By:

The Georgia Institute of Technology

Launch Initiative Team

(GIT LIT)

NASA Student Launch

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Georgia Institute of Technology

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This Failure Modes and Effects Analysis (FMEA) table describes possible failure modes of the rover system. Each item is scored from 1-3 on severity, difficulty of detection, and probability. Difficulty of detection refers to the chance of the system to detect that a failure has occurred or is going to occur. In the rover system, most failures are mechanical and cannot be detected by the system. The total risk is the product of the three scores and ranges from 1 to 27. Failure modes with a higher score have a higher priority. 120

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1. Introduction

1.1. Team Summary

The following table contains a summary of the team information, including the names and contact information of the student team lead and the team faculty advisors.

Table 1.1.1: Team Summary

Team Summary	
School Name	Georgia Institute of Technology
Mailing Address	270 Ferst Drive, Atlanta GA 30332 - 0150
Team Name	Georgia Institute of Technology Launch Initiative Team (GIT LIT)
Project Title	Mile High Club
Project Lead	Shravan Hariharan
Project Lead e-mail	shravan.hariharan@gatech.edu
Safety Officer	Coulter Schrum
Team Advisors	Dr. Michael Steffens and Dr. Alicia Sudol
Team Advisor Emails	Steffens, Michael J <msteffens3@gatech.edu>; Sudol, Alicia M <alicia.sudol@gatech.edu>;
Team Advisor Phone Numbers	Sudol, Alicia M: (404)-894-3967 Steffens, Michael J: (404)-894-3214
NAR Section	Primary: Southern Area Rocketry (SoAR) #571
NAR Contact, Number, & Certification Level	Alton Schultheis NAR Number: 98790 Certification Level: Level 2 Certified for HPR by NAR

1.2. Team Structure

GIT LIT is composed of 19 students, of various class levels and majors. To work more effectively, the team is broken down into groups that focus on special tasks. Each subteam has a lead supported by several specialized task groups. Subteam members were selected based on each individual's area of expertise and personal interest. The following figures show the breakdown of the team by subteam, major, and class level.

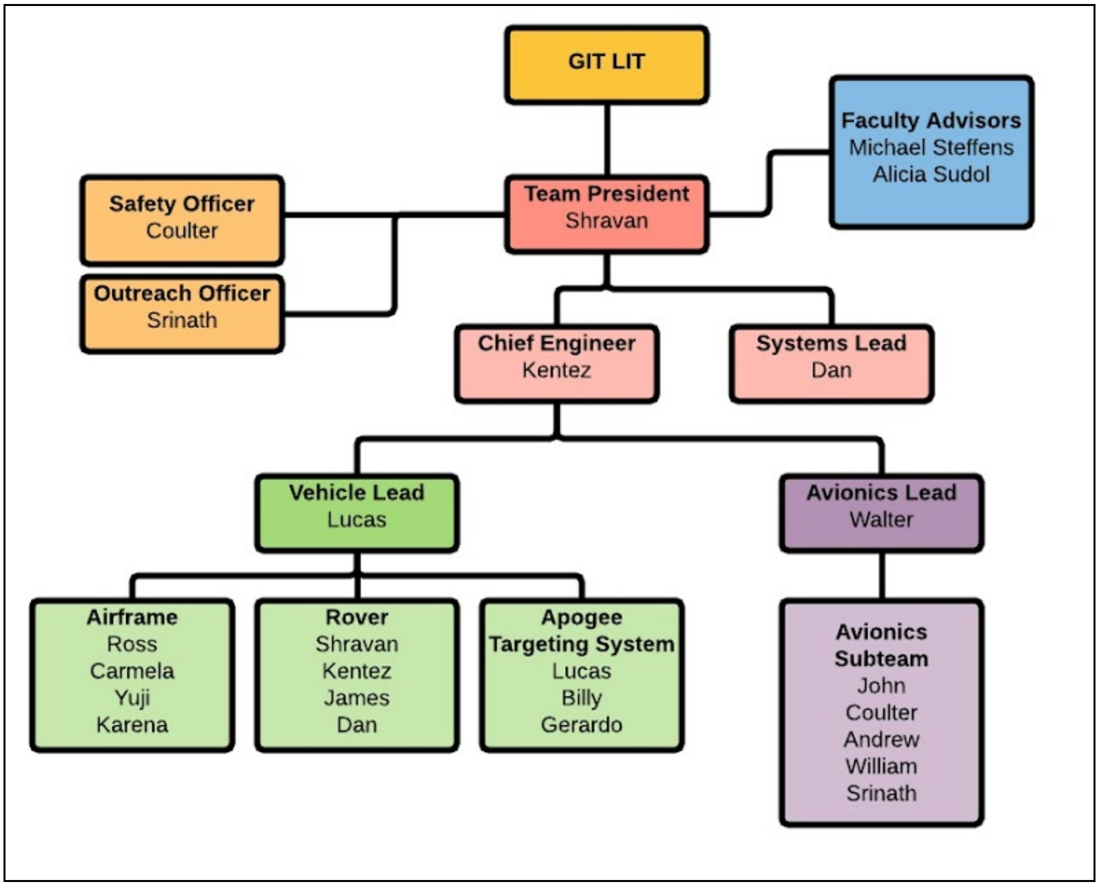


Figure 1.2.1: Team Organization

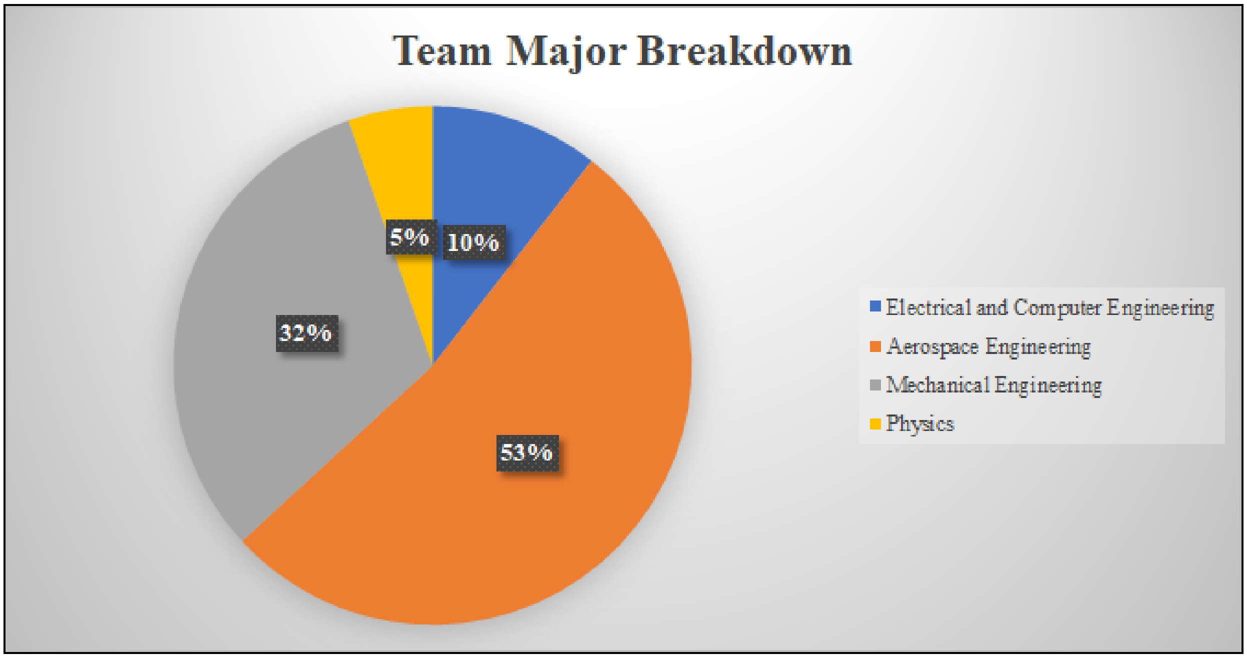


Figure 1.2.2: Team Major Breakdown

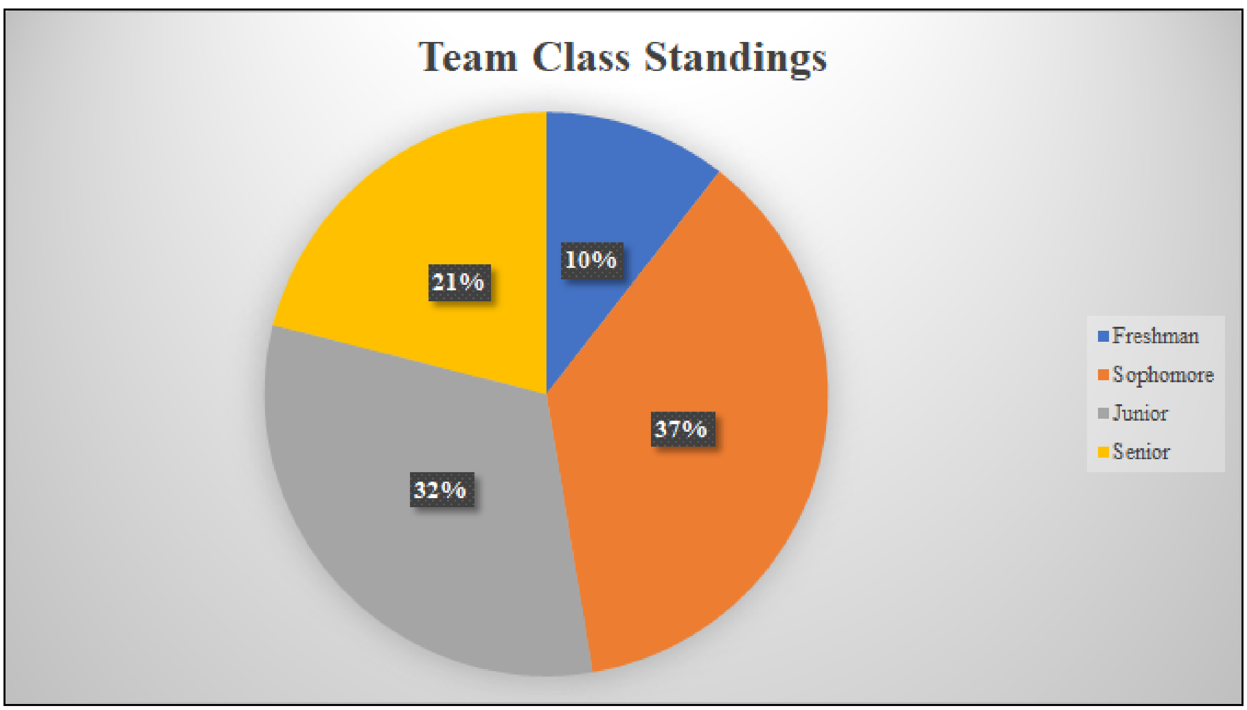


Figure 1.2.3: Team Class Standing Breakdown

1.3. Launch Vehicle Summary

The launch vehicle is currently dimensioned to be 102 inches in length, with a G12 fiberglass tube of outer diameter 5.5 inches. Having taken all systems into consideration, the rocket is projected to weigh 37 lbs. The Stratologger CFs, Raspberry Pi, Gyro/Accelerometer sensors, and batteries will be housed in the avionics bay, which is located in the avionics section. The avionics section also include the Apogee Targeting System (ATS). The rover bay, which houses the rover and rover deployment system, is adjacent to the nose cone. An Aerotech L1390G rocket motor has been selected to provide the thrust to potentially bring the rocket to an apogee of 5533 ft. The ATS use a control algorithm to actuate flaps, inducing additional drag with a goal of reducing the apogee to 5,280 feet. Upon reaching apogee, a 45 in drogue parachute will deploy from a compartment between the booster and avionics sections. A main parachute with a 16 ft diameter will be deployed when the vehicle falls below 800 ft above ground level. It will decrease the vertical velocity enough to ensure that the kinetic energy of each independent section of the rocket remains well below 75 ft-lbf.

1.4. Payload Summary

This year's rocket will have two preliminary Payloads. First, the rocket will contain an Apogee Targeting System (ATS), in order to accurately meet the NASA mile apogee target. This system will use a set of deployable, servo-actuated flaps as an air-brake systems, with an onboard computer to measure the flight of the rocket and move the flaps accordingly. The ATS will induce enough drag to allow the rocket to accurately meet the apogee target. The second rocket payload will be a deployable rover. Upon the landing of the rocket, a lead-screw actuated system will separate the rocket nose cone and body tube section, upon which a rover will drive out of the rocket. This autonomous rover will move over 5 feet away from the rocket, and deploy a set of functional solar panels,

2. Changes Made Since Proposal

2.1. Changes to Vehicle

The team has made significant progress since the submission of the proposal. In addition to further developing alternative designs for the different systems and, ultimately, selecting preferred options through analytical procedures, the team began to plan out the assembly of the launch vehicle as a whole. The integration process comprised of multiple additional assessments, including risk analysis, stress simulations, and physical construction considerations that were used to evaluate the compatibility of the different sections of the rocket. Revisions to the original designs were made to address the high risk elements identified through the assessment process. These changes can be broken out by section.

Airframe & Propulsion

Table 2.1.1: Changes Since Proposal: Airframe & Propulsion

Feature Changed	Old Value	New Value	Reason
Total Length	102 in	120 in	Due to incorporation of the Rover payload, and an increase in the length of the Avionics bay and parachute compartments
Total Mass	541 oz	590 oz	Due to incorporation of Rover payload, increased length of shock cord, and larger motor selection
Fins	N/A	N/A	To retain a stability margin exceeding 2.0 at launch rail exit, the fins had to be decreased to account for the change in mass distribution throughout the rocket, and increase in overall length
Centering Ring	Fiberglass	Alum.	To decrease weight, it was determined that the centering rings should be machined to remove excess material, and leave only a skeleton structure with adequate strength. Since fiberglass is difficult to machine with precision, aluminum was selected as the new material
ATS Payload Section	N/A	N/A	For the purpose of being able to access the Apogee Targeting System (ATS) mechanism, <u>a separate, removeable section was added</u> between the booster section and the avionics bay section. This section, housing both the ATS mechanism and the main parachute, will be riveted to the booster tube and attached to the avionics bay via shear pins
Rover Payload Section	N/A	N/A	The Rover section will be located between the nosecone and the avionics bay, with shear pin connections to the avionics bay and friction+lead screw connection to the nosecone

			(see Rover section for clarification)
Motor Selection	L1150R	L1390G	Due to increases in the computed masses of the different payloads, as well as the increase in mass of tubing needed, a larger motor was selected (still using RMS 75-3840 casing). This will allow the launch vehicle to overshoot the targeted 1 mile apogee such that the ATS mechanism can be successfully implemented

2.2. Changes to Payload

The Proposal showed all of the alternative designs that were visualized as potential solutions to the Rover and Mile Apogee challenges. Since then the team has taken each concept through very thorough inspection by comparing their performances in evaluation matrices. Although there are no changes from the Proposal, as we still intend to pursue both of those challenges using designs initially shown in the Proposal report, many variables have been finalized, so a brief update of the overall state of each system's designs are provided below.

Table 2.1.2: Changes Since Proposal: ATS

Feature Changed	Old Value	New Value	Reason
Actuator - Stepper Motor	N/A	N/A	Evaluation process (shown in ATS section of report) led to selection of a stepper motor as the primary actuator due to its ability to simultaneously provide high torque and position control
Total Mass Increase	N/A	40 oz	The selection of the stepper motor increased total mass, as stepper motors have low power to mass efficiencies

Table 2.1.3: Changes Since Proposal: Rover Mechanism

Feature Changed	Old Value	New Value	Reason
Lead screw mechanism	N/A	N/A	The evaluation process, which can be seen in the Rover System section, led to us choosing a lead screw-based rover deployment mechanism due to its reliability and mechanical simplicity.
Drive train tracks	N/A	N/A	Tracks were chosen due to their reliability over rough terrain

Spring loaded solar panel deployment	N/A	N/A	Chosen for mechanical simplicity

2.3. Changes to Project Plan

The project plan has not changed since the submission of the Proposal. The team is retaining all project milestones, outreach activities, and funding activities, which are described below in the Project Plan section.

3. Safety

3.1. Safety Overview

GIT LIT is dedicated to maintaining safe operating conditions for all team members and bystanders during the design, construction, assembly, and launch of our rocket. Coulter Schrum is the team safety officer and will be responsible for upholding all requirements listed in section 5.3 of the college and university SLI handbook. This includes monitoring and emphasizing safety during the design, construction, assembly, and launch of the rocket.

3.1.1. Design, Construction, and Assembly Safety

Table 3.1.1 highlights some of the hazards and resulting safety protocol associated with the build stages of the launch vehicle. Each member of GIT LIT has been made aware of hazards such as these and have agreed to follow the safety guidelines provided. The goal for any safety protocol is to identify potential hazards and mitigate the risk of danger. A comprehensive safety checklist used throughout the competition cycle will be included in the FRR report.

Table 3.1.1 Build Process Hazard Identification.

Hazard Identification	**Risk Level**	**Safety Protocol**
Power Tools: Primarily saws and drills.	High	• Always use eye protection. • Never operate solo. • Ensure a clean working environment. • Store Tools when finished.
Adhesives/Epoxy	Low	• Always use eye protection. • Wear gloves and mask when mixing and applying epoxy. • Clean up after use.
Electrical: Prototyping, soldering.	Medium	• Ensure there is a rubber contact point when dealing with high voltages.

		• Use eye protection and a fan when soldering. • Ensure soldering equipment is powered off and properly stowed when not in use.

Hazard risk levels are determined as follows:

High - life altering injury and death are potential outcomes of disobeying safety protocol.

Medium - Injury requiring general first aid is a potential outcome of mishandled safety procedures.

Low - It is generally good practice to adhere to safety guidelines in low risk situations although no serious threat to health is present.

Further hazard analysis for the handling of dangerous materials can be found in Table 3.3.1 below and should be consulted whenever dealing with a potentially harmful material.

3.1.2. Launch Safety

The safety officer will be present at each of the team's test flights and official launches. The team will adhere to the safety restrictions of the FAA and the launch site in question. Alton Schultheis, our team mentor, has a level 2 NAR HPR certification and will be the official flyer for the high power launches. Additionally, the team will strictly follow the rules laid out by the NAR high power safety protocol. Every team member attending launches is required to read the NAR launch rules, the launch checklist, and sign off to ensure each member is well informed. The launch checklist contains detailed instructions on preparing rocket payload, assembling charges, packing chutes, assembling the motor, and prepping the vehicle. The final launch checklist will be specific to the final design of the launch vehicle and will be aimed to minimize risk, inform all members, and ensure that no step is forgotten in the launch process. Each of the protocols and safety procedures listed above will help to reduce the overall risk for hazard associated with launching high power model rockets.

3.2. Mission Assurance

Table 3.2.1 lists the possible failure modes and respective failure prevention procedures that the launch vehicle may encounter during testing. These considerations have been taken into account to further ensure that each hazardous situations can be avoided.

Table 3.2.1 Failure Modes

Potential Failure	***Effects of Failure***	***Failure Prevention***
Apogee Targeting System (ATS)	Vehicle will not reach target altitude	Test ATS using subscale launch vehicles
Rover Deployment System Opening	Vehicle will break apart due to torques on different sections	Ensure receiver and transmitter are kept isolated during rocket flight
Body structure buckling on takeoff	Launch failure, damage to launch vehicle, unable to be reused, flying shrapnel towards personnel	Test structure to withstand expected forces at launch with a factor of safety. Have properly sized couplers connecting sections.
Drogue separation	Main parachute will deploy at high speed and may rip or disconnect from vehicle, launch vehicle may become ballistic	Perform ground test and flight test.

Fins	Fins could fall off, causing unstable flight. Fins break or disconnect from launch vehicle, unable to be classified as reusable	Test fin at attachment points using expected forces to ensure strength of attachment method. Avoid fins with sharp pointed edges, ensure parachute is large enough to minimize impact kinetic energy, test fin at attachment points using expected forces to ensure strength of attachment.
Launch buttons	Launch vehicle will separate from rail, causing an unstable flight	Ensure launch rail is of proper size to accommodate the buttons, ensure buttons slide easily into rail.
Main parachute separation	High impact velocity may damage vehicle and make it unrecoverable, vehicle may become ballistic causing serious injury or death	Perform ground test and flight test to ensure efficacy of deployment method.
Motor failure	Motor explodes, damaging launch vehicle	Follow NAR regulations and manufacturer’s instructions when assembling motor. Assemble motor under supervision.
Motor retention	Motor casing falls out, lost motor case, could damage persons/property	Test reliability of motor retention system
Payload separation	Main parachute may not deploy correctly, higher impact velocity may damage launch vehicle, or cause personal/property damage	Perform ground and flight test to ensure efficacy of deployment method
Thrust plate failure	Motor goes through vehicle, damage to vehicle, causing it to be not reusable	Test plate and attachment method to withstand expected launch forces with a factor of safety

3.3. Material Handling

Table 3.3.1 aims to thoroughly identify the risk and severity associated with all of the potentially dangerous materials used throughout the building and launch processes.

Table 3.3.1. Safety Risks

Hazard	***Severity***	***Likelihood***	***Mitigation & Control***
Batteries Leak/Explode	Burns, skin and eye irritation	Low	Wear safety glasses and gloves when handling. Make sure no shorts exist in circuits using batteries. If battery gets too hot, stop its use and disconnect it from any attached circuits. Discharge and properly store Li-Po’s when not in use.
Black Powder	Explosions, burns, skin and eye irritation	Medium	Wear safety glasses, gloves when handling black powder. Be careful when pouring black powder. Operate in a static-free environment.
Dremel	Cuts and scrapes	Medium	Only operate tools with supervision of teammates. Use tools in appropriate manner. Wear safety glasses to prevent debris from getting into eyes.
Power Tools	Cuts, punctures, and scrapes	Medium	Only operate power tools with supervision of teammates. Use tools in appropriate manner. Wear safety glasses to prevent debris from getting into eyes.
Epoxy/Glue	Toxic fumes, skin and eye irritation	High	Wear gloves, nitrile for epoxy, face masks, and safety glasses. Work in well ventilated area.
Exacto/Craft Knives	Cuts, serious/fatal injury	Medium	Only use knives with teammate supervision. Only use tools in appropriate manner. Do not cut in the direction towards oneself.

Fire	Burns, serious/fatal injury	Low	Keep a fire extinguisher nearby. If an object becomes too hot, or does start a fire, remove power (if applicable) and be prepared to use the fire extinguisher.
Hammers	Bruises, serious/fatal injury	Medium	Be aware of where you are swinging the hammer, so that it does not hit yourself, others, or could bounce and hit someone.
Hand Saws	Cuts, serious/fatal injury	Medium	Only use saws with teammate supervision. Only use tools in appropriate manner. Wear safety glasses to prevent debris from getting in eyes.
Waterjet Cutter	Cuts, serious/fatal injury, flying debris	Low	Only operate under supervision of Undergraduate/Graduate Learning Instructors, and with other teammates. Follow proper operating procedures, wear safety glasses.
Improper dress during construction	Cuts, serious/fatal injury	High	Wear closed toed shoes, tie back long hair, do not wear baggy clothing.
Power Supply	Electrocution, serious/fatal injury	Medium	Only operate power supply with teammate supervision. Turn off power supply when working with circuitry.

Environmental Concerns

The team understands that building a rocket requires the use of many equipment and/or materials throughout the entire design process. Despite the complexity of building a rocket, the environment must be taken into account at all times. Hazardous materials must be properly disposed of. Launches may only take place on authorized days and times. Recently there have been lots of burn bans in the area, knowing that we will not launch the vehicle until these bans are lifted. Additionally, the Material Safety Data Sheet (MSDS) for each material used must be thoroughly read by each team member. Team ARES will do its best to ensure that the negative impact on the environment is at a minimum while designing and launching the vehicle.

The rocket vehicle has several methods for which it can interact with its environment, and in turn, be affected by its environment. The rocket motor expels propellant at high velocity and temperature, and is capable of igniting any flammable materials near the launch pad. The vehicle motor could explode, causing shrapnel to fly at people and property, and could cause a fire. After launch, the rocket accelerates upward and becomes a hazard to flying machines and animals, so the rocket will not be launched in the presence of birds or airplanes/helicopters in the immediate launch vicinity. Excessive windy conditions clouds in the launch vicinity may obscure the launch vehicle as it climbs to apogee, which could make the vehicle a ballistic threat to people and property if the parachutes do not deploy.

3.4. Vehicle Safety

Table 3.4.1 Vehicle Safety Risks

	Function	Failure Type	Impact	S	Potential Causes	Detection Method	D	O	RPN
Ascent	Motor	explosion	- rocket disintegrates -rocket falls to the ground	3	- motor manufacture error - inappropriate propellant used	N/A	1	1	3
		no ignition	- rocket does not fly	3	- ignition wire not connected properly to the motor - propellant oxidized before	N/A	1	1	3
	Thrust plate	structural integrity fails	- motor shoots through rocket, damaging all systems	3	- material used to make thrust plate was already compromised - epoxy failed	N/A	1	1	3
	Centering rings	all breaks during flight	- motor tilted, forcing the rocket to arc	2	- epoxy failed - material used did not have enough strength				
	Fins	fin(s) separate(s) during flight	- the rocket losses stability - the rocket may	3	- epoxy failed	N/A	1	2	6

			arc during flight						
	Rover	rover section separates during flight	- rover falls to ground - cannot complete challenge	3	- someone sits on the receiver and prematurely separates the rover section	N/A	1	1	3
	ATS	ATS flaps not pushed out symetrically	- the rocket arcs during the flight - the rocket loses stability and disassembles in the middle of the air	3	- not enough lubricant for one of the flaps	N/A	1	1	3
	Couplers	Couplers break during flight	-the rocket comes apart mid flight	3	-couplers cannot withstand the moments applied during flight	N/A	1		0
	Shear pins/rivets	Shear pins break mid flight	-rocket comes apart mid-flight	3	- vibrates out in flight - could not withstand external forces	N/A	1		0
	Structural integrity	The rocket buckles mid-flight	- recovery system doesn't work			N/A	1		0
Recovery	A-bay	connection failures	-rocket comes apart	3	- wiring disconnects before or during flight	N/A	1	1	3
	altimeters	does not detect the height	-parachutes do not deploy - rocket crash to ground - rover challenge not possible	3	- manufacturing error of the altimeter - does not send signal	N/A	1	1	3
	ejection charge	-does not fire	-parachutes do not deploy - rocket crash to ground - rover challenge not possible	3	- does not ignite - no signal from avionics bay - oxidized black powder - altimeter malfunction	N/A	1	2	6

	rivets	do not come apart	-parachutes do not deploy - rocket crash to ground - rover challenge not possible	3	- not enough force to break	N/A	1	1	3
	bulkheads & u-bolt	breaks during flight	-parachutes do not deploy - rocket crash to ground - rover challenge not possible	3	- epoxy fails - structure of the bulkheaad is not strong enough	N/A	1	1	3
	shock cords	damaged by ejection charges	-parachutes do not deploy - rocket crash to ground - rover challenge not possible	3	- cannot withstand the force of the rocket	N/A	1	1	3
	main parachute	does not deploy	-parachutes do not deploy - rocket crash to ground - rover challenge not possible	3	- altimeters didn't work	N/A	1	2	6
		strings get tangled	-parachutes do not deploy - rocket crash to ground - rover challenge not possible	3	- parachute wasn't packed properly	N/A	1	2	6
		parachute deploys damaged	-parachutes do not deploy - rocket crash to ground - rover challenge not possible	3	- ejection charges went off incorrectly	N/A	1	1	3

	drogue parachute	does not deploy	-parachutes do not deploy - rocket crash to ground - rover challenge not possible	3	- altimeters didn't work	N/A	1	2	6
		strings get tangled	-parachutes do not deploy - rocket crash to ground - rover challenge not possible	3	- parachute wasn't packed properly	N/A	1	2	6
		parachute deploys damaged	-parachutes do not deploy - rocket crash to ground - rover challenge not possible	3	- ejection charges went off incorrectly	N/A	1	1	3

How to ensure rocket is built safely

To achieve straight alignment of tube sections and have fins be perfectly straight and spaced out evenly, a wooden fin template was designed that marks the position of the fins around the retention ring by using a Trotec laser cutter. Unfortunately, this template only made the fins equally spaced out and did not function well for aligning the fins vertically. In the subscale, as the fins were epoxied onto the body tube and centering rings, a ruler was used to make sure the fins remained vertical. Epoxy was added to all surfaces where the fins touched the body tube and coupler rings. Therefore, for the full scale, a fin alignment tool will be created by placing two templates parallel to each other and connecting these two with vertical plates aligned with the slots for the fins on the templates. The template will have a hole size of the booster stage airframe so that the vertical slots could be marked precisely onto the booster stage airframe. Once the markings are drawn, the slots will be cut by OMAX Waterjet.

3.5. Purchase, Shipping, and Transporting of Rocket Motors

Team A.R.E.S.'s mentor, Alton Schultheis, has a level 2 High Powered Rocketry certification from the NAR which clears him to launch larger impulse rockets. The mentor is the person who officially launches the rocket, and he will be present for all launches. Alton's NAR number and Certification level are listed as follows:

- NAR Number: 98790
- Certification Level: Level 2 Certified for HPR by NAR

3.6. Launch Procedures

Table 3.6.1 Launch Preparation

Prepare Payload Recovery System	
	Ensure batteries and switches are wired correctly
	Ensure batteries, power supply, switches, microprocessor, GPS, pixhawk is/are wired correctly
	Install and secure fresh batteries into battery holders
	Insert payload recovery electronics into payload recovery bay
	Connect appropriate wires
	Arm altimeter with output shorted to verify jumper settings. This is done to verify battery power and continuity
	Disarm Altimeter, un-short outputs
Prepare Body Recovery System	
	Ensure batteries and switches are wired correctly

	Ensure batteries, power supply, switches, microprocessor, GPS, pixhawk is/are wired correctly
	Install and secure fresh batteries into battery holders
	Insert body recovery electronics into payload recovery bay
	Connect appropriate wires
	Arm altimeter with output shorted to verify jumper settings. This is done to verify battery power and continuity
	Disarm Altimeter, un-short outputs
Assemble Charges	
	Test e-match resistance to see if it is within specifications
	Remove protective cover from e-match
	Measure amount of black powder used in testing
	Place e-match on tape with sticky side up
	Pour black powder over e-match
	Seal Tape
	Re-test e-match
Check Altimeters	
	Ensure altimeters are disarmed
	Connect charges to ejection wells
	Turn on altimeters to verify continuity

	Disarm altimeters
Pack Parachutes	
	Connect drogue shock cord to booster section and body section
	Attach drogue parachute to drogue shock cord
	Pack drogue parachute
	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 drogue parachute bay between ejection charges and parachute
	Insert drogue parachute and shock cord into drogue parachute bay
	Insert booster section into lower body section, and secure with shear pins
	Attach main parachute shock cord to upper body section and lower payload parachute bay
	Attach main parachute to main parachute shock cord
	Pack main parachute
	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 main parachute bay between ejection charges and parachute
	Insert main parachute and shock cord into main parachute bay and
	Insert upper body section into the lower section of the payload parachute bay, and secure with shear pins
	Attach payload parachute shock cord to payload section
	Attach parachute to the end of the payload parachute shock cord
	Pack payload section parachute
	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
	Insert drogue parachute and shock cord into upper payload parachute bay
	Insert payload section into payload parachute bay and secure with shear pins
Assemble motor	
	Follow manufacturer's instructions
	Do not get grease on propellant grains or delay grain
	Do not install igniter

	Install Motor in launch vehicle
	Secure motor retention system
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
	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	
	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

Table 3.6.2 Launch Checklist

PRE-LAUNCH		
Checklist	**Performer**	**Inspector**

Pack all necessary equipment/supplies the night before team leaves for the launch site.		
On the morning of departure, check to make sure all necessary equipment/supplies have been stored in a secure manner.		

LAUNCH		
Checklist	**Performer**	**Inspector**
Prepare Payload Bay		
Ensure the batteries and switches are properly connected to the altimeters.		
Ensure the batteries, power supply, switches, data recorders, and pressure sensors are properly wired.		
Install and secure new batteries into the battery holders.		
Insert the altimeter into the bay.		
Arm the altimeters to verify the jumper settings. Check the battery voltage and continuity once the altimeters have been armed. Disarm the altimeters afterwards.		
Assemble Charges		
Test e-match resistance and make sure it is within specifications.		
Remove protective cover from e-match.		
Measure the required amount of black powder that was determined during testing.		

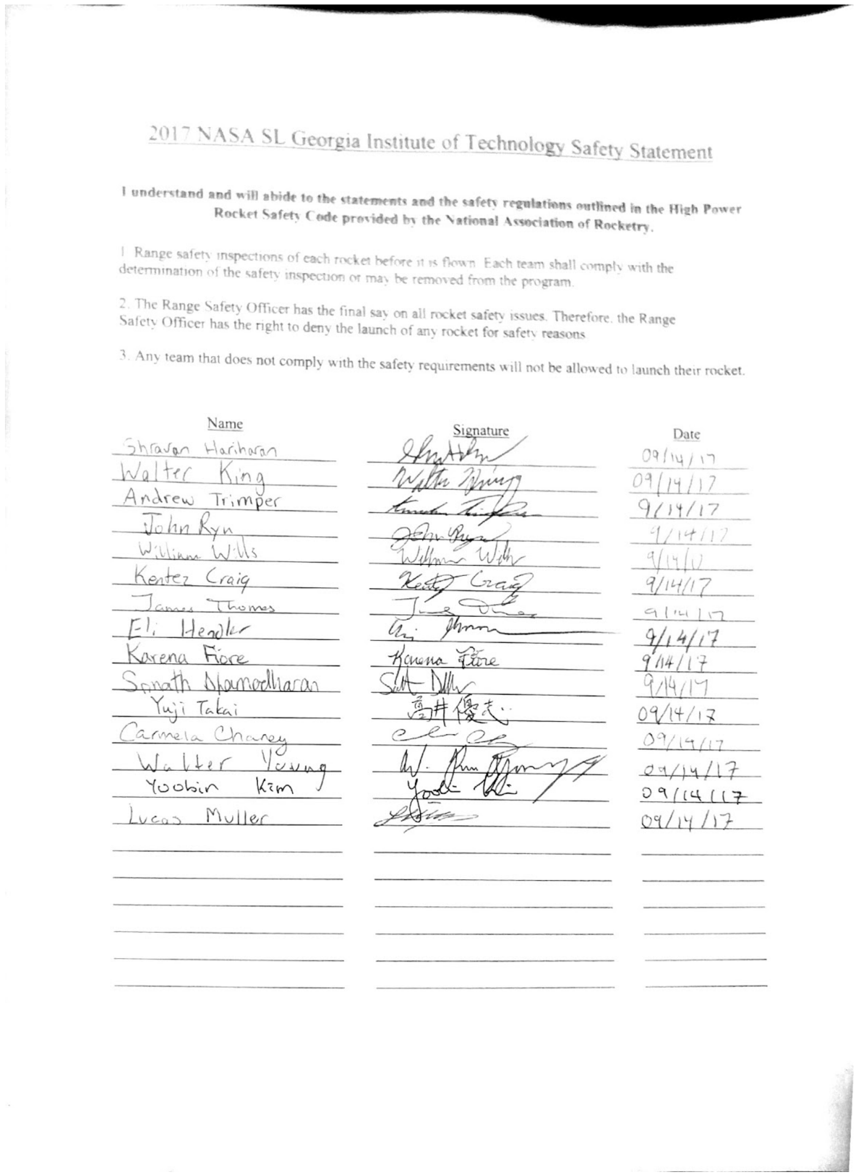
Place e-match on tape with the sticky side facing up.		
Pour the black powder over the e-match and seal the tape.		
Retest the e-match resistance.		
Check Altimeters (Figure 1 for configurations)		
Ensure altimeters have been properly disarmed.		
Connect charges to the ejection wells/altimeter bay.		
Turn on altimeters and verify continuity. Disarm altimeters afterwards.		
ALTIMETER 1		
ALTIMETER 2		
Pack Parachutes		
Connect drogue shock cord to booster section and altimeter.		
Make sure shock cord and parachute have no tears, burns or frays		
Fold excess shock cord so it does not tangle.		
Add Nomex cloth to ensure only the Kevlar shock cord is exposed to ejection charge.		
Insert altimeter bay into drogue section and secure with shear pins.		
Pack main chute.		
Attach main shock cord.		

Tug on both ends of the shock cord or recovery harness. It should be firmly attached.		
Assemble Motor		
Follow manufacturer’s instruction.		
Use the necessary safety equipment needed such as gloves and safety glasses.		
Be careful not to get any grease on propellant or delay grain.		
Do not install the igniter until at launch pad.		
Install motor in launch vehicle.		
Secure motor retention system.		
Final Preparation		
Make sure fin flaps are aligned properly		
Inspect the launch vehicle. Verify the CG in order to make sure it is in safe range. Add nose weight in the MAS if necessary.		
Connect shock cord to nose cone, install nose cone, and secure with shear pins.		
Bring launch vehicle to the range safety officer (RSO) table for inspection.		
Bring launch vehicle to pad, install on pad, and verify that it can move freely.		
Install igniter in launch vehicle.		
Touch igniter clips together to make sure they will not fire igniter when connected.		

Make sure clips are not shorted to each other or blast deflector.		
Arm altimeters via switches and wait for continuity check for both.		
Launch		
Watch flight so launch vehicle sections do not get lost.		

POST-LAUNCH		
Checklist	**Performer**	**Inspector**
Recovery		
Recover launch vehicle, document landing.		
Disarm altimeters if there are any unfired charges.		
Disassemble launch vehicle, clean motor case, other parts, and inspect for damage.		
Record altimeter data and download payload data.		

3.7. 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		9/14/17
Sanath Damodharan		9/14/17
Yuji Takai		09/14/17
Carmela Chaney		09/14/17
Walter Young		09/14/17
Yoobin Kim		09/14/17
Lucas Muller		09/14/17

Figure 3.7.1 Team Safety Agreement

4. Launch Vehicle

4.1. Launch Vehicle Overview

Mission Statement

The mission of our launch is to safely deliver a vehicle to that integrates multi-disciplinary systems that fulfills the requirements stated in the following section. The vehicle must launch a rover to an altitude of exactly one mile (5,280 feet), and and safely deploy the recovery system. The vehicle will utilize the Apogee Targeting System (ATS) to predict and adjust the apogee after the vehicle has launched to attain the highest level of precision possible. Following recovery, a rover is to autonomously deploy a solar panel after traveling a minimum of five feet from the launch vehicle. The vehicle must have proven efficacy before the launch to ensure the safety of all participants in the competition.

General Breakdown of Major Payloads and Design Features

Table 4.1.1: Overall Feature Dimensions

Overall Specs	Value
Overall Length	102 in
Rocket Diameter	5.562 in
Rocket Mass	590 oz
Apogee	5533 ft
Nosecone Section	21.75 in
Avionics Bay Section	12.0 in
Apogee Targeting System Section	20.75 in
Booster Section	27.4 in
Motor Housing Length	20.9 in
Motor Housing Diameter	3.162 in
Bulkhead Thickness	0.375 in
Centering Ring Thickness	0.25 in

Table 4.1.2: Materials of major airframe components

Materials	Components
G10 Fiberglass	bulkheads, fins, thrust plate
G12 Fiberglass	body tubes, couplers, nosecone
Aluminum 6061	ATS components, centering rings

Figure 4.1.1 OpenRocket Full-scale Model

Nose cone

The nose cone will be secured to the launch vehicle via the supporting beam from the rover tube. There will be two metal beams extending from the rover tube which will be screwed onto the brackets inside the shoulder of the nose cone. During the flight, these beams will be kept within the rover tube. Once the launch vehicle has landed onto the ground safely and the radio signal for deployment is received by the rover deployment system, the beams will slide outwards, pushing the nose cone out from the rover tube and allowing the rover to eject itself from the housing tube. The nose cone will be placed on the front end of the rover tube. The team has decided to utilize the 5.5 inch Fiberglass ogive nose cone with a 4:1 length to diameter ratio.

Rover

The rover tube houses the rover, the rover deployment system, the main parachute and the shock cord. The rover with the deployment system will be placed in the front half of the tube separated from the main parachute with the shock cord by a bulkhead. One end of the shock cord will be attached to I-bolt on this bulkhead and the other end to the I-bolt on body tube bulkhead of the avionics bay. The front end of the rover tube is attached to the nose cone and the back end of it is attached to the avionics. As written in the nose cone design, there will be two supporting beams inside the rover tube that will attach the nose cone to the rover tube. The rover tube will be secured to the avionics bay via rivets during the vertical ascent of the launch vehicle. After the altimeter within the avionics bay detects that the rocket has descended to 1,500 ft, the ejection charge on the front end of the avionics bay is ignited, breaking the rivets securing the rover tube to the avionics and deploying the main parachute.

Avionics Bay

Avionics bay houses all the electronic components related to the parachute deployments and control of the ATS system. The front end of the avionics bay will be connect to the rover tube and the back end will be attached to the ATS tube. At both separation points, rivets will be used for securing the assembly during the ascent of the launch vehicle. When the launch vehicle reaches apogee, the ejection charge on the ATS tube side will be ignited, breaking the rivets and deploying the drogue parachute. There will be 12 wires in total traversing from the avionics bay to other sections. Eight of them will be connecting the altimeters to the blast caps. There will be four blast caps in total, two on each side of the avionics bay, and each blast cap will be linked to two altimeters within the avionics bay via two wires. two wires will be used for redundancy, ensuring that the parachutes will be deployed at the determined altitude. The other four wires will traverse through where the drogue parachute and the shock cord are housed and will be connected to the motor of the ATS system. At the deployment of the drogue parachute, these four wires will be disconnected by the force that separates the avionics bay and the ATS tube. The avionics bay is designed so that the assembly and disassembly could be conducted easily. There are mainly two subassemblies: one consists of body tube and coupler bulkhead and a tray on which all the electronic components are mounted, and the other consists of the avionics coupler tube and coupler and body tube bulkheads. With the two guidance rails inside the coupler tube, the tray is slided in and out with the correct orientation so that the key switches match their holes on the coupler tube.

Apogee Targeting System

ATS tube houses the drogue parachute, the shock cord, and the ATS system. The front end of the ATS tube will be attached to the avionics bay via rivets, while the back end will be attached to the booster stage via shear pins. Shear pins are used for the connection between the ATS tube and the booster stage because these two sections will not be separated anytime during the flight or post-landing when the rover deploys and making the ATS system apart from the booster stage will allow easier access to the ATS system for calibration or fixture of malfunction.

Booster

The booster stage is attached to the back end of the ATS tube via shear pins. It consists of the motor mount tube, the motor, two centering rings, a thrust plate, four fins, and a retention ring. The booster stage airframe will be constructed from 5.5 inch diameter G12 filament wound fiberglass tube.

4.2. Mission Success Criteria

Overall Criteria

1. Rocket accelerates to a velocity of 52 fps at rail exit
2. Rocket including payload delivered to exactly 5,280 feet above ground level
3. Rocket deploys drogue parachute and subsequently deploys main parachute
4. Rocket safely returns to ground (has kinetic energy < 75 ft-lbf)
5. Motor retained in the rocket during recovery
6. Rover deploys from rocket remotely
7. Rover autonomously travels 5 feet from launch vehicle
8. Rover deploys set of solar cell panels that power battery

Derivation

For the launch to be successful, the rocket must safely launch to reach near 5280 ft apogee, and recover safely to deploy the payload once on the ground. The Georgia Tech USLI team aims to get within 2% of the 5280 ft goal. The mission success will be measured by two altimeters which will measure the altitude of the rocket. Any overshoot or undershoot will mean an unsuccessful mission. The vehicle will achieve this goal by implementing an Apogee Targeting System that will function reliably, and have the ability to predict the apogee and adaptively vary the drag coefficient of the launch vehicle during flight in order to get closer to hitting the target apogee.

The vehicle will have a stable ascent. The rocket will never exceed an angle of flight 5 degrees from vertical in any direction. The rocket components will not deflect more than 1/2 inch in any direction. Additionally, the rocket must accelerate to greater than 52 fps and have a stability factor greater than 2 at launch tower exit.

After successful flight, the launch vehicle must land safely. During all parts of flight, the motor must be retained in the vehicle. When the rocket reaches the 5280 ft apogee, the drogue parachute must deploy. The main parachute will deploy at 750 feet above the ground. To be successful, the vehicle will land with a kinetic energy of less than 75 ft-lbf (~100 J). When the rocket lands, the vehicle will deliver the payload undamaged.

For the rover to be successful, the rover must remotely deploy remotely. It will move at least 5 ft away from the launch vehicle, and proceed to deploy solar panels. The solar cells will power a battery. Most importantly, the mission can only be a success if all participants are following safety protocol, and no members are injured by the rocket. If the rocket satisfies these criteria, the Georgia Tech USLI team will consider the mission a success.

Alternative Design

To arrive at the current rocket design, several alternative options were considered for the body tube size and the nose cone shape.

The diameter of the body tube was determined by the length diameter ratio. To keep the rocket stable, the center of gravity should be located above the center of pressure. However, the stability should not be too large. If the stability is too large, then any gust of wind can permanently alter the trajectory. The rocket should be able to correct its path if it is hit with an unexpected force. The rocket should have a stability rating of greater than 2.0 when leaving the launch rod. Therefore, the stability of the rocket should be slightly greater than 2.0. Changing the rocket diameter can change the location of both the center of gravity and the center of pressure. Using the rocket diameter used in the USLI 2016-2017 launch, diameters located around 5.5 inches were simulated on OpenRocket software. Because the team will be purchasing the body tube, the standard sizes of 5", 5.5", and 6" those diameters were simulated. The estimates for component lengths and weights for the simulation were based on estimations from the USLI 2016-2017 teams, scaling from the subscale launch, and estimates from preliminary designs.

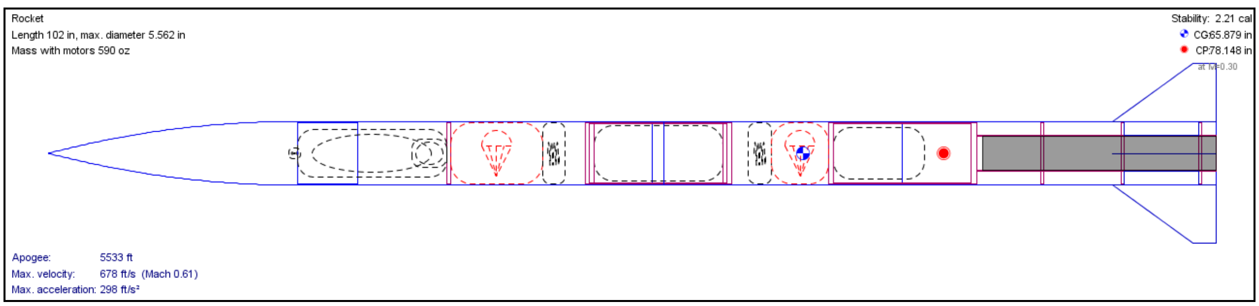


Figure 4.2.1: OpenRocket model with 5.5" diameter body tube

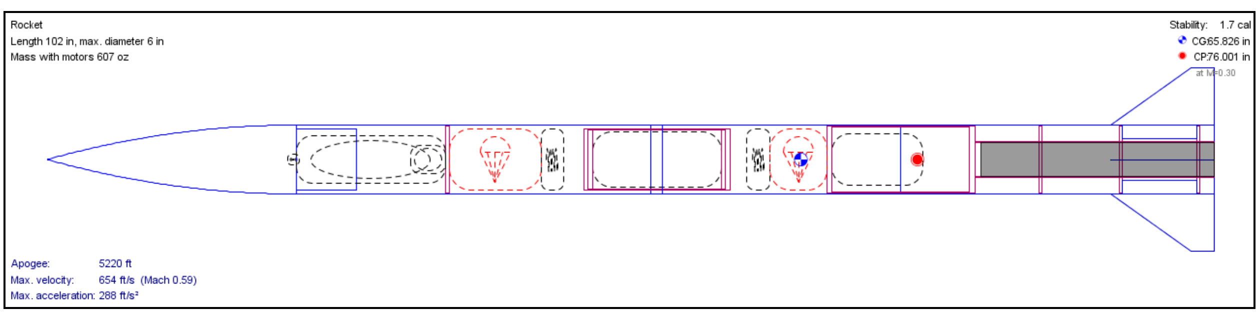


Figure 4.2.2: OpenRocket model with 6" diameter body tube

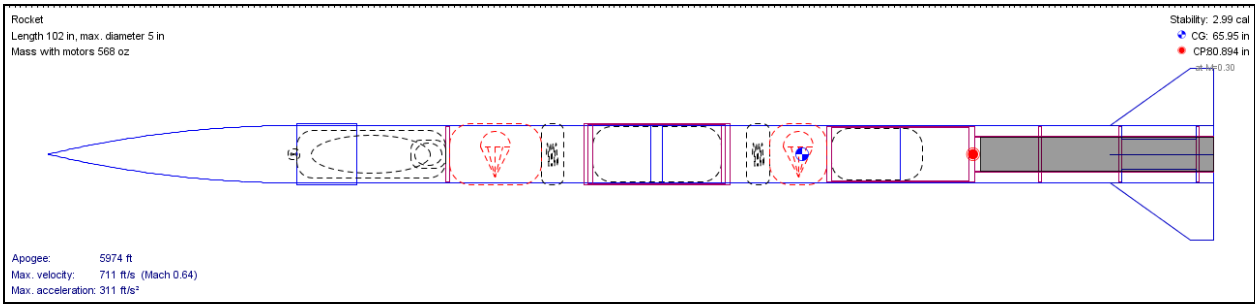


Figure 4.2.3: OpenRocket model with 5” diameter body tube

The stability for the 6” diameter tube was 1.7 which is below the required stability for launch. Additionally, the large body tube made the rocket heavier which decreased our predicted apogee. The stability for the 5.5” diameter tube was 2.2 which is above the required stability of 2 for launch. The stability for the 5” diameter was 3.07 which would satisfy the stability requirement. However, a smaller body tube would give the rover less room inside the rocket. Additionally, it would also make the avionics bay smaller. This was deemed as undesirable because the avionics bay would be easier to debug and check connections with a larger diameter. For these reasons, the rocket diameter of 5.5 inches is the current leading design for the rocket.

Additional options for the nose cone shapes were also investigated. The purpose of the nosecone is to reduce drag on the rocket. Common nose cone shapes are shown below in Figure 4.2.4.

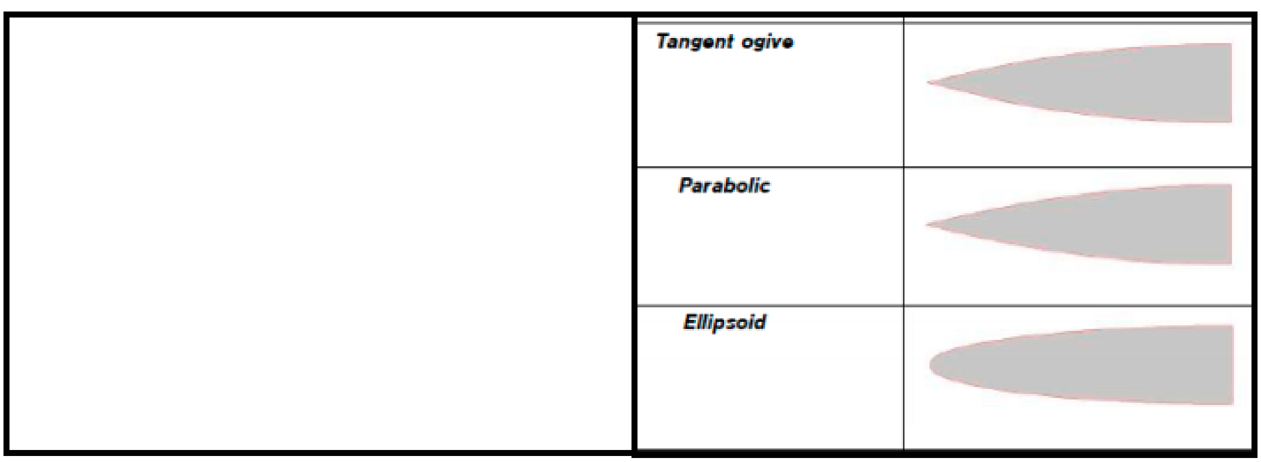


Figure 4.2.4: Common nose cone shapes

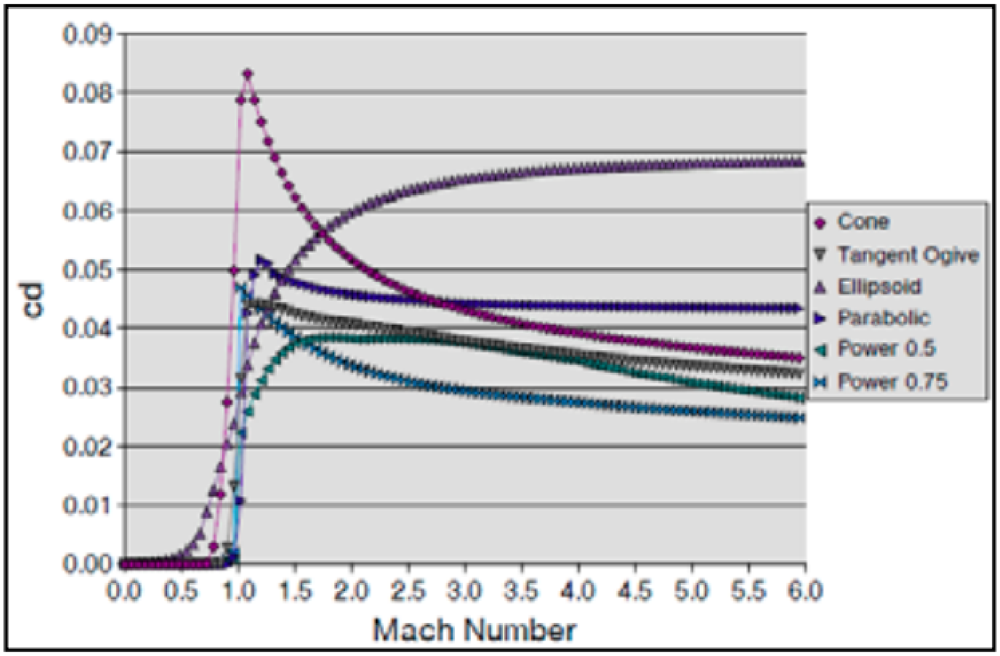


Figure 4.2.5: Drag coefficients for different nose cone shape

Figure 4.2.5 shows the experimentally determined coefficients of drag for different nose cone shapes. Past rockets maximum velocity were around 700 ft/s or .622 mach. According to the diagram shown above, 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.

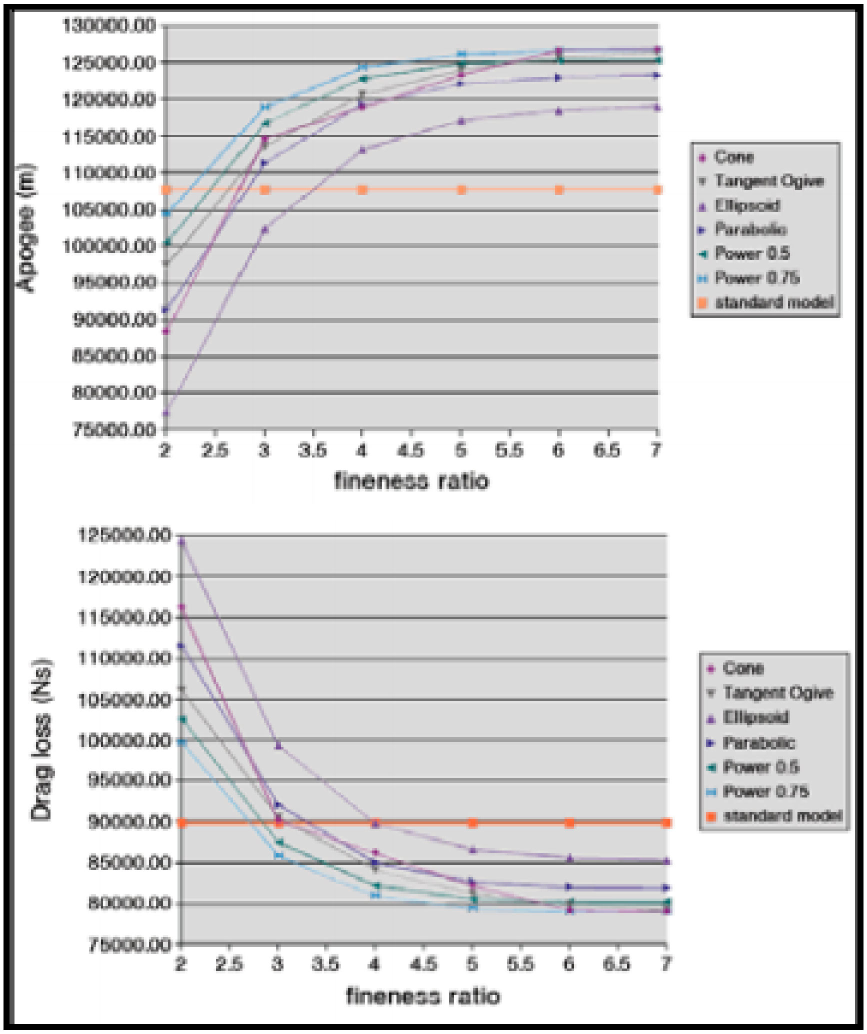


Figure 4.2.6: Apogee and drag loss vs fineness ratio

Further experiments have been done done to calculate the both the drag loss and the highest apogee on the rocket for various fineness ratios. The fineness ratio is the ratio of width to height, with a low fineness ratio being a shorter and wider nose cone, and a high fineness ratio being a longer and thinner nose cone. For apogee, the cone reaches the highest apogee, but only for extremely large fineness ratios. Because of weight limits on the rocket, the nose cone is limited in length. For mid range fineness ratios, the Power .75 and the Tangent Ogive nose cones were reaching the highest apogee, and at around a fineness ratio of 4, the return on fineness ratio drastically levels. The drag losses were also compared. The drag loss is the amount of fluid friction generated by the nosecone. Therefore, a lower drag loss would be preferred to prevent energy from the rocket from being used to overcome fluidic friction. The lowest drag loss was again the cone, but also only for very high fineness ratios. The tangent ogive and the power 0.75 had consistently the lowest drag ratios for the mid ranged fineness ratios. Note that these studies are done for much higher power rockets than the final rocket. To confirm these results applied to less powerful rockets, OpenRocket simulations were performed. A fineness ratio of 3.9 was used.

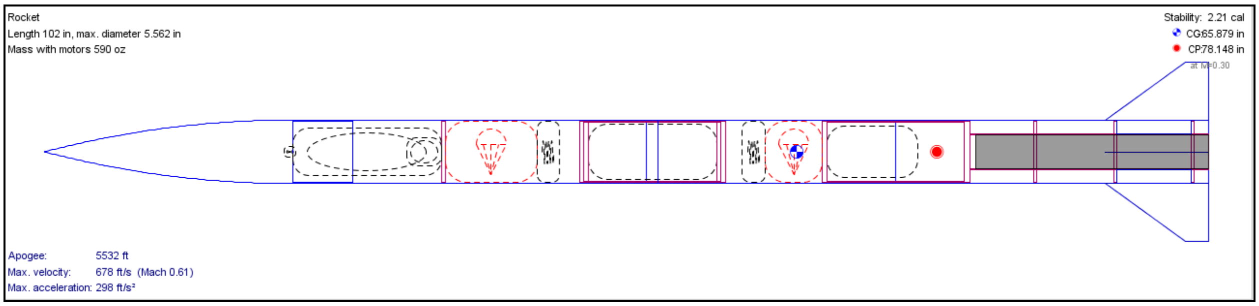


Figure 4.2.7: OpenRocket model with tangent ogive nose cone

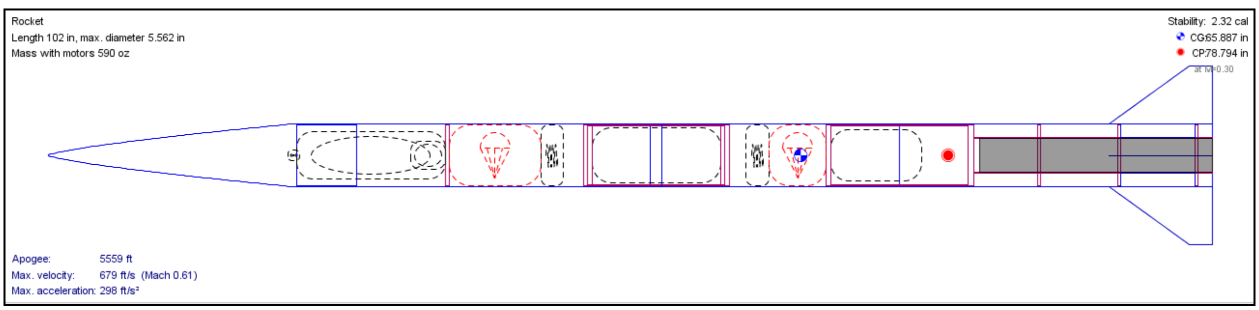


Figure 4.2.8: OpenRocket model with power 7.5 nose cone

The apogee of the rocket with the tangent ogive was 5532 ft, and the apogee of the 0.75 power was 5559 ft. Ideally, the 0.75 power series would be selected. However, the 0.75 power series nose cone is commercially created. The team would have to manufacture a fiberglass nose cone which is outside of the budget constraints of the project. However, the ogive nose cone is widely available for purchase and could be substituted with minimal effect on the apogee. Therefore, the best option for the nosecone is the tangent ogive nose cone with a fineness ratio of 3.9.

Additionally, the ATS system could have been placed anywhere on the rocket. The ATS location should be as close to the center of pressure as possible. The ATS system will create additional forces where the system is located. If the ATS system was located near the center of pressure, it will have minimal effect on where the center of pressure is located and the stability of the rocket. This will allow for a streamline deceleration of the rocket. Using the OpenRocket simulation discussed above, the center of pressure is located just above the motor. Therefore, this was where the ATS bay was decided to be housed.

4.3. Launch Vehicle Requirements

General Function Trees

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 Figure 4.3.1 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 ft 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.

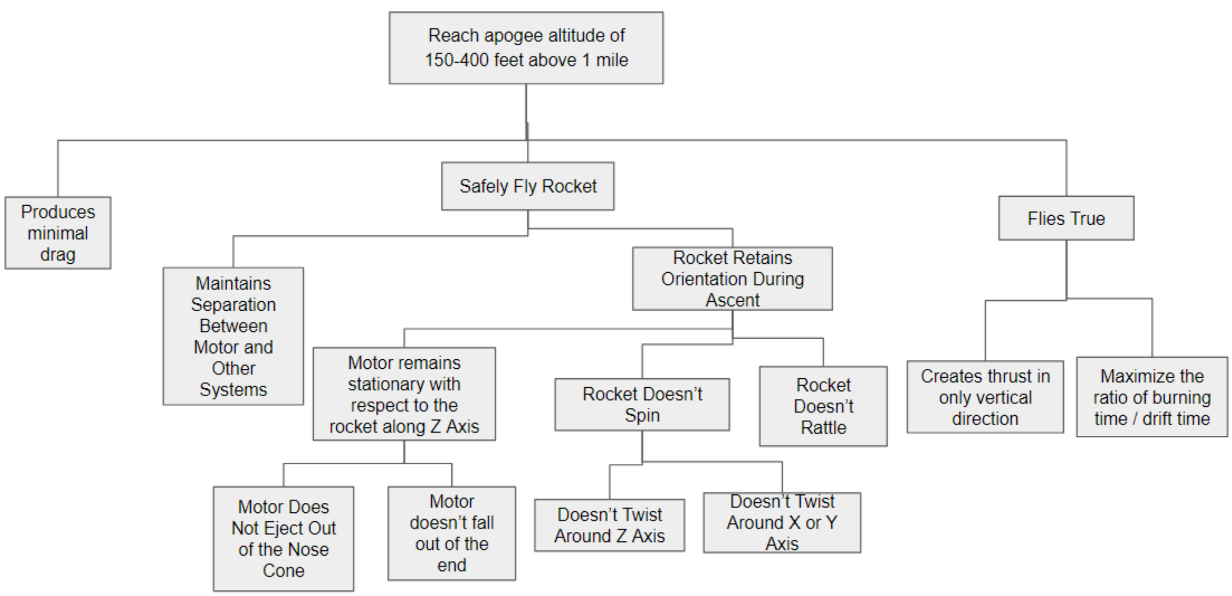


Figure 4.3.1: Vehicle ascent function tree

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. Figure 4.3.2 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.

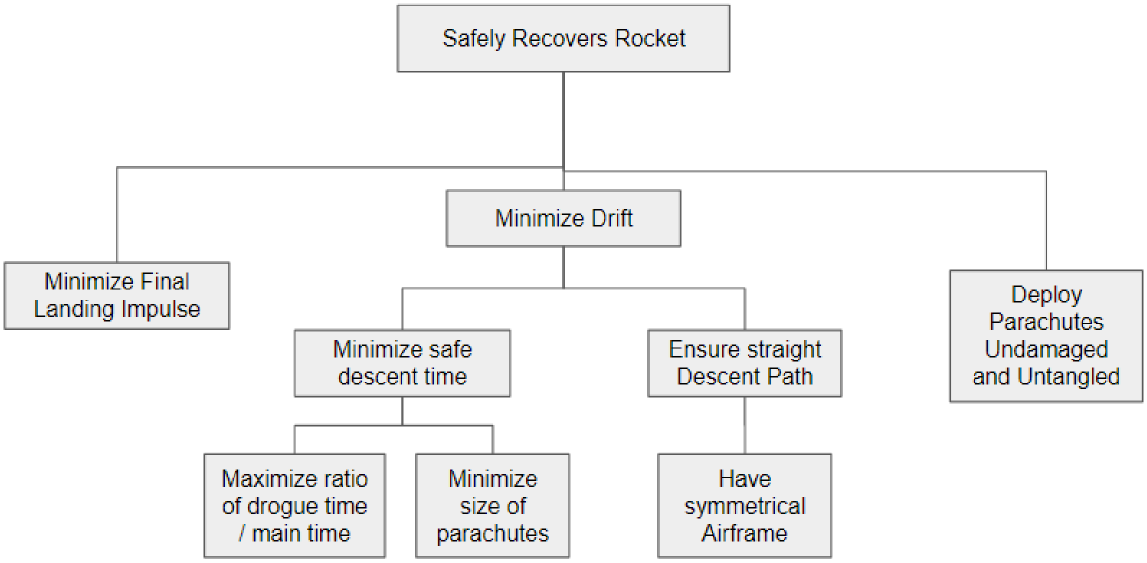


Figure 4.3.2: Vehicle Recovery System Function Tree

Payload Delivery:

The final subsystem of functions is the successful delivery of the payload. Shown in Figure 4.3.3 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 i returns to the ground the rocket then must incorporate some system that allows for the rver to leave the rocket unharmed.

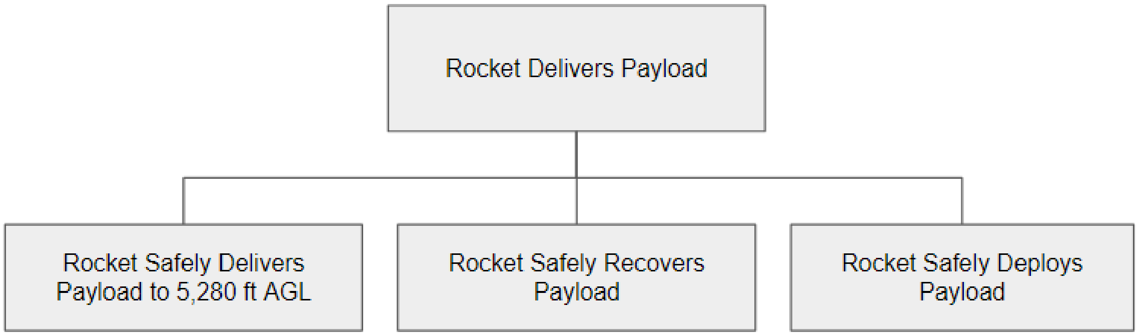


Figure 4.3.3: Payload Delivery Function Tree

4.4. Launch Vehicle Design

4.4.1. Booster

The booster stage is attached to the back end of the ATS tube via shear pins. It consists of the motor mount tube, the motor, two centering rings, a thrust plate, four fins, and a retention ring. The booster stage airframe will be constructed from 5.5 inch diameter G12 filament wound fiberglass tube. The layout of the booster section is illustrated in Figure 4.4.1 and Table 4.4.1 shows the key dimensions of the booster stage.

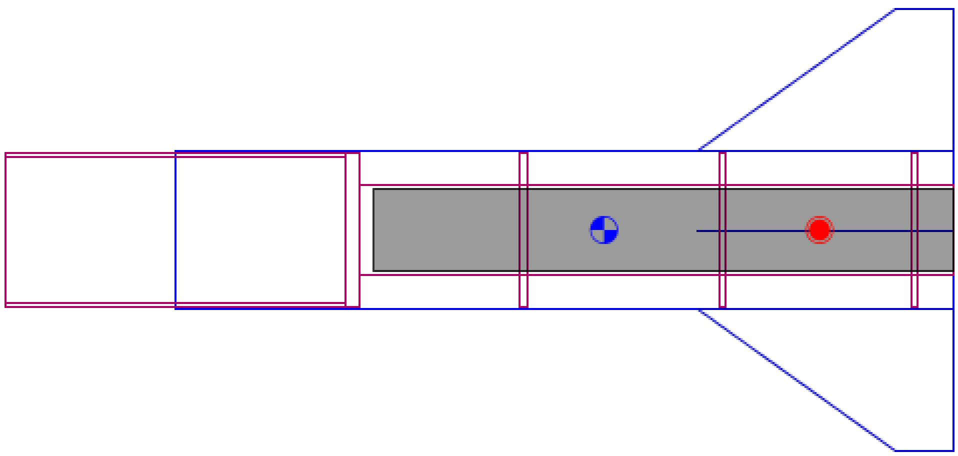


Figure 4.4.1: Booster section layout

Table 4.4.1: Tubing Mass

Property	Values
Gross Mass	258.57 oz (7330 g)
Length	33.40 in (84.84 cm)
Outer Diameter	5.562 in (14.13 cm)
Inner Diameter	5.376 in (13.66 cm)
Bottom width*	15.562 in (39.53 cm)

In order to ensure that the fins are attached vertically and spaced equally onto the motor mount tube, a template has been created which marks the position of the fins around the retention ring by using a Trotec laser cutter for the subscale vehicle. The template can be seen in Figure 4.4.2. Unfortunately, this template only made the fins equally spaced out and did not function well for aligning the fins vertically. Thus, for the full scale, a fin alignment tool will be created by placing two templates parallel to each other and connecting these two with vertical plates aligned with the slots for the fins on the templates. The template will have a hole size of the booster stage airframe so that the vertical slots could be marked precisely onto the booster stage airframe. Once the markings are drawn, the slots will be cut by OMAX Waterjet.

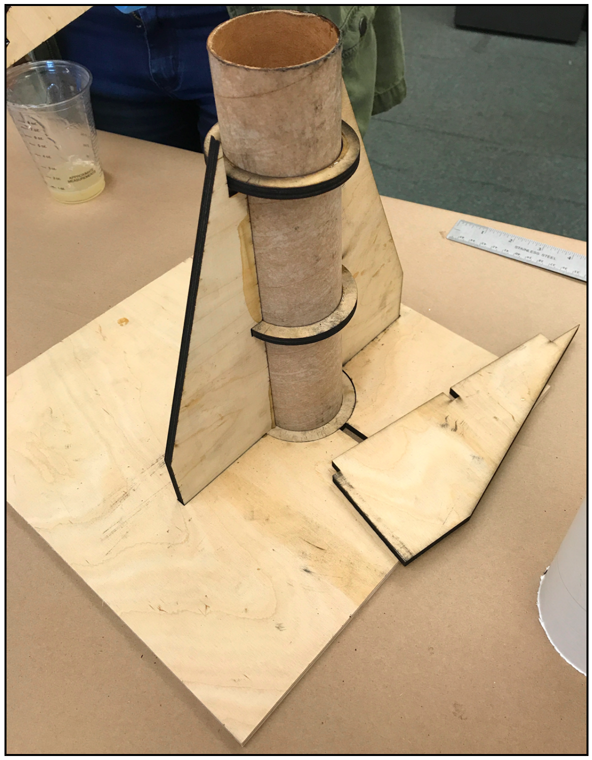


Figure 4.4.2: Fin alignment template for subscale

Motor Mount Tube

The motor mount tube will be manufactured by cutting a 75mm brown kraft paper (LOC) tube into 21 inches, the length of the motor. The motor mount tube with the centering rings ensure the motor to be aligned properly with the entire launch vehicle.

Centering Rings

The centering rings will be constructed from 6061-aluminum using OMAX Waterjet. 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 in Figure 4.4.3.

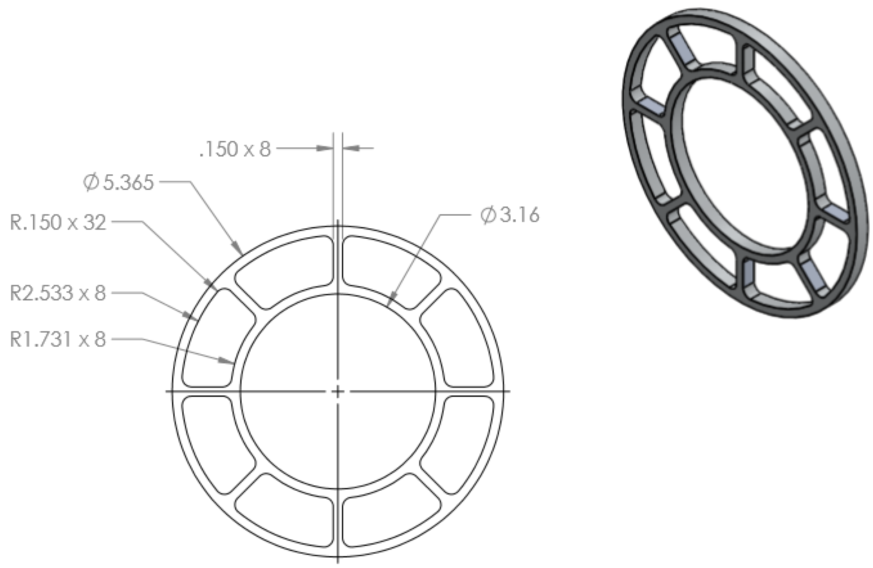


Figure 4.4.3: Detailed drawing of centering ring

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.

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 drogue parachute from the hot air ejected from the motor. The thrust plate will be manufactured from G10 filament wound fiberglass using OMAX Waterjet. The drawing of the part is shown below.

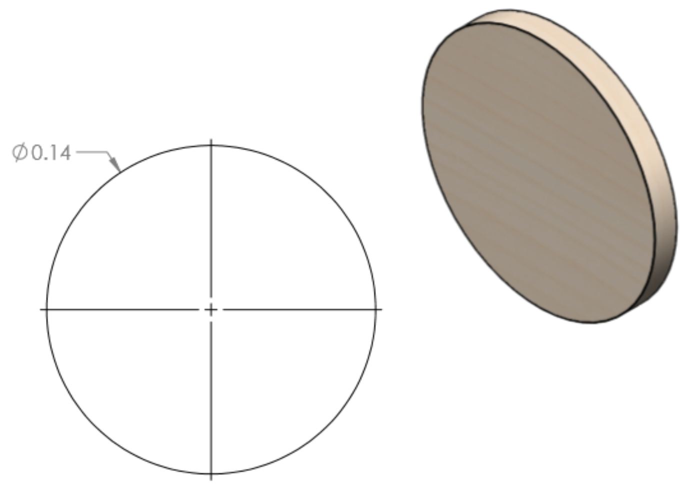


Figure 4.4.4: Detailed drawing of the thrust plate

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.

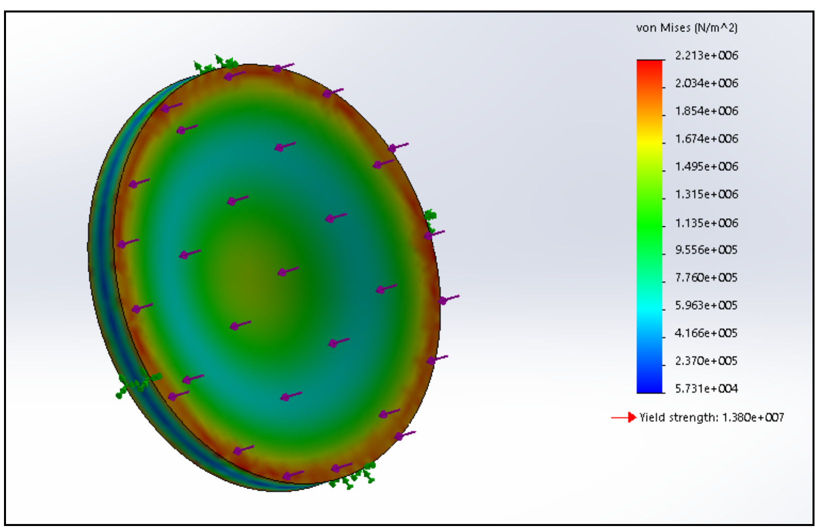


Figure 4.4.5: FEA stress plot for thrust plate

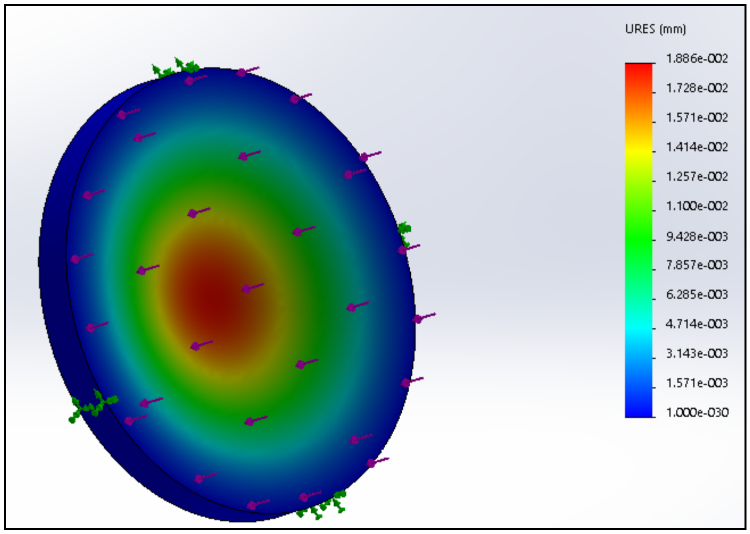


Figure 4.4.6: FEA displacement plot for thrust plate

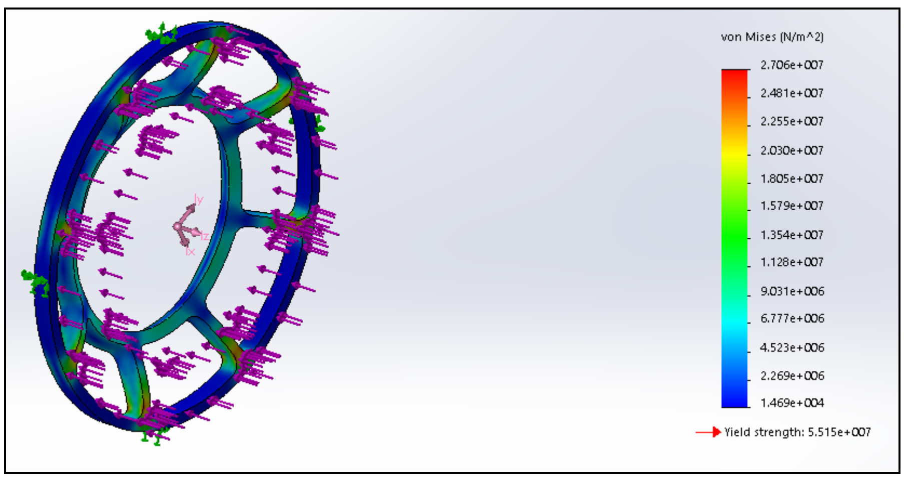


Figure 4.4.7: FEA stress plot for centering ring

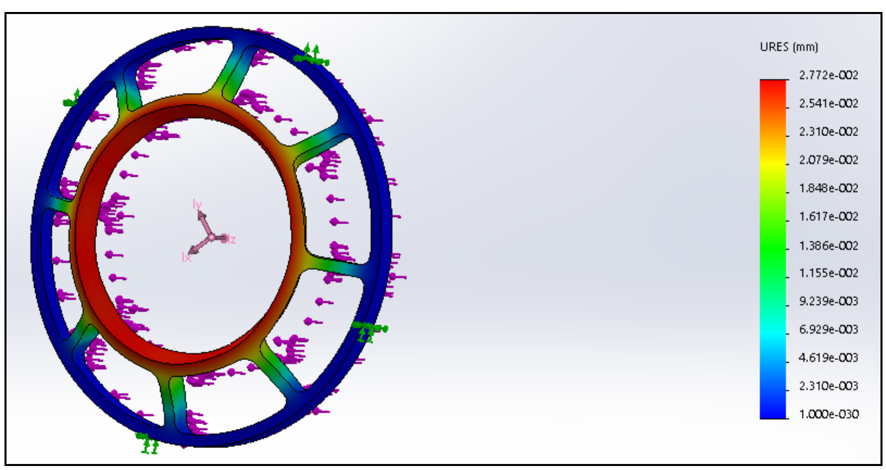


Figure 4.4.8: FEA displacement plot for centering ring

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 4.4.2: 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}

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. The rendering and detailed drawing of the fins are shown below in Figure 4.4.9 and in Figure 4.4.10, respectively.

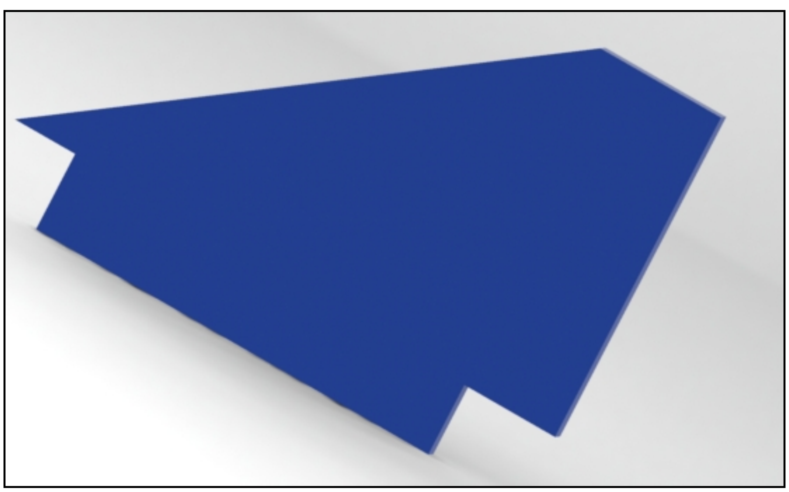


Figure 4.4.9: Fins rendering

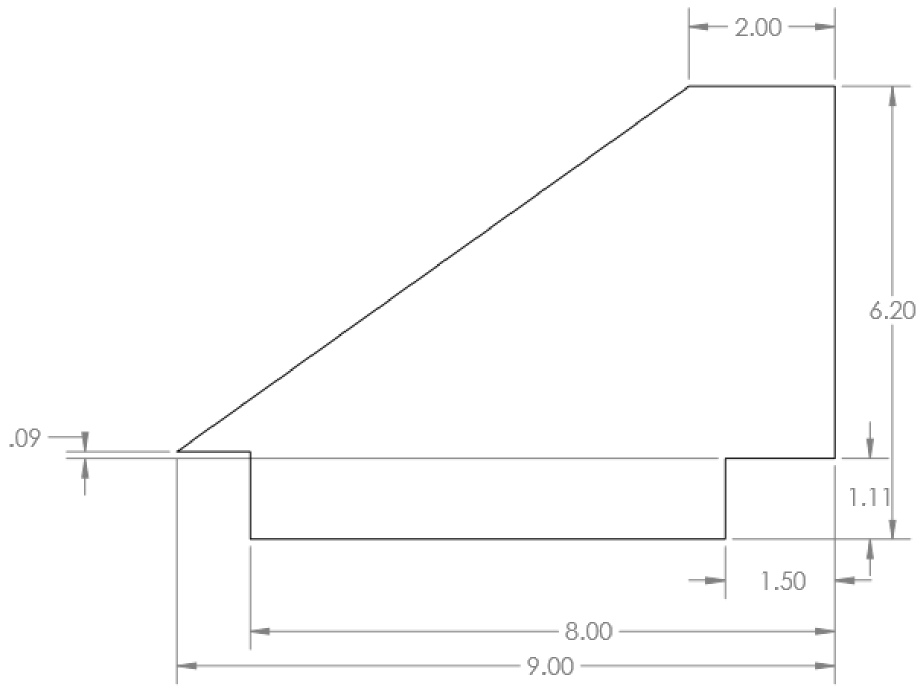


Figure 4.4.10: Detailed drawing of the fin

Subscale launch vehicle

In order to test the ATS system, a subscale rocket was designed and has been constructed. The subscale vehicle utilizes a 3 inch white kraft paper tube for all the body tubes, brown kraft paper tube for couplers, and plywood for the bulkheads, centering rings, and the fins. The motor that will be used for the subscale launch is AeroTech J250FJ. The initial design included the rover deployment; however, since the the length to diameter was too large, there was a risk that the structural integrity will be lost by the lack of strength of the LOC tube. Hence, the team decided to eliminate the rover deployment system from the subscale and to instead conduct a ground test at the subscale launch site. In addition, due to the fact that coupler tube was narrow, the ATS is not housed inside the coupler tube between the booster and the ATS sections, but placed above the coupler tube instead. The final CAD design, section layout, as well as the actual image of the subscale vehicle are shown in Figure 4.4.11, in Figure 4.4.12, and in Figure 4.4.13 respectively.

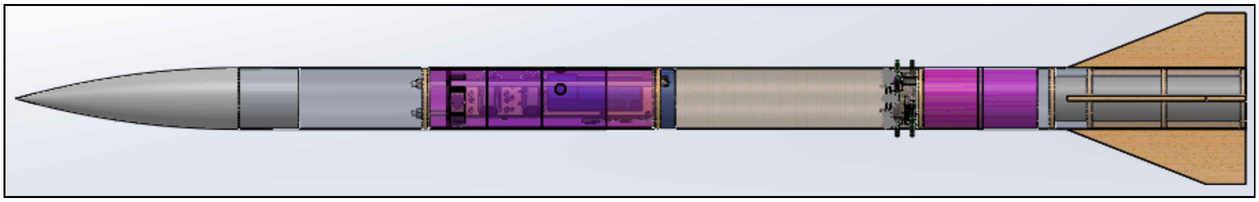


Figure 4.4.11: Final CAD design of subscale vehicle

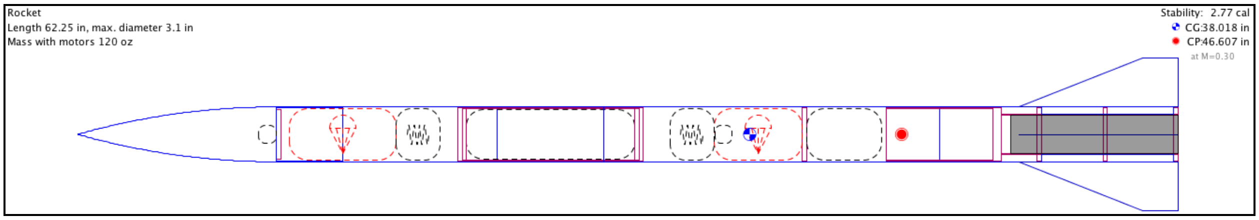


Figure 4.4.12: OpenRocket model of the subscale vehicle

Figure 4.4.13: Actual image of the subscale vehicle

Although the subscale vehicle will have a lower maximum velocity, it will experience a relatively similar acceleration and motor burn time as shown in Table 4.4.3, comparing the main properties of the full scale and subscale launch vehicles.

Table 4.4.3: Properties of full scale and subscale launch vehicles

Property	Full scale vehicle	Subscale Vehicle
Body tube outer diameter	3.10 in	5.562 in
Apogee altitude	3790 ft	5537 ft
Maximum velocity	582 ft/s	679 ft/s
Maximum acceleration	270 ft/s^2	298 ft/s^2
Motor burnout time	2.796 s	2.911 s
Stability margin at rail exit	2.85	2.22
Velocity at rail exit	65.7 ft/s	70.3 ft/s

Mass Breakdown Chart

The following tables summarize the material, weight, and locations of the components in each section of launch vehicle. The weights are based on material density estimation. “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 4.4.4: Nose cone section mass breakdown

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

Table 4.4.5: Rover tube section mass breakdown

Component	Material	Mass (oz)	Location (in)
Body tube	G12 fiberglass	52.10	0
Rover deployment system	N/A	24.00	0
Rover	N/A	32.00	10
Bulkhead	G10 fiberglass	6.07	13
Main parachute	Ripstop nylon	20.80	13.5
Shock cord	Tubular nylon	3.44	21.5

Table 4.4.6: Avionics bay mass breakdown

Component	Material	Mass (oz)	Location (in)
Avionic bay coupler tube	G12 fiberglass	22.00	0.375
Avionic bay strip	White kraft paper	0.66	5.875
Body tube bulkhead	G10 fiberglass	9.10	0 and 12.375
Coupler tube bulkhead	G10 fiberglass	8.38	0.375 and 12
Electronics tray	N/A	27.00	0.75

Table 4.4.7: ATS section mass breakdown

Component	Material	Mass (oz)	Location (in)
Body tube	G12 fiberglass	35.50	0.00
Drogue parachute	Ripstop nylon	2.54	9.375
Shock cord	Tubular nylon	3.44	7.375
Bulkhead	G10 fiberglass	9.10	14.375
ATS system	N/A	32.60	14.75

Table 4.4.8: Booster section mass breakdown

Component	Material	Mass (oz)	Location
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	18.25 and 25.25
Fin	G10 Fiberglass	9.50	31.90
Retention ring	6061-aluminum	1.35	24.40
Motor (with propellant)	N/A	136.83	13

4.4.2. Structure

Separation points of the rocket

The figure below illustrates the separation points of the full-scale launch vehicle. The separation type as well as the separation time of each separation points are summarized in Table 4.4.9.

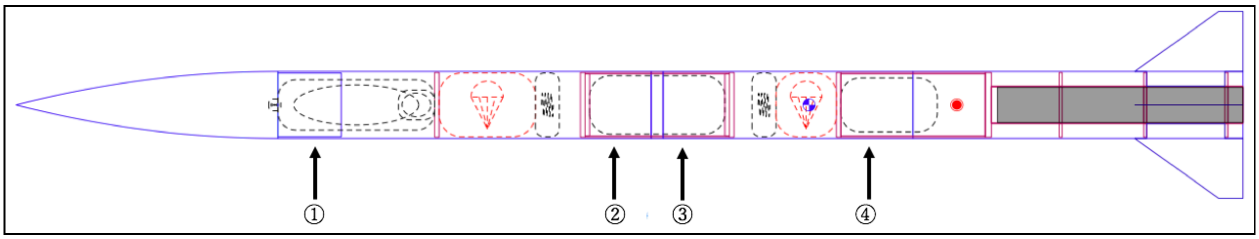


Figure 4.4.14: Separation points on the launch vehicle

Table 4.4.9: Type and separation time for each separation points

No.	Location	Separation type	Separation time
1	Nose Cone - Rover Tube	Supporting beams from rover tube	Rover deployment
2	Rover Tube - Avionics Bay	Rivet	Main parachute deployment
3	Avionics Bay - ATS Tube	Rivet	Drogue parachute deployment
4	ATS Tube - Booster Stage	Shear Pins	Not applicable

Nose Cone Section

The nose cone houses the GPS so that team will be able to detect the launch vehicle's location after landing. The nose cone will be secured to the launch vehicle via the supporting beam from the rover tube with brackets. There will be two metal beams extending from the rover tube whose brackets will be epoxyed to the inner wall of the shoulder of the nose cone. During the flight, these beams will be kept within the rover tube. Once the launch vehicle has landed onto the ground safely and the radio signal for deployment is received by the rover deployment system, the beams will slide outwards, pushing the nose cone out from the rover tube and allowing the rover to eject itself from the housing tube. The nose cone will be placed on the front end of the rover tube. 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 in Figure 4.4.15. Figure 4.4.16 depicts the nose cone section layout using OpenRocket and Table 4.4.10 summarizes the significant properties of the nose cone.

Figure 4.4.15: Nose cone rendering

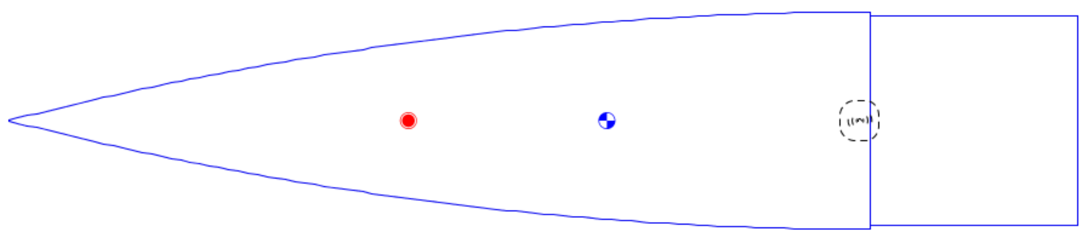


Figure 4.4.16: Nose cone section layout

Table 4.4.10: Nosecone section properties

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)

Rover Tube Design

The rover tube houses the rover, the rover deployment system, the main parachute and the shock cord. The rover with the deployment system will be placed in the front half of the tube separated from the main parachute with the shock cord by a bulkhead. One end of the shock cord will be attached to U-bolt on this bulkhead and the other end to the U-bolt on body tube bulkhead of the avionics bay. The front end of the rover tube is attached to the nose cone and the back end of it is attached to the avionics bay. As written in the nose cone design, there will be two supporting beams inside the rover tube that will attach the nose cone to the rover tube. The rover tube will be secured to the avionics bay via rivets during the vertical ascent of the launch vehicle. After the altimeter within the avionics bay detects that the rocket has descended to 1,500 ft, the ejection charge on the front end of the avionics bay is ignited, breaking the rivets securing the rover tube to the avionics and deploying the main parachute. The layout of the rover section is depicted below in Figure and Table , listing the important properties of the rover tube follows.

Figure 4.4.17: Rover tube layout

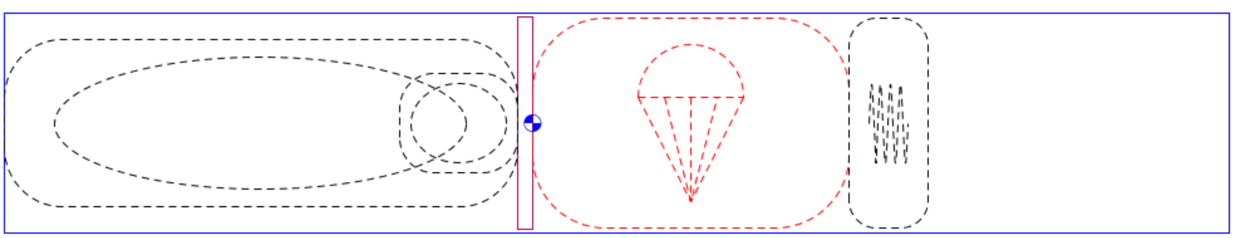


Table 4.4.11: Rover tube properties

Property	Values
Gross Mass	142.34 oz (4035 g)
Length	31.00 in (78.74 cm)
Outer Diameter	5.562 in (14.13 cm)
Inner Diameter	5.376 in (13.66 cm)

Avionics Bay

Avionics bay houses all the electronic components related to the parachute deployments and control of the ATS system. The front end of the avionics bay will be connect to the rover tube and the back end will be attached to the ATS tube. At both separation points, rivets will be used for securing the assembly during the ascent of the launch vehicle. When the launch vehicle reaches apogee, the ejection charge on the ATS tube side will be ignited, breaking the rivets and deploying the drogue parachute. The layout of the avionics bay is shown below in Figure 4.4.18 and the key properties of the avionics bay are summarized in Table 4.4.12.

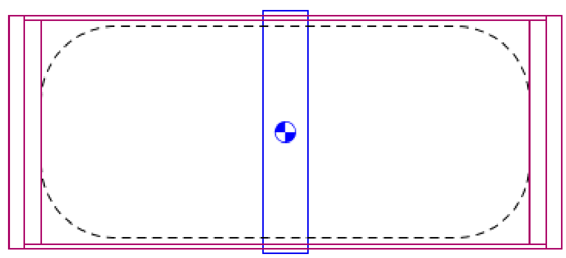


Figure 4.4.18: Avionics Bay Layout

Table 4.4.12: Avionics Bay properties

Property	Values
Gross Mass	84.62 oz (2399 g)
Length	12.00 in (30.48 cm)
Outer Diameter	5.374 in (13.65 cm)
Inner Diameter	5.169 in (13.13 cm)

There will be 12 wires in total traversing from the avionics bay to other sections. Eight of them will be connecting the altimeters to the blast caps. There will be four blast caps in total, two on each side of the avionics bay, and each blast cap will be linked to two altimeters within the avionics bay via two wires. two wires will be used for redundancy, ensuring that the parachutes will be deployed at the determined altitude. The other four wires will traverse through where the drogue parachute and the shock cord are housed and will be connected to the motor of the ATS system. At the deployment of the drogue parachute, these four wires will be disconnected by the force that separates the avionics bay and the ATS tube.

The avionics bay is designed so that the assembly and disassembly could be conducted easily. There are mainly two subassemblies: one consists of body tube and coupler bulkhead and a tray on which all the electronic components are mounted, and the other consists of the avionics coupler tube and coupler and body tube bulkheads. With the two guidance rails inside the coupler tube, the tray is slided in and out with the correct orientation so that the key switches match their holes on the coupler tube.

Apogee Targeting System Tube

The ATS tube houses the drogue parachute, the shock cord, and the ATS system. The front end of the ATS tube will be attached to the avionics bay via rivets, while the back end will be attached to the booster stage via shear pins. Shear pins are used for the connection between the ATS tube and the booster stage because these two sections will not be separated anytime during the flight or post-landing when the rover deploys and making the ATS system apart from the booster stage will allow easier access to the ATS system for calibration or fixture of malfunction. The layout of the ATS section and the important properties of the ATS tube are shown in Figure 4.4.19 and in Table 4.4.13 respectively.

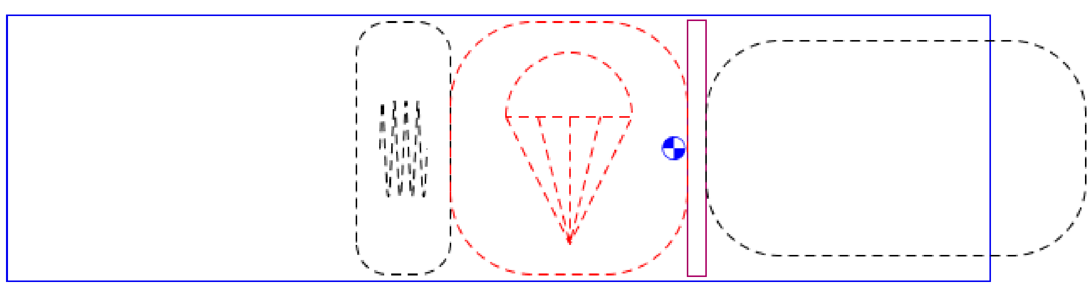


Figure 4.4.19: ATS section layout

Table 4.4.13: ATS tube properties

Property	Values
Gross Mass	83.18 oz (2358 g)
Length	20.75 in (52.71 cm)
Outer Diameter	5.562 in (14.13 cm)
Inner Diameter	5.376 in (13.66 cm)

GPS Bay

The GPS Bay allows for the addition of mass to the top of the rocket. This is an effective way to raise the location of the CG if an increase in stability is needed. The Mass is held towards the top of the rocket inside the nose-cone. The system is essentially in a PVC pipe. The PVC pipe is capped on both ends. The mass is added to the system in the form of metal weights. The PVC pipe is epoxied to the the centering rings, and the centerings rings are epoxied up to the inside of the nose cone shoulder to ensure the Mass Addition System is stable and doesn't move during the launch, flight, or landing of the rocket.

One End of the system

Opposite end of the system

The location of the added mass is important because it is situated towards the top of the rocket. Any addition of mass would have a bigger impact on the center of gravity (CG) of the rocket. If, after the construction of the rocket, the CG is slightly lower than was anticipated, extra mass could be added to move the CG back to what was initially calculated.

Assembled GPS Bay

4.4.3. Recovery System

Table 4.4.14: Parachute Shape Options

Shape	Pros	Cons
Toroidal	Shortest drop time due to highest coeff of drag	Typically most expensive parachute shape
Flat Sheet	Cheapest chute shape	Not very efficient. Allow a considerable amount of horizontal sway during descent
Round	very stable in descent reasonably easy to make longest drop time	Provides no lift

Table 4.4.15: Parachute material options

Material	Pros	Cons
Polythene		Not good quality Tend to burn or tear easily
Nylon / ripstop nylon	Durable Widely available Cheap Good wind resistance Good elasticity Lightweight	Sensitive to UV exposure Melts at high temperatures
¼ mil Aluminized Polyester	Thin Highly visible	
Silk	Light Thin Easy to fold and pack Fire resistant	For military silk: poor visibility
Kevlar	Extra strength recovery insurance Heat and flame resistant Abrasion resistant	May be expensive Sensitive to UV Difficult to manufacture ($$)
Terylene	Strong Heat resistant	

Selected Shape/Material

Basic, round, ripstop nylon was chosen because it has a small packing volume and is cost-effective. It has good wind-resistance and elasticity, is lightweight, and is widely available. Even though ripstock nylon is sensitive to UV exposure and melts at high temperatures, the pros outweigh the cons. Heat damage to the parachutes can be avoided by packing the parachutes properly and correctly setting up the ejection charges.

Considering Packing Volume

Packing volume is important in a rocket with several payloads. Room must be allocated correctly so each payload can function properly. The rover was removed from the subscale since it is being designed for the full-scale and wouldn't fit in the rocket. Also, the parachutes can only be compressed so much, so the rover was removed from the subscale in favor of the parachutes. This is why we chose round, ripstop nylon, since it has a small packing volume.

Ejection Charge

To start the recovery system deployment, ejection charges will be used. 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 4.4.16: 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 4.4.17: 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

Shock Cord

The table below shows multiple different properties of possible shock cords used for the recovery system. The shock cords are made of elastic, kevlar, or rubber. The Kevlar #100 has the lowest price per length and the smallest diameter, and therefore the smallest packing volume. The Kevlar Cord 300# is the strongest.

Table 4.4.18: Shock Cord Comparison

Name	**Strength (lb)**	**Stretch**	**Price/ft ($)**	**Diameter (in)**
HEAVY-DUTY ELASTIC SHOCK CORD	**45**	**100%**	**0.38**	**0.125**
Kevlar Cord 100#	**100**	**NA**	**0.33**	**0.03**

Kevlar Cord 300#	**300**	**NA**	**0.51**	**0.1**
RUBBER RIBBON	**NA**	**NA**	**0.73**	**0.375**

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 assume the velocity of the parachute will start out at zero. The equations below will show the calculations used to calculate the necessary lengths of each shock cord to absorb the total kinetic energy of the rocket.

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

$$E = \frac{1}{2} m v_a^2$$

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 590 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.

$$E = \frac{1}{2} k x^2$$

$$F_K = kx$$

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

Table 4.4.19: Shock Cord Lengths

Name	Required Stretched Main Length (ft)	Required Drogue Length (ft)
HEAVY-DUTY ELASTIC SHOCK CORD	**57**	**9.9**
Kevlar Cord 100#	**26**	**4.44**
Kevlar Cord 300#	**8.5**	**1.48**
RUBBER RIBBON	**NA**	**NA**

All options could withstand the kinetic energy of the rocket. The best option is the heavy duty elastic shock cord. The elastic shock cord will stretch more and absorb more energy than the kevlar cords. For the force put on the shock cord, the shock cord will put the same amount of force onto the bulkhead. For example, the Kevlar 300 cord would put 300 lbs of force onto the bulkhead. Therefore, to protect the structure of the airframe, the heavy duty elastic shock cord will be used at a length greater than 114 ft for the main, and 20 for the drogue. It is recommended to use a shock cord greater than 228 ft for the main, and greater than 40 for the drogue to achieve a factor of safety of 2.

Bulkhead Finite Element Analysis

The bulkhead will have a maximum load of 45 lbs. This number was taken from the maximum force the shock cord can apply before breaking. The force will be applied by the shock cord through the bolt attached to the eyebolt. The edges of the bulkhead will be fixed to the body tube. The following stress plot was obtained.

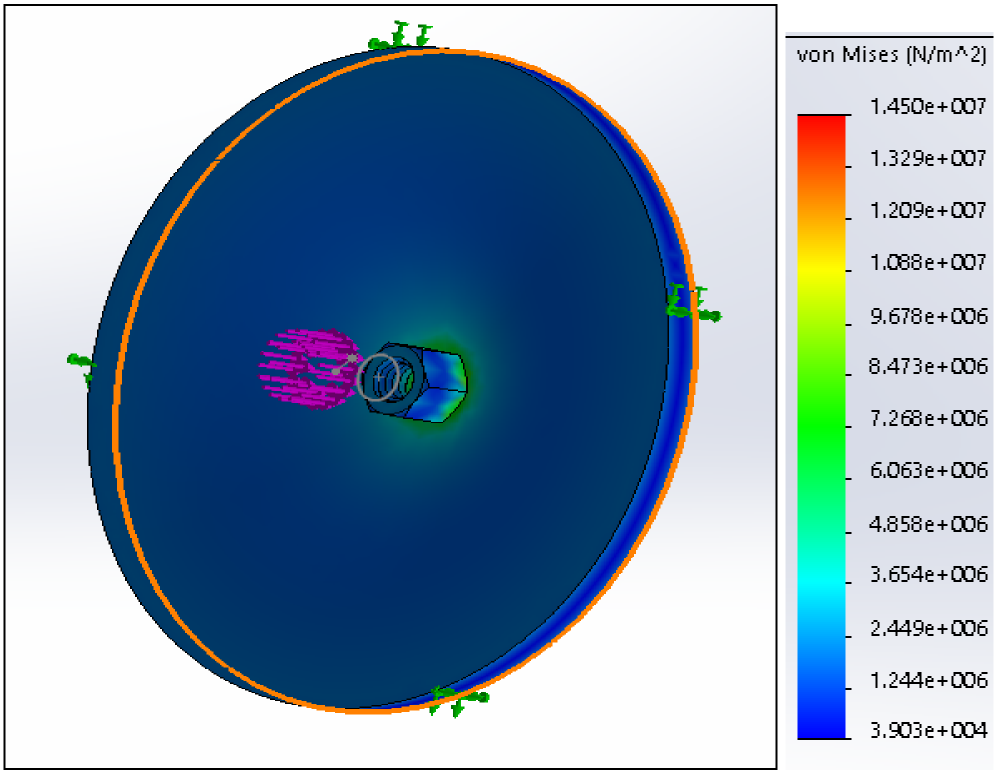


Figure 4.4.20: Bulkhead FEA Stress Plot

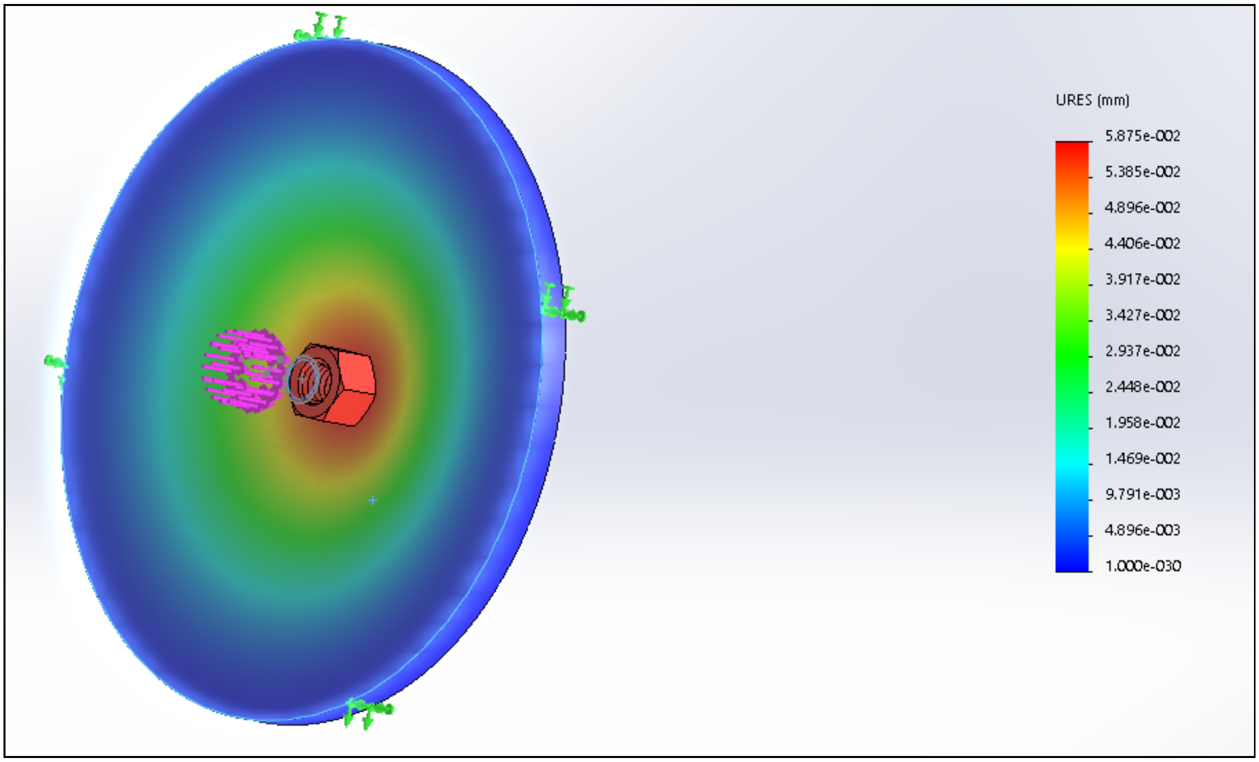


Figure 4.4.21: Bulkhead FEA Stress Plot

The factor of safety of the fiberglass G10 bulkhead was 8. The bulkhead can be considered safe to be placed on the rocket. The maximums displacement of the bulkhead would occur at the center of the bulkhead, and would be .058 mm.

4.5. Launch Vehicle Performance Analysis

4.5.1. Center of Pressure and Center of Gravity

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. According to the OpenRocket simulation, the static stability margin is always above 2.0 which is required by the competition's regulation. (Figure in section illustrates the change in locations of CP and CG, and the stability margin throughout the mission.) Below, Figure 4.5.1, illustrates the location of CG and CP at Mach 0.3. The blue circle indicates the CG and the red the CP.

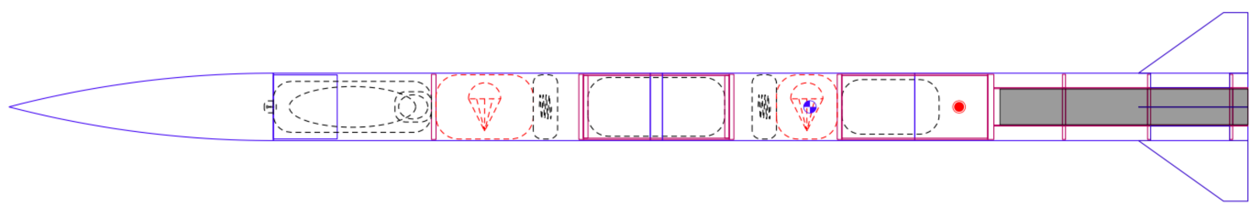


Figure 4.5.1: The locations of CG and CP of the launch vehicle

4.5.2. Motor Selection

Before running any OpenRocket simulations with different motors, the benefits and drawbacks of long and short burn time motor were evaluated. Such consideration was made since even if two motors have similar total impulse, different burn times result in different consequences namely, the running time of ATS system and the structural requirements. The shorter the burn time is, the longer coasting time the rocket have, allowing a longer control time for the ATS to attain the targeted apogee. However, since the rocket will experience a higher acceleration with shorter time, a dramatically higher stress will be applied to the thrust plate, centering rings, and the retention ring. In order to make these components endure this high stress, materials with higher strength must be used, which usually translates to choosing denser materials, increasing the overall weight of the rocket and decreasing the apogee altitude. The pros and cons of long and short burn time are summarized in Table 4.5.1.

Table 4.5.1 : Pros and cons of short and long burn time

Long burn time		Short burn time	
Pro	Con	Pro	Con
Less stress on components	Less time for ATS control	More time for ATS control	More stress on parts
Lighter motor retention system	Carrying more fuel for longer	Carrying fuel for less time	Heavier motor retention mechanism

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 5,500 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 4.5.2: Motor Simulation Results

Motor name	Total impulse	Max. vehicle mass (oz)
AeroTech L1150	784 lbf·s (3489 N·s)	501
Cesaroni L890SS	831 lbf·s (3695 N·s)	547
AeroTech L1520TP	847 lbf·s (3769 N·s)	557
AeroTech L1390G	887 lbf·s (3946 N·s)	593
Cesaroni L1355SS	905 lbf·s (4025 N·s)	622
Cesaroni L1350	962 lbf·s (4280 N·s)	656

AeroTech L1420	1038 lbf·s (4616 N·s)	726
Animal Motor Works L1400SK	1066 lbf·s (4741 N·s)	751
Cesaroni L2375-WT	1103 lbf·s (4905 N·s)	790
AeroTech L2200G	1147 lbf·s (5104 N·s)	833

With the consideration of the burn time, maximum vehicle mass to reach approximately 5,500 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. Table 4.5.3 compares the specifications of each motor and Table 4.5.4 summarizes the flight performances of the rocket (without the ATS activated) for each motor obtained by OpenRocket simulation.

Table 4.5.3: Specifications of each motor

Property	**L850 W**	**L1150 R**	**L1390 G-P**
Total impulse	831 lbf·s (3695 N·s)	784 lbf·s (3489 N·s)	887 lbf·s (3946 N·s)
Average thrust	176.85 lbs (786.67 N)	247.40 lbs (1100.49 N)	305.63 lbs (1359.49 N)
Maximum thrust	266.35 lbs (1184.80 N)	294.43 lbs (1309.71 N)	370.90 lbs (1649.83 N)
Burn time (s)	4.70	3.17	2.91
Gross mass (oz)	129.6	129.6	136.7

Table 4.5.4: Flight performance of the launch vehicle with different motors

Property	**L850 W**	**L1150 P**	**L1390 G-P**
Apogee altitude (ft)	5090	4732	5535
Rail exit velocity (ft/s)	61.8	67.7	70.3
Maximum velocity (ft/s)	585	600	679
Maximum acceleration (ft/s^2)	209	235	298
Time to apogee (s)	18.3	17.4	18.4

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 5,500 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 below in Figure 4.5.2 and in Table 4.5.5, respectively.

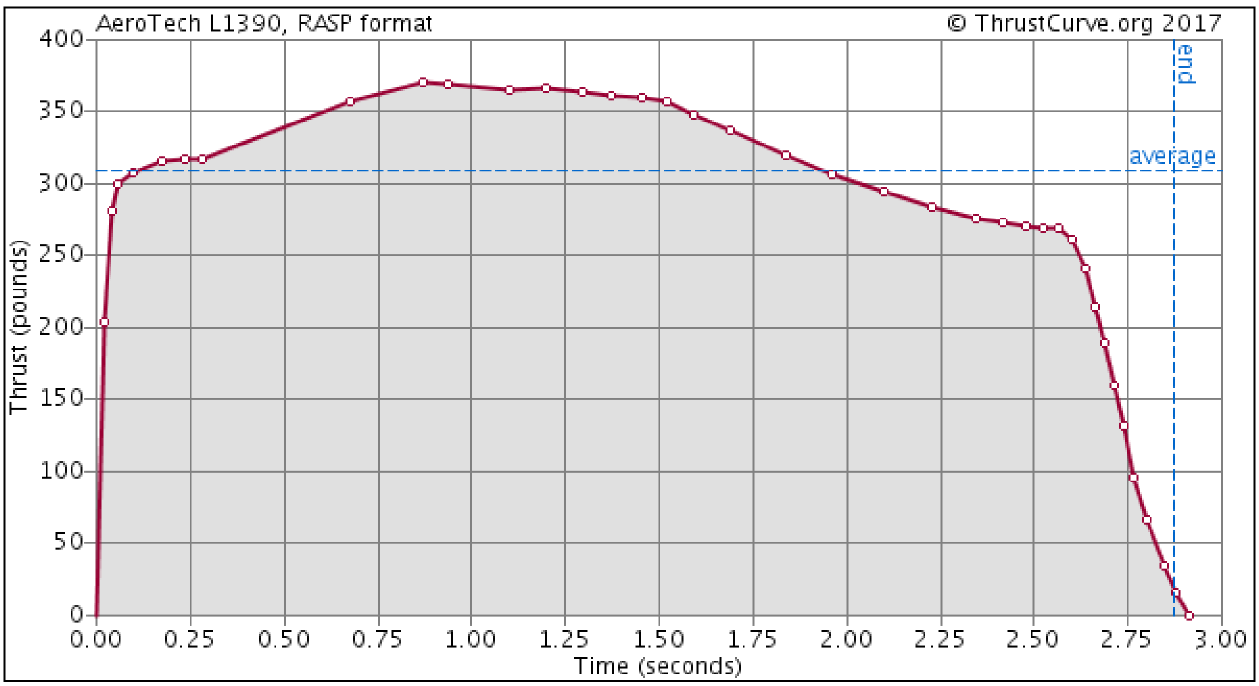


Figure 4.5.2: AeroTech L1390 G-P Thrust Curve

Table 4.5.5: AeroTech L1390 G-P specifications

Property	**Value**
Diameter	2.95 in (75.0 mm)
Length	20.87 in (530.10 mm)
Total mass	136.72 oz (3876 g)
Propellant mass	69.60 oz (1973 g)
Average Thrust	305.63 lbs (1359.49 N)

Maximum Thrust	370.90 lbs (1649.83 N)
Total Impulse	887 lbf·s (3946 N·s)
Burn time	2.91 s

4.5.3. Kinetic Energy at Landing

The kinetic energy of a mass is given by the following equation:

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

Where T is kinetic energy, v is velocity, and m is mass. The velocity at landing according the openrocket is 12.0 ft/s. Predictions of the masses of the nosecone/rover, ATS/booster after motor burnout, and avionics bay are shown in the following table, along with their respective calculated kinetic energies.

Table 4.5.5 Kinetic Energy for Rocket Modules

Module/Modules	Mass (oz)	Mass (lb)	Kinetic energy (ft*lbf)
Nosecone/Rover	136.1	8.51	59.75
ATS/Booster	266.02	16.6	70.665
Avionics bay	84.7	5.3	32.145

The kinetic energy of the rocket at landing is the combination of these three components. 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. Therefore, the total kinetic energy of the rocket is 114 ft*lbf.

4.5.4. Altitude Predictions

Formulaic Calculations of Rocket Flight Profile

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

1) Motor burning

   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 4.5.1

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 4.5.2

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 4.5.3

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 4.5.4

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

Equation 4.5.5

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 4.5.6

2) Coasting

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

$$M_C = m_r + m_m - m_p$$

Equation 4.5.7

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 4.5.8

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 4.5.9

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

Equation 4.5.10

Flight Simulations

As a primary tool for flight simulation, the team uses the OpenRocket software. Based on the material densities of each component, the gross mass of each section and of the entire launch vehicle were calculated. Although certain masses such as the epoxy were not reflected with perfect accuracy in the OpenRocket model, the ATS system will be designed such that the launch vehicle will still be able to attain the target apogee. The gross mass along with the length of each section of the rocket are summarized below in Table .The mass value of the booster section includes the mass of the motor and the propellant.

Table 4.5.6: Launch vehicle section mass and length breakdown

Section	Gross Mass (oz)	Length (in)
Nose Cone	20.96	21.75
Rover Section	142.34	31.00
Avionics Bay	84.62	12.75
ATS Section	83.18	20.75
Booster Section	258.57	27.40
Total	589.67	101.9

The OpenRocket model of the full scale rocket was created to verify the equations 4.5.1 through 4.5.10 presented in the previous section. Figure 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 in Table . 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.

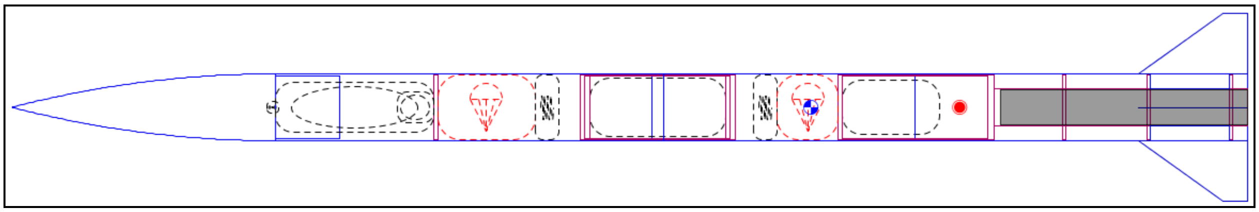


Figure 4.5.3 OpenRocket model of the full scale launch vehicle

Table 4.5.7: Flight specifications of the launch vehicle

Property	Value
Center of Gravity	65.879 in
Center of Pressure	78.148 in
Apogee altitude	5532 ft
Maximum velocity	679 ft/s
Maximum acceleration	237 ft/s^2
Rail exit velocity	70.3 ft/s
Thrust-to-weight ratio	8.39
Ground hit velocity	12.0 ft/s

The OpenRocket model is designed so that the apogee altitude of the launch vehicle without the ATS system activated would be approximately 5,500 ft. 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 will prove that the motor selection was appropriate and that vehicle safety requirements are met.

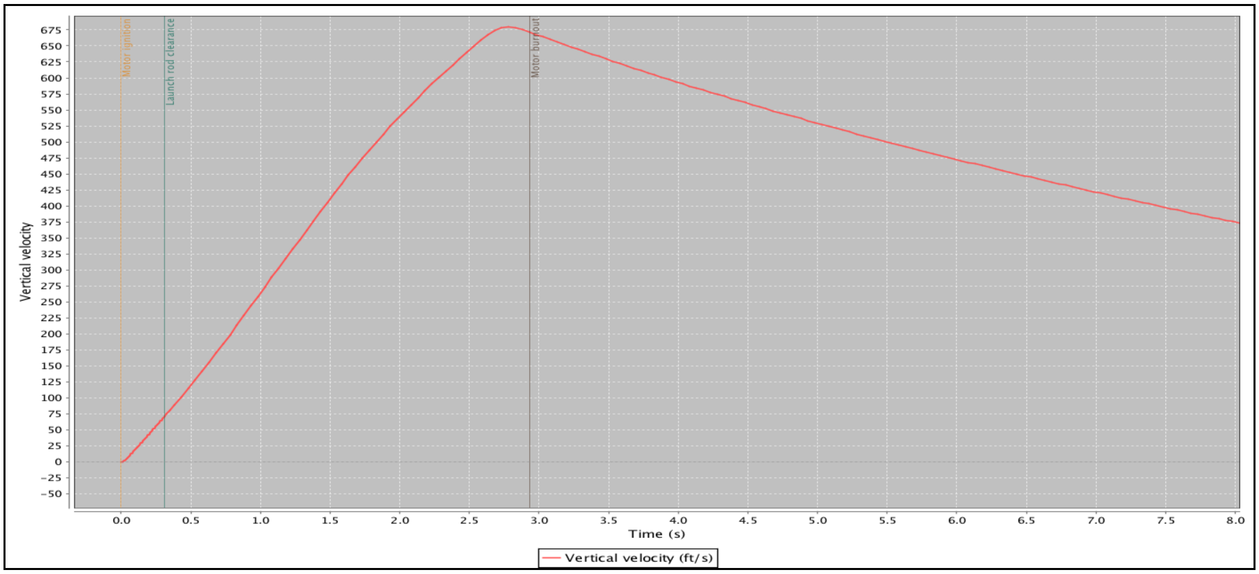


Figure 4.5.4 Vertical velocity vs time (until motor burnout)

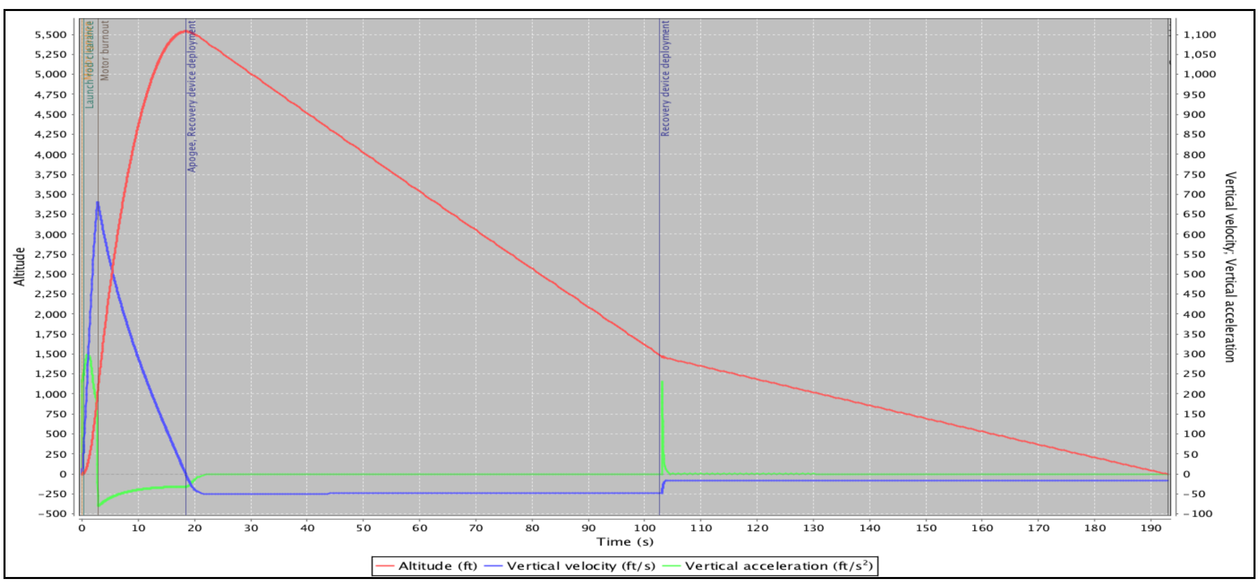


Figure 4.5.5 Altitude, vertical velocity, acceleration vs time

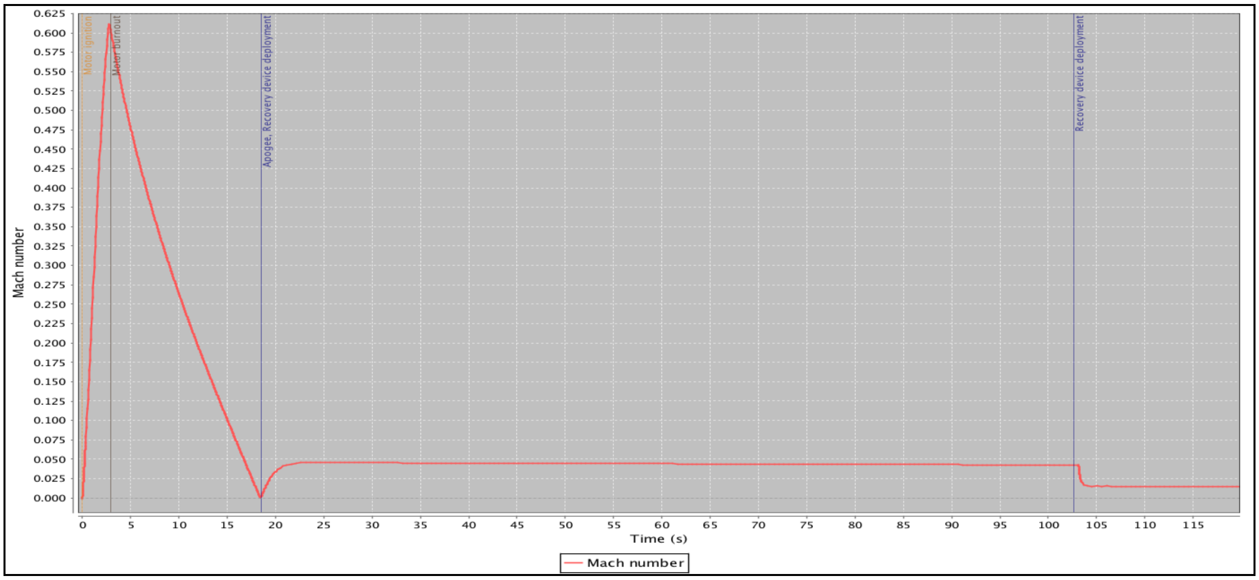


Figure 4.5.6 Mach number vs time

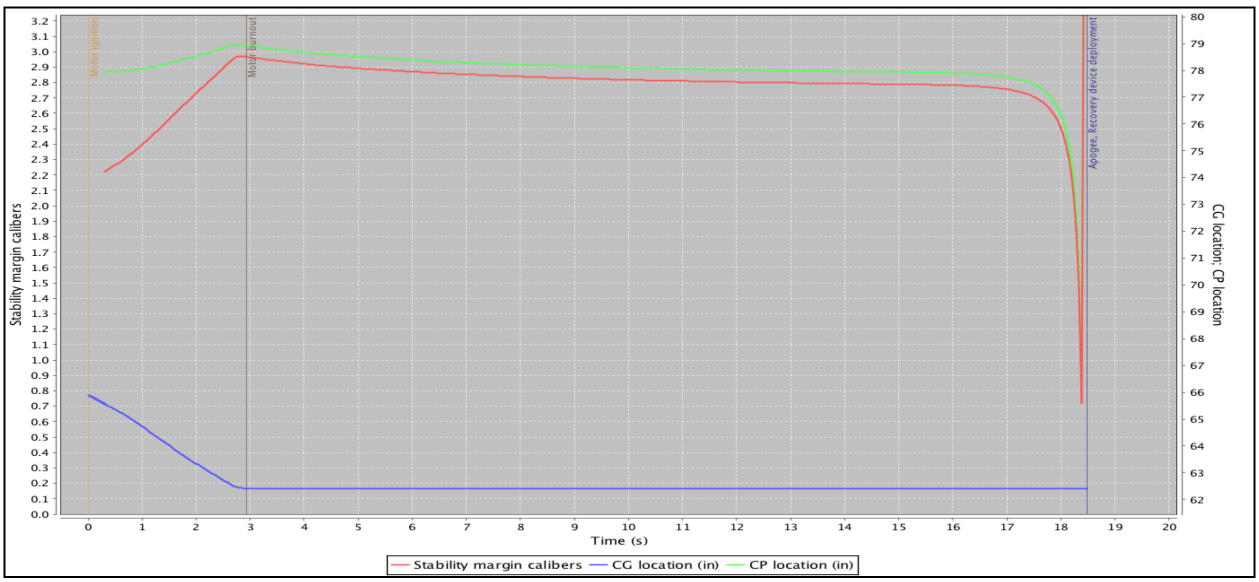


Figure 4.5.7 Stability margin, CG location, CP location vs time

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 that the vehicle ascents vertically without any wind, and from the apogee, it experiences a wind with constant. Another assumption is made that 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 4.5.11

Based on Equation 4.5.11, drift due to 0, 5, 10, and 15 ft/s were calculated, and the results are summarized in Table .

Table 4.5.8 Drift distance of the launch vehicle due to different wind speeds

Wind speed (ft/s)	**Drift distance (ft)**
0	0
5	722.5
10	1445
15	2167.5

To verify that the hand calculations are accurate, OpenRocket simulations with the various wind speeds were conducted. The values obtained from Equation 4.5.11 and the OpenRocket simulation were similar. The two methods elucidated that the launch vehicle's recovery system will meet the requirement that the recovery area will be 2,500 ft radius from the launch vehicle until 17 ft/s. Beyond this wind speed, the launch vehicle will not be recovered in the required area. The following figures depicts the lateral displacement of the launch vehicle with the different wind speeds.

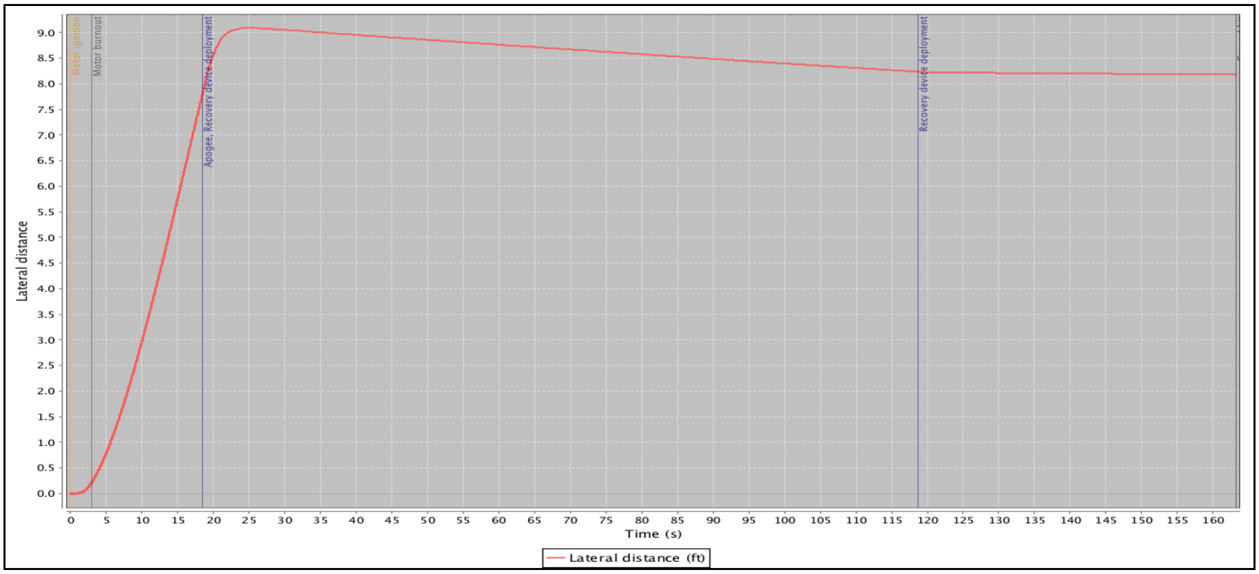


Figure 4.5.8 Lateral distance vs time when 0 ft/s wind is applied to the launch vehicle

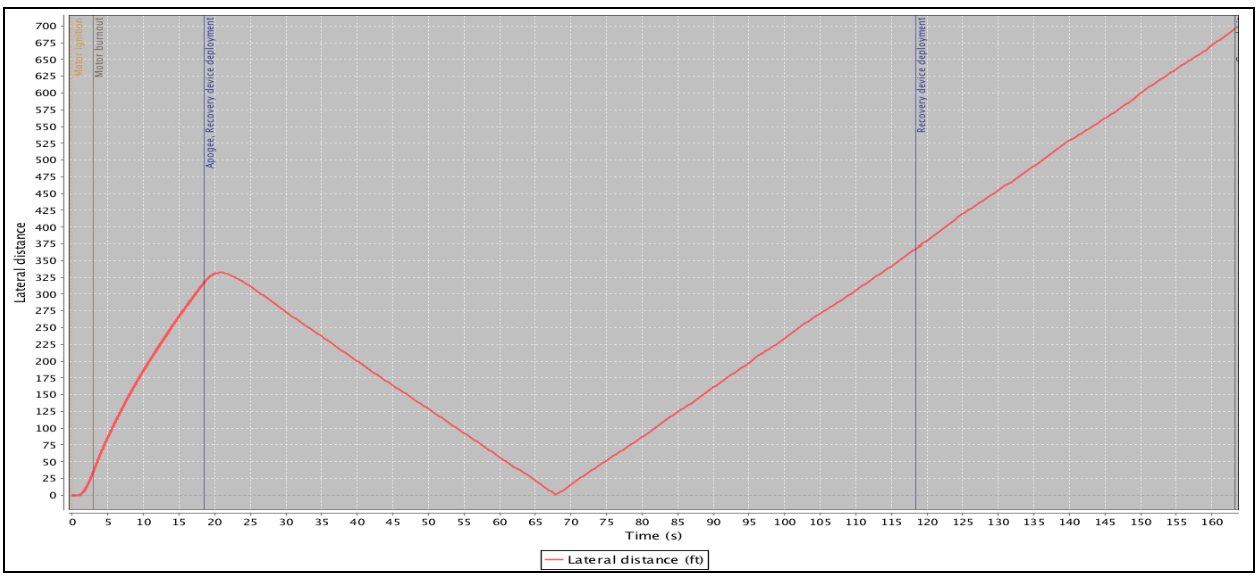


Figure 4.5.9 Lateral distance vs time when 5 ft/s wind is applied to the launch vehicle

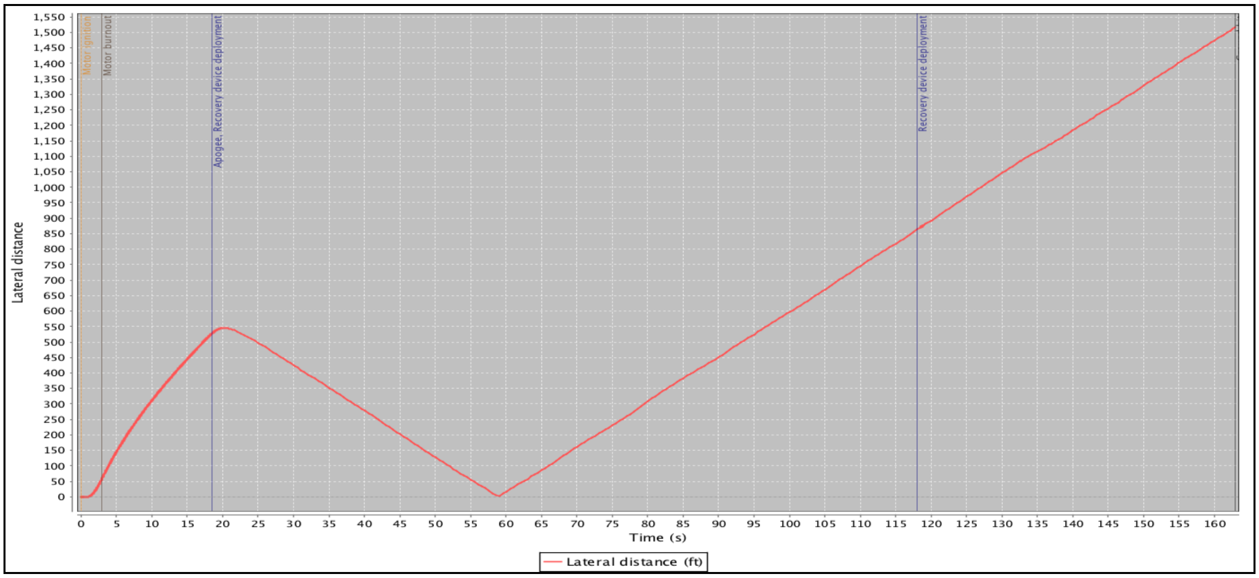


Figure 4.5.10 Lateral distance vs time when 10 ft/s wind is applied to the launch vehicle

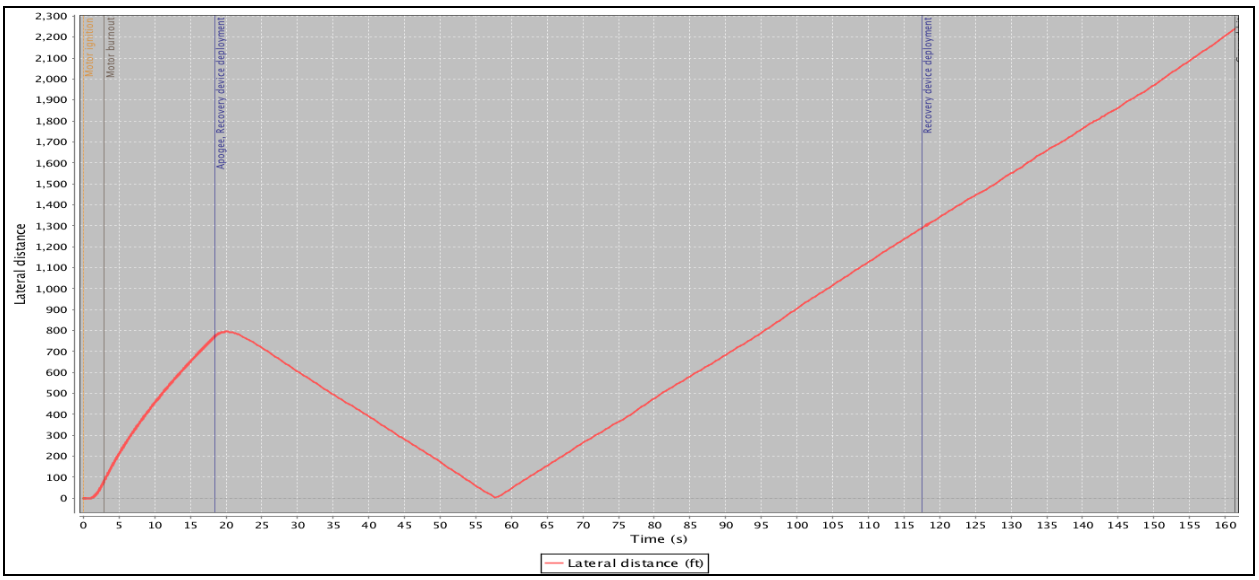


Figure 4.5.11 Lateral distance vs time when 15 ft/s wind is applied to the launch vehicle

5. Apogee Targeting System (ATS)

5.1. ATS Overview

5.1.1. Mechanism Overview

The purpose of the Apogee Target System (ATS) is to adjust the apogee of a rocket by providing additional drag force after the burnout. Considering the unpredictability of external factors such as wind gust that cannot be simulated, it is crucial to a system that can adjust any deviation from ideal flight. Even though the rocket motor was chosen to address this problem, since the rocket motor can address only by providing more specific impulse than needed, the ATS is crucial to maximize the control over the rocket.

Variable drag force is provided by adjusting surface areas by actuating flaps, which are controlled by motors and integrated board. Because it is not possible to communicate with the rocket during flight, a circuit has to be integrated to control the motors when needed by itself. The board was programmed to adjust flaps to match the actual flight profile to the ideal flight profile.

5.1.2. Requirements

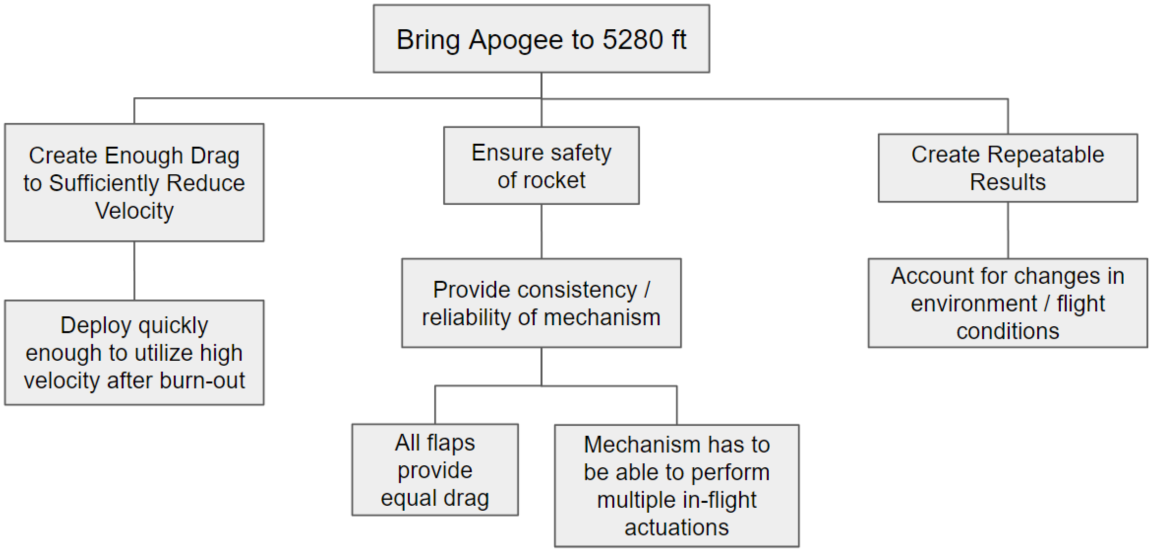


Figure 5.1.1 ATS Function Tree

The figure above is the function tree of ATS. Even though the main purpose of ATS is simply bring apogee to 5280 ft, there are many sub functions needed to do so efficiently. First subfunction the ATS has to create enough drag. Since the maximum surface area of the ATS is constant, the ATS must be quickly deploy to take a full advantage of fast velocity and high drag. Second subfunction of ATS is to ensure the safety of the rocket. Even though it is explicitly mentions, the ATS should not affect safety of the rocket. To do so, the mechanism must be able to provide consistent and balanced drag throughout the flight. Last subfunction is that the mechanism should adapt to different situations and take necessary actions by itself because communication with rocket is not possible during the flight.

Table 5.1.1 ATS Solution Table

	Solutions			
Function	**1**	**2**	**3**	**4**
Deploy quickly enough to utilize high velocity after burn-out	Use high power DC motor	Use pneumatic motor	Use high powered servo motor	Use solenoid motor
All flaps provide equal drag	Use microcontroller to determine and adjust positions of the flaps	Make system that only can fully open or close the flap		
Mechanism has to be able to perform multiple in-flight actuations	The motor must be bidirectional	Have a battery large enough to allow for several actuations	Use compressed air tank to drive pneumatic actuator	
Account for changes in environment / flight conditions	Make velocity adjustment towards the end of coasting	Maximize ballistic coeff to minimize drag effects of wind		

After the function of ATS was set, the solution table was built. In the table, possible solutions are given for each function stated in function tree. The function tree and solution table became bases for concept development and evaluation.

Three initial designs that satisfies both function tree and solution table were created.

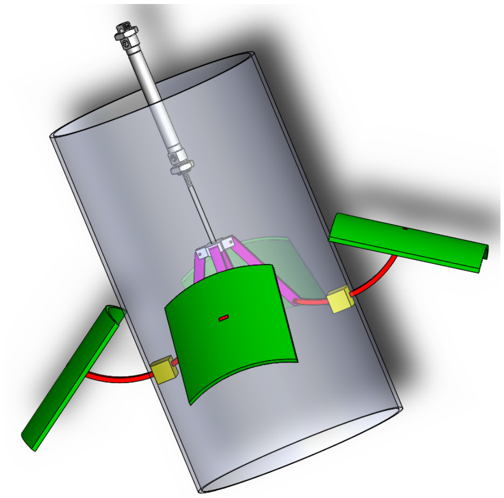


Figure 5.1.2 Design 1

The unique features of this design is that the flaps are vertical, the system is actuated by pneumatic motor. This concepts was approved for further evaluation as the flaps can have large surface area and does not affect the structural integrity of the body tube.

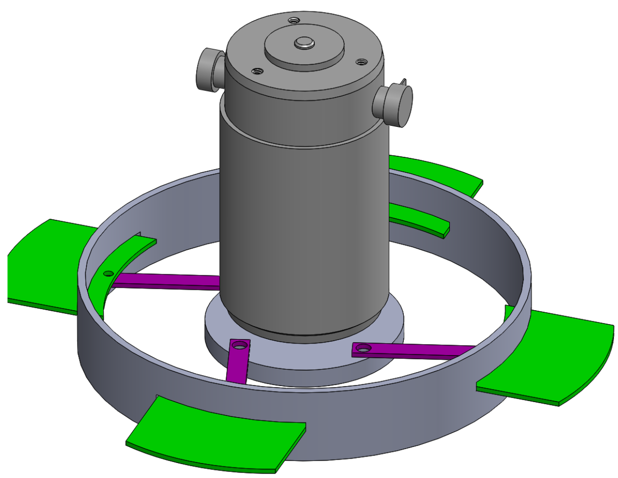


Figure 5.1.3 Design 2

This concepts of ATS extends the flaps horizontally, giving advantage over the first concept as it does not need strong motors to actuate the motion because the motor is not pushing the flaps against drag force. Therefore it was approved for further evaluation.

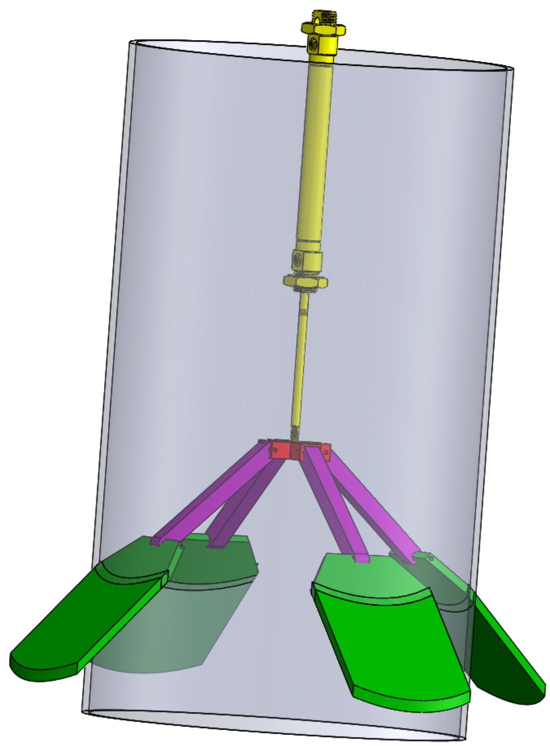
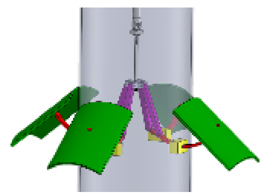
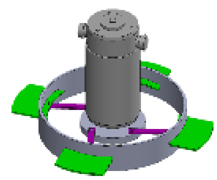
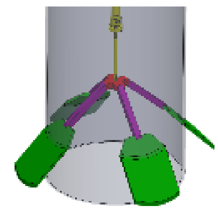


Figure 5.1.4 Design 3

This concept was variation of the first concept. After thorough evaluation of the first concept, the first concept revealed one of its critical weakness, which is force provided by pneumatic motor on top of the drag force pushing down the metal slit, a yellow part on the figure. By making the motion of the flap linear, it reduced the stress on any of the parts on the body tube; therefore, it was approved for further evaluation.

To choose the final concept, an evaluation table was used; the criteria are based on the feasibility and functionality which is based on the function tree; the feasibility was emphasized during the evaluation due to limited resources. After careful evaluation, the second concept was chosen for the final design.

Table 5.1.2 ATS Evaluation Table

Concept		1		2		3	
Criteria	**Importance**						
Low Weight	5	1	5	2	10	1	5
Vertically Compact	7	2	14	3	21	1	7
Deployment Speed	10	3	30	2	20	3	30
Low Actuation Force Needed	10	1	10	3	30	2	20
High Drag per Surface Area	8	1	8	1	8	3	24
High Maximum Drag Force	8	3	24	2	16	2	16
High Manufacturability	8	1	8	3	24	2	16
Low Complexity	6	1	6	3	18	2	12
Ease of Maintenence	5	1	1	3	3	2	2
Inexpensive	2	1	2	3	6	2	4
Low Software Complexity	3	3	9	1	3	3	9
Total Possible:	**216**						
Total			117		159		145
Relative Total			54.17%		73.61%		67.13%
Scores Range: 1 - 3 (*1 = bad, 3 = great*)							

A requirements table was created to further develop the second (chosen) concept.

Table 5.1.3 ATS Requirements Table

Requirement	Verification	Success Criteria
All components in ATS must not deform as a result of drag force	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	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	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	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	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 prevent instabilities	Analysis The model of the rocket will be generated using Openrocket	The location of ATS on Open Rocket Model must be below CG
Motor must be able to fully retract and extend all flaps without any hinderance	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	Test The motor will be actuated multiple times	The flaps shoud retract and extend at the same speed
ATS must not generate any moment on the vehicle when actuated	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	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	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	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

One of the most important requirements is a factor of safety of 2 for all components. Since this must be met during the design process, simulation were completed; simulations gave a deep insight on the possible improvement of the design for the full scale model. The approximate maximum drag force is 25N. The simulation result is the following. It is assumed that each component is also under 25N and there is no contact surface that provides normal force.

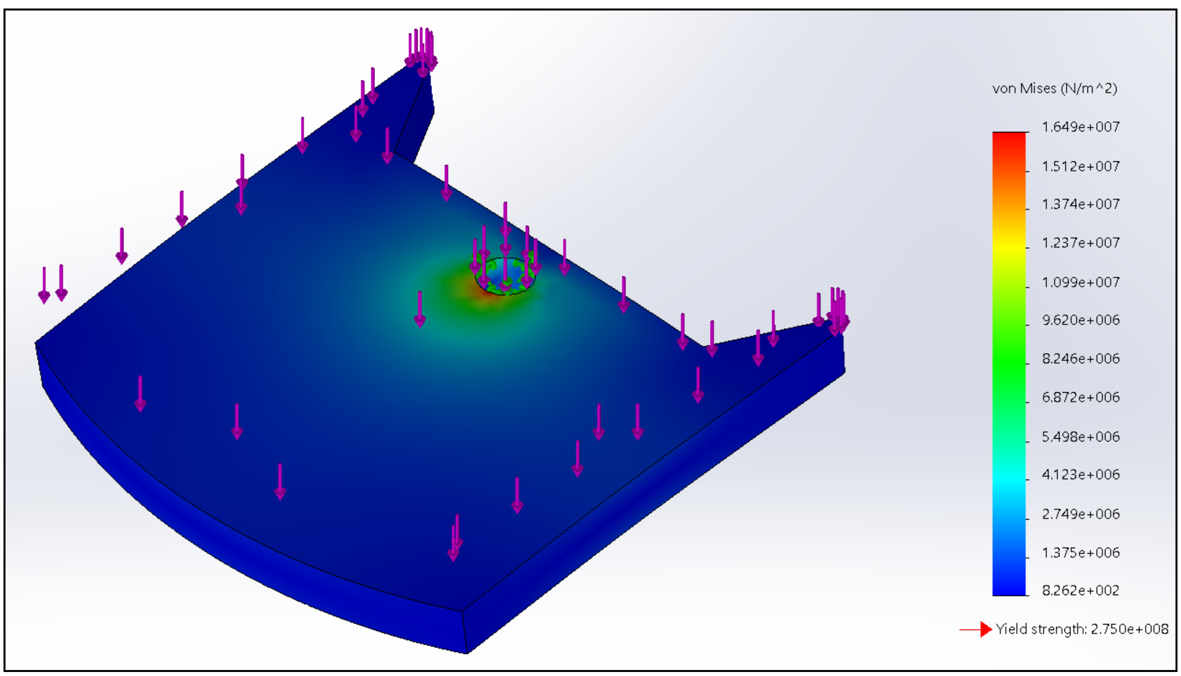


Figure 5.1.5 Force Analysis on The Flap

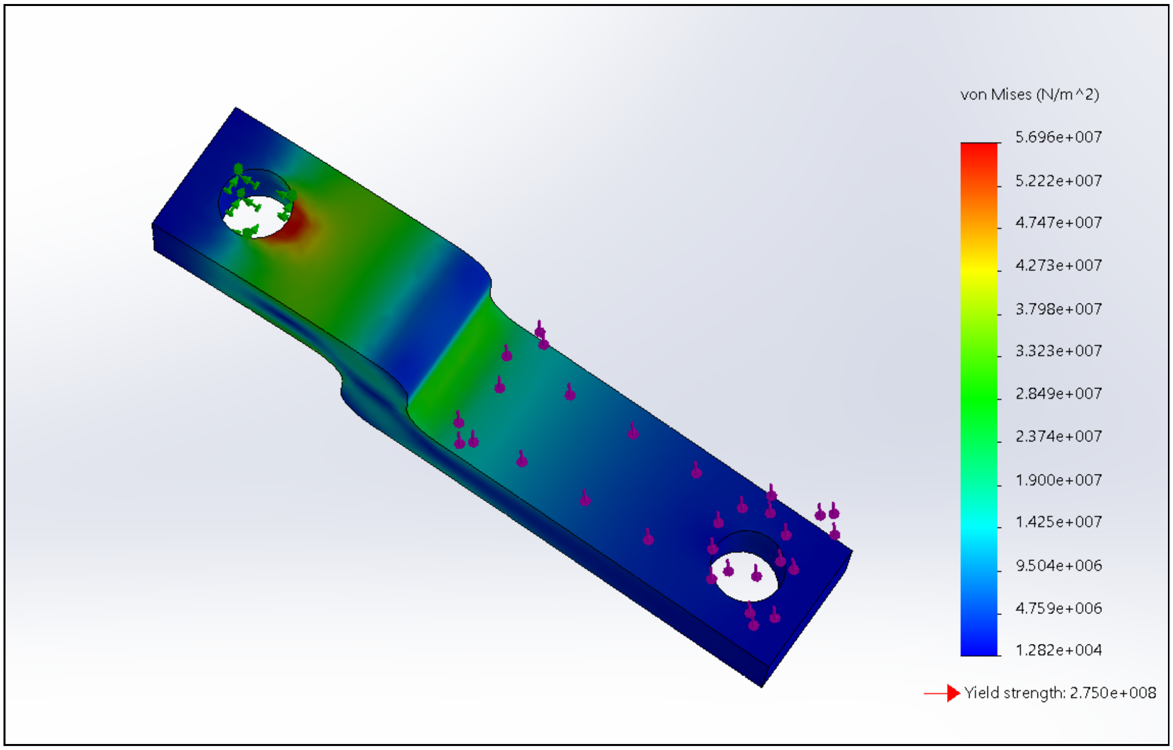


Figure 5.1.6 Force Analysis on The Angled Arm

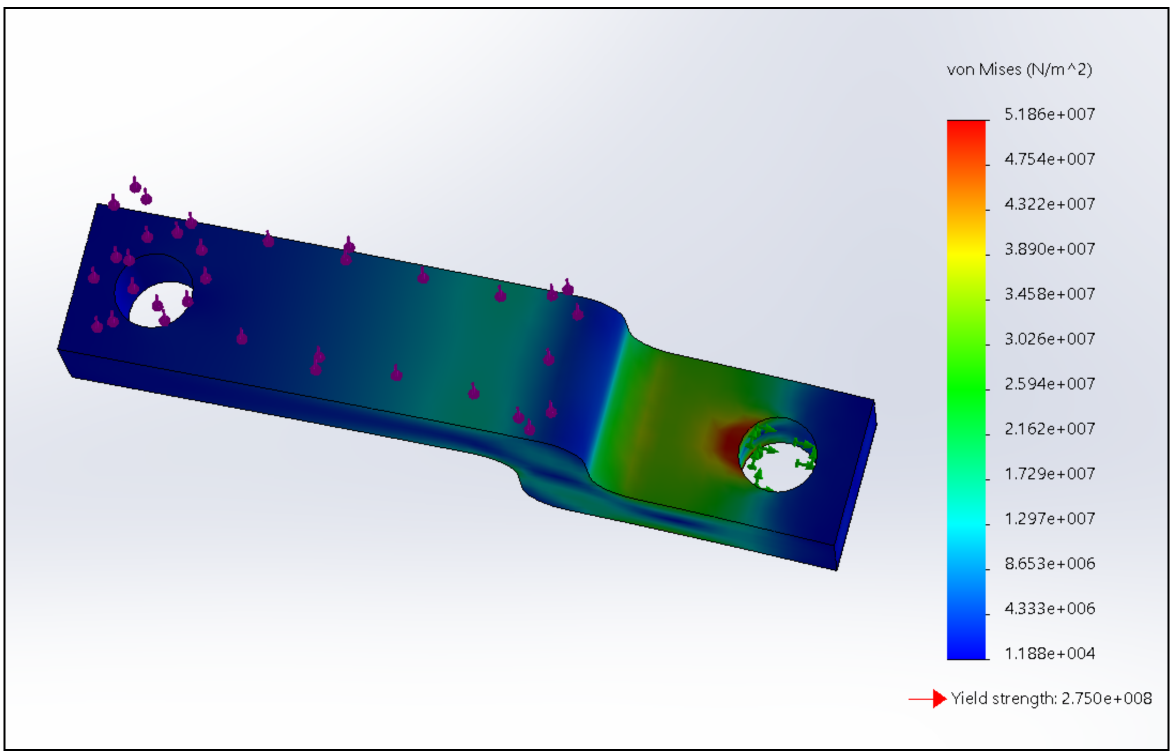


Figure 5.1.7 Force Analysis on The Angled Arm (different configuration)

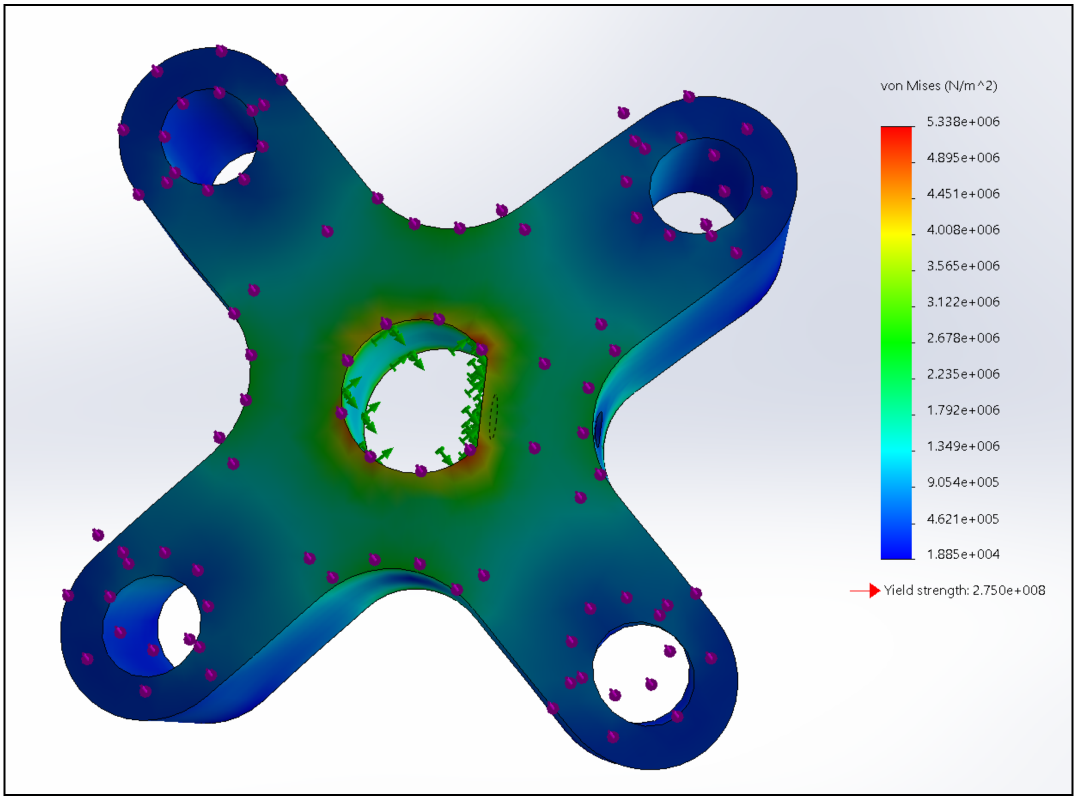


Figure 5.1.8 Force Analysis on The Coupler

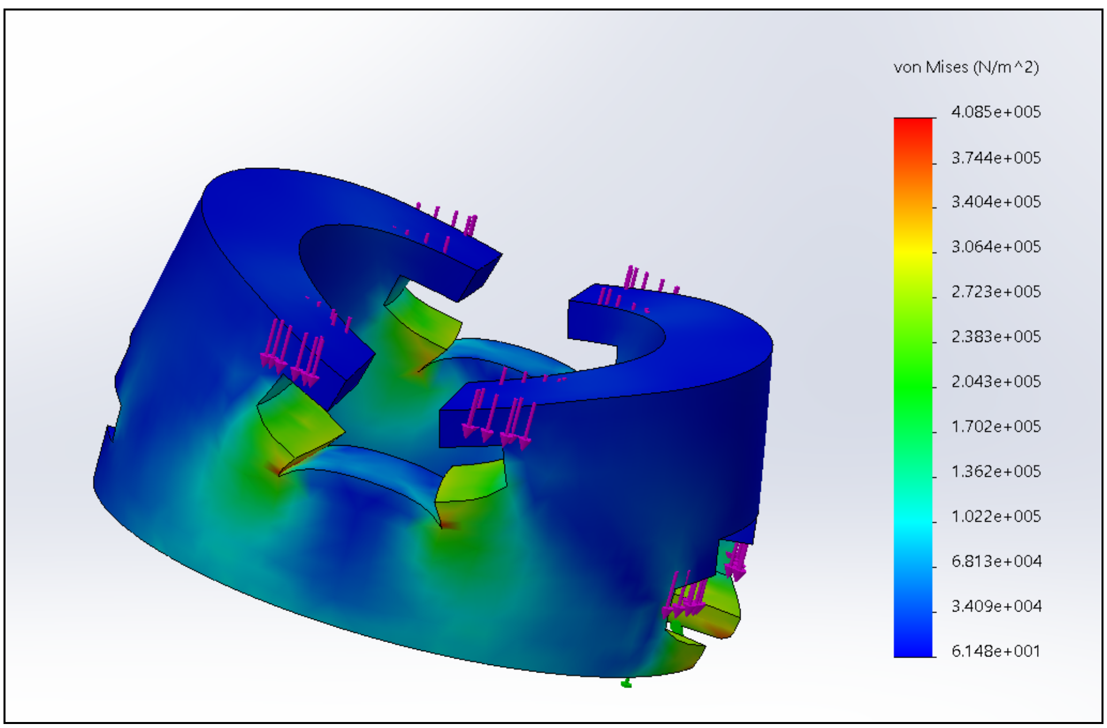


Figure 5.1.9 Force Analysis on The Flap Support

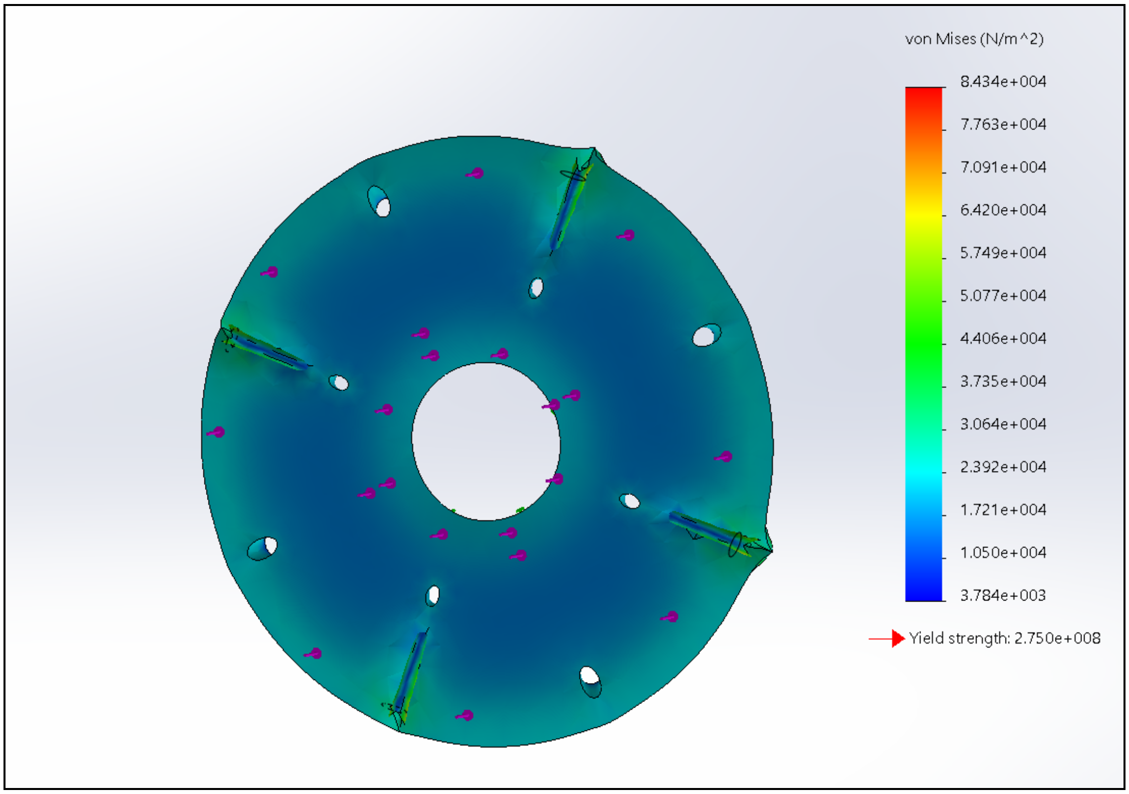


Figure 5.1.10 Force Analysis on The Motor Holding Plate

Analysis on the partially assembled ATS revealed that as a whole system, the components will not be damaged. However, since this analysis was under assumption that the flaps lean against the flap support, the component that had problem in the individual analysis might have to be revised.

5.2. ATS Mechanical Design

5.2.1. Design Breakdown

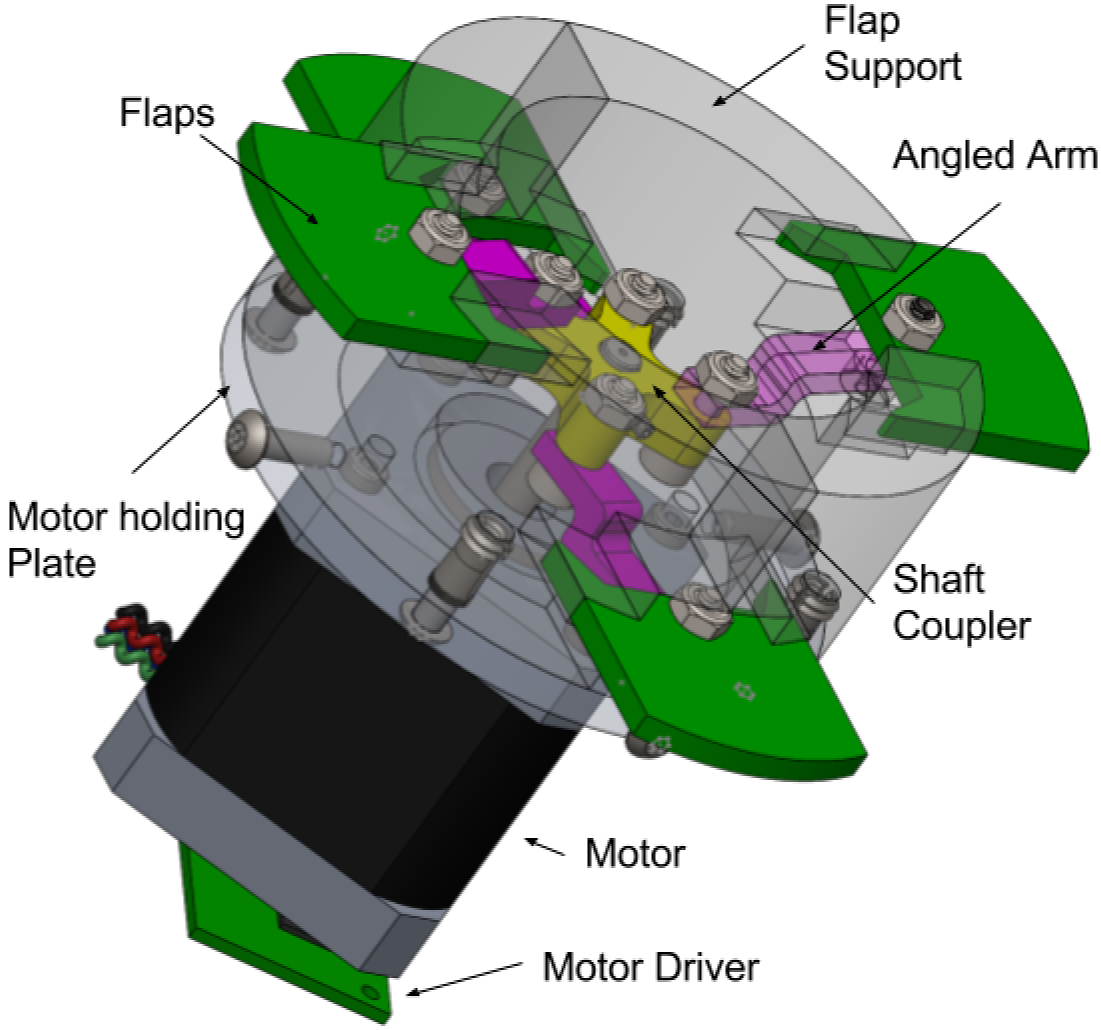


Figure 5.2.1 Final Design for ATS

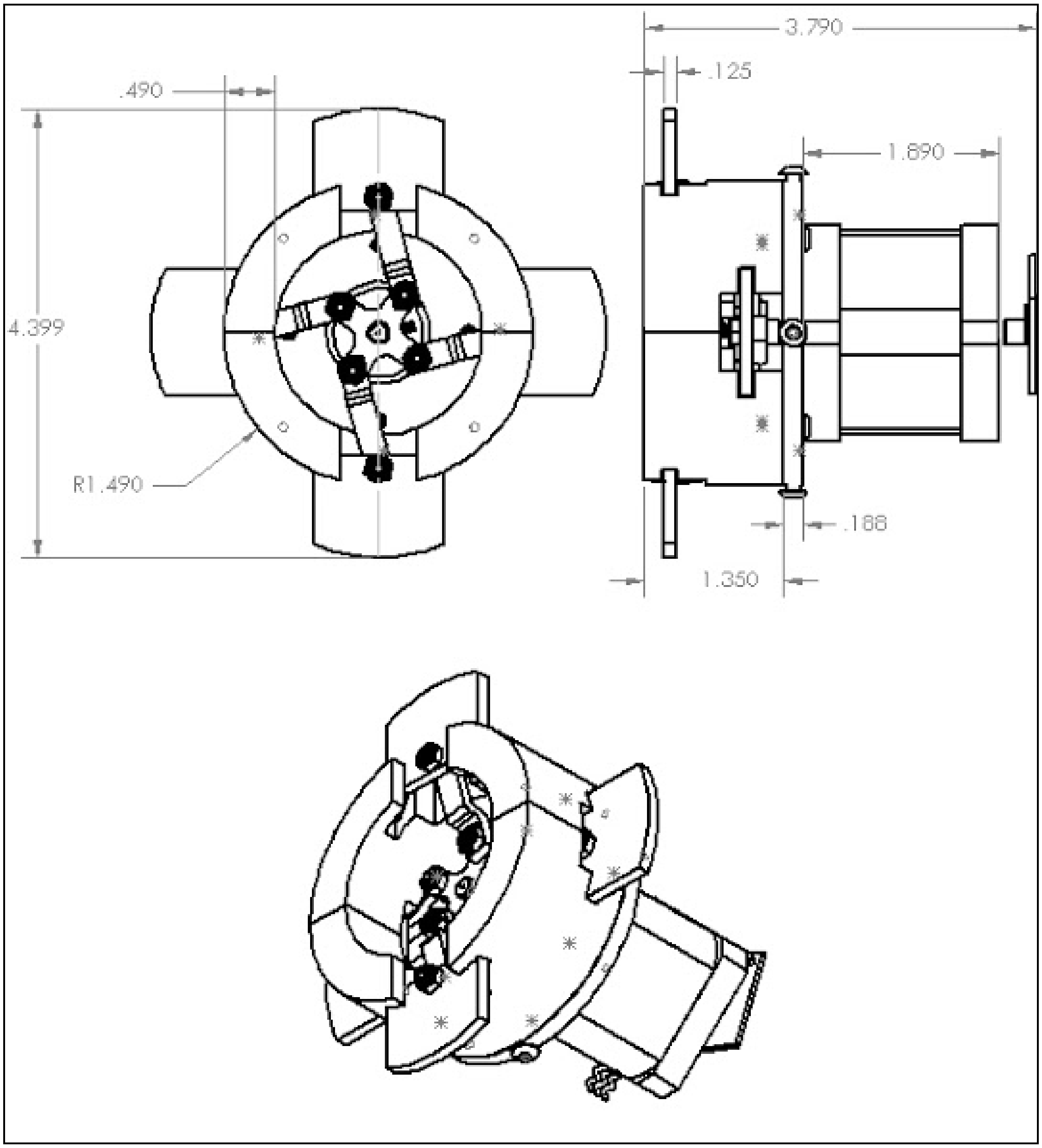


Figure 5.2.2 Sketch of the Final Design for ATS (subscale)

The figures presented above are the CAD model and sketch of final design for the ATS. ATS is composed of four flaps, four angular arms, flap support, coupler motor holding plate, motor, its driver and bolts and nuts which connects components in ATS. Figure on the next page is the detailed drawing of the flaps, angular arms, flap support, coupler and motor holding plate, which are manufactured.

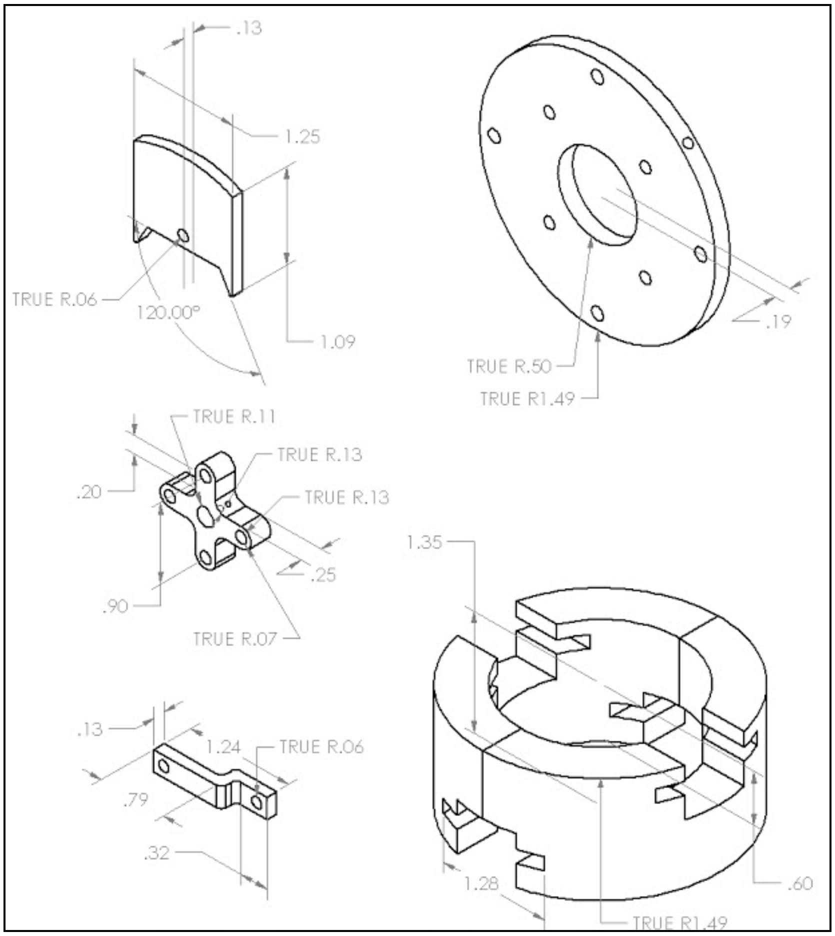


Figure 5.2.3 Detailed Drawing of the Components in ATS (subscale)

In ATS, flaps provide extra surface area when needed. Front side of ATS has a curve which matches the curvature of the body tube. It also has two tabs at the end; these tabs prevent flaps to over extended and get stuck. Each flap has approximately 0.13 inch square of area. The coupler has the D shaped hole that matches with the shape of the shaft on the motor. Four holes on the arm of the couplers connect coupler to the angled arms. Angled arms are designed to maximize the area of flaps by preventing flaps from overlapping. All these components are supported by the flap support. The flap support provides surface that flap can lean against so that the coupler or the angled arm will not receive too much stress during flight. The flap support that four slits where the flap comes out. It is supported by the motor holding plate which connects flap support and the motor. The motor needs the motor holding plate because its size is too small that the flap support cannot be put top of the motor. The material used for the flap support, flaps, angled arms, coupler and motor holding plate are made from Aluminum 6061 because of its light weight, high tensile strength and cheap price. The thickness of these parts are based on the requirement that the factor of safety must be bigger than 2, limitation of waterjet manufacturing and available aluminum sheet thickness.

5.2.2. Assembly Procedure

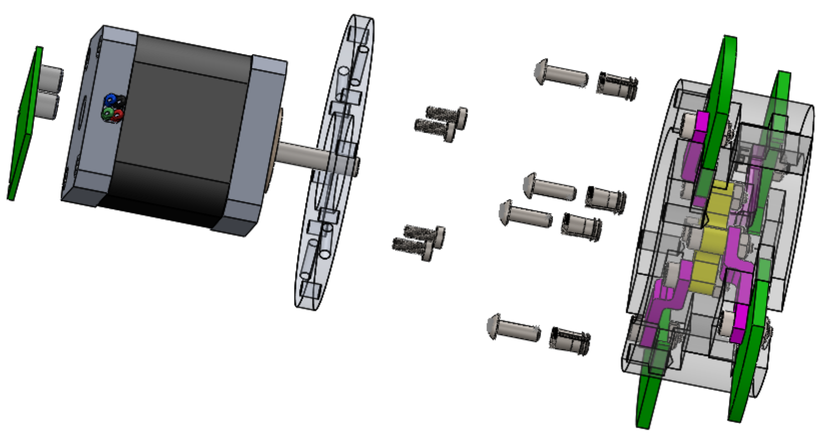


Figure 5.2.4 Lateral Exploded View of ATS

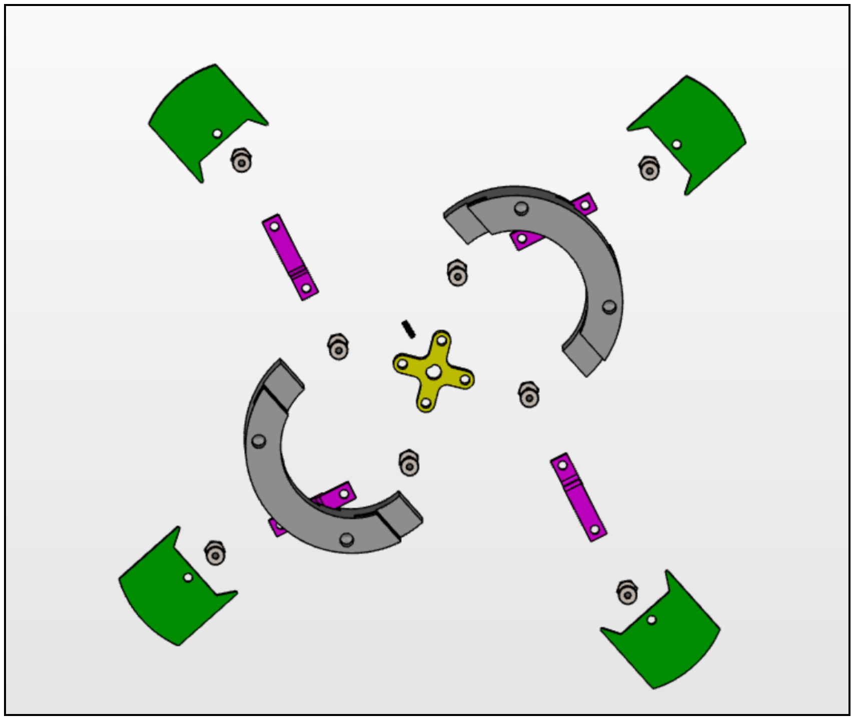


Figure 5.2.5 Exploded view of ATS

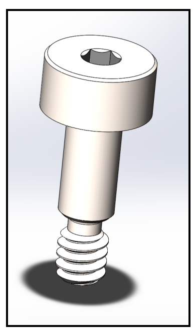


Figure 5.2.6 Bolt for Angled Arms and Flaps

The flaps, angled arms and the coupler are held by the bolt shown above. This bolt allows the horizontal movement of flaps, and angled arms.

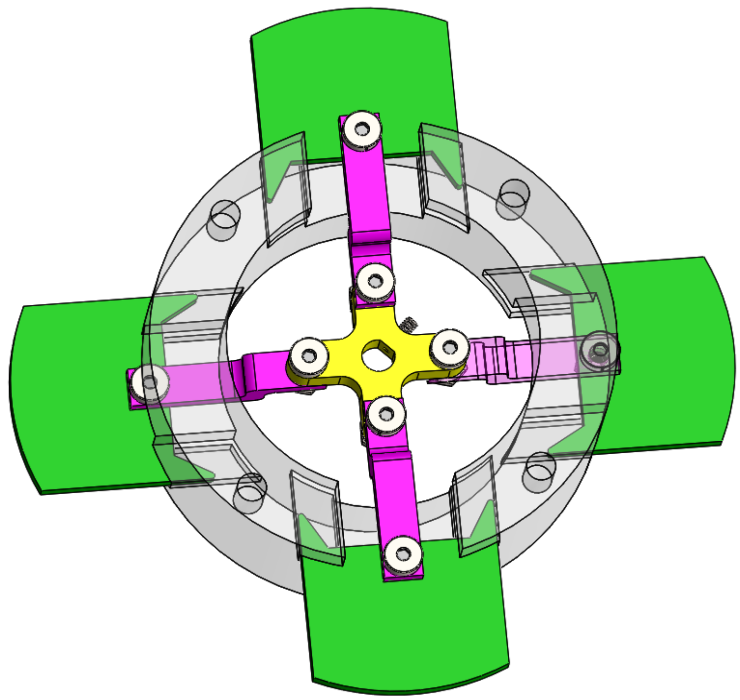


Figure 5.2.7 Fully Extended Figure

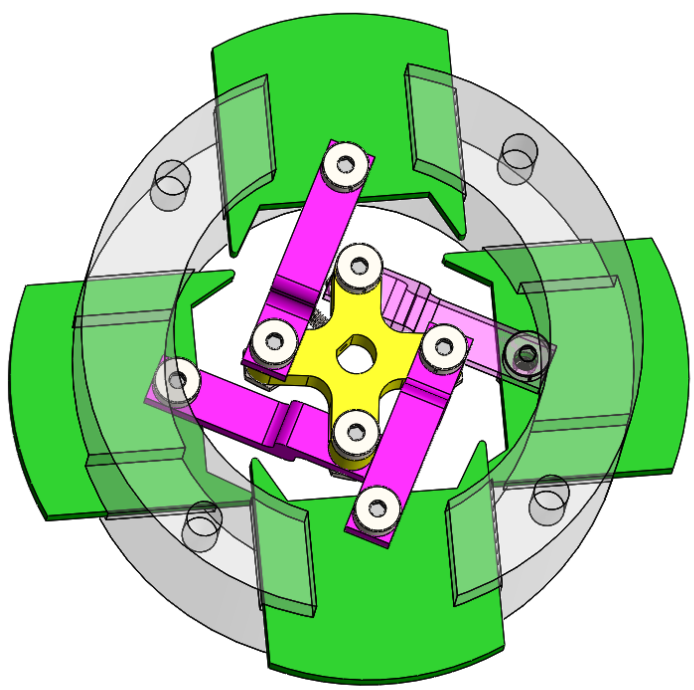


Figure 5.2.8 Fully Retracted Configuration Figure

The motor holding plates, motor and the flap support is connected with regular screws with different sizes. Since the flap support only has pilot hole without threads, inserts are used to hold screws in place. As mentioned above, because angle arms and freely rotate horizontally, when the coupler rotate, they can push and pull the flaps.

The assembly of ATS started by connecting flaps and angled arms with the bolts. Then the coupler is connected to all four arms. The coupler is connected to motor shaft and fixed by a small screws. Before the flap support is assembled, The motor holding plate is fixed to the motor. After, the whole system sits inside flap support and is adjusted so that the flaps can come out of slits on the flap support. Then the motor holding plate and the flap supported is fixed with screws. Since it is difficult to print screw holes, press fits were used so that the screw can be fixed to the flap support.

5.2.3. Motor

Table 5.2.1 Motor Pros and Cons

	Types of Motor				
	DC motor	**Pneumatics**	**Servo Motor**	**Solenoid Motor**	**Stepper Motor**
Pros	Position control	High force	Accurate position control	High force	Easy position control
		Rapid actuation		Rapid actuation	No gearing required
Cons	Slow	Requires air tank	Slow actuation	Small stroke length	Low torque at high speed
	Requires gearing	Heavy	Low torque	High power draw	Low efficiency

For the final design, a stepper motor is used because it could have different configurations which allows precise control of drag force and it can be controlled easily relative to other motors Even though the motor is relatively weak compared to other types of motor, it should be good enough because the interlocking parts and surfaces are lubricated.

5.2.4. Stepper Driver

Table 5.2.2 DRV8825 Stepper Motor Driver Specifications

Property	Value	Significance
Size	0.6″ × 0.8″	Small footprint, space-efficient
Weight	1.6 g	Lightweight, small impact on mass
Minimum operating voltage	8.2 V	Rather high minimum voltage
Maximum operating voltage	45 V	Large upper limit of voltage
Continuous current per phase	1.5 A	Large current per phase
Maximum current per phase	2.2 A	Large current per phase
Minimum logic voltage	2.5 V	Works with 3.3V logic
Maximum logic voltage	5.25 V	Also works with 5V logic
Microstep resolutions	full, 1/2, 1/4, 1/8, 1/16, and 1/32	multiple options on resolution
Reverse voltage protection	N	Need to be careful with reverse voltage

Bulk packaged	N	Lightweight packaging, easy to damage
Header pins soldered	N	Soldering required

The DRV8825 Stepper Motor Driver was recommended for use with the chosen motor by Pololu Robotics and Electronics. The driver supports the voltages and currents necessary for successful operation of the stepper motor. Care must be taken as the driver has little protection from faulty circuitry and does not come pre-soldered.

Several problems were faced when integrating the stepper motor into the system. The stepper motor has a relatively high minimum operating voltage compared to the rest of the ATS circuits and and therefore imposes new demands in power. Some of the problems included not supplying enough current, not supplying enough voltage, using a power source with an overly limited capacity, and physical integration via soldering into the system, as wires must travel through the body of the rocket to the ATS compartment from the avionics bay. Other than the obviously necessary step and directions pins, the driver also requires two inputs into the pins labelled SLEEP and RESET to operate properly, which was not initially realized.

5.2.5. Stratologger CE Altimeter

Table 5.2.3 StratoLoggerCF Specifications

Property	**Value**	**Significance**
Power	4V – 16V, nominal 9V battery	Easy to obtain and integrate a power source
Current consumption	1.5 ma	Incredibly low current consumption
Output current	Do not exceed 5 amperes (actual current is battery	High upper current limit

	dependent)	
Output “on” time	1.0 second	Low delay
Launch detect	160' to 300' AGL, default 160'	Sufficient launch detect
Main deploy altitude	100' AGL to 9,999' AGL	Sufficient deploy altitude
Maximum altitude	100,000' MSL	High altitude limit
Altitude resolution	1' up to 38,000' MSL < 2' to 52,000' MSL < 5' to 72,000' MSL	Good enough resolution for ATS calculations
Analog to Digital	24 bit Sigma Delta	Unnecessary
Calibration accuracy	+/- 0.05% typical	High accuracy
Measurement precision	+/- (0.1% reading + 1 foot) typical	High accuracy
Flight data logged	Altitude, temperature, battery voltage	Useful and convenient data logs
Number of flights stored	16	Overly high flight capacity
Recording time per flight	Over 18 minutes	Overly high flight recording time
Sample rate	20 samples per second	Sufficient sampling rate
Operational temperature	-40C to +85C (-40F to +185F)	Sufficient operating temperatures
Dimensions	2.0"L x 0.84"W x 0.5"H	Compact and space-efficient
Weight	0.38 oz	Lightweight, low mass impact

The StratoLoggerCF is also used as the main altimeter; features that make it optimal are also listed in the Recovery sections of this document. The main appeal for ATS is the serial port, which will function as an input to the microcontroller to poll for current altitude. The StratoLoggerCF has sufficient accuracy and output rates to make it useful for apogee analysis.

Wiring the serial connection to the microcontroller should be trivial, and minimal code will be necessary for functionality.

5.2.6. Raspberry Pi 3 Model B+

Table 5.2.4 Raspberry Pi 3 Model B+ Specifications

Feature	**Significance**
Quad Core 1.2GHz Broadcom BCM2837 64bit CPU	Massive processing power when used solely as a microcontroller
1GB RAM	Sufficient RAM to run ATS software
BCM43438 wireless LAN and Bluetooth Low Energy (BLE) on board	Ease of connectivity, able to interact with microcontroller while inside rocket
40-pin extended GPIO	Plenty of configurable inputs and outputs
4 USB 2 ports	Multiple ports for necessary devices while testing and setting up
4 Pole stereo output and composite video port	Useful for testing without need for external device
Full size HDMI	Useful for testing without need for external device
CSI camera port for connecting a Raspberry Pi camera	Unnecessary but a possible opportunity to capture flight
DSI display port for connecting a Raspberry Pi touchscreen display	Unnecessary, likely will be unused
Micro SD port for loading your operating system and storing data	Easy and compact storage
Upgraded switched Micro USB power source up to 2.5A	Useful when testing, will likely be unused on the board

While complex when used just as a microcontroller, the Raspberry Pi 3 offers several advantages over typical microcontrollers such as Arduino boards. The major advantages will be during initial setup and testing, during which the Pi can function as a full microcomputer, eliminating the necessity of another device to code and configure on. Using a Pi allows a multitude of coding languages to be used and reduces restrictions on software. The several ports and antennas on the Raspberry Pi make an excellent board to develop on while mitigating time wasted on connectivity issues.

The Raspberry Pi also has an officially supported HAT (Hardware Attached on Top) that was flown to the ISS in the Astro Pi mission - the Sense HAT. The Sense HAT has many useful features with official well-documented C++ and Python libraries and packages that make integration into the circuit easy while functioning as cheap components. The hardware including in the Sense HAT is listed below.

Table 5.2.5 Sense HAT Hardware

Sensor	**Significance**
Gyroscope	Likely will become a core component of the ATS system in tracking rocket orientation
Accelerometer	Likely will become a core component of the ATS system in tracking rocket acceleration
Magnetometer	Unnecessary but data logging may reveal interesting trends
Temperature	Monitor internal temperature of the rocket for component safety
Barometric pressure	Unnecessary but data logging may reveal interesting trends
Humidity	Unnecessary but data logging may reveal interesting trends

While the Raspberry Pi and Sense HAT combination has a plethora of uses, it also substantially increases power demand of the circuits and uses significantly more space than a smaller microcontroller would. This is offset by the number of uses for each component along with the combined versatility that mitigates needs for other sensors.

5.2.7. Safety/Precautions/Challenges

A key factor in safety for the ATS system is redundancy and isolation from other systems. This is the reason the ATS system includes an additional altimeter on a different circuit from the altimeter used for the Recovery systems. The team is currently examining the option to indirectly connect both altimeters to both systems so that in case an altimeter malfunctions, the output from the other can be used.

Additionally, the connections between components are vital to the success of the ATS. For this reason, wires were directly soldered when possible and then sufficiently insulated with shrink wrap and electrical tape. As few connectors as possible were used to ensure they did not dislodge during the flight.

Shown below is a Failure Mode Effects Analysis (FMEA) chart, which lists the possible failure modes of the ATS section as well as the associated risk.

Table 5.2.6 FMEA Chart

Function	Failure	Potential Causes	Detection Method	Impact	Severity (1 -3)	Detection Difficulty (1 -3)	Prob. (1 - 3)	Risk (1-27)	Risk Priority Number (Risk/27)
sends data to motor boards to actuate motor	Raspberry Pi sends bad data	Software Error	Check coding before launch	Motor does not actuate or actuate in wrong configuration	2	1	1	2	0.07407
			Simulate flight using pressure/ vacuum chamber		2	1	1	2	0.07407
	Raspberry Pi fails to sends data	Faulty Wiring	Check wiring before flight	Motor does not actuate	2	1	1	2	0.07407
records the height at specified rate	Altimeter fails to send data due to internal error	Faulty Wiring	Check wiring before flight	ATS is not actuated	2	1	1	2	0.07407
		Faulty Altimeter	Simulate flight using pressure/ vacuum chamber	ATS is not actuated	2	1	1	2	0.07407

	Altimeter sends wrong data	Faulty Altimeter	Simulate flight using pressure/ vacuum chamber	ATS is actuated during burnout or actuated at wrong time	3	1	1	3	0.11111
powers altimeter	The connection between the altimeter and the battery severs	Faulty Wiring	Check wiring before flight	ATS is not actuated	2	1	1	2	0.07407
	Battery dies during flight	Faulty Battery	Check the voltage of the battery before flight	ATS is not actuated	2	3	1	6	0.22222
Powers motor	Battery dies during flight	Faulty Battery	Check the voltage of the battery before flight	ATS is not actuated	2	3	1	6	0.22222
	The connection between the motor and the battery severed	Faulty Wiring	Check wiring before flight	ATS is not actuated	2	1	1	2	0.07407
extends / retracts flap	The motor does not actuate due to internal failure	Impact at launch	Check the manufacturing specs if possible; unless specified in specs, there is none	ATS is not actuated	2	3	3	18	0.66667
		Vibration	Check the manufacturing specs if possible; unless specified in specs, there is none	ATS is not actuated	2	3	3	18	0.66667
holds components	threadlocker breaks and twists out	Vibration	N/A	Components may be disassemble d; Due to imbalanced force,	3	3	3	27	1.00000

				moment is created					
received signal from Pi and actuates motor	cannot actuate motor	Faulty Wiring	Check wiring before flight	ATS is not actuated	2	1	1	2	0.07407
		Faulty Board	Run simulation before flight to check the board	ATS is not actuated/ actuated at wrong time	3	1	1	3	0.11111
connects motor driver to stepper motor	connection severed	vibration	N/A	ATS is not actuated	2	1	3	6	0.22222

The FMEA reveals that several problems cannot be detected during flight. Therefore, to deal with those issues, the only possible action is rigorous inspection and testing to satisfy the requirements and prevent failures.

5.3. ATS Software

5.3.1. Diagrams

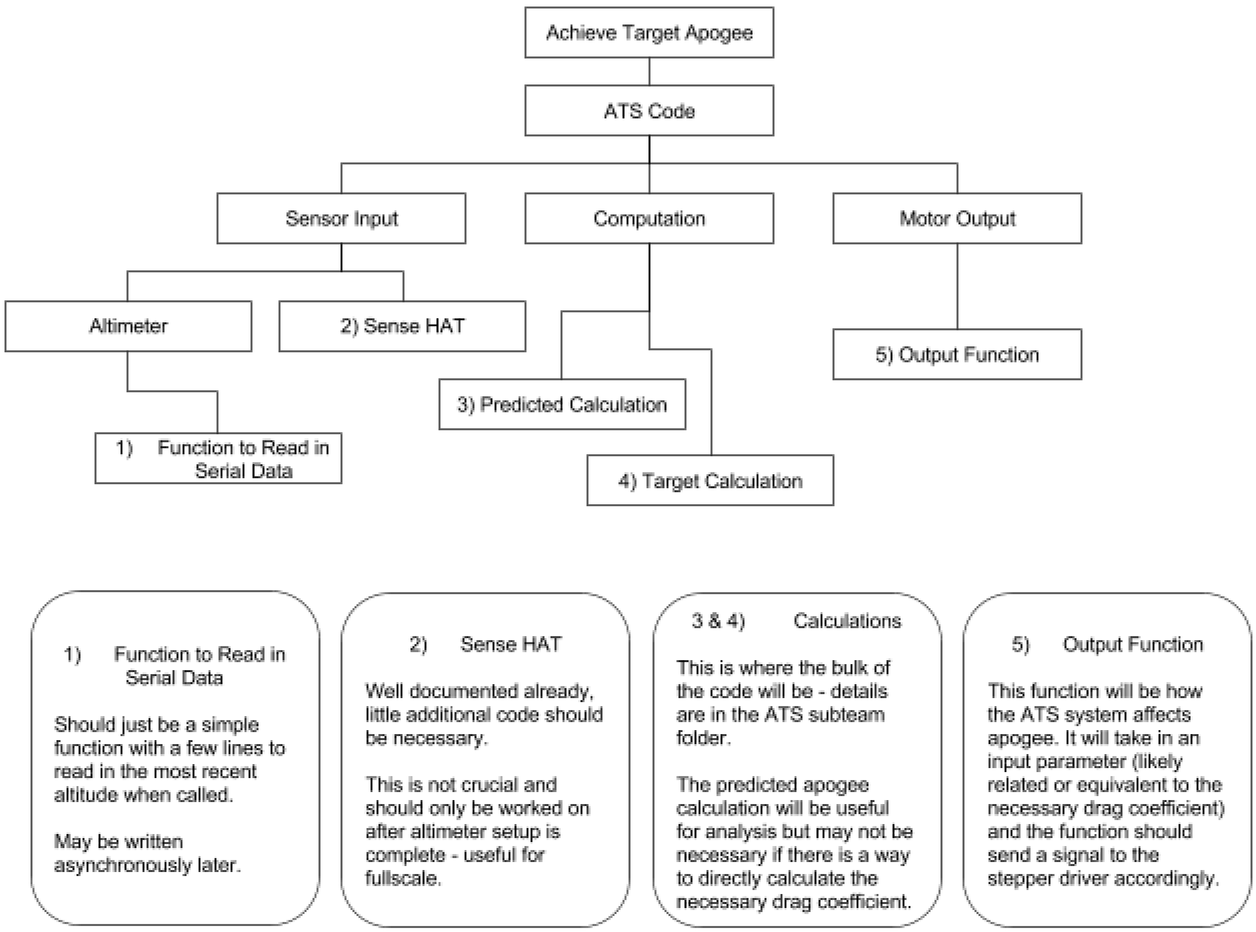


Figure 5.3.1 ATS Software Function Tree

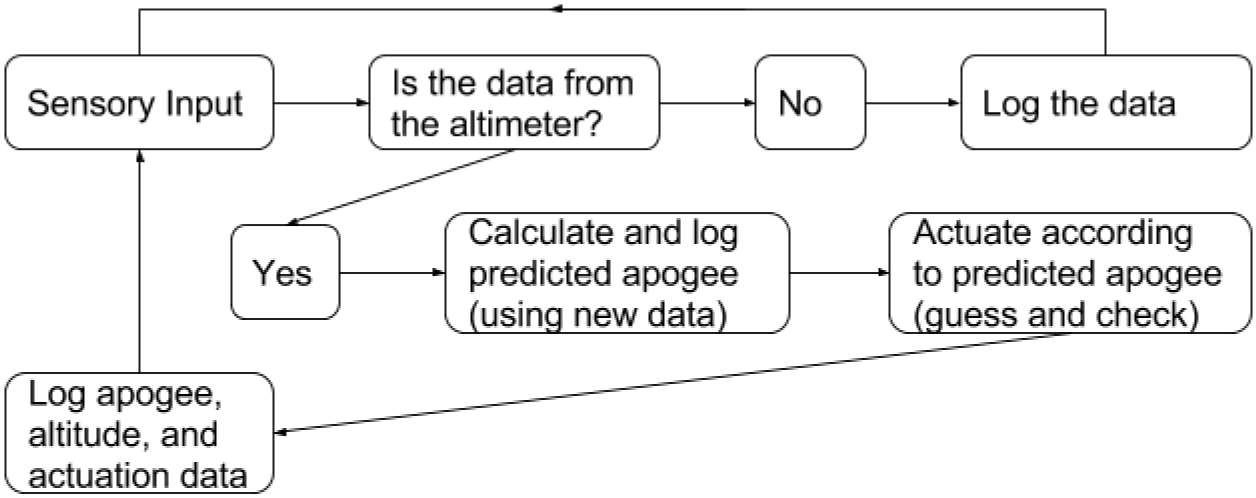


Figure 5.3.2 ATS Software Flowchart

5.3.2. Collecting Sensory Data

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

5.3.3. Calculations

While asynchronously recording data, the rest of the ATS software will be directed at processing altimeter output to predict an apogee and actuate accordingly in a loop. The code will use a method of numerical integration such as Euler's method to iteratively calculate the altitude of the rocket based on the equation for acceleration. Using Euler's method as an example, 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 should be 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 are not directly calculating the drag coefficient needed to reach target apogee, and ideally this ideal drag coefficient will be reach 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 small (significantly less than 30 seconds) so there will be little time to correct these errors.

In theory it would be possible to perform a direct calculation of the drag coefficient and actuate accordingly, but a proper method for this has not been reached by the team as of yet. If one is found, this process may be used for actuation while predicted apogee will still be calculated as it will be convenient for later analysis.

5.3.4. Actuation

The first goal in actuation is to prevent actuation while the rocket engine is burning, which would be unproductive and create large torques on the ATS drag panels. This will be done by an initial software loop which will constantly check altimeter data to determine if the speed of the rocket is increasing with time, and if so, prevent actuation (while still calculating and logging apogee predictions).

The remaining actuation code will translate a drag coefficient output from the calculations into actuation of the ATS. This will require a way to correlate drag coefficient to the corresponding percent of full actuation; members of our team will be running simulations to calculate this beforehand, and the results will be hard-coded (whether an equation or simple look-up table). When the necessary drag coefficient is calculated, it will be used as an input for a function that, using a stepper motor driver object, will send the necessary direction and step signals to the motor driver to reach the necessary actuation percentage.

5.3.5. Safety/Precautions/Challenges

Given that in a case of power failure any reading or writing to the microSD card in the Raspberry Pi may be suddenly halted, care must be taken when doing so. The logging portions of the code should only have files open when absolutely necessary to minimize the time during which power failure would be a significant threat to the data files.

As mentioned previously, the code must also be thoroughly optimized to ensure the apogee calculations are accurate. This is completed through rigorous review and analysis of the code during development and after assembling the different functionalities of the code as a whole. Testing the code with false data is also used to simulate cases of both success and failure in order to inspect the performance of the ATS software. As few applications as possible are run on the Pi during flight (such as booting through a terminal rather than a desktop GUI) to ensure as much as possible of the CPU's time is spent on ATS calculations.

6. Rover System

6.1. Rover Overview

6.1.1. Mechanism Overview

During flight, the rover is housed within the body of the rocket. After landing, it is the function of the deployment system to get the rover out of the rocket and onto the ground so it can complete its mission. During launch, the entire rocket will experience rapid acceleration as well as shocks from drogue deployment, main chute deployment, and landing. It will also undergo vibration. As with all systems, the rover deployment system must survive these loads and still perform as expected. Once the rocket lands, we don't know what orientation it will be in. It is important that the mechanism can still deploy the rover regardless of the rocket's orientation or any obstructions that may be in the vicinity. In order to accomplish its goal, the rover deployment system must be robust enough to withstand the vibrations and shock of launch, and reliable enough to function in any landing scenario. The table below lists possible solutions to many of the rover system functions.

Table 6.1.1 Rover Solution Table

	Solutions			
Function	**1**	**2**	**3**	**4**
Not damaged by vibration	Size the rover to take up as much of the available space as possible to limit room for vibrations and oscillations to develop	Use springs attached to rover section for vibration damping	Build rover to be highly resistant to vibration	

Not damaged by landing	Encapsulate the rover in foam for vibration/landing protection	Rover is suspended within rocket body	Decrease overall landing velocity to a point safe for rover and associated components	Rover wheels have suspension
Rocket opens	Use ejection charges to separate stages	Use servo motors to open a small door that is integrated into body of rocket	Lead screw mechanism opens rocket longitudinally	Using a servo, Rocket "unscrews" its top and bottom - top section will have to be larger in diameter than the bottom
Rover comes out of rocket	Expelled by force with a blast of compressed air	Rover drives out of rocket body	Released by pin as rocket opens	Rover pushed out by lead screw mechanism
Does not get stuck on rocket	Separate nosecone without a tether	Distance sensor used to change rover direction	Use a GPS system to guide the rover away from the rocket	Lidar used for obstacle avoidance
Does not get stuck on terrain	Rover is spherical	Wheels larger than rover body so it can be driven upside down or right side up	Use treads for higher traction	
Rover deploys in proper orientation	Wheels have conical shaped caps to correct rover orientation	Rover is spherical	Use gyroscope and accelerometer to determine orientation, and move wheels	Distance sensor to detect where the walls of the rocket are

			accordingly	
Does not get stuck on parachute / cord	Rover body has simple silhouette with no protrusions	Rover has a shell with a smooth exterior	Deploy from nosecone and first body tube section without tethering nosecone	
Solar panels unfold reliably	Spring loaded	Actuated with servo	Actuated with solenoid	Open from centripetal force
Solar panels provide power	Panels are wired to battery	Panels deployed in one up one down configuration to ensure one of them will provide power to light onboard led	Have redundancy in panels to account for single component failure	Panels attached to motor that rotates according to readings from a light sensor so that panels face upwards

Table 6.1.1 FMEA chart for rover system

Component	Function	Failure	Potential Causes	Impact	Severity	Detection Difficulty	Probability	Risk (1-27)
Radio Transmitter	Radio Transmitter sends activation signal	Signal does not send properly	Insufficient battery, Rocket lands out of range, Obstacle obstructs signal	Rover deploym ent system is not activated	3	3	1	9
Radio Receiver	Receives activation signal	Does not receive signal	Electrical malfunc-tion	Rover deploy-ment system is not activated	3	3	1	9
deployment	Rotates	Inadequat	Rocket is	Rocket	3	3	1	9

		e torque to open rocket	stuck on terrain	does not open				
motor	threaded rod	Does not rotate	Damage from launch	Rocket does not open	3	3	1	9
Threaded rod	Moves carriage	Becomes disconnected from motor	Vibration or shock from launch	Rocket does not open or falls open uncontrolled	3	3	2	18
Carriage	Moves support beams	Becomes jammed on guide rails	Poor assembly of guide rails	Rocket does not open	3	3	1	9
Support beams	Connect carriage to nose cone	Fall out of brackets	Vibration from launch	Rocket does not open	3	3	1	9
Front support bracket	Supports threaded rod, support beams, and guide rail	Bracket breaks	Vibration or shock from launch	Rocket may not open properly	2	3	1	6
Rover deployment mechanism	Gets rover out of the rocket and onto the ground	Mechanism breaks	Damage from launch	Rover does not deploy	3	3	1	9
Rover battery	Powers rover control system, drive motors, and solar panel deployment	Battery cannot power rover systems	Not properly charged	Rover does not function	3	1	1	3
Rover control system	Controls rover drive train and solar panel deployment	Does not activate drive train	Damage from launch	Rover does not move	3	3	1	9

Rover control system	Controls rover drive train and solar panel deployment	Does not activate solar panel deployment	Damage from launch	Solar panel does not unfold	2	3	1	6
Rover drive motors	Rotate wheels to move rover	Do not properly rotate wheels	Insufficient battery, damage from launch	Rover does not move properly	3	2	1	6
Solar Panel Motor	Actuates solar panel unfolding mechanism	Does not actuate mechanism	Damage from launch	Solar panel does not deploy	2	3	1	6
Solar panel unfolding mechanism	Unfolds solar panel	Does not unfold solar panel properly	Damage from launch	Solar panel does not deploy properly	2	3	1	6
Solar panel power system	Uses solar panel to generate power	Does not generate power	Damage from launch	Solar panel does not generate power	2	3	1	6

This Failure Modes and Effects Analysis (FMEA) table describes possible failure modes of the rover system. Each item is scored from 1-3 on severity, difficulty of detection, and probability. Difficulty of detection refers to the chance of the system to detect that a failure has occurred or is going to occur. In the rover system, most failures are mechanical and cannot be detected by the system. The total risk is the product of the three scores and ranges from 1 to 27. Failure modes with a higher score have a higher priority.

6.1.2. Rover Requirements

The rover system must perform three different functions to complete our task successfully as illustrated below in Figure 1. This task is most easily simplified into a few base functions: Deployment, Drivetrain, and Solar Panels.

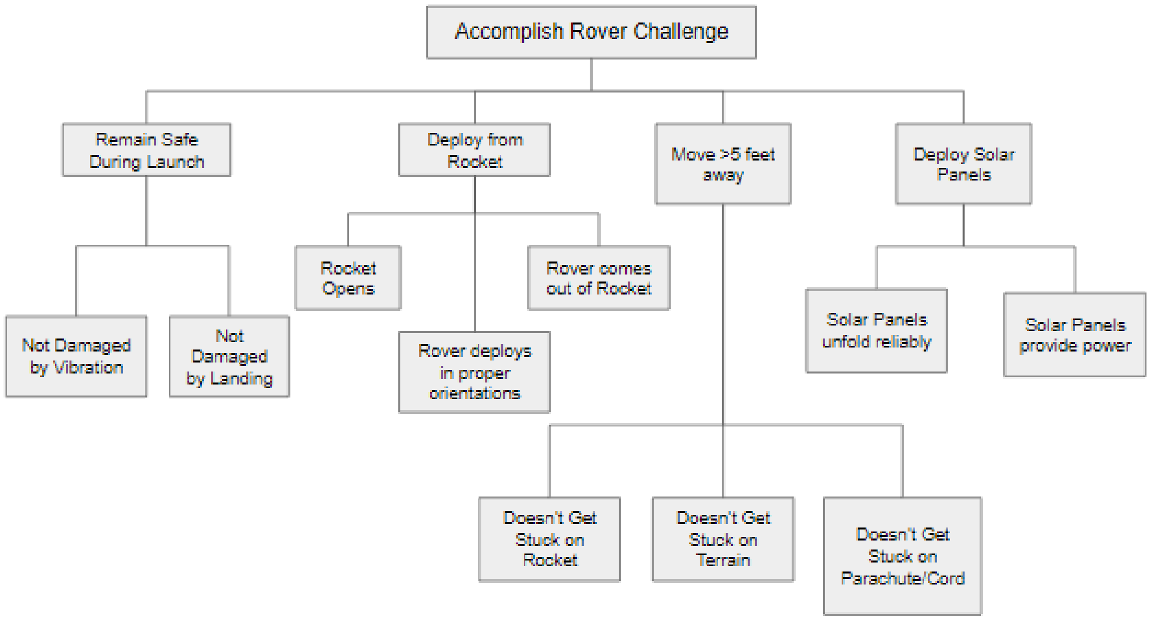


Figure 6.1.1 Overall Rover Challenge Function Tree

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 Figure 6.1.2.

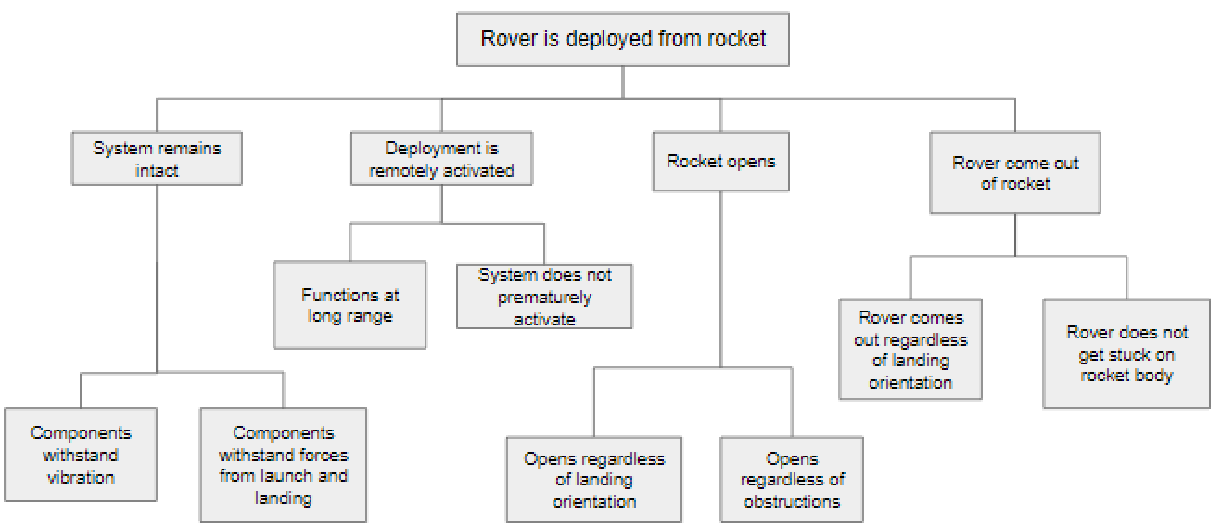


Figure 6.1.2 Rover Deployment Function Tree

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 nosecone 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.

Drivetrain

After a successful deployment, the rover must move a minimum of 5 feet away from the rocket. Figure 6.1.3 illustrates the challenges of remaining intact during flight, being able to overcome any terrain, and have the ability to not interfere with other components.

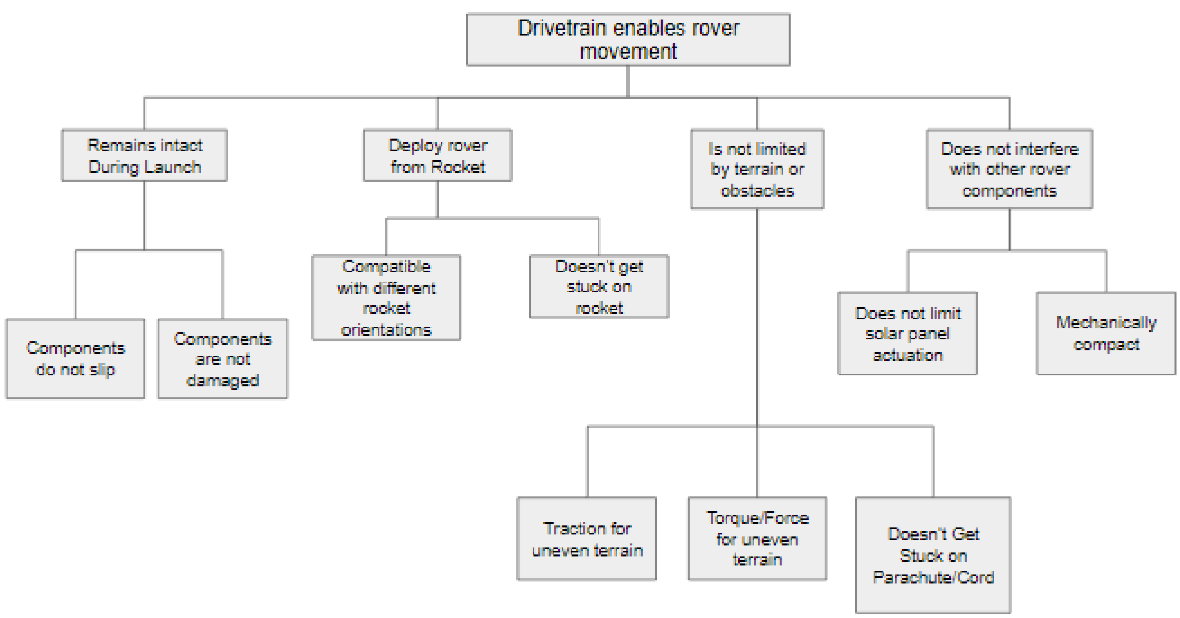


Figure 6.1.3 Drivetrain Function Tree

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 >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.

Solar Panels

Once the rover has reached a distance of at least 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 Figure 6.1.4.

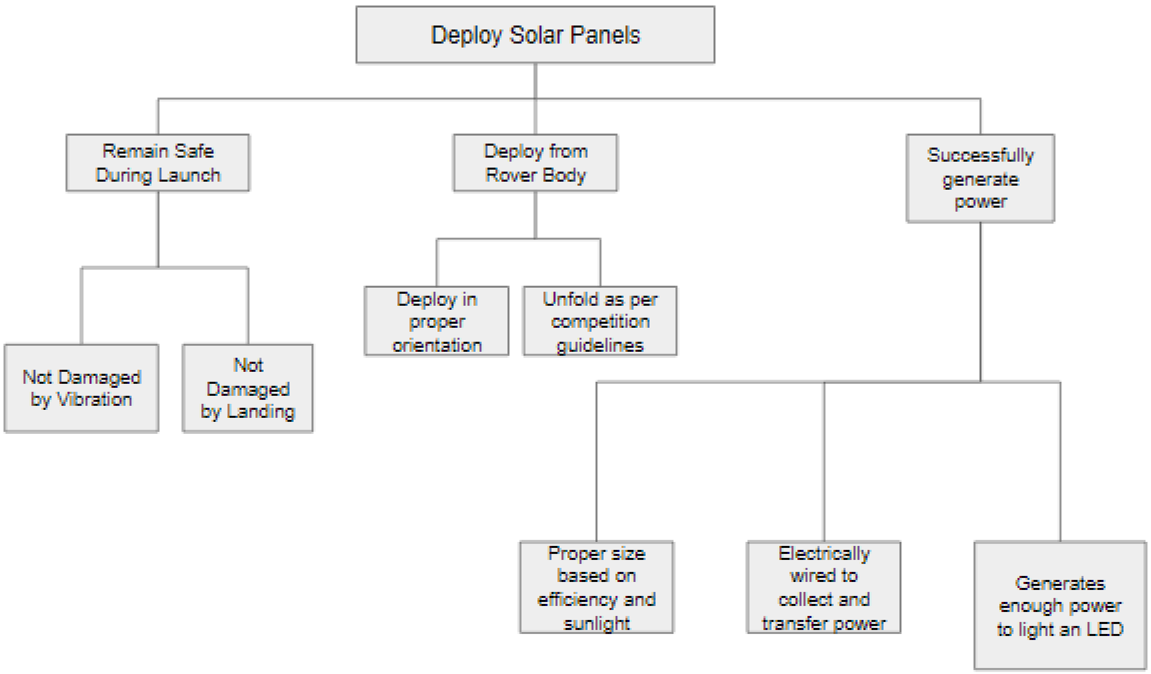


Figure 6.1.4 Solar Panels Function Tree

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.

6.2. Mechanical Design

Rover Deployment System

Table 6.2.1 Rover Deployment Solution Table

	Solutions			
Function	**1**	**2**	**3**	**4**
Components withstand vibration	System is mounted on vibration damping mounts	Use a mechanism that actively counters vibration, cancelling it out	Use simple design with lock nuts and strong epoxy that will resist vibration	
Components withstand forces from launch and landing	System is mounted on shock-absorbing foam	Mount mechanism on a suspension system within the rover bay	Use sturdy materials that will resist shocks	Use a much bigger parachute to reduce landing shock
Functions at long range	Use strong radio transmitter to send signal	Send activation signal using laser communication	Deploy drone to fly closer to rocket then transmit activation signal	
System does not prematurely activate	Implement arming switches that are only activated just prior to launch	Keep radio transmitter turned off until after landing	Verify ground-level altitude and no motion from on-board sensors before activating	
Opens regardless of landing orientation	Axial lead screw mechanism	Open side hatch with a lead screw strong enough to roll the rocket over	Ejection charges blow the nose cone off	

Opens regardless of obstructions	Axial lead screw mechanism strong enough to push entire rocket body	Ejection charges strong enough to remove nose cone past any obstructions	Land vertically to ensure no obstructions around nose cone area	
Rover comes out regardless of landing orientation	Hang rover from a pin so it can rotate freely to proper orientation	Push rover out using walls, positioning it so any orientation is viable	Use sensors on rover to change driving direction to accommodate orientation	Expel rover using ejection charges or compressed air
Rover does not get stuck on rocket body	Position rover perpendicularly so it drives away from rocket body	Nose cone remains attached to rocket body after opening so it can't block rover	Rover has sensors and steering to avoid obstacles	Rover uses sensors to determine if stuck, then drives the other way

Some of the major solutions listed in the table above are evaluated in the table below.

Table 6.2.2 Deployment Evaluation Matrix

Concept		1		2		3	
Criteria	**Import - ance**	Lead Screw Separation		Ejection Charge Separation		Side Hatch	
Low Weight	6	2	12	3	18	2	12
High Manufacturability	8	2	16	3	24	1	8
Low Complexity	6	1	6	3	18	1	6
Ease of Maintenance	4	1	4	2	8	1	4
Low cost	3	1	3	3	9	2	6
Low Software Complexity	3	2	6	3	9	2	6
Reliability	10	3	30	1	10	1	10
Payload Safety	10	3	30	1	10	3	30
Rover Orientation	8	3	24	2	16	1	8
Total Possible:	**174**						
Total			131		122		90
Relative Total			75.29 %		70.11 %		51.72 %
Scores Range: 1 - 3 (1 = bad, 3 = great)							

The criteria used to evaluate the three design options are largely based on general good design practices such as high manufacturability, low complexity, ease of maintenance, and reliability. These criteria should be taken into account in any design, and are especially important in cases such as ours in which time is limited. Low weight is an important factor because a design that is too heavy would require a stronger rocket motor and could be a safety concern. Payload safety and rover orientation are highly important. In order to complete the rover challenge, the deployment mechanism must keep the rover safe and deploy it in an orientation in which it can drive. If either of these functions is not met, the challenge will likely be failed. Based on this evaluation matrix, the lead screw mechanism was chosen and prototyped.

The prototype was originally designed to fly on the subscale rocket. However, once the rocket was constructed, it was decided that the cardboard body tubes were not strong enough to safely support the prototype without risk of buckling. Instead, the prototype was built in a separate body tube with the same diameter as the subscale rocket. The prototype perfectly accomplishes its goal of removing the nose cone. Much was learned from the design and manufacturing of this lead screw mechanism prototype.

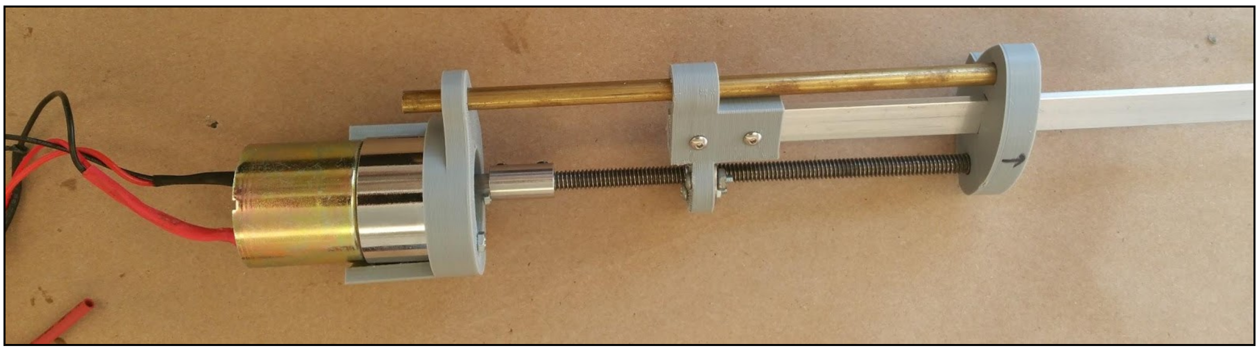


Figure 6.2.1. The lead screw separation system prototype outside of body tube

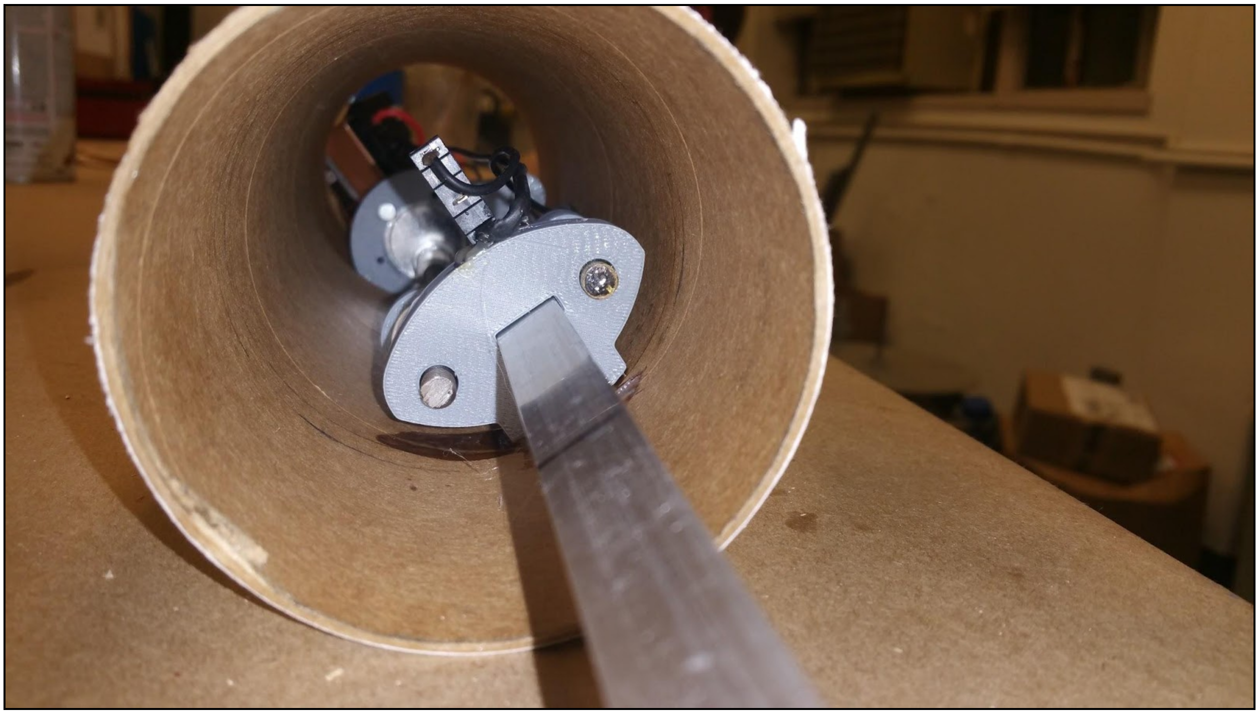


Figure 6.2.2. The lead screw separation prototype inside its body tube

The lead screw design prototype accomplished its goal of removing the nose cone, however, there are many aspects of the design that will be improved for the full scale rocket. One of the biggest issues was space. Assembling the system in such a small tube was very difficult. The greatest challenge was epoxying the motor bracket and front support bracket into the tube. The prototype was built in a 3” diameter body tube, while the full scale rocket will have a 5.5” diameter, so there will already be more space. In addition, the full scale system will be built on a tray made from a cut-out section of a cardboard coupler tube. The motor bracket and front support bracket, as well as the radio receiver and battery, will be mounted to the tray, which will then be epoxied into the rover bay tube. This will make assembly of the system much easier.

The nose cone was never actually attached to the prototype. This is because the nose cone bracket was designed with the assumption that, once attached, the nose cone would never need to be removed. The support beam would need to be screwed into the bracket, which would then be epoxied to the bulk plate in the nose cone. Because of the nose cone’s shoulder, the screws in the bracket would be completely inaccessible. Since the nose cone used to test the prototype will also be used for the subscale rocket, it cannot be permanently attached to the prototype.

Whenever possible, systems should be designed so they can be disassembled if changes need to be made. This was taken into consideration during design of the full scale nose cone brackets.

Figure 6.2.3. The motor, shaft coupler, and threaded rod used in the subscale prototype

The threaded rod was connected to the motor shaft using a shaft coupler with set screws. One side of the threaded rod was filed down, forming a D-shaft shape. This prevented the threaded rod from rotating relative to the motor shaft, which was already D-shaped. This method of securing the threaded rod and the motor worked well, and will be used in the full scale design.

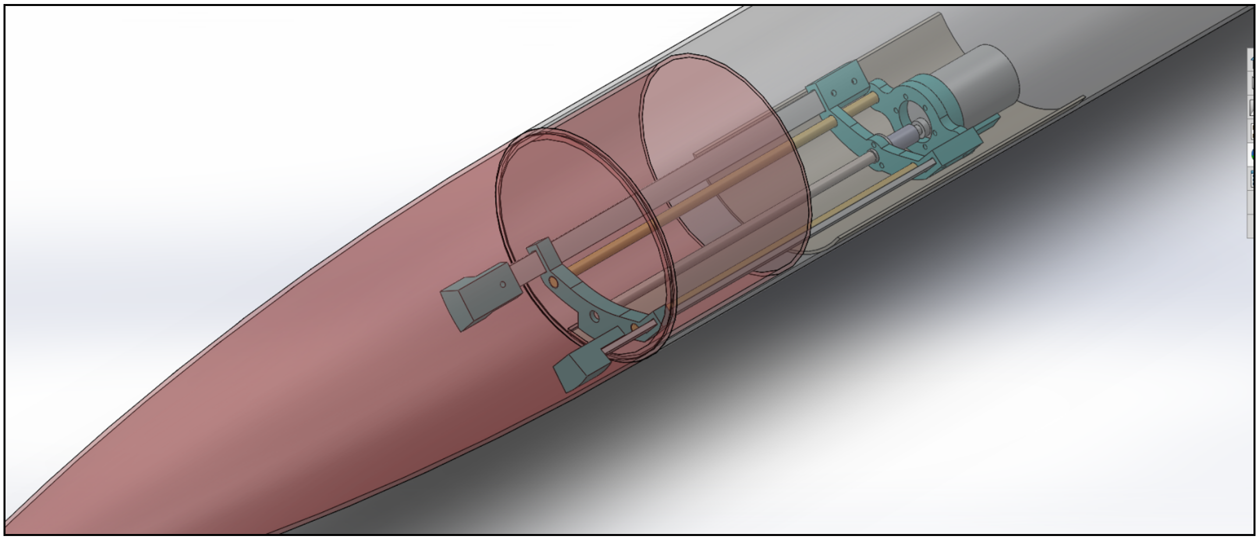


Figure 6.2.4 Full scale rover deployment CAD - Closed

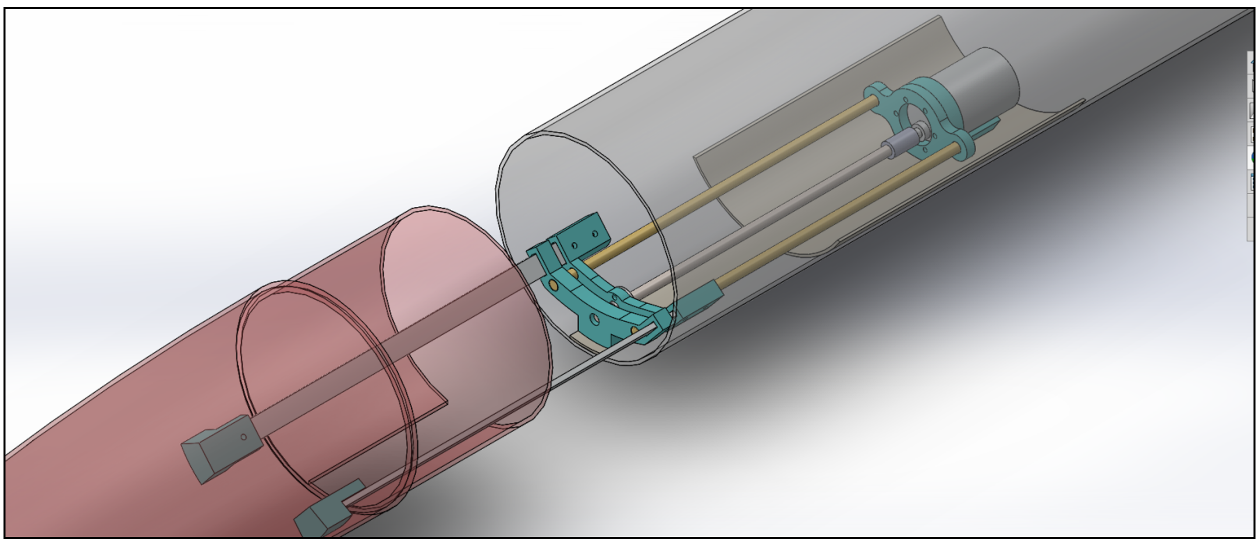


Figure 6.2.5 Full scale rover deployment CAD - Open

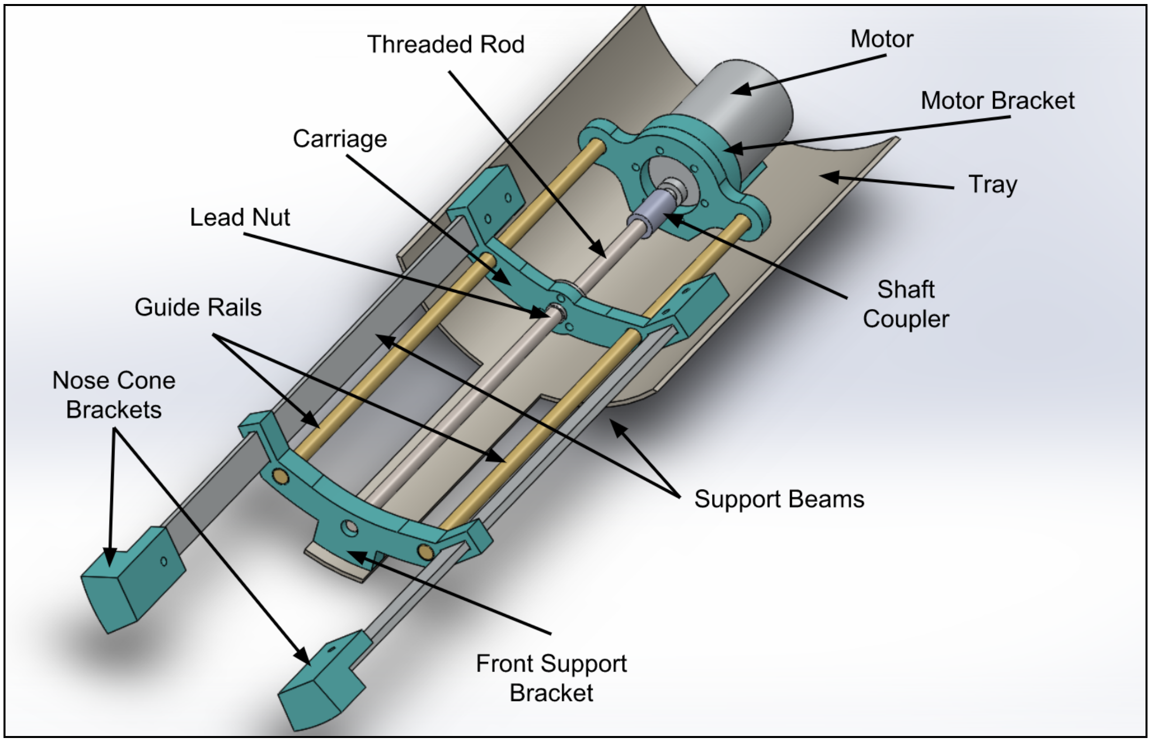


Figure 6.2.6. Labeled diagram of rover deployment without tube and nose cone

Table 6.2.3 Rover Parts List

Part	Material	Function Summary
Motor	N/A	Turns the threaded rod
Motor Bracket	3D printed ABS Plastic	Secures motor and guide rails
Tray	Cardboard	Base for mounting brackets
Shaft Coupler	Aluminum	Attaches threaded rod to motor shaft
Support Beams	Aluminum	Connect nose cone to carriage
Front Support Bracket	3D printed ABS Plastic	Provides support
Nose Cone Bracket	3D printed ABS Plastic	Connects support beams to nose cone
Guide Rails	Brass	Guide and support carriage
Lead Nut	Steel	Moves along threaded rod as it rotates
Carriage	3D printed ABS Plastic	Connects lead nut to support beams
Threaded Rod	Steel	Rotates, causing lead nut to move

Since the orientation of the lead nut is fixed by the carriage, as the threaded rod turns, the lead nut is pushed forward in the direction of the nose cone. The lead nut is screwed into the carriage, which is connected to the support beams. The support beams are then connected to the nose cone by the nose cone brackets. The guide rails run from the motor bracket to the front support bracket and are stationary. They guide and support the carriage as it moves along the threaded rod. The motor bracket secures the motor and the guide rails. The front support bracket and the motor bracket are mounted to the tray which goes inside the rover bay body tube. The brackets will be 3D printed due to their complex geometry.

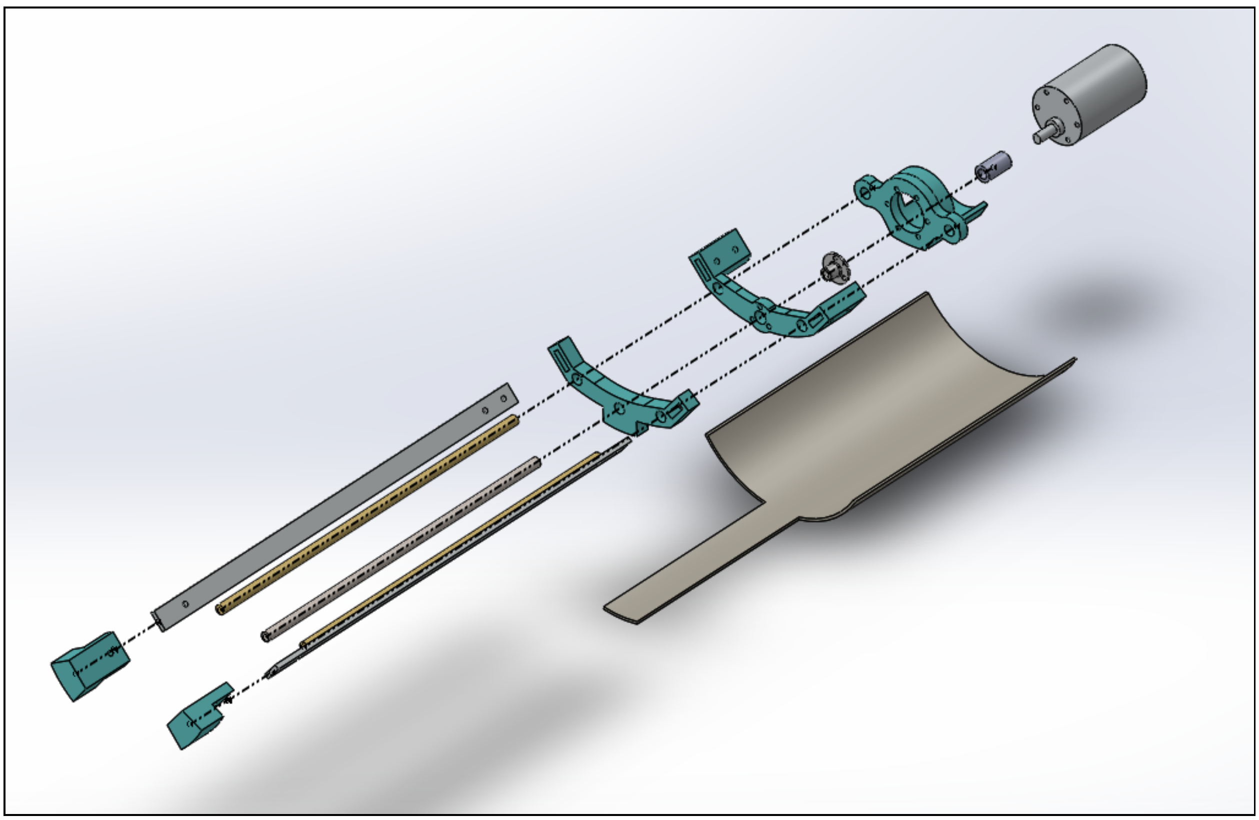


Figure 6.2.7. Exploded view of the rover deployment mechanism

The most complex parts in the rover deployment mechanism are the brackets that hold other components in place. The nose cone bracket, front support bracket, motor bracket, and carriage will all be 3D printed because of their complex geometry.

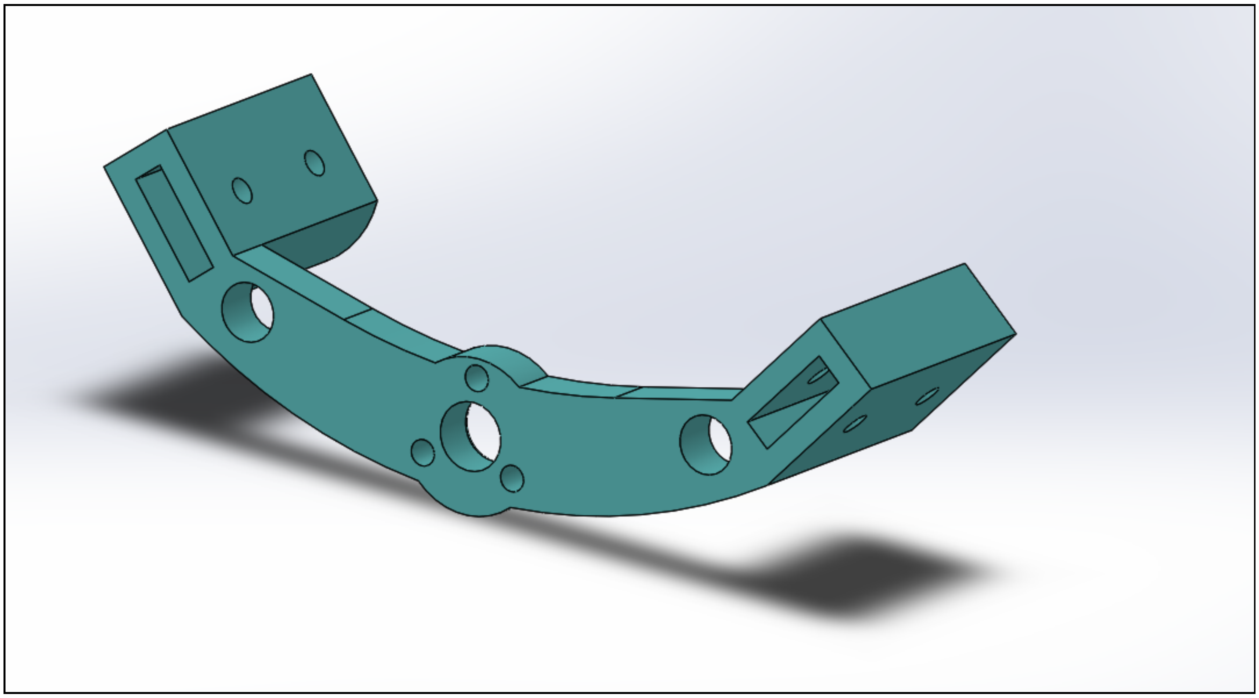


Figure 6.2.8**.** CAD for the carriage.

The carriage is a very important part. As can be seen in Figure 6.2.6, the lead nut is screwed into the carriage. Since the carriage rides along guide rails and therefore cannot rotate, this connection prevents the lead nut from rotating. Locking the orientation of the lead nut is what causes it to undergo linear motion when the threaded rod rotates. The other primary function of the carriage is to carry this linear motion from the lead nut to the support beams. The beams fit into the slots on both sides of the carriage, and are secured by screws. The holes next to the support beam slots are for the guide rails, which keep the carriage aligned and provide support. The subscale prototype functioned well with only a single guide rail. However, since the full scale will need to support more weight and there is additional space, two guide rails are used. The carriage is curved to fit along the inside of the rover bay tube and take up as little space as possible. This leaves more room in the rover bay for the rover itself.

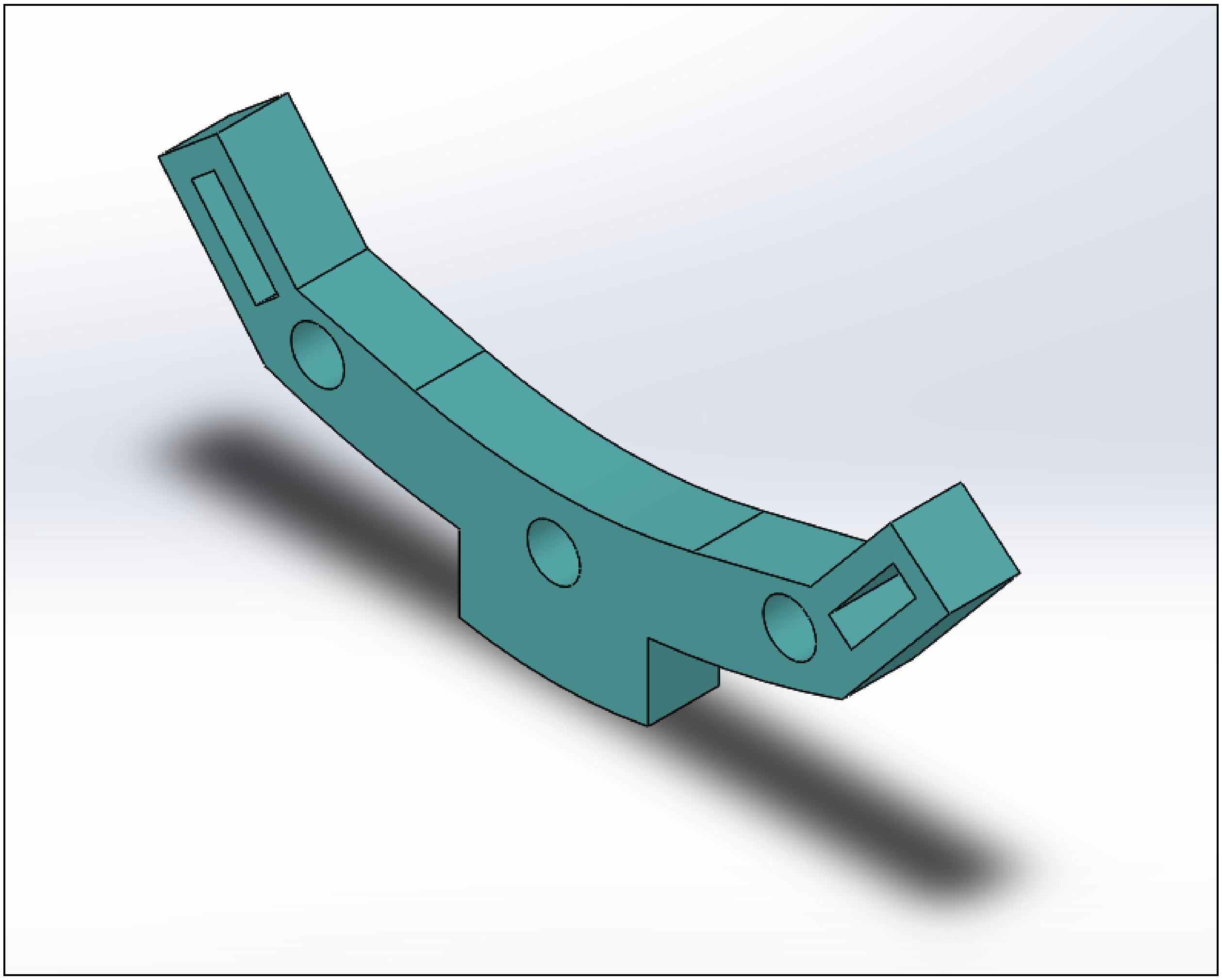


Figure 6.2.9. This is an image of the CAD for the front support bracket.

The front support bracket supports the threaded rod, guide rails, and support beams. As can be seen in Figure 6.2.7, the holes in the front support bracket line up with the holes in the carriage. This is so the threaded rod, guide rails, and support beams all remain parallel. The support beams connect the carriage to the nose cone, and as they move, they slide through the front support bracket.

In the worst case scenario, the rocket may land on a rock or sloped terrain such that it is not lying horizontally, and the nosecone is not touching the ground. Should this happen, the front support bracket would need to support the entire weight of the nose cone. The greatest load would occur when the mechanism is fully extended and either completely right side up or upside down. These scenarios have been simulated using Solidworks Simulation.

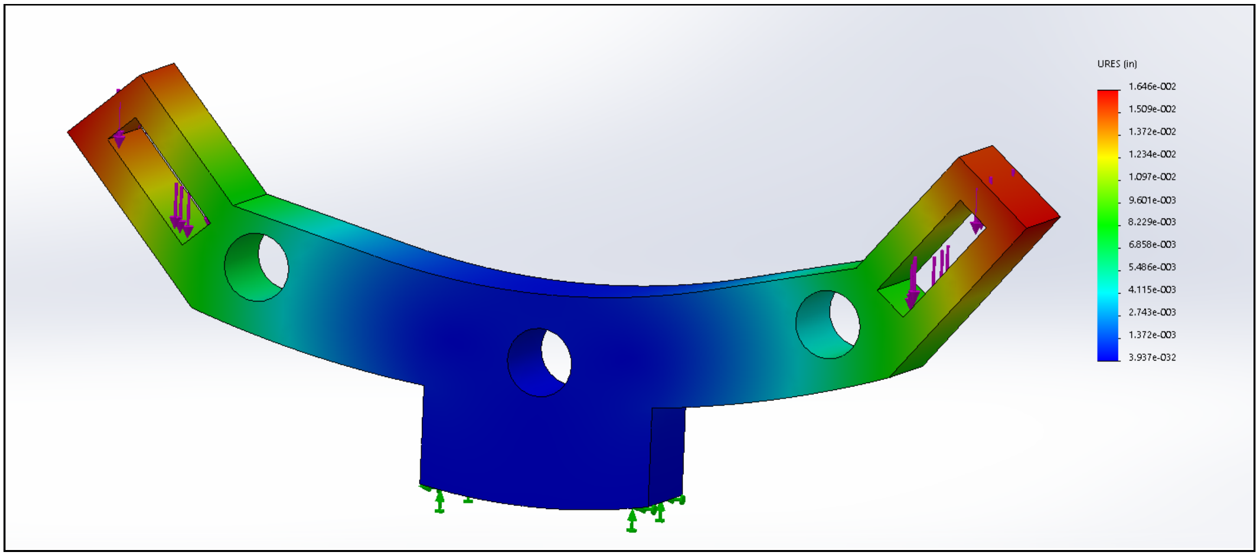


Figure 6.2.10. FEA of front support beam with downward load

This image shows the results of a deformation simulation of a worst case scenario load on the front support bracket. In this case, the rocket has landed with the front support bracket at the bottom of the rover tube, so the load from the weight of the nose cone through the support beams is downward.

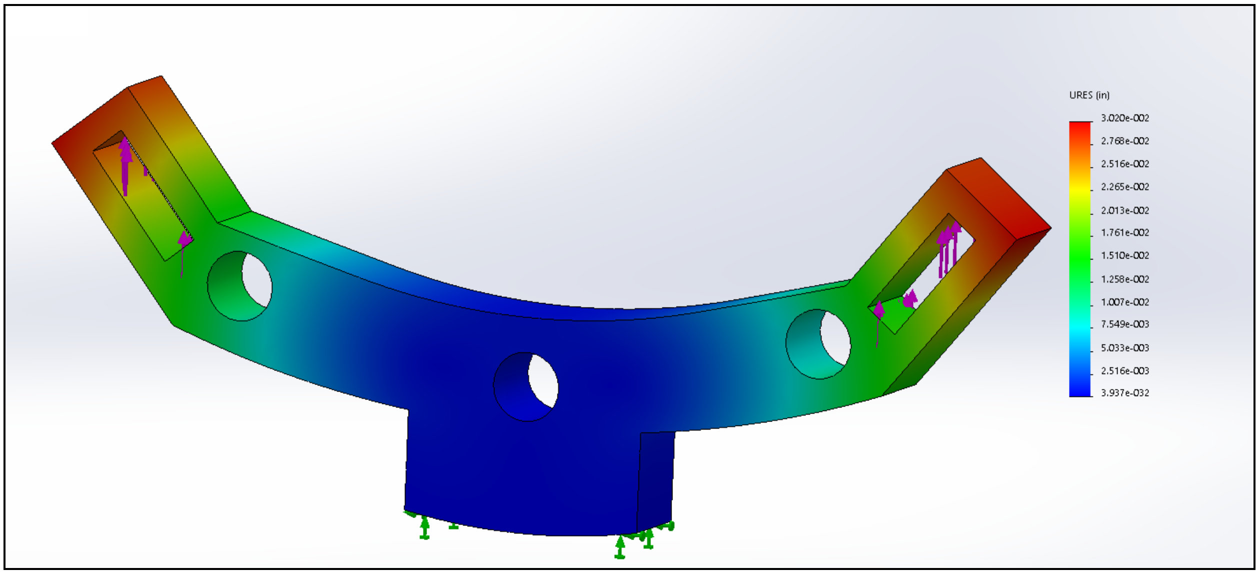


Figure 6.2.11. FEA of front support beam with downward load

This image shows deformation simulation results for a different worst case scenario in which the rocket lands with the front support bracket on the top of the rover bay tube. In this case, the load is upward on the bracket because it would be upside down.

The simulations shown above were using the material properties of ABS plastic. These images show the deformation of the parts in true 1:1 scale, with redder portions being more deformed. The maximum deformation with the load going downwards is approximately 0.0164”, and with the load upwards it is 0.0302”. In both cases, the deformation is very low. These simulations show that if the front support bracket is 3D printed from ABS plastic, it should be strong enough to support the weight of the nose cone even in a worst case scenario. Once the design for the rover deployment system is finalized, we will perform physical tests on the 3D printed bracket to verify this result.

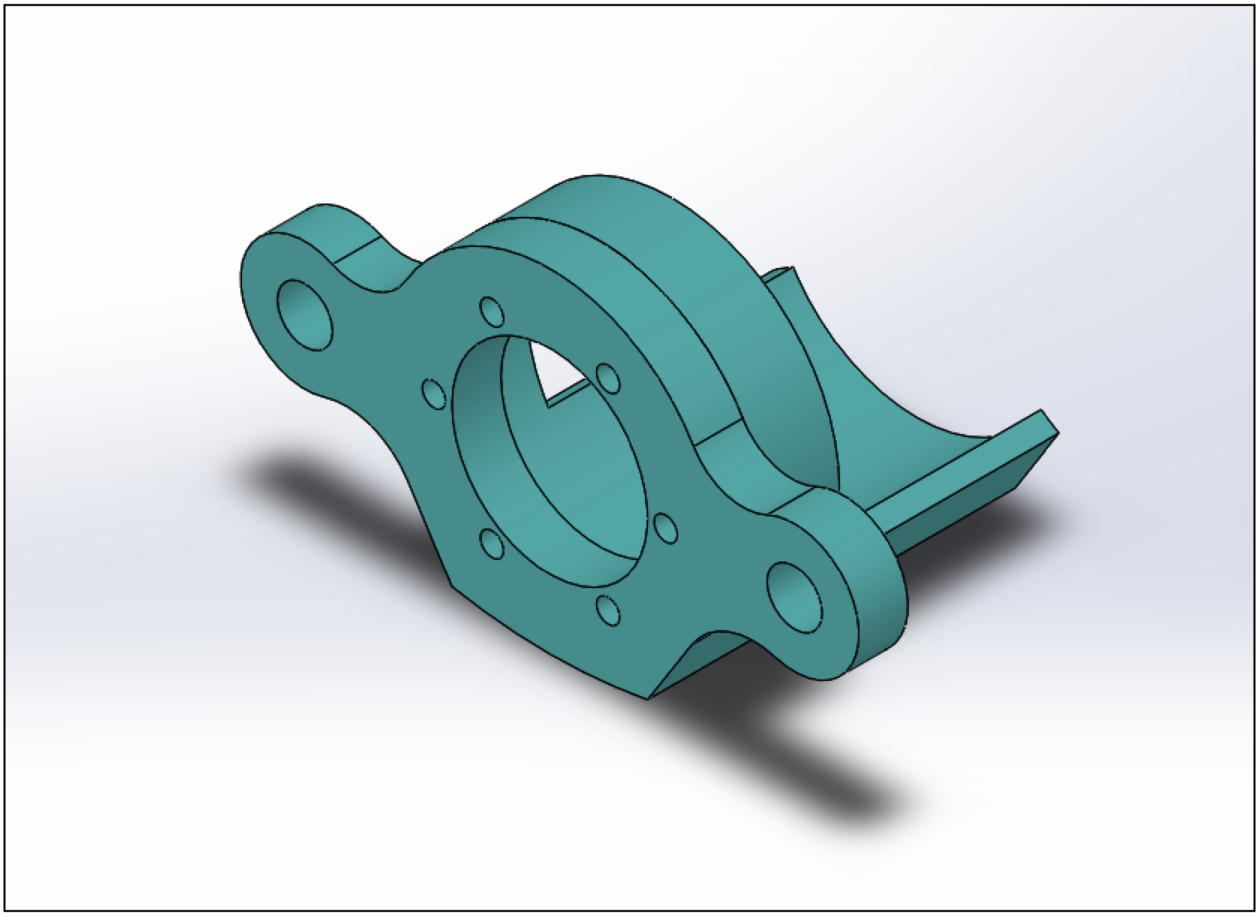


Figure 6.2.12**.** This is an image of the CAD for the motor bracket.

The purpose of the motor bracket is to hold the motor in place and support the back ends of the guide rails. The bottom surface of the bracket is curved to fit the inside surface of the tray, to which it will be epoxied. The holes on the front face of the bracket line up with the mounting holes on the front of the motor. Referring to Figure 6.2.6, it can be seen that the shaft is offset from the center of the motor. The motor is oriented such that the shaft is as close to the tray as possible. This saves space in the rover bay.

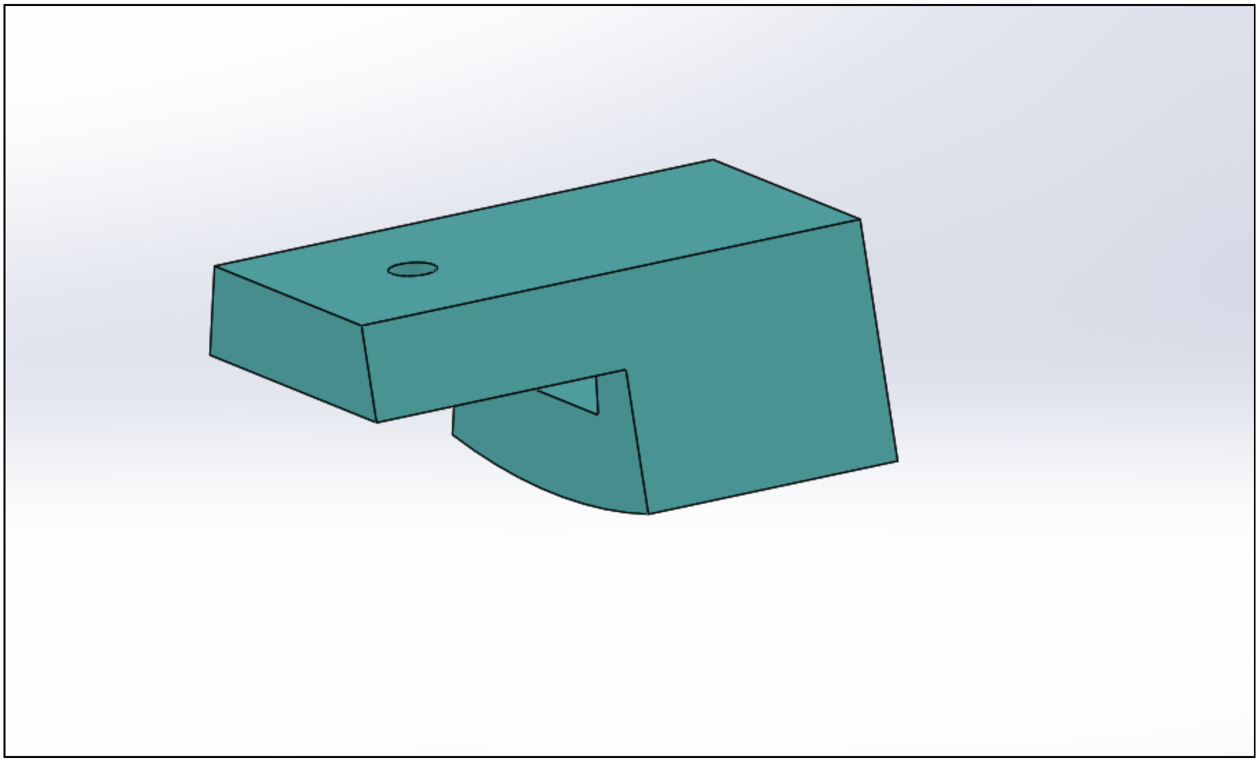


Figure 6.2.13**.** This image shows the CAD of the nose cone bracket

There are two nose cone brackets: one for each support beam. The support beam slides into the slot in the body of the bracket and is held in place by a single screw. Each bracket will be epoxied to the inside of the nose cone, so the bottom is curved to fit this surface.

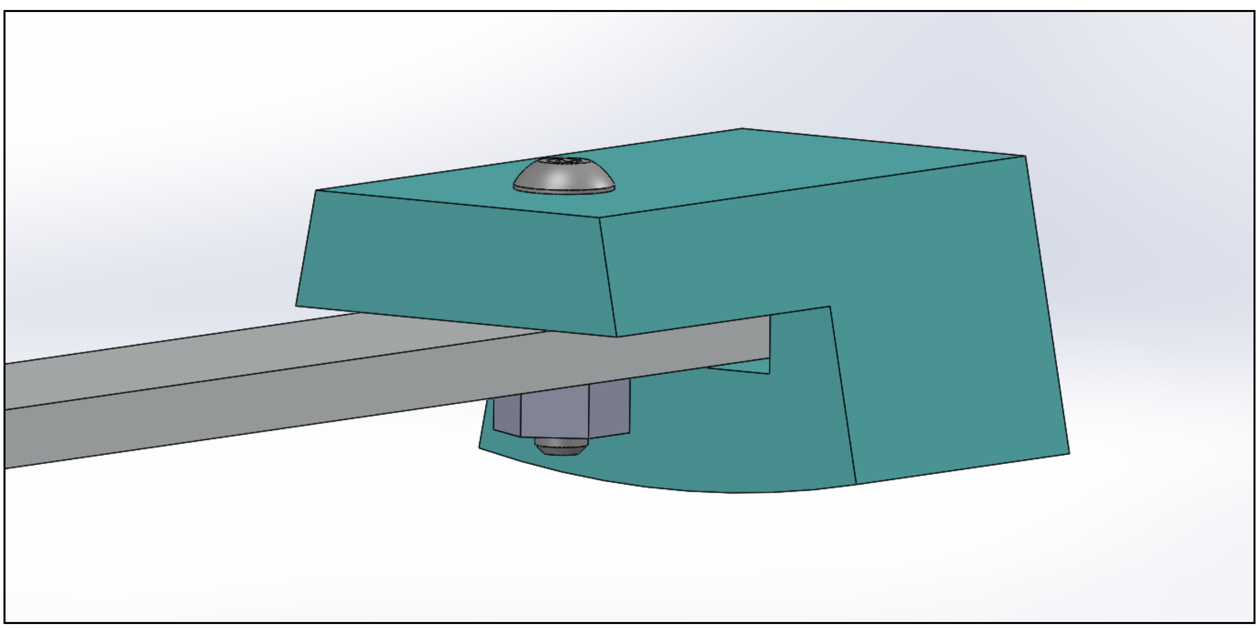


Figure 6.2.14. This image shows how the support beam is secured by the nose cone bracket.

Each support beams slides into the slot in its bracket, and is held in place by a single screw. By only using one screw for each beam, this design makes it much easier to unscrew the beams and remove the nose cone from the rest of the rocket. This is important because the nose cone will need to be removed in order to access the rove deployment mechanism to perform maintenance or replace the battery.

The motor is a 12V DC speed reduction geared motor. It was chosen due to its high torque and compact size. The same motor was used in the subscale prototype, and it had no difficulty supplying sufficient torque to push off the nose cone. A shaft coupler is used to connect the motor shaft to the threaded rod.

The electrical components of the system are not shown in the figures above, but they include a battery to power the receiver and the motor, a radio receiver, a receiver controlled switch, and a limit switch. Once the receiver detects the signal from the transmitter, it activated the receiver-controlled switch. This closes a circuit between the battery and the motor, turning on the motor. The limit switch will be mounted near the front support bracket such that it is pressed when the carriage has reached the end of the threaded rod and the rocket is fully open. The carriage will press the switch, which will be wired to open the motor's circuit, turning it off. This ensures that the system will not break itself by trying to push the carriage past the front support bracket.

As can be seen in the function tree shown in Figure 6.1.2, the design for the rover deployment system must account for a number of factors. First and foremost, the deployment system must remain intact and operational. When the rocket is first launched, there is a sudden change in momentum. During flight, it experiences vibration. Finally, there is the impact of landing. Like all other systems, the rover deployment mechanism must survive these loads and remain operational. As stated in the handbook, the deployment of the rover must be remotely activated. When the rocket lands, it will likely be far away and there may be obstacles blocking the line of sight to the rocket. Remote activation must still work despite these challenges. Premature activation of the system would result in the rocket opening up at an unexpected time, possibly during flight. This would be highly unsafe and must be avoided. The primary function of the deployment system is, of course, to get the rover out of the rocket. To do this, the rocket must first open up. The rocket's position on the ground after it lands is unknown, therefore it must be able to open and expel the rover in any orientation. The exact location of landing is unknown. The rocket could land in a ditch, on a rock, or surrounded by any number of obstructions. These obstructions must not hinder the rover deployment system. Additionally, as the rover drives away, it must not get stuck on any part of the rocket itself.

Rover Drivetrain

Table 6.2.4 Rover Drivetrain Solution Table

	Solutions			
Function	**1**	**2**	**3**	**4**
Components do not slip during launch	Have flanges on wheels to limit track slippage	Use wheels instead of tracks	Have multiple interlocking parts to provide redundancy for slippage	
Components are not damaged during launch	Encapsulate the rover in foam for vibration/landing protection	Rover is suspended within rocket body	Decrease overall landing velocity to a point safe for rover and associated components	Rover wheels have suspension
Compatible with different rocket orientations	Create drivetrain that functions in forward and reverse	Use gyroscope to measure orientation before executing movement commands	Use wheels that turn to allow rover to correct orientation	
Rover does not get stuck on rocket	Expelled by force with a blast of compressed air	More power provided to drivetrain if location does not change		

Traction for uneven terrain	Use track system with high friction	Use spikes on wheels to dig into terrain	Wider wheel/track width for larger contact surface area	
Torque/Force for uneven terrain	Powerful motors to drive wheels/track	Compressed air for additional pushing force		
Doesn't get stuck on parachute/cord	Large wheels to roll over cords	Large tracks to roll over cords		
Does not limit solar panel actuation	Wheels/tracks oriented with gaps for solar panels	Wheels/tracks and solar panels on different sides of rover	Low power system to limit power directed to drivetrain, more power for solar panels	
Mechanically compact	Drive two wheel axle with one motor	Narrow width wheels		

Table 6.2.5 Drivetrain Evaluation Matrix

Concept		1		2	
Criteria	**Importance**	Wheels		Tracks	
Low Weight	6	2	12	2	12
High Manufacturability	8	3	24	2	16
Low Complexity	6	3	18	2	12
Inexpensive	3	2	6	2	6
Traction	10	1	10	3	30
Durability	7	3	21	3	21
Risk of Slippage	5	3	15	1	5
Reliability	8	1	8	2	16
Total Possible:	**159**				
Total			114		118
Relative Total			71.70 %		74.21 %
Scores Range: 1 - 3 (1 = bad, 3 = great)					

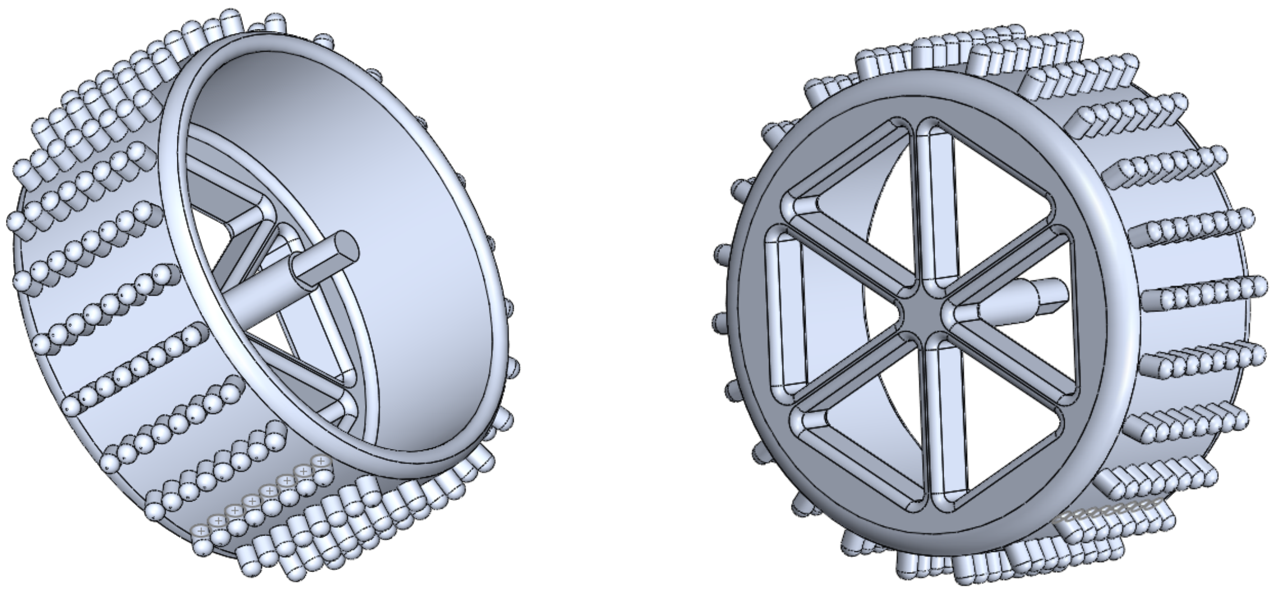


Figure 6.2.15: Illustrates the most reliable concept for moving over the ground.

The wheel has knobs on the surface to dig through unsettled terrain and provide increased grip/traction. The center and a portion of the front face was hollowed out for weight reduction purposes, with spokes left for structural support. From the central hub on the front face a thick post extends for the majority of the wheel diameter. The post decreases in thickness and shape into a d-shaft to allow for motor coupling/connection. The increased thickness until the coupling point is there to reduce flex and sway as the wheels carry the distributed weight of the rover and transmit the torque from the motor to the ground. Finally, the fillets while providing minor weight reduction were actually created to prevent user injury from the likely sharp corners that would be generated in manufacturing of the wheel.

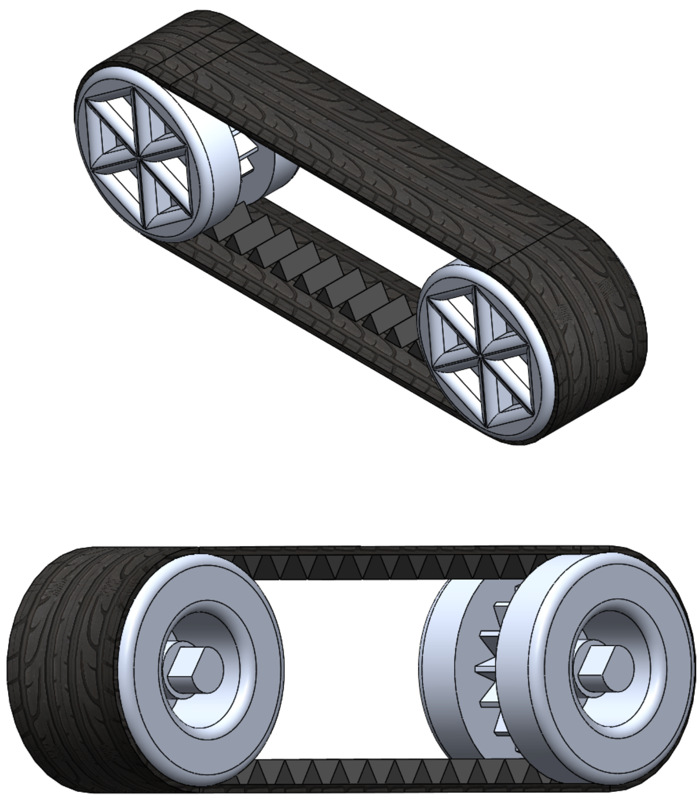


Figure 6.2.16: Tread Concept

Illustrates a very useful concept for the occasion when the terrain conditions will vary wildly and are overall a major concern. The wheel design can possibly permit a hazard to lift the rover out of a proper driving configuration whether a wheel got stuck in a hole or was too small to maneuver over a terrain obstacle. The basic wheel design from Figure 6.2.1 carries over into the design of the track wheels a lot, with the weight reduction and motor attachment methods. The major difference wheel wise is the implementation of the teeth in the center of the wheel which engage with the teeth that comprise the belt that allows the system to move over terrain. The belt which is commercially available will be the part actually coming into contact with the ground and moving the rover. The major concern with tracked systems is that the track will disengage from the drive pulleys rendering the vehicle immobile. This situation will be addressed by the deep flat sided grooves that are cut into the drive wheels. Those grooves are intended to totally encapsulate the section of the belt with the teeth to ensure that the belt does not try to climb out of its track. Therefore, the belt and the system as a whole will remain functional by the careful design of the drive system and the constant tension held between the pulleys.

Solar Panel Deployment

Table 6.2.6 Solar Panel Evaluation Matrix

Concept		1		2		3	
Criteria	**Import-ance**	Servo turning multiple flaps		Servo removing arm to hold down spring loaded panels		Servo mounted directly to solar panel	
Low Weight	6	2	12	3	18	3	18
High Manufacturability	8	2	16	3	24	2	16
Low Complexity	6	1	6	2	12	3	18
Durability	7	2	14	2	14	2	14
Inexpensive	3	1	3	2	6	3	9
Reliability	10	3	30	1	10	3	30
Total Possible:	**120**						
Total			81		84		105
Relative Total			67.5%		70.0%		87.5%
Scores Range: 1 - 3 (1 = bad, 3 = great)							

Table 6.2.7 Solar Panel Solution Table

	Solutions			
Function	**1**	**2**	**3**	**4**
Not damaged by vibration	Use springs on the solar panel mounts	Decrease size of solar panel compartments so less room for movement		
Not damaged by landing	Cushion solar panel compartments	Contain all solar panel components within the rover body	Mount solar panels on suspension	
Deploy in proper orientation	Use gyroscope to determine rover orientation	Have solar cells on both sides of panel	Deploy different panels at different angles to account for sunlight angle	
Unfold as per competition guidelines	Use spring-loaded panels, that unfold when the panels are pushed out of the rover body	Run current through shape-memory skeleton to extend folded panels		
Proper size based on efficiency and sunlight	Include factor of safety of 2 for solar panel size	Use high efficiency solar panels to maximize power	Conduct ground testing under worst case conditions to determine necessary size	
Electrically wired to collect and transfer power	Redundancy in power storage	Solid core wire to increase durability and strength	Digital display to show transfer of power	

Generates enough light to power an LED	Conduct testing under worst case light conditions	Use low power LED with high contrast to natural light	Power only LED with solar panel energy, all other components with stored batteries	

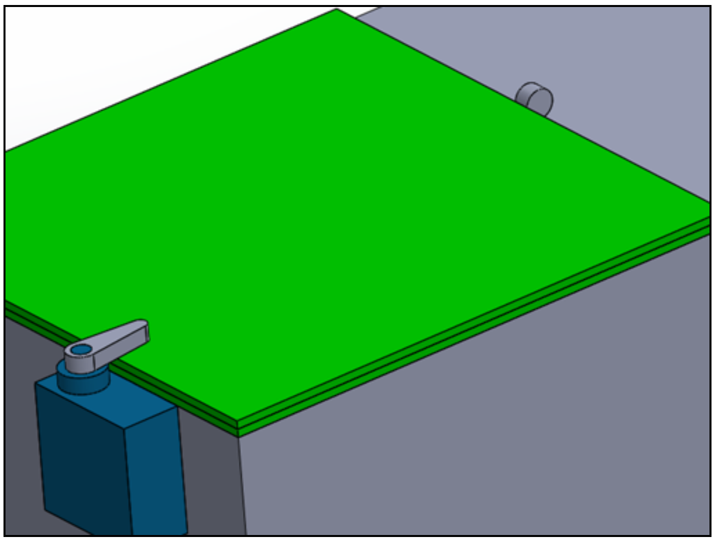


Figure 6.2.17: Solar Panel Design

This shows half of the second solar panel design. Because the rover could potentially deploy upside down, this design will be on the top and bottom of the rover to ensure at least one set of solar panels get direct sunlight.There are two solar panels lying face to face with each other, connected by a torsion spring on the end away from the motor. The servo motor attached to the back end of the rover prevents the solar panels from folding out. Upon solar panel deployment the servo arm will turn, causing the panels to spring open. The spring will be light enough such that if the opposite (under) side opens as well the rover won't flip over.

6.3. Electronics and Software

6.3.1. Electronics Overview

The electronics hardware included in the rover subsystem consists of two systems: the rover deployment system and the rover control system. Both systems function independently and remove any chance of a failure when communicating between the systems. Although the rover control system is naturally dependent on the rover deployment system, as the rover cannot drive away from the rocket if it is not deployed from the rocket, the avionics and rover subteams have taken care at every step to remove unnecessary dependencies that could induce a risk to the rover system as a whole.

6.3.2. Control Electronics

The rover control system functions as a method for controlling the rover after it is deployed from the rocket fuselage. This system is centered around an ATMEGA8 microcontroller chip designed on a PCB with the necessary components to provide digital and analog inputs and outputs. This ATMEGA8 chip is the same chip used on the arduino uno, and is compatible with the arduino programming language. The benefits of using the arduino programming language are extensive, and will be discussed in detail in the software section below. The avionics subteam discussed using an arduino with off-board sensors and motor controllers, but eventually decided to design an arduino on a PCB. The sensors needed for successful operation of the rover should be minimal, but the avionics subteam has mainly considered the need for encoders and a gyro. If servos are used for driving the rover, encoders will not be necessary, as servos have built-in encoders. If servos are not used, however, encoders will have to be accounted for in the wiring diagram below. In addition, the avionics and rover subteams will determine, based on motor choice, whether it is necessary to include a gyro on the PCB to ensure that the rover drives in a straight line. This option will minimize the possibility of wire disconnections and allow sensors and motor controllers to be integrated on the same PCB as the microcontroller. An added benefit of using a single PCB is that the overall volume occupied by electronics will be minimized. The overall space taken by rover electronics is critical, as the rover's deployment will be perpendicular to the rocket's fuselage. This deployment method severely limits overall space for rover electronics. A photo of the circuit design for the PCB is shown in Figure 6.3.1 below.

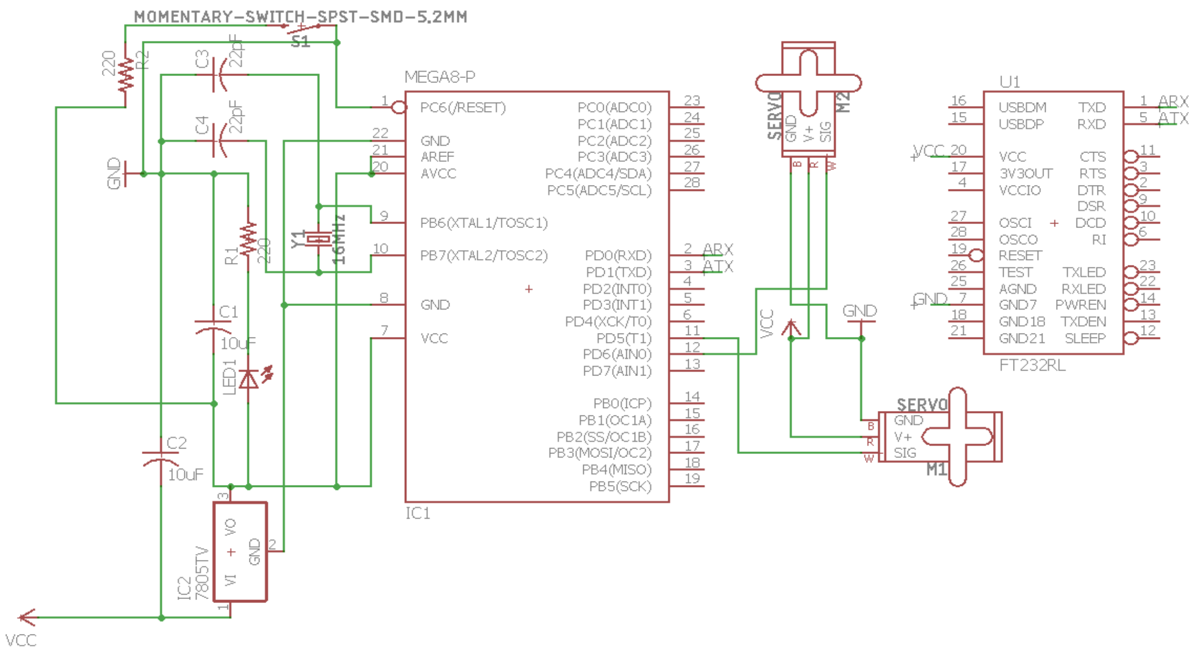


Figure 6.3.1 Rover Control Circuit

6.3.3. Deployment Electronics

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, receiver-controlled-switch, and limit switch. A flowchart of the deployment system's function is outlined in Figure 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. A circuit diagram of the system can be found on Figure 6.3.3.

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, if necessary. 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. 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.

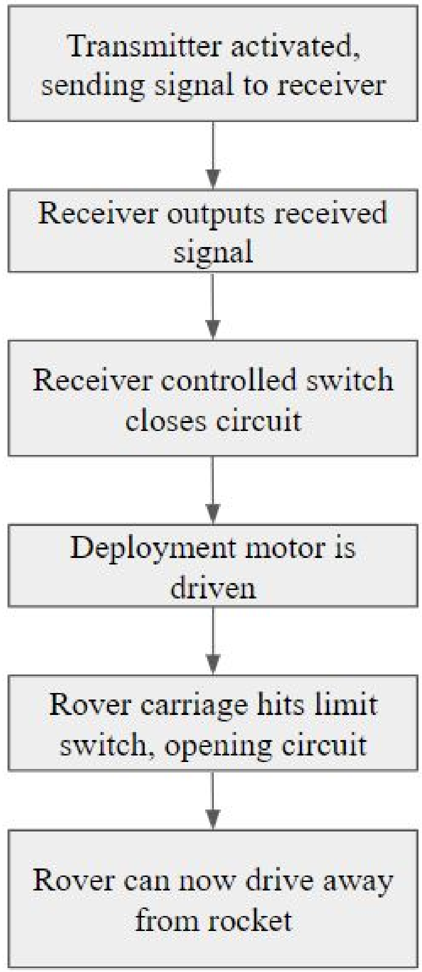


Figure 6.3.2 Rover Deployment Flowchart

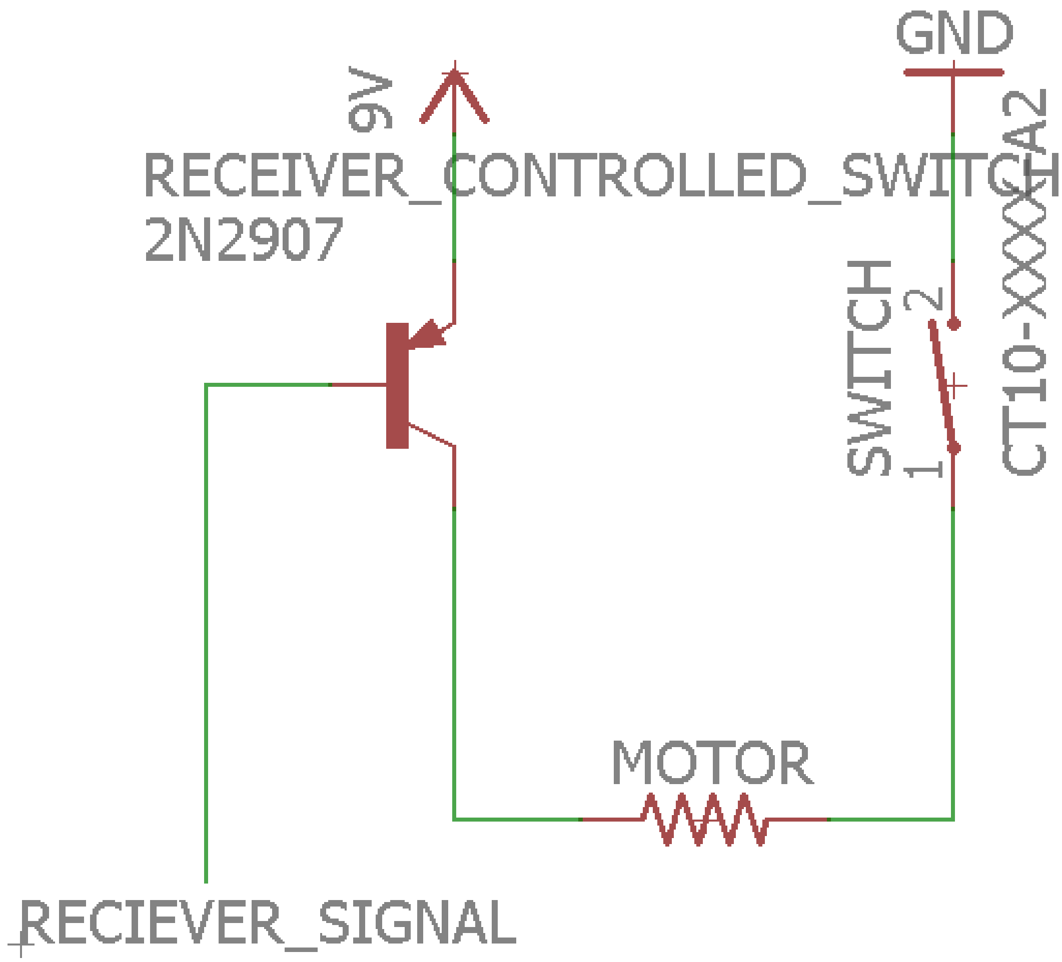


Figure 6.3.3 Rover Deployment Circuit

6.3.4. Software

The software running on the rover subsystem will be limited to only the rover control system. The rover deployment system is functional without a microcontroller of any kind, and thus does not need to run software to be functional. As the rover control system consists of an ATMEGA8 microcontroller for processing data, the initial choice of programming language is arduino, which is built for such a 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 industry, making many libraries closed-source. Arduino is a language built on open-source principles, and is not widely used in industry, so it was easy to find libraries for servo control, gyro reading, and encoder control.

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. After deployment of the rover, the microcontroller will have to send the appropriate PWM signals to the drive system in order to induce the forward motion of the rover. The rover will take in output from the encoders on the drive system and use a PID (Proportional, Integral, Derivative) controller to determine if the rover is driving straight and to determine how far the rover has moved since deployment. With encoders on both sides of the rover, it is possible to determine the difference between each side's distance measurement and correct for any misdirection that the rover might take. This method of steering, along with a gyro, will ensure that the rover proceeds from the rocket in the way that we intend it to, which is currently straight away from the rocket, perpendicular to deployment system motion. After the rover has finished moving at least 6 feet from the rocket, a servo will trip a mechanical system that will flip the solar panels down. At this time, the solar panels will begin charging the battery that drives the rover.

Table 6.3.1 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++					

7. Flight Systems and Avionics

7.1. Objective

The avionics of the rocket can be categorized in terms of three different subsystems: the recovery system, the Apogee Targeting System(ATS), and the challenge.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 avionics of ATS system are responsible for for performing kinematic calculations and actuating the mechanics of the ATS system in accordance with these calculation in order to achieve a near ideal apogee. The avionics of the challenge system are responsible for initiating the deployment of the rover vehicle after landing and for controlling the motors and actuators that allow the rover to move and extend it's solar cells. The electronics and software of the ATS and challenge system are discussed in the Apogee Targeting System Section and the Rover System Section respectively.

7.2. Success Criteria

The minimum success criteria for the avionics system as a whole is the safe recovery of the vehicle after launch. Complete mission success shall be defined as the flawless operation of the recovery system, the ATS system, and the challenge system. The table below contains a list of success requirements for the three subsystems.

Table 7.2.1 Mission Success Criteria for Avionics

Requirement	*Associated Subsystem(s)*	*Requirement Verification*	*Success Criteria*
The vehicle will be capable of adjusting its flight path in order to achieve a predetermined apogee	ATS	Subscale flight test	Apogee within 2% of target
The rover will be deployed upon landing	Challenge System	Ground testing of the rover and its deployment mechanism. Range testing of the radio system	The rover is able to successfully exit the vehicle and continue on to complete its tasks.
The rover avionics will be capable of instructing the rover to traverse 5 feet of ground	Challenge System	Ground testing	The rover traverses a minimum of 5 feet of ground upon exiting the rocket
The rover avionics will be capable of controlling the deployment of solar cells once the rover has moved 5 feet from the rocket	Challenge System	Ground testing	The rover deploys the solar cells after moving 5 feet from the rocket
The launch vehicle return will to earth in a safe and controlled manner	Recovery System	Subscale flight test	Altimeters deploy charges at the proper altitudes and the vehicle is safely recovered
The rocket will be recovered quickly efficiently	Recovery System	Subscale flight test	The coordinates of the landing location are received from launch vehicle and the vehicle is retrieved in a timely manner
A flight log of the vehicle's launch will be recorded.	Recovery, ATS	Subscale flight test	The data will be recovered and readable after flight

7.3. Recovery System

7.3.1. Overview

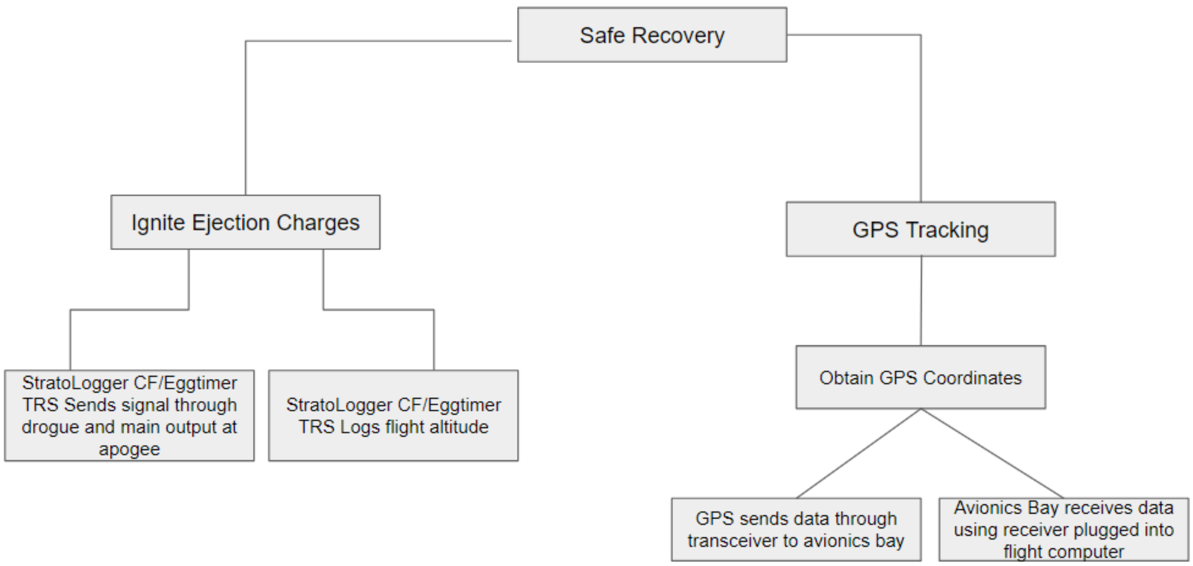


Figure 7.3.1 Recovery System Function Tree

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 7.3.1 above. 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 Figure 7.3.2.

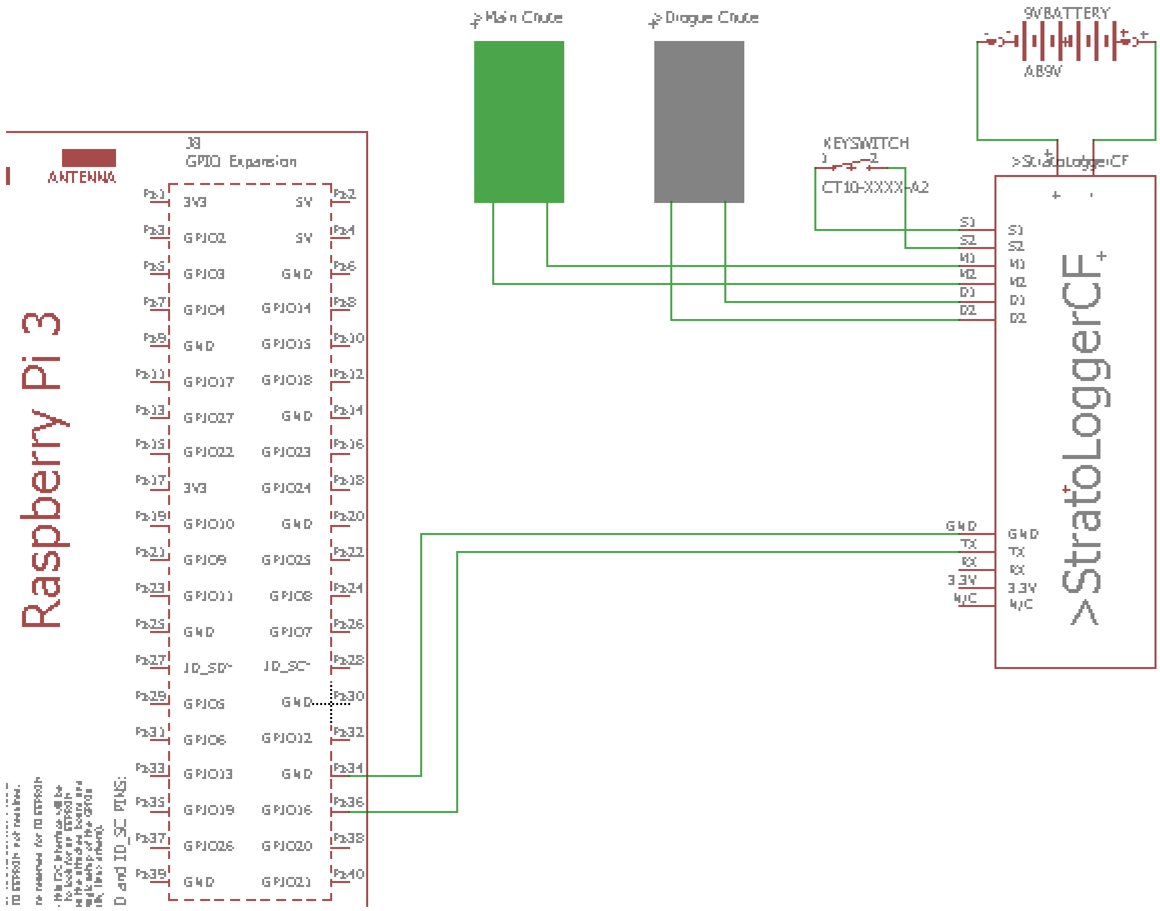


Figure 7.3.2 Recovery System Wiring

7.3.2. Altimeter

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 7.3.3 lists the different ports of StratoLogger CF and briefly describes the functionality of each. Figures 7.3.4 and 7.3.5 shows a more detailed view of the StratoLogger CF schematic.

Table 7.3.1 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.

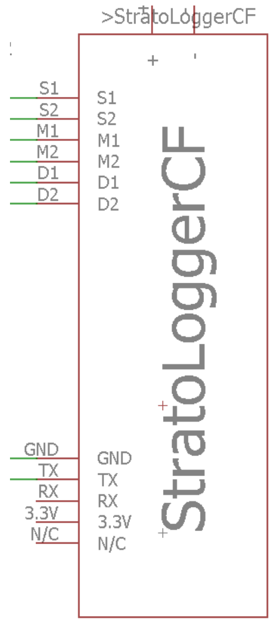


Figure 7.3.4 StratoLogge rCF Schematic

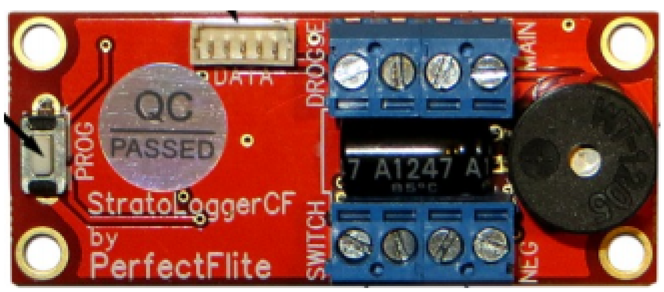


Figure 7.3.5 StratoLogger CF Altimeter

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 7.3.2 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%)

7.3.3. 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 Figure 7.3.6.

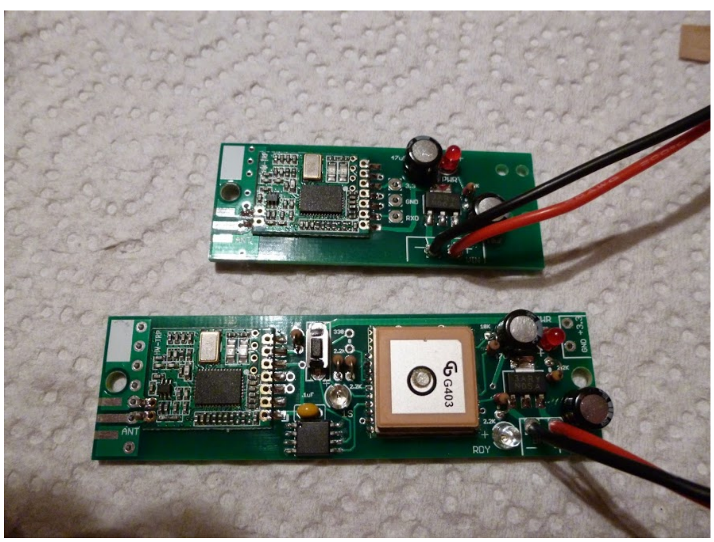


Figure 7.3.6 Assembled Eggfinder GPS Tracking System

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.

7.3.4. Safety

In order to ensure a cost effective, safe, and durable power system for the rocket's electronics, disposable Duracell 9V batteries will be used. One will be used to power both the main and backup recovery systems (the two altimeters).

7.3.5. 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.

7.4. Avionics Bay Structures

7.4.1. Introduction

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 avionics bay.

There are ten primary components housed in the subscale avionics bay: three rotary switches, two altimeters, two nine volt batteries, one UBEC power supply, one Raspberry Pi, and one lithium polymer(lipo) battery. The number and type of components housed in the full scale avionics bay will be very similar, if not identical. A photo of the subscale avionics bay can be seen below.

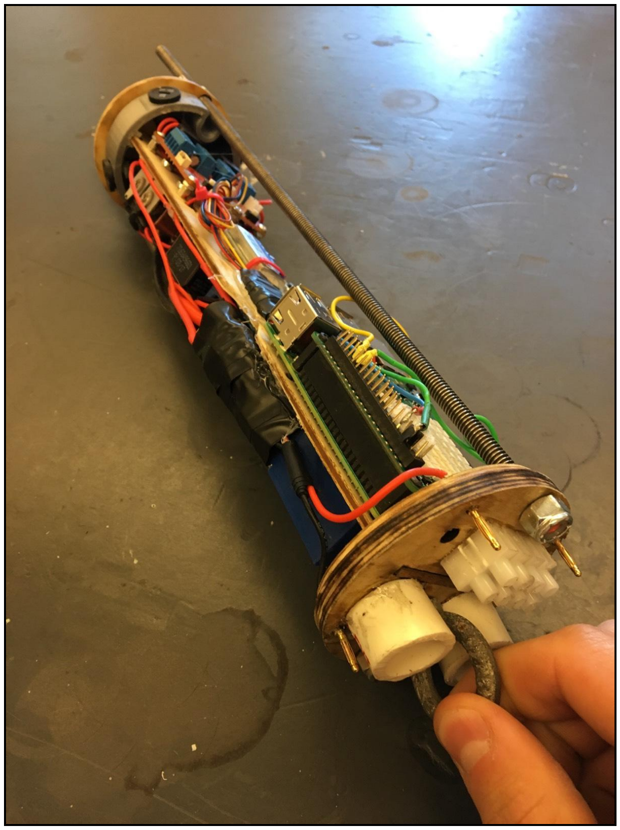


Figure 7.4.1 Subscale Avionics Bay

7.4.2. Design Considerations

The primary design considerations for the subscale avionics bay were space and organization. The location of each component was chosen carefully to allow all electrical connections between components to be as short and easy to follow as possible. Choosing a three inch diameter body tube for subscale rocket made fitting all the necessary avionics into the tube a challenge. The entire avionics bay, and its associated components, were modeled in Solidworks to ensure that all components would ensure everything would fit within the body tube without complication.

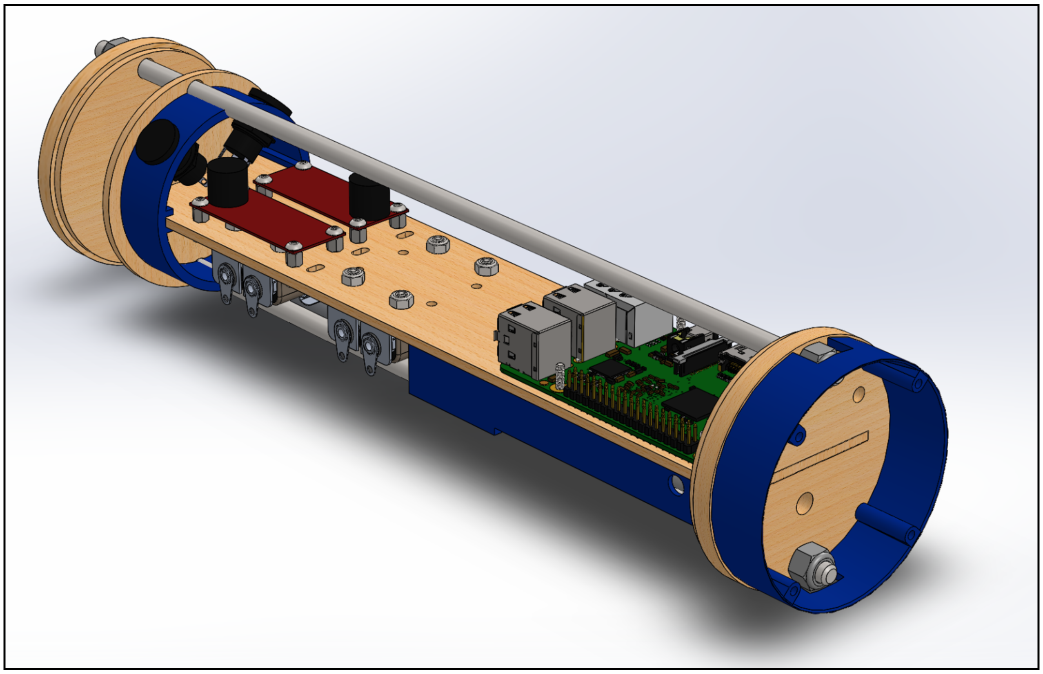


Figure 7.4.2 Subscale Avionics Bay CAD Assembly

Another challenge is severing the connections between the avionics bay and the ATS bay when the drogue chute is deployed at apogee. This challenge will be addressed with a ring of four friction fit connectors mounted within the body tube between the avionics bay and the ATS bay. When the two sections are fit together, the connectors will join, providing a clean and reliable connection between the avionics bay and the ATS bay. These connectors will also allow for a clean separation of the wires when the ejection charge is triggered at apogee. Bullet connectors were chosen to test this interface on the subscale rocket.

7.4.3. Subscale Manufacturing

The structure of subscale avionics bay is comprised of an avionics tray, two bulkheads, and a centering plate(which helps to keep the avionics bay centered in the body tube). In total six profiles were cut from either ⅛ inch and ¼ inch birch plywood to construct these parts. All mounting holes and pass-throughs for wiring were cut from these pieces were also cut with the laser. This allowed for faster and more accurate assembly of the avionics bay than drilling these holes manually as has been done by the team in the past. The prototype for the avionics tray and centering plate cut from ⅛ inch plywood are shown below.

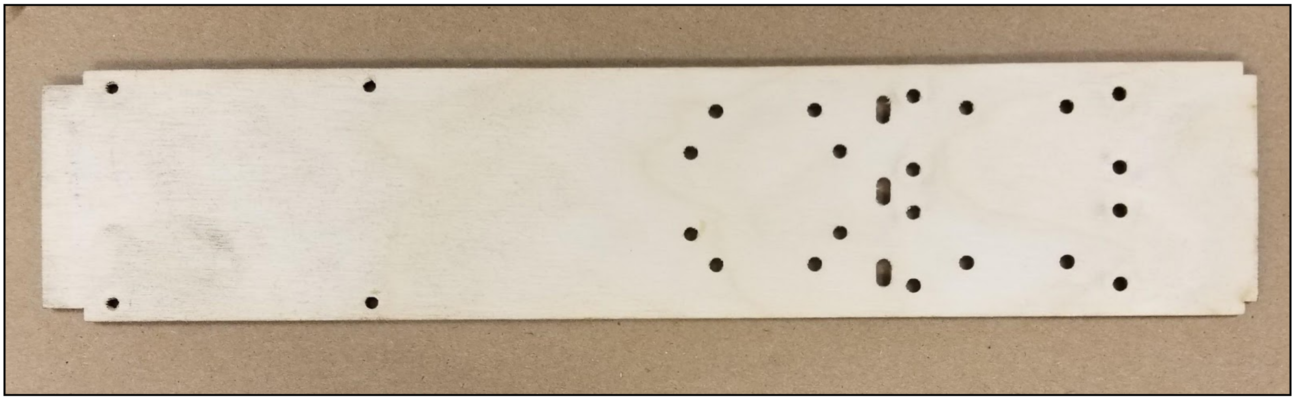


Figure 7.4.3 Avionics Bay Tray Prototype

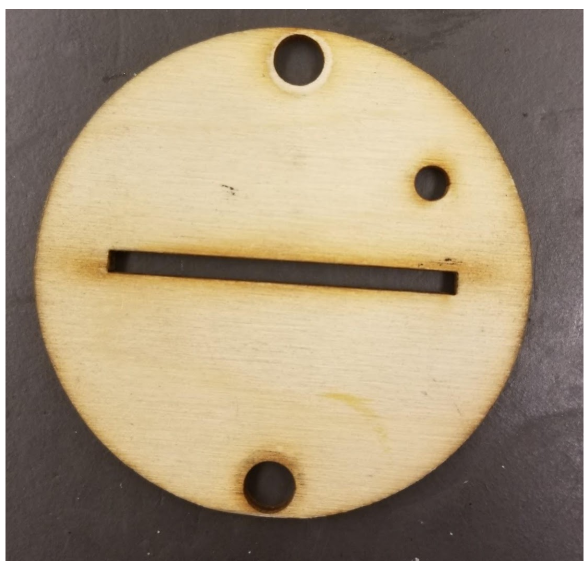


Figure 7.4.4 Subscale Centering Plate

In addition to the six wooden parts, the avionics bay also contains three 3D printed parts: a lipo battery mount, a rotary switch mount, and a breakaway connection ring. These parts were printed from polylactic acid plastic(PLA) on desktop 3D printers. Photos of these components can be found below.

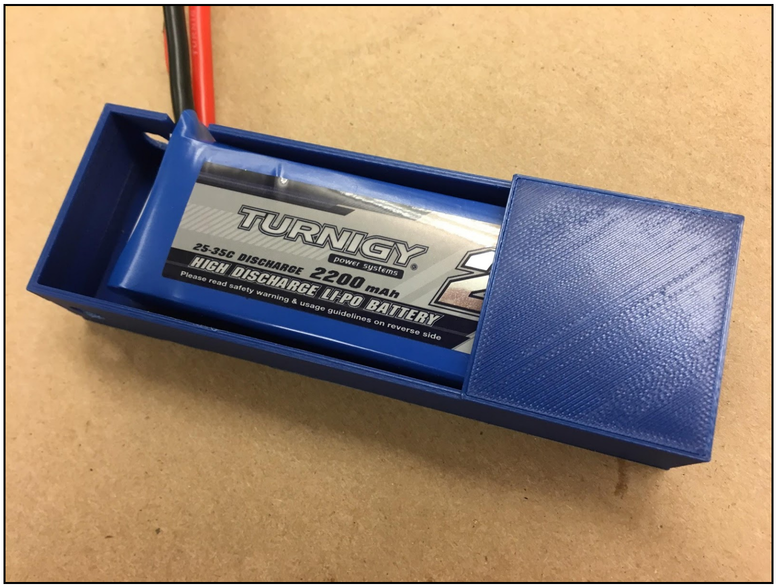


Figure 7.4.5 Battery Box

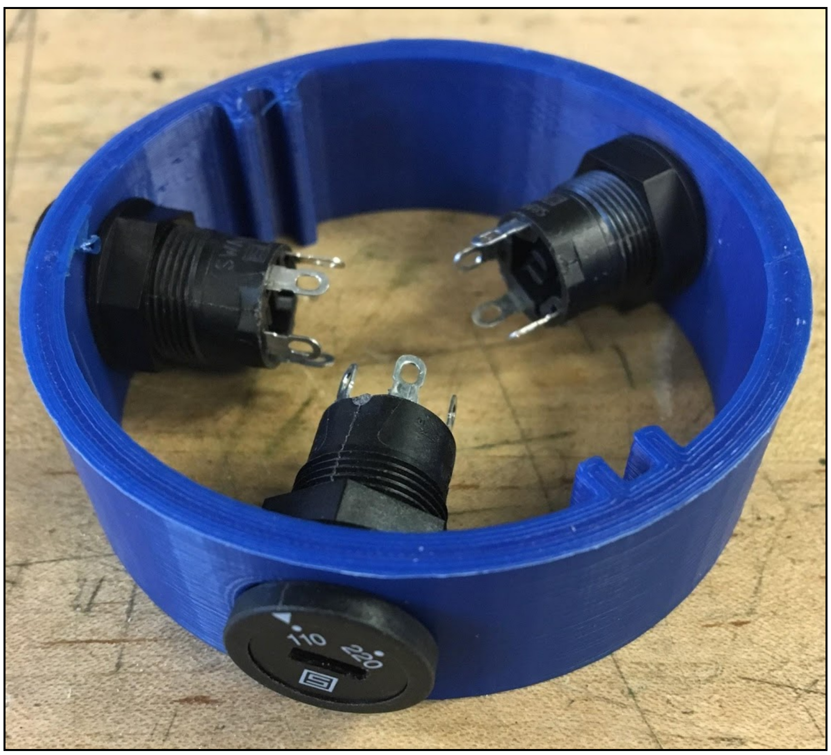


Figure 7.4.6 Rotary Switch Mount

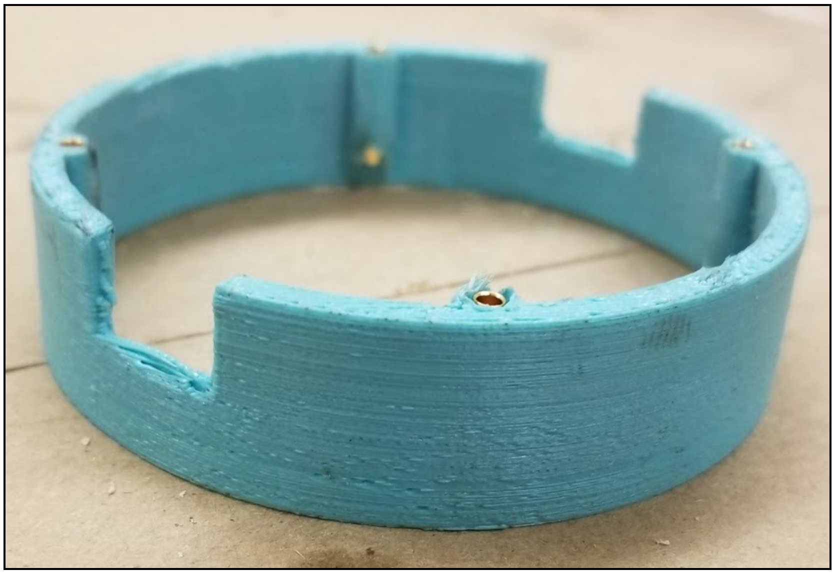


Figure 7.4.7 Connector Ring

7.4.4. Full Scale Considerations

A number of things were learned during the construction of the subscale avionics bay. First, with the equipment we currently have access to, laser cut parts are far faster and far easier to manufacture than 3D printed parts. Multiple iterations of a part are often made in order to properly account for the tolerance. As some prints are quite lengthy and prints sometimes fail, this process can be very time intensive for 3D printed parts. Prior to constructing the subscale avionics bay, the team was considering implementing a one-piece, 3D printable, avionics bay. While this option is still being considered, subscale construction has made a laser cut avionics tray appear as a more viable option. Additionally, the subscale construction process revealed that the interface between the avionics bay and the ATS bay needs to be reconsidered. Subscale testing showed that it was extremely difficult to align the bullet connectors while fitting the sections of the rocket together. Getting a reliable connection between the two sections proved near impossible. For the subscale flight, the bullet connectors will not be mounted in the ring. The connectors will be pushed together prior to joining the rocket sections and the excess wire will simply sit in the body tube between the avionics bay and ATS bay. For full scale, the interface will be redesigned to allow the connectors to be easily aligned and connected as the sections of the rocket are fit together. This redesign may require a move to something other than bullet connectors and, at the very least, a redesign of the connector ring that mounts within the body tube.

7.5. Failure Analysis

In order to help identify, prioritize, and correct potential failures of the avionics system, a failure analysis was performed. First, a block diagram was created in order to visualize the dependencies within the system. Next, a Failure Mode and Effects Analysis (FMEA) chart was created to pinpoint and prioritize likely failures of the system. These resources will be invaluable in determining what should be tested and with what stringency prior to launch. These resources are displayed below.

Table 7.5.1 Avionics FMEA Chart

Component	*Function*	*Failure*	*Potential Causes*	*Detection Method*	*Impact*	*Severity (1-3)*	*Detection Difficulty (1-3)*	*Probability (1-3)*	*Risk (1-27)*	*Risk Priority Number (Risk/27)*
9 Volt Batteries	Provide power to the altimeters	Does not provide sufficient power to the altimeters	Manufacturer defect	Check voltage prior to flight	Altimeters do not function correctly	3	1	1	3	0.111
			Using old battery			3	1	1	3	0.111
Lipo Batteries	Provide power to the UBEC, ATS system, and the GPS system	Does not provide sufficient power to UBEC, ATS, or GPS system	Manufacturer defect	Check voltage prior to flight	ATS and or GPS system do not function correctly	2	1	1	2	0.074
			Battery was not charged prior to flight			2	1	1	2	0.074
UBEC Power Supply	Provide regulated power to the Raspberry Pi	Does not provide sufficient and regulated power to the Raspberry Pi	Manufacturer defect	Verify expected behavior of component prior to flight	Raspberry Pi does not function correctly	2	2	1	4	0.148
			Faulty wiring	Multimeter		2	1	1	2	0.074
Stratologger CF Altimeters	Deploy parachutes, record peak altitude and relay real-time altimeter data to the	Fails to ignite electric matches	Bad connection with screw terminals	Multimeter	Chutes not deployed	3	1	2	6	0.222
		Fails to report peak apogee	Manufacturer defect	Test functionality on subscale	No apogee altitude for competition	2	3	1	6	0.222

	Raspberry Pi				judgment					
		Fails to send data to Raspberry Pi	Faulty Wiring	Multimeter	Raspberry Pi cannot make apogee calculations for ATS system	2	1	2	4	0.148
Electric Matches	Ignite the ejection charges	Does not ignite charge	Manufacturer defect	Visual inspection	Chutes not deployed	3	3	1	9	0.333
			Faulty Wiring			3	2	2	12	0.444
Ejection Charges	Separate rocket sections and expel parachutes	Do not ignite, Do not expel parachute	Damp or otherwise corrupted powder	Visual inspection and on site ejection charge testing	Chutes not deployed	3	1	1	3	0.111
Raspberry Pi	Control ATS system and record flight log	Does not send commands to ATS system	Loss of power/ brown out	Ground Testing	ATS does not function properly	2	3	2	12	0.444
			Faulty Wiring	Multimeter		2	1	2	4	0.148
		Does not record flight log	Software Bug	Code testing	No post-flight data to analyze	2	3	2	12	0.444
Sense Hat	Provide sensor data for the Raspberry Pi	Fails to send sensor data to Raspberry Pi	Manufacturer Defect	Prior Testing	Raspberry Pi does not have sensor data for flight log and ATS calculations	1	2	1	2	0.074
Connector Ring	Allows for clean separation of avionics bay to ATS bay connections	Connections do not separate	Ejection charge not strong enough	Ejection charge testing	Drogue chute does not deploy	3	1	1	3	0.111

	when the drogue charge is ignited at apogee	Connectors break at separation	Cold solder joint	Visual inspection	Requires repair after launch	1	2	2	4	0.148
		Connector ring breaks or comes free at separation	Poor design	Finite Element Analysis and ground testing	Requires repair after launch	2	1	1	2	0.074
			Improper gluing	Visual inspection	Requires repair after launch	1	3	1	3	0.111
Eggfinder TX	Transmit GPS coordinates to ground station during launch and after landing	Does not transmit data	Faulty Assembly	Visual inspection and ground testing	No GPS coordinates to aid in locating rocket after flight	2	2	2	8	0.296
			Faulty Wiring	Multimeter		2	1	2	4	0.148
Eggfinder RX	Receive the data transmitted by the Eggfinder TX	Does not receive data	Faulty Assembly	Visual inspection and ground testing	No GPS coordinates to aid in locating rocket after flight	2	2	2	8	0.296
			Faulty Wiring	Multimeter		2	1	2	4	0.148
Computer	Display and record the GPS data	Data is not displayed or recorded	Battery Dies	Look at battery percentage	No GPS coordinates to aid in locating rocket after flight	2	1	1	2	0.074
			Bad USB connection	GPS testing prior to launch with same laptop		2	1	1	2	0.074

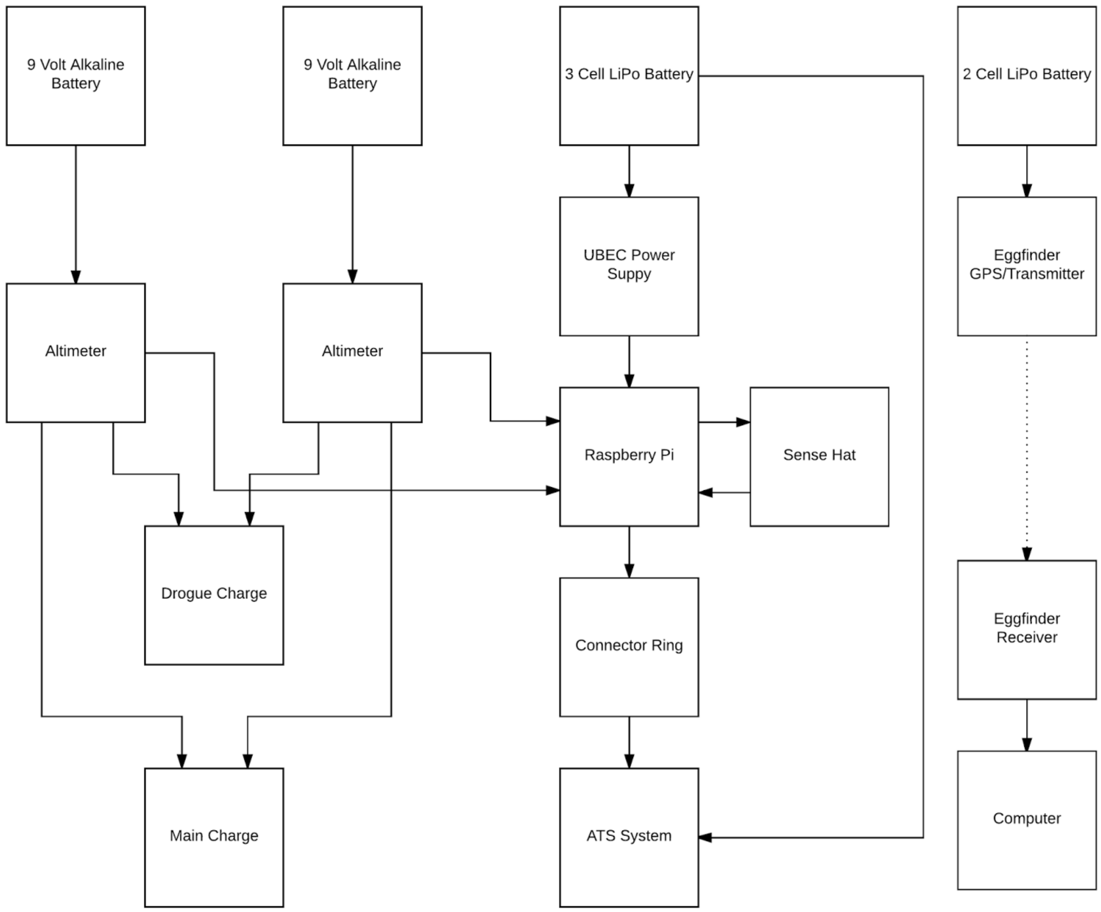


Figure 7.5.1 Avionics Block Diagram

8. Project Plan

8.1. Verification Plan

Both the NASA requirements as well as Team Derived requirements for all rocket systems can be found in the respective PDR sections. In addition to each requirement, the success criteria, design features, and verification plans are listed. The launch of the rocket will be considered a success after the verifications of all requirements, in addition to the completion of all safety procedures.

8.2. 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.

8.3. Budget

The projected budget for GIT LIT for the 2017-2018 competition cycle is $7,394.36, with Table 8.3.1 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 8.3.1.

Table 8.3.1 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**

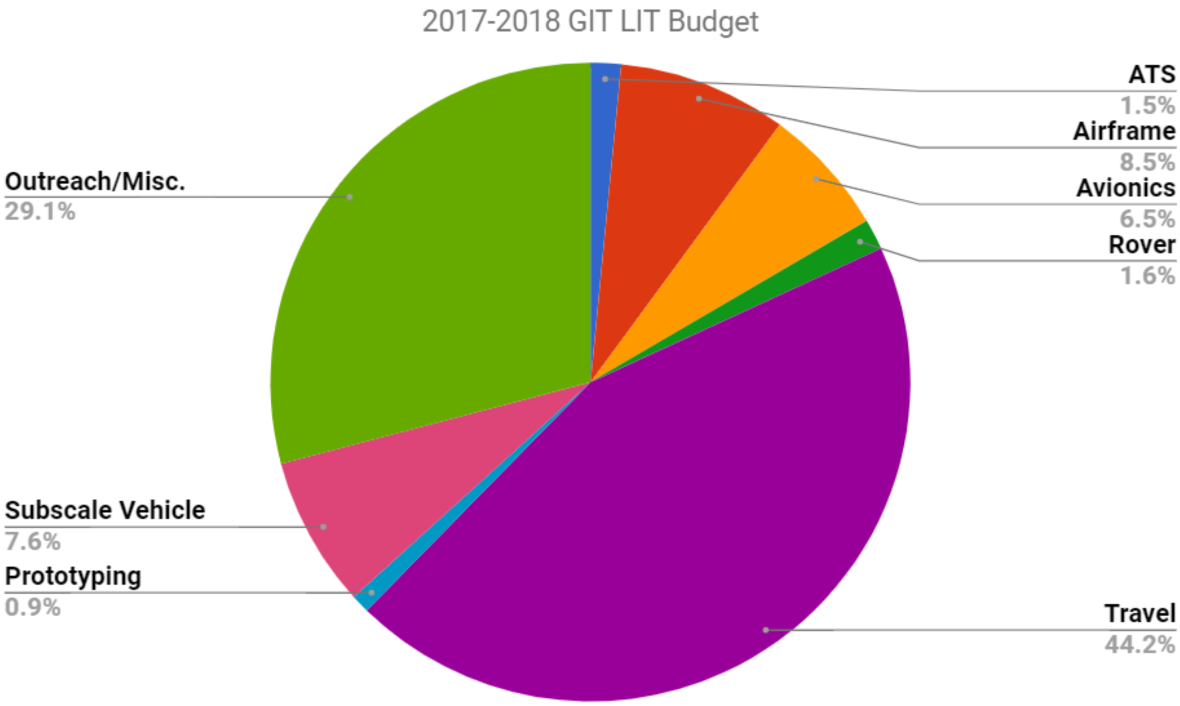


Figure 8.3.1 Team Budget Distribution

Tables 8.3.2 and 8.3.3 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 8.3.2 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 8.3.3 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**

8.4. 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 8.4.1 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 8.4.1 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.)	November 2017
Corporate Donations	$1,000 (est.)	January 2017
Orbital ATK Travel Stipend	$400 (est.)	April 2017
Total	**$9,875.23 (est.)**	

Table 8.4.2 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 8.4.2 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

8.5. 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 8.1 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.

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

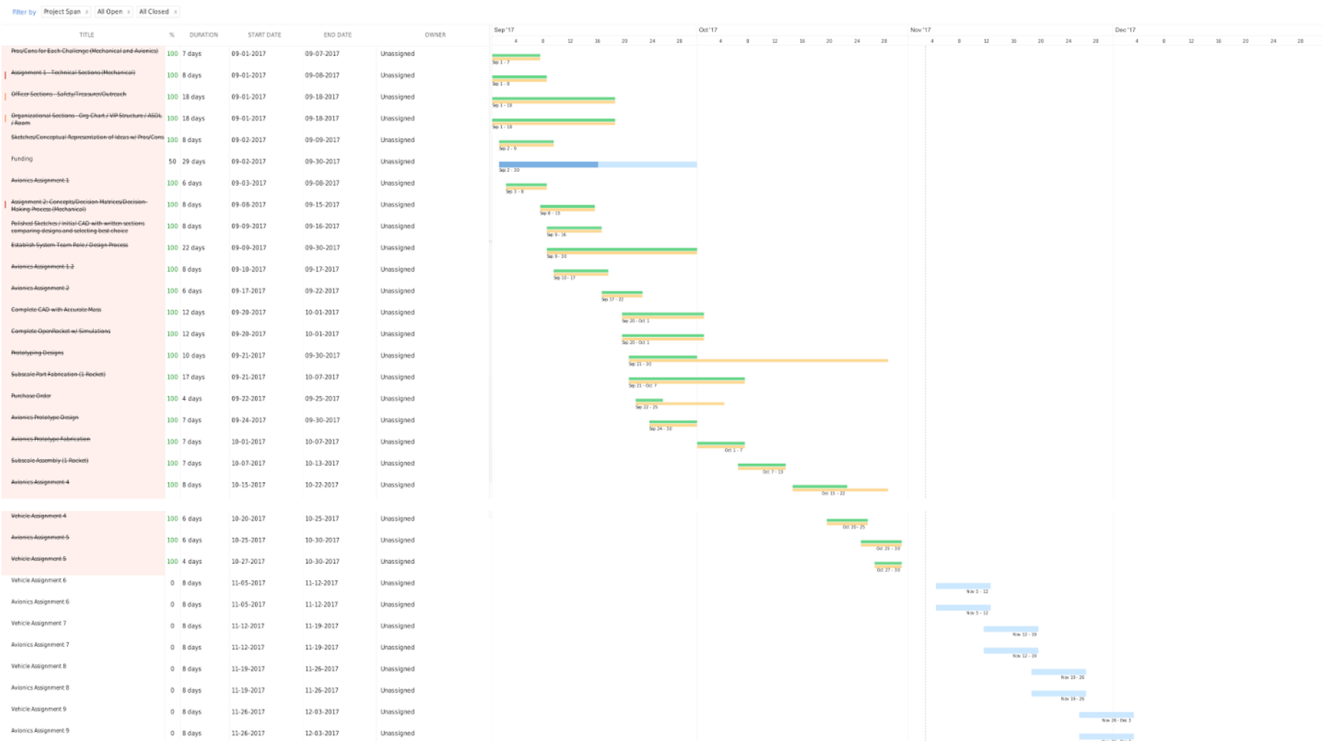


Figure A.1 Gantt Chart

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

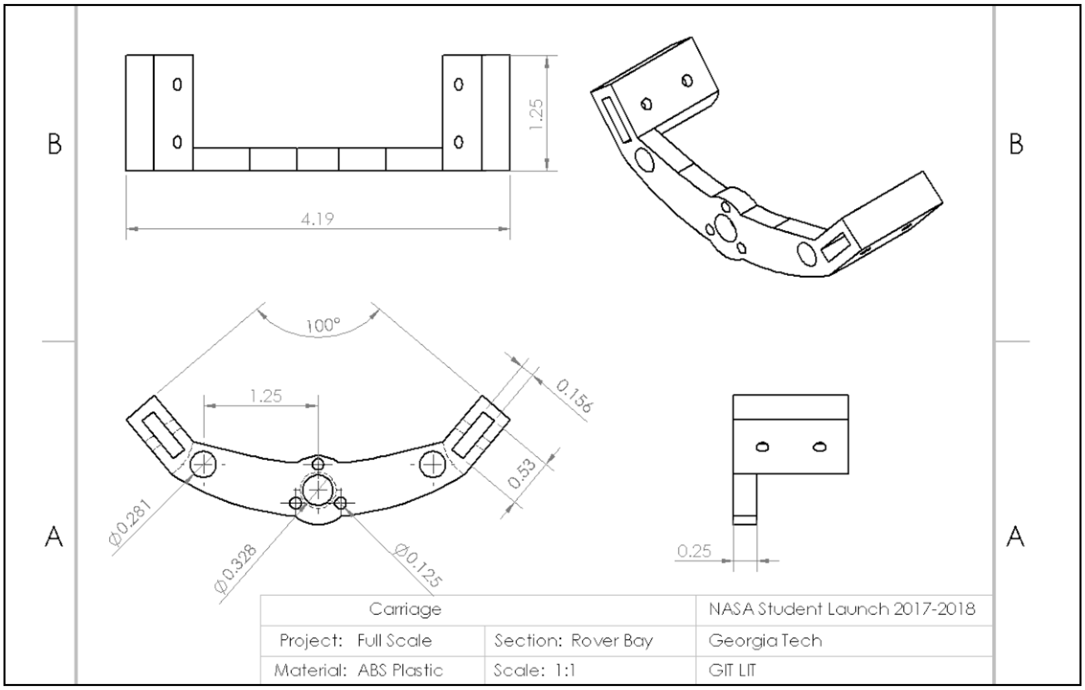
B. Planned Fabrication Tasks

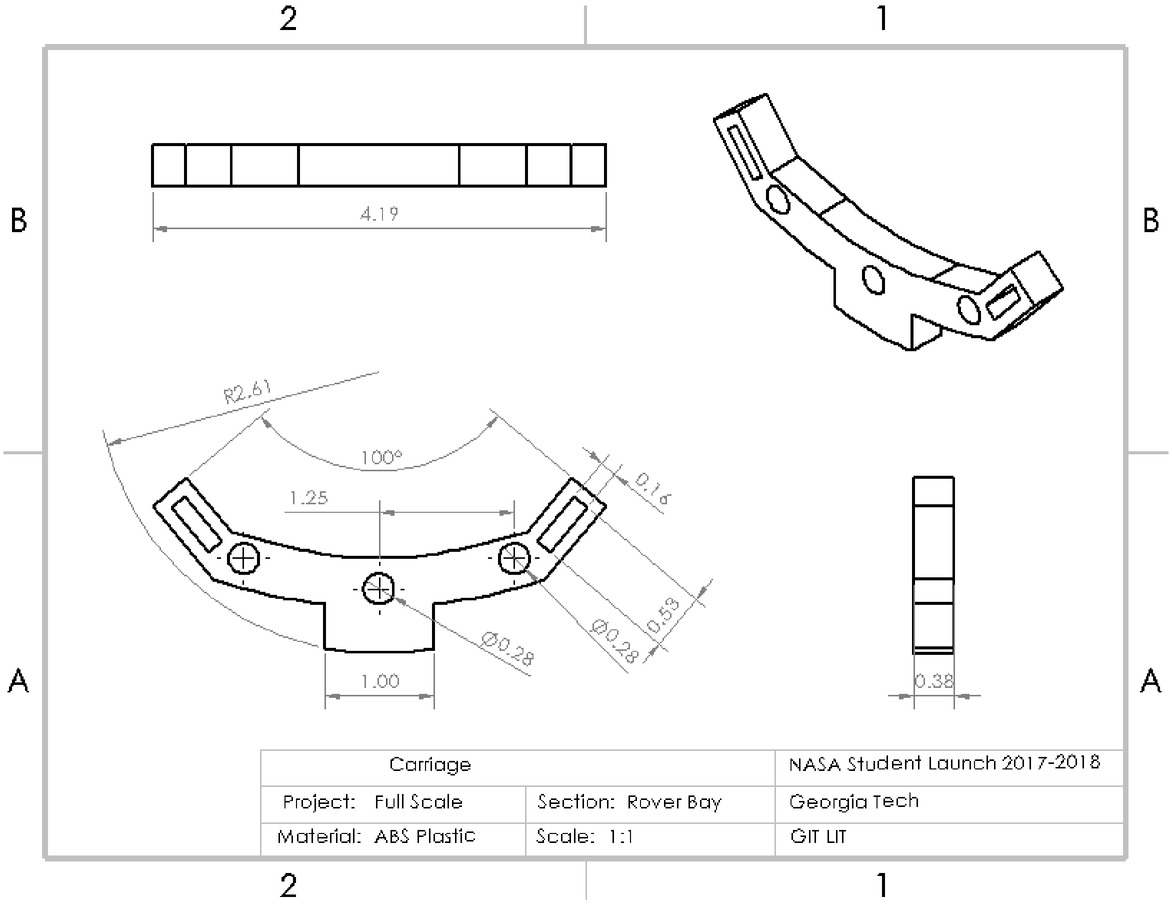
Type of Task	#	Task Description	DONE	Material Handled	Fabrication Techniques	Est. Time	Fabrication Locations
Machining	1	3D Print Servo Brackets	NO	PLA/ABS	3D Printer	< 1hr	Inv Studio / AE MakerSpace
	2	Cut Motor Tube to Length	NO	Cardboard	Chop Saw	< 1hr	Inv Studio / SCC
	3	Cut Tubing to Length	NO	Fiberglass	Chop Saw	< 1hr	Inv Studio
	4	Drill Shear Pin Holes (8)	NO	Fiberglass	Drill	< 1hr	RR room / Inv Studio
	5	Drill Rivet Holes (4)	NO	Fiberglass	Drill	< 1hr	RR room / Inv Studio
	6	Drill wire routing holes into bulkheads/centering rings	NO	Fiberglass	Drill	< 1hr	RR room / Inv Studio
	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
	9	Cut out Thrust Plate	NO	Plywood	Laser Cutter	< 1hr	Inv Studio / AE MakerSpace
	10	Fin Features for Brackets	NO	Fiberglass	Mill	1-2 hrs	BME Shop
	11	Flap Features for Brackets	NO	Fiberglass	Mill	1-2 hrs	BME Shop
	12	Flats into Shafts	NO	1024 Steel	Mill/Grinder	1-2 hrs	Montgomery MM
	13	Fin Brackets	NO	6013 Aluminum	Waterjet	1-2 hrs	Inv Studio / SCC
	14	Avionics Bay Tray Brackets	NO	6013 Aluminu	Waterjet	1-2 hrs	Inv Studio / SCC

				m			
	15	Fins Cut Out	NO	Fiberglass	Waterjet	2 hrs	Inv Studio
	16	Avionics Bay bulkheads (2 coupler, 2 body)	NO	Fiberglass	Waterjet	1-2 hrs	Inv Studio
	17	Cut Out Bottom Plate	NO	6061 Aluminum	Waterjet	1-2 hrs	Inv Studio / SCC
	18	Cut Out Bevel Ring Gear	NO	6061 Aluminum	Waterjet	1-2 hrs	Inv Studio
	19	Cut Out Flaps	NO	6061 Aluminum	Waterjet	1-2 hrs	Inv Studio
	20	Set Screws for gears / servo hub attachments	NO	Brass / Aluminum	Drill, Saws, etc...	2 hrs	Anywhere you can
	21	Cut servo hub to length	NO	Aluminum		<1hr	Inv Studio
	22	Drill gears bore diameter	NO	Brass	Drill	<1hr	Inv Studio
			NO				
Assembly	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		Fin-Roll Mechanism		
	26	Bottom Plate Brackets Installed	NO				
	27	Motor Cap + Bottom Plate + Servo Brackets Installed to Body Tube	NO				
	28	Motor Measured Out + Dimensional Sketch of Booster ASSY	NO				

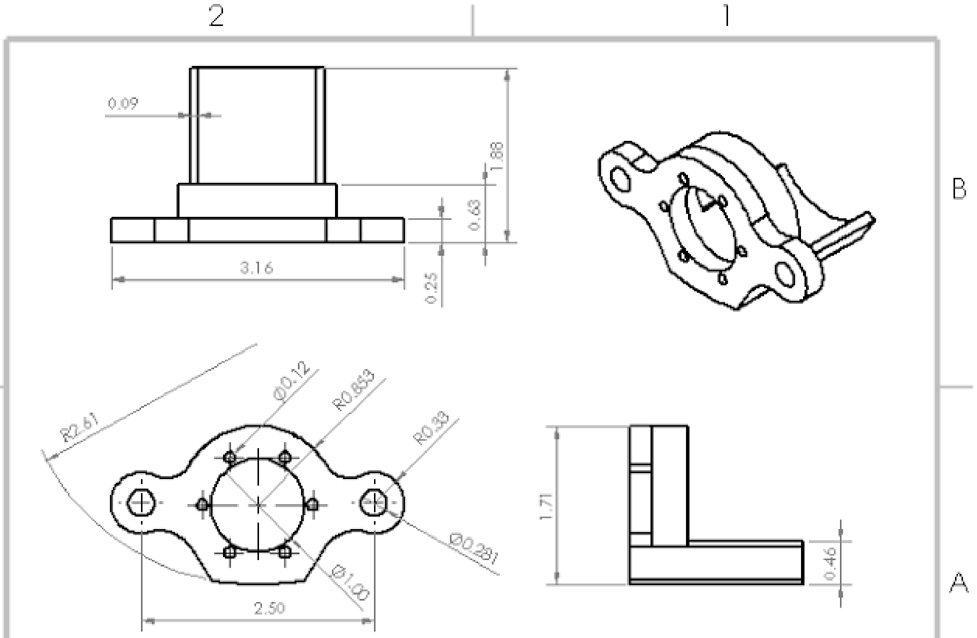
	29	MAS Bulkhead ASSY (PVC fitting + Ubolt)	NO				
	30	MAS Bulkhead Epoxied	NO				
	31	Fins Epoxied to Tubing (Nice, LARGE Fillets)	NO				
	32	Shock Cord Cut to Length	NO				
	33	Parachute Attached to Shock Cord & Quick Links	NO				
	34	Ejection Charges Created	NO				
	35	Fin Roll System ASSY	NO				
			NO				
Testing	36	Ground Ejection Test (main)	NO				
	37	Ground Ejection Test (drogue)					

C. Rover Deployment Engineering Drawings

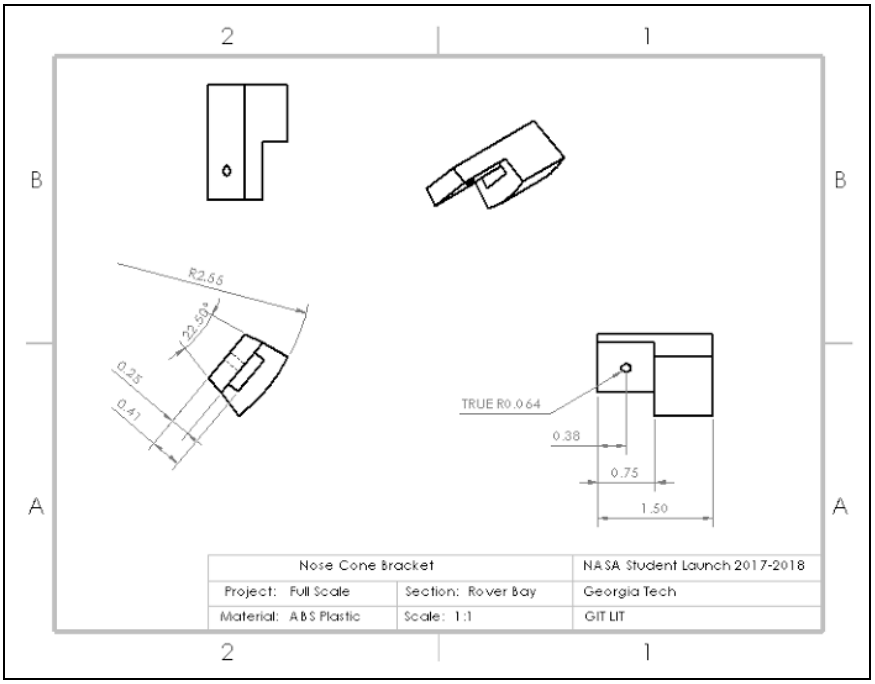


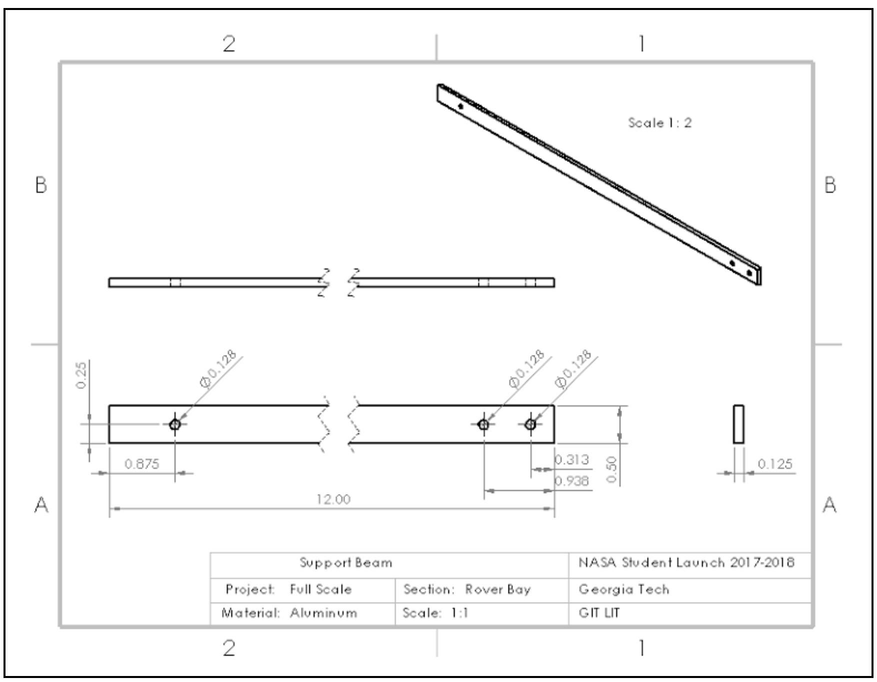


4.19
R2.61
100°
1.25
0.16
0.53
Ø0.28
Ø0.28
1.00
0.38
Carriage
NASA Student Launch 2017-2018
Project: Full Scale
Section: Rover Bay
Georgia Tech
Material: ABS Plastic
Scale: 1:1
GIT LIT



Motor Bracket		NASA Student Launch 2017-2018
Project: Full Scale	Section: Rover Bay	Georgia Tech
Material: ABS Plastic	Scale: 1:1	GIT LIT


R2.55
22.50°
0.25
0.41
TRUE R0.064
0.38
0.75
1.50
Nose Cone Bracket
NASA Student Launch 2017-2018
Project: Full Scale
Section: Rover Bay
Georgia Tech
Material: ABS Plastic
Scale: 1:1
GIT LIT


Scale 1: 2
0.25
Ø0.128
Ø0.128
Ø0.128
0.875
0.313
0.938
0.50
0.125
12.00
Support Beam
NASA Student Launch 2017-2018
Project: Full Scale
Section: Rover Bay
Georgia Tech
Material: Aluminum
Scale: 1:1
GIT LIT

D. 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.