication Tasks

C. NAR High Power Rocketry Safety Code

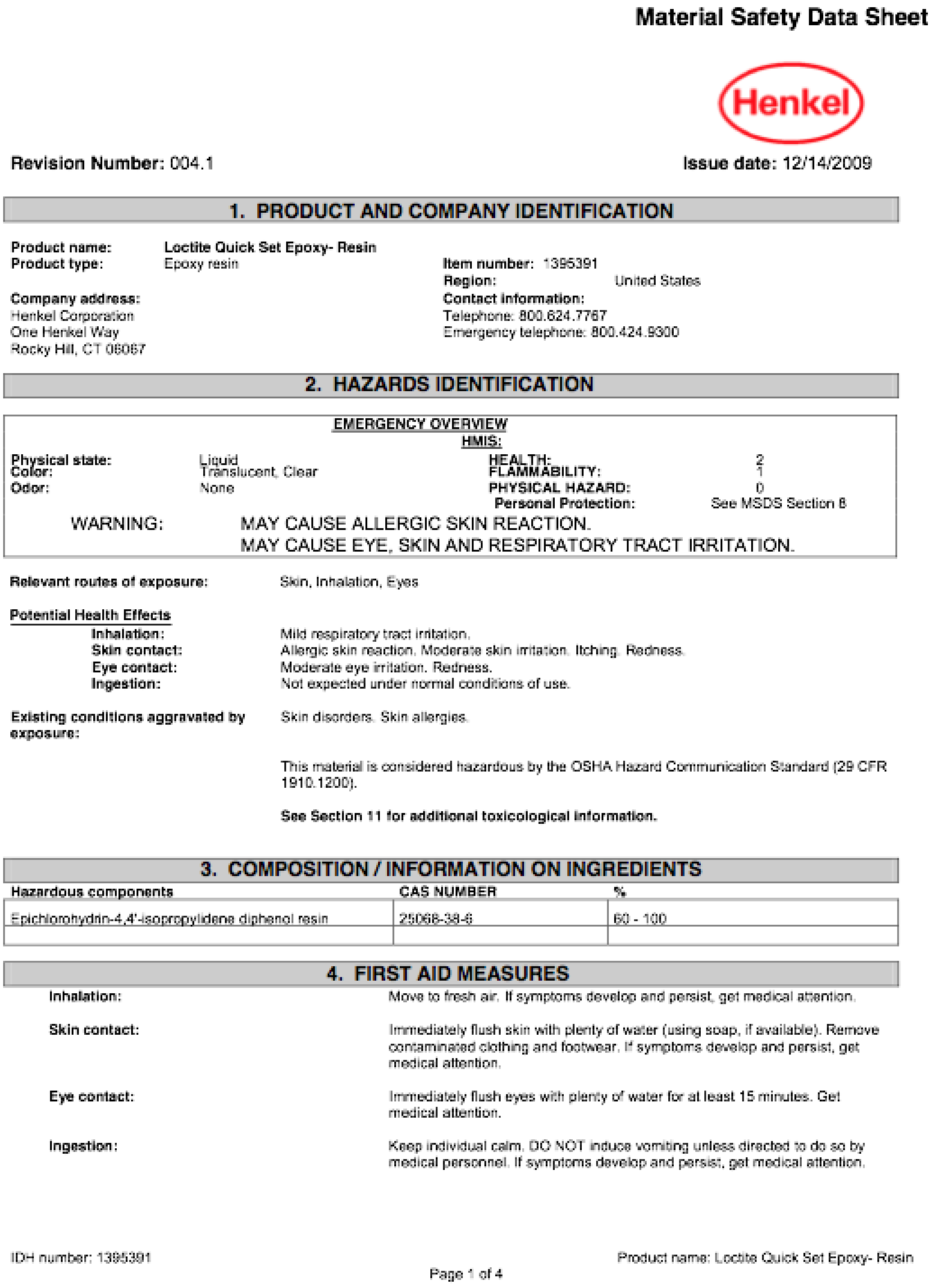
1. **Certification**. I will only fly high power rockets or possess high power rocket motors that are within the scope of my user certification and required licensing.
2. **Materials**. I will use only lightweight materials such as paper, wood, rubber, plastic, fiberglass, or when necessary ductile metal, for the construction of my rocket.
3. **Motors**. I will use only certified, commercially made rocket motors, and will not tamper with these motors or use them for any purposes except those recommended by the manufacturer. I will not allow smoking, open flames, nor heat sources within 25 feet of these motors.
4. **Ignition System**. I will launch my rockets with an electrical launch system, and with electrical motor igniters that are installed in the motor only after my rocket is at the launch pad or in a designated prepping area. My launch system will have a safety interlock that is in series with the launch switch that is not installed until my rocket is ready for launch, and will use a launch switch that returns to the "off" position when released. The function of onboard energetics and firing circuits will be inhibited except when my rocket is in the launching position.
5. **Misfires**. If my rocket does not launch when I press the button of my electrical launch system, I will remove the launcher's safety interlock or disconnect its battery, and will wait 60 seconds after the last launch attempt before allowing anyone to approach the rocket.
6. **Launch Safety**. I will use a 5-second countdown before launch. I will ensure that a means is available to warn participants and spectators in the event of a problem. I will ensure that no person is closer to the launch pad than allowed by the accompanying Minimum Distance Table. When arming onboard energetics and firing circuits I will ensure that no person is at the pad except safety personnel and those required for arming and disarming operations. I will check the stability of my rocket before flight and will not fly it if it cannot be determined to be stable. When conducting a simultaneous launch of more than one high power rocket I will observe the additional requirements of NFPA 1127.
7. **Launcher**. I will launch my rocket from a stable device that provides rigid guidance until the rocket has attained a speed that ensures a stable flight, and that is pointed to within 20 degrees of vertical. If the wind speed exceeds 5 miles per hour I will use a launcher length that permits the rocket to attain a safe velocity before separation from the launcher. I will use a blast deflector to

prevent the motor's exhaust from hitting the ground. I will ensure that dry grass is cleared around each launch pad in accordance with the accompanying Minimum Distance table, and will increase this distance by a factor of 1.5 and clear that area of all combustible material if the rocket motor being launched uses titanium sponge in the propellant.

8. **Size**. My rocket will not contain any combination of motors that total more than 40,960 N-sec (9208 pound-seconds) of total impulse. My rocket will not weigh more at liftoff than one-third of the certified average thrust of the high power rocket motor(s) intended to be ignited at launch.
9. **Flight Safety**. I will not launch my rocket at targets, into clouds, near airplanes, nor on trajectories that take it directly over the heads of spectators or beyond the boundaries of the launch site, and will not put any flammable or explosive payload in my rocket. I will not launch my rockets if wind speeds exceed 20 miles per hour. I will comply with Federal Aviation Administration airspace regulations when flying, and will ensure that my rocket will not exceed any applicable altitude limit in effect at that launch site.
10. **Launch Site**. I will launch my rocket outdoors, in an open area where trees, power lines, occupied buildings, and persons not involved in the launch do not present a hazard, and that is at least as large on its smallest dimension as one-half of the maximum altitude to which rockets are allowed to be flown at that site or 1500 feet, whichever is greater, or 1000 feet for rockets with a combined total impulse of less than 160 N-sec, a total liftoff weight of less than 1500 grams, and a maximum expected altitude of less than 610 meters (2000 feet).
11. **Launcher Location**. My launcher will be 1500 feet from any occupied building or from any public highway on which traffic flow exceeds 10 vehicles per hour, not including traffic flow related to the launch. It will also be no closer than the appropriate Minimum Personnel Distance from the accompanying table from any boundary of the launch site.
12. **Recovery System**. I will use a recovery system such as a parachute in my rocket so that all parts of my rocket return safely and undamaged and can be flown again, and I will use only flame-resistant or fireproof recovery system wadding in my rocket.
13. **Recovery Safety**. I will not attempt to recover my rocket from power lines, tall trees, or other dangerous places, fly it under conditions where it is likely to recover in spectator areas or outside the launch site, nor attempt to catch it as it approaches the ground.

D. Epoxy MSDS

(http://www.mcoe.us/view/1719.pdf)



Material Safety Data Sheet

Henkel

Revision Number: 004.1

Issue date: 12/14/2009

1. PRODUCT AND COMPANY IDENTIFICATION

Product name: **Loctite Quick Set Epoxy- Resin**
Product type: Epoxy resin

Item number: 1395391
Region: United States

Company address:
Henkel Corporation
One Henkel Way
Rocky Hill, CT 06067

Contact information:
Telephone: 800.624.7767
Emergency telephone: 800.424.9300

2. HAZARDS IDENTIFICATION

EMERGENCY OVERVIEW

Physical state: Liquid
Color: Translucent, Clear
Odor: None

HMIS:
HEALTH: 2
FLAMMABILITY: 1
PHYSICAL HAZARD: 0
Personal Protection: See MSDS Section 8

WARNING: MAY CAUSE ALLERGIC SKIN REACTION.
MAY CAUSE EYE, SKIN AND RESPIRATORY TRACT IRRITATION.

Relevant routes of exposure: Skin, Inhalation, Eyes

Potential Health Effects

Inhalation: Mild respiratory tract irritation.
Skin contact: Allergic skin reaction. Moderate skin irritation. Itching. Redness.
Eye contact: Moderate eye irritation. Redness.
Ingestion: Not expected under normal conditions of use.

Existing conditions aggravated by exposure: Skin disorders. Skin allergies.

This material is considered hazardous by the OSHA Hazard Communication Standard (29 CFR 1910.1200).

See Section 11 for additional toxicological information.

3. COMPOSITION / INFORMATION ON INGREDIENTS

Hazardous components	CAS NUMBER	%
Epichlorohydrin-4,4'-isopropylidene diphenol resin	25068-38-6	60 - 100

4. FIRST AID MEASURES

Inhalation: Move to fresh air. If symptoms develop and persist, get medical attention.

Skin contact: Immediately flush skin with plenty of water (using soap, if available). Remove contaminated clothing and footwear. If symptoms develop and persist, get medical attention.

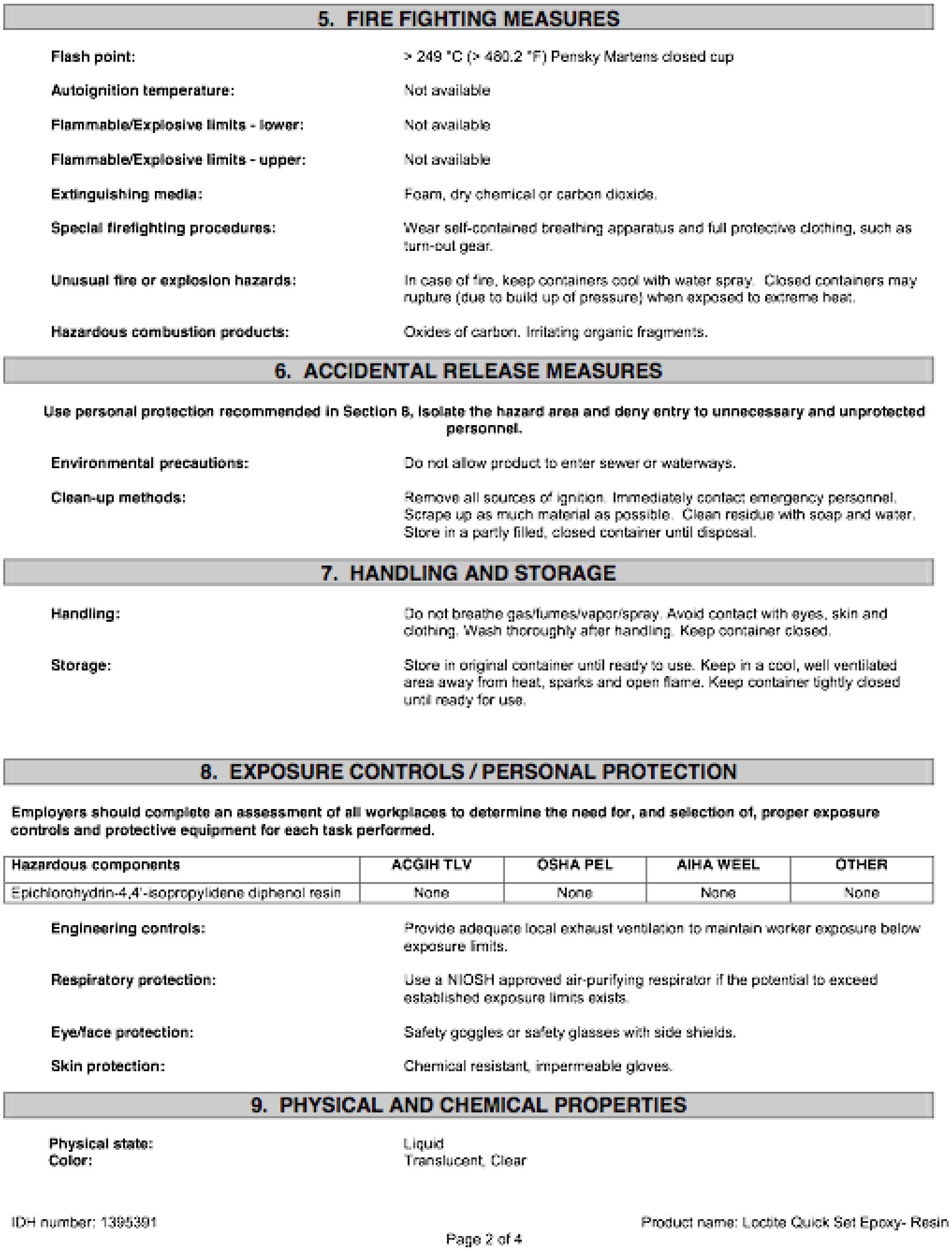
Eye contact: Immediately flush eyes with plenty of water for at least 15 minutes. Get medical attention.

Ingestion: Keep individual calm. DO NOT induce vomiting unless directed to do so by medical personnel. If symptoms develop and persist, get medical attention.

IDH number: 1395391

Product name: Loctite Quick Set Epoxy- Resin

Page 1 of 4



5. FIRE FIGHTING MEASURES

Flash point:	> 249 °C (> 480.2 °F) Pensky Martens closed cup
Autoignition temperature:	Not available
Flammable/Explosive limits - lower:	Not available
Flammable/Explosive limits - upper:	Not available
Extinguishing media:	Foam, dry chemical or carbon dioxide.
Special firefighting procedures:	Wear self-contained breathing apparatus and full protective clothing, such as turn-out gear.
Unusual fire or explosion hazards:	In case of fire, keep containers cool with water spray. Closed containers may rupture (due to build up of pressure) when exposed to extreme heat.
Hazardous combustion products:	Oxides of carbon. Irritating organic fragments.

6. ACCIDENTAL RELEASE MEASURES

Use personal protection recommended in Section 8, isolate the hazard area and deny entry to unnecessary and unprotected personnel.

Environmental precautions:	Do not allow product to enter sewer or waterways.
Clean-up methods:	Remove all sources of ignition. Immediately contact emergency personnel. Scrape up as much material as possible. Clean residue with soap and water. Store in a partly filled, closed container until disposal.

7. HANDLING AND STORAGE

Handling:	Do not breathe gas/fumes/vapor/spray. Avoid contact with eyes, skin and clothing. Wash thoroughly after handling. Keep container closed.
Storage:	Store in original container until ready to use. Keep in a cool, well ventilated area away from heat, sparks and open flame. Keep container tightly closed until ready for use.

8. EXPOSURE CONTROLS / PERSONAL PROTECTION

Employers should complete an assessment of all workplaces to determine the need for, and selection of, proper exposure controls and protective equipment for each task performed.

Hazardous components	ACGIH TLV	OSHA PEL	AIHA WEEL	OTHER
Epichlorohydrin-4,4'-isopropylidene diphenol resin	None	None	None	None

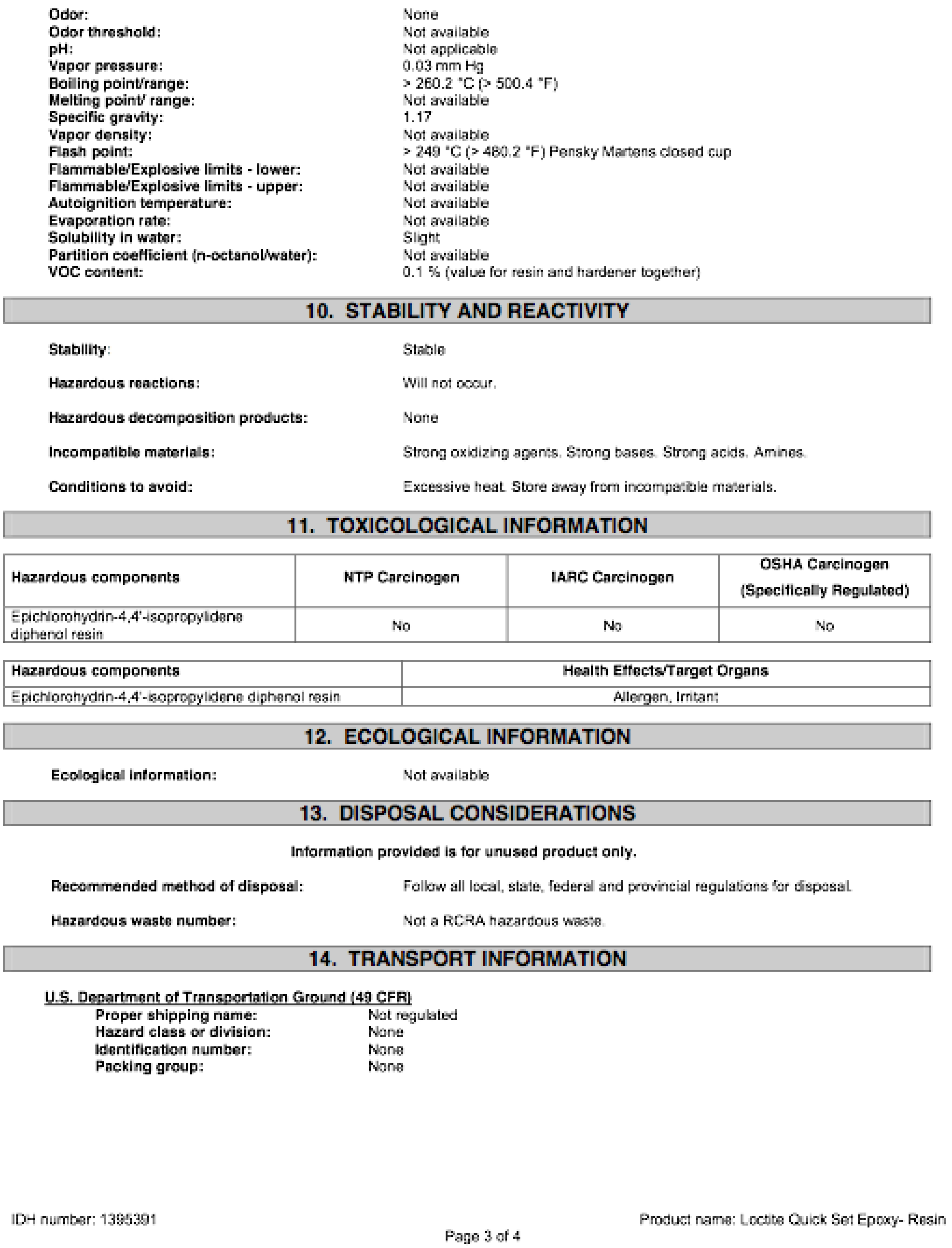
Engineering controls:	Provide adequate local exhaust ventilation to maintain worker exposure below exposure limits.
Respiratory protection:	Use a NIOSH approved air-purifying respirator if the potential to exceed established exposure limits exists.
Eye/face protection:	Safety goggles or safety glasses with side shields.
Skin protection:	Chemical resistant, impermeable gloves.

9. PHYSICAL AND CHEMICAL PROPERTIES

Physical state:	Liquid
Color:	Translucent, Clear

IDH number: 1395391 Product name: Loctite Quick Set Epoxy- Resin

Page 2 of 4



Odor:	None
Odor threshold:	Not available
pH:	Not applicable
Vapor pressure:	0.03 mm Hg
Boiling point/range:	> 260.2 °C (> 500.4 °F)
Melting point/ range:	Not available
Specific gravity:	1.17
Vapor density:	Not available
Flash point:	> 249 °C (> 480.2 °F) Pensky Martens closed cup
Flammable/Explosive limits - lower:	Not available
Flammable/Explosive limits - upper:	Not available
Autoignition temperature:	Not available
Evaporation rate:	Not available
Solubility in water:	Slight
Partition coefficient (n-octanol/water):	Not available
VOC content:	0.1 % (value for resin and hardener together)

10. STABILITY AND REACTIVITY

Stability:	Stable
Hazardous reactions:	Will not occur.
Hazardous decomposition products:	None
Incompatible materials:	Strong oxidizing agents. Strong bases. Strong acids. Amines.
Conditions to avoid:	Excessive heat. Store away from incompatible materials.

11. TOXICOLOGICAL INFORMATION

Hazardous components	NTP Carcinogen	IARC Carcinogen	OSHA Carcinogen (Specifically Regulated)
Epichlorohydrin-4,4'-isopropylidene diphenol resin	No	No	No

Hazardous components	Health Effects/Target Organs
Epichlorohydrin-4,4'-isopropylidene diphenol resin	Allergen, Irritant

12. ECOLOGICAL INFORMATION

Ecological information:	Not available

13. DISPOSAL CONSIDERATIONS

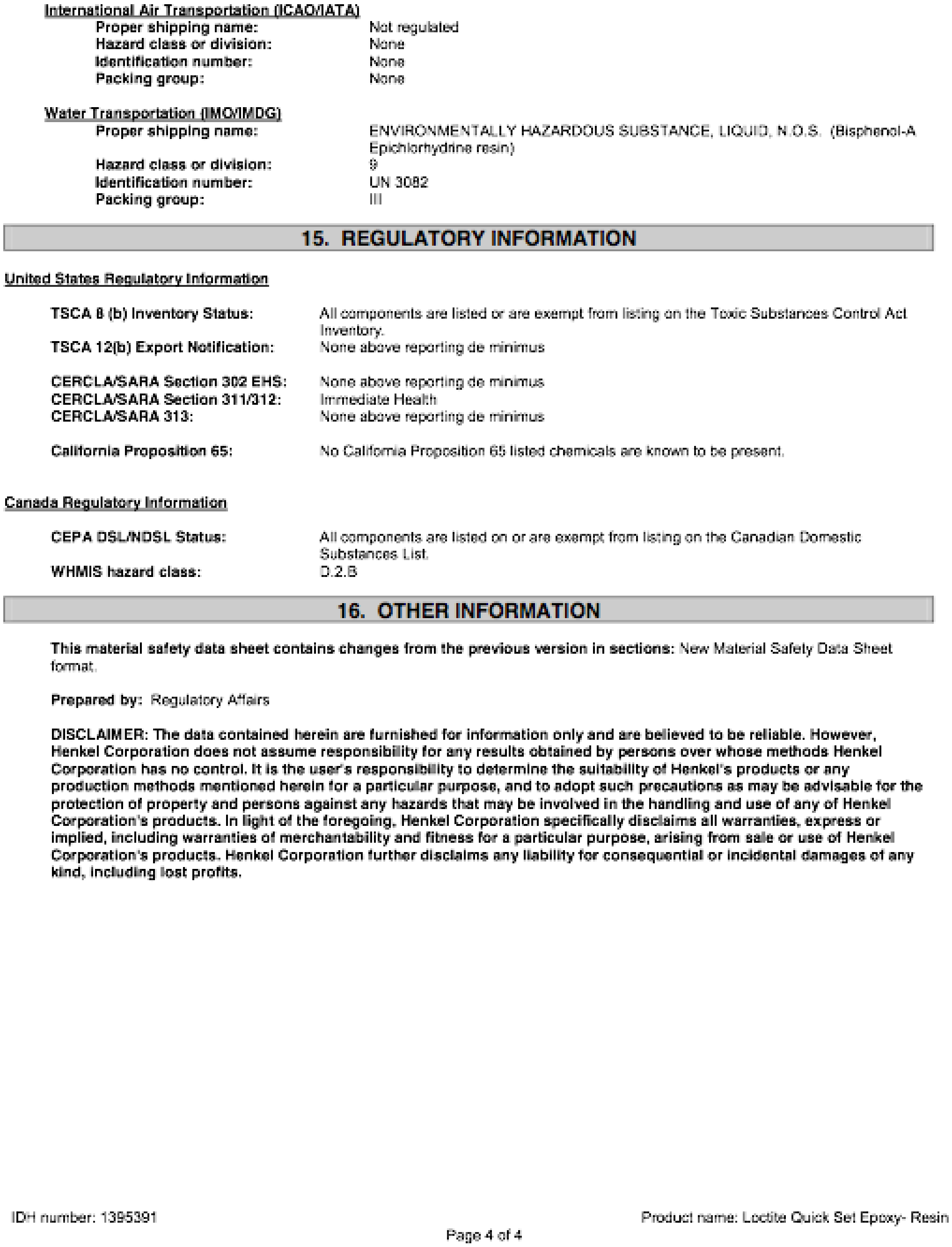
Information provided is for unused product only.

Recommended method of disposal:	Follow all local, state, federal and provincial regulations for disposal.
Hazardous waste number:	Not a RCRA hazardous waste.

14. TRANSPORT INFORMATION

U.S. Department of Transportation Ground (49 CFR)

Proper shipping name:	Not regulated
Hazard class or division:	None
Identification number:	None
Packing group:	None



International Air Transportation (ICAO/IATA)

Proper shipping name:	Not regulated
Hazard class or division:	None
Identification number:	None
Packing group:	None

Water Transportation (IMO/IMDG)

Proper shipping name:	ENVIRONMENTALLY HAZARDOUS SUBSTANCE, LIQUID, N.O.S. (Bisphenol-A Epichlorhydrine resin)
Hazard class or division:	9
Identification number:	UN 3082
Packing group:	III

15. REGULATORY INFORMATION

United States Regulatory Information

TSCA 8 (b) Inventory Status:	All components are listed or are exempt from listing on the Toxic Substances Control Act Inventory.
TSCA 12(b) Export Notification:	None above reporting de minimus
CERCLA/SARA Section 302 EHS:	None above reporting de minimus
CERCLA/SARA Section 311/312:	Immediate Health
CERCLA/SARA 313:	None above reporting de minimus
California Proposition 65:	No California Proposition 65 listed chemicals are known to be present.

Canada Regulatory Information

CEPA DSL/NDSL Status:	All components are listed on or are exempt from listing on the Canadian Domestic Substances List.
WHMIS hazard class:	D.2.B

16. OTHER INFORMATION

This material safety data sheet contains changes from the previous version in sections: New Material Safety Data Sheet format.

Prepared by: Regulatory Affairs

DISCLAIMER: The data contained herein are furnished for information only and are believed to be reliable. However, Henkel Corporation does not assume responsibility for any results obtained by persons over whose methods Henkel Corporation has no control. It is the user's responsibility to determine the suitability of Henkel's products or any production methods mentioned herein for a particular purpose, and to adopt such precautions as may be advisable for the protection of property and persons against any hazards that may be involved in the handling and use of any of Henkel Corporation's products. In light of the foregoing, Henkel Corporation specifically disclaims all warranties, express or implied, including warranties of merchantability and fitness for a particular purpose, arising from sale or use of Henkel Corporation's products. Henkel Corporation further disclaims any liability for consequential or incidental damages of any kind, including lost profits.