By:

The Georgia Institute of Technology Launch Initiative Team (GIT LIT)

NASA Student Launch
2017-2018 Proposal
September 20th, 2017

Georgia Institute of Technology
School of Aerospace Engineering
270 Ferst Drive, Atlanta GA 30332-0150

Table of Contents

1. Introduction

1.1. School Information

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. Student Participation

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.

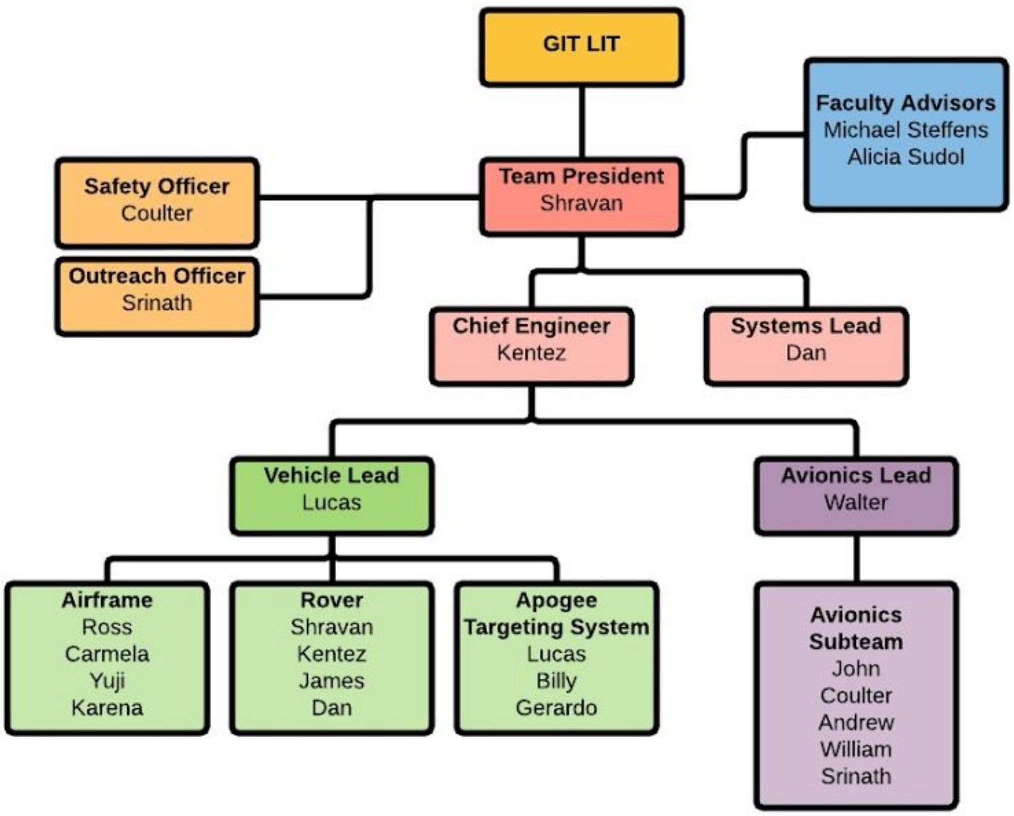


Figure 1.2.1: Team Organization

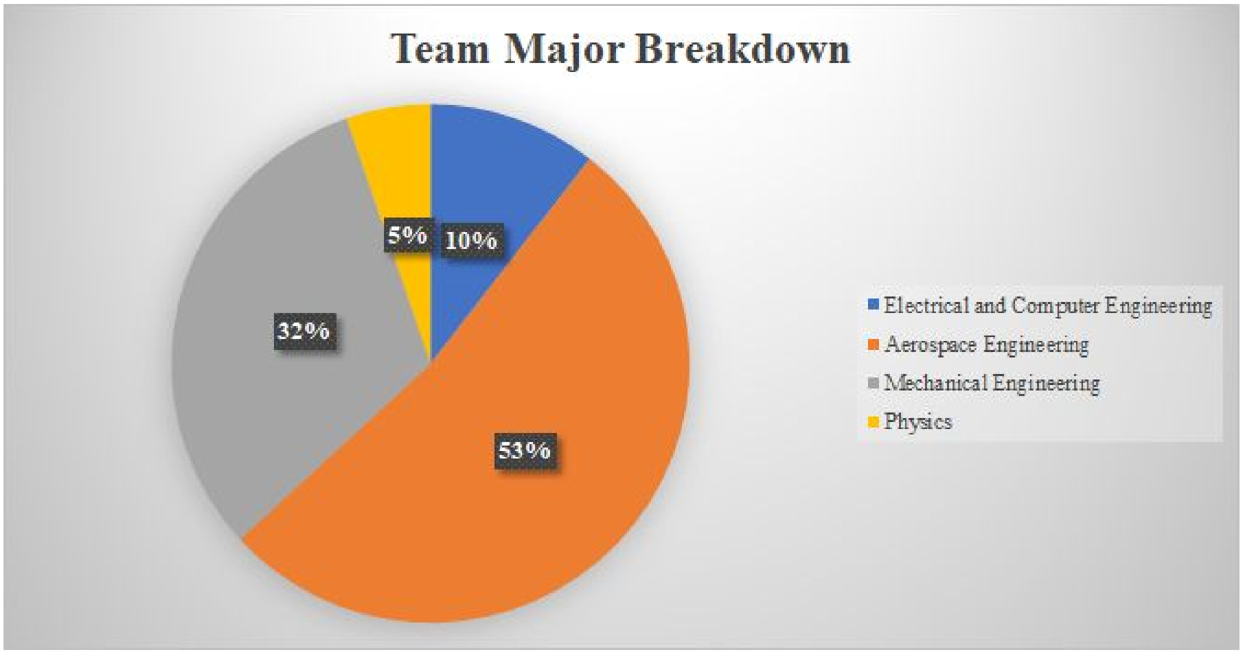


Figure 1.2.2: Team Major Breakdown

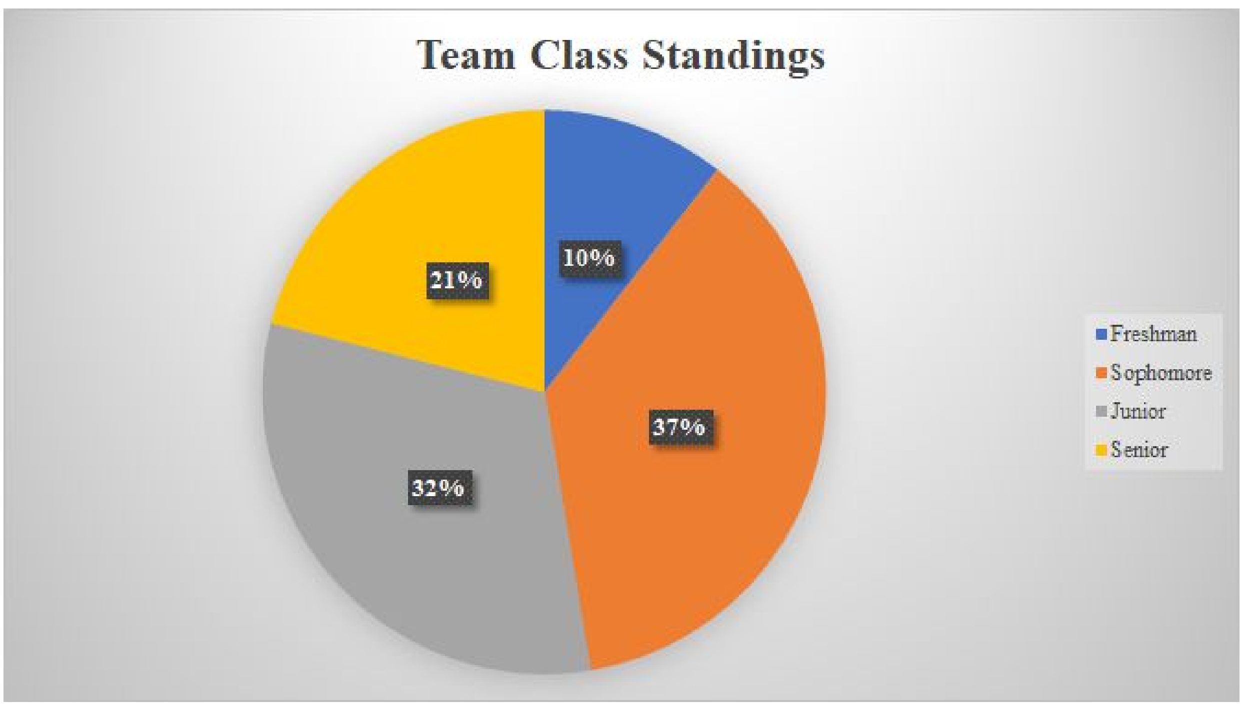


Figure 1.2.3: Team Class Standing Breakdown

1.3. Facilities and Equipment

This section details the facilities, equipment, and software available to the team for use throughout the design, build, and testing process.

1.3.1. Facilities

In order to manufacture the launch vehicle, GIT LIT has access to multiple student-run makerspaces across campus. The largest of these, the Invention Studio, is open to students from 10:00 a.m. to 5:00 p.m. from Monday to Friday. The team also has multiple PI's (Prototyping Instructors), who work as staff members in the Invention Studio and therefore have 24 hour access to the facilities 7 days a week. In addition to the Invention Studio, the team also has access to the Aero Maker Space (open Monday-Friday 9-5) and the Student Competition Center (open 24 hours), which are additional student workshops. These workshops have the following equipment:

- Laser Cutter
- CNC Mill & Lathe
- Water Jet Cutter
- Mills, Lathes, & Drill Presses
- Basic Power Tools
- Basic Hand Tools
- Oscilloscope
- Soldering Station
- Multimeter
- LCR Meter

In addition to student manufacturing workspaces, the team also has 24 hour access to a small classroom 7 days a week, where subteams can meet and work on small tasks that do not require heavy manufacturing.This classroom contains tables and chairs, as well as a projector. Finally, the team has weekly access to a large auditorium, where large, full-team meetings as well as presentations can be held.

In terms of testing facilities, GIT LIT will utilize an open circuit, Low Speed Wind Tunnel, which will be available for use under the supervision of a graduate student from 9 a.m. to 6 p.m, Monday through Friday (Figure 1.3.1). This will enable the team to understand and optimize the aerodynamic characteristics of our rocket and understand how to optimize parameters for the desired performance. The low speed wind tunnel is equipped with a 42” x 42” x 42” test section, pitot tubes utilizing Barocel vacuum pressure transducers, multichannel signal filtering, and computer data acquisition systems. Although the wind tunnel has only a maximum mean velocity of 78 ft/s, useful data can still be gathered through the use of flow similarity transformations.

1.3.2. Software

All members of the team have access to commercial design and testing software, courtesy of the Georgia Tech Office of Information Technology. In addition to that, the team uses open-source rocket simulation software as well as IDE’s for microcontroller programming. Some of the specific software packages are listed below:

- OpenRocket
- NX7, Abaqus (FEA)
- SolidWorks, AutoCAD (FEA and CAD)
- MATLAB, Simulink
- Autocoders (control algorithms)
- COMSOL (Multi-physics modeling and simulation)
- JMP (Data Analysis, Statistical Software)

These industry standard softwares are further enhanced with standard software packages such as various internet access capabilities and Microsoft Office 2016.

1.4. NAR/ TRA

High Power Rocketry refers to the classification of model rockets that use larger motor sizes and weigh more than the current laws and regulations for unrestricted model rockets allow.

Specifically, a rocket exceeds the definition of a model rocket under NFPA 1122 and classifies as a High Powered Rocket under NFPA 1127 for the following criteria:

A. Use of a motor with more than 160 N of total impulse or 80 N average thrust
B. Exceeds 125 grams of propellant
C. Weighs more than 1500 grams (53 oz)

As a team who will be participating in the NASA Student Launch, we will be involved in High Power Rocketry (HPR), which has a number of regulations in place due to the NAR/TRA.The National Association of Rocketry (NAR) and Tripoli Rocketry Association (TRA) are regulatory groups that both specify sets of rules for the different classifications of rocket sizes.Launching High Power Rockets requires more preparation than launching model rockets, largely due to safety concerns. FAA clearances must be arranged and all local, state, and federal laws must be taken into consideration. Legally speaking, High Powered Rockets follow regulations that fall under code 1127 from the National Fire Protection Association (NFPA).

As students of an accredited educational institution, we are permitted to work on this project with the requirement that operations occur under the supervision of an NAR/TRA certified mentor. Our NAR mentor, certified to the level required, will be responsible for all motor handling operations. Such procedures include purchase, transportation, storage, and operation at launch site. The mentor will be the official owner of the rocket, as is required for legal purposes. Our mentor is Gerardo Mora, and he is certified by NAR for Level 2 High Powered Launches.

All NAR/TRA personnel involved with Team A.R.E.S. will enforce compliance with the NAR high power safety code regarding the rocket operation, rocket flight, rocket materials, and launch site activities (see Appendix A for HPR Safety Code).

2. Safety

2.1. Mission Assurance

The safety officer will be primarily responsible for creating and implementing the team's safety protocols. The safety officer will work closely with the sub-team leads to ensure that all members are taking necessary safety precautions when working with potentially dangerous equipment or devices throughout all stages of design, construction, and flight. To help ensure a low risk working environment, both a safety and launch checklist have been created and will be improved as the rocket's final design becomes more clear. The safety officer will follow the responsibilities mentioned in section five of the student launch handbook. All FAA restrictions will be follow, and the team will adhere to the safety code of the respective launch site.

2.2. Material Handling

The construction of the rocket will require the use of materials that each have specific safety protocols and procedures. These materials include the rocket motor, the ejection charge of the parachute, and the batteries required for the rocket. The Safety Officer will brief all members on these protocols and procedures. The briefing will include knowledge and close proximity access to Material Safety Data Sheets (MSDS) for all potentially hazardous substances. The precautions taken are found on the safety checklist and will ensure safe usage of all materials by the team.

2.3. Vehicle Safety

In order to ensure reliability of the team's design and construction, ground testing will be performed. Methods of loading (impulsive and static) for parachute deployment and constant thrust will be performed to test the rocket and collect data. The data collected will be used to validate models and create a Pre-Flight Inspection Checklist for rocket system components.

2.4. Purchase, Shipping, Storing, and Transporting of Rocket Motors

Alton Schultheis, our team mentor, has a level 2 NAR HPR certification which permits him to launch larger impulse rockets, requiring that he is present. All purchases and storing of the motors will be done through the Georgia Tech Ramblin' Rocket Club, which stores motors in a flammable-materials cabinet. These purchases will be from certified reputable vendors. The motors will be transported in a sealed, flame retardant, and durable container.

2.5. Launch Site Safety

The Safety Officer (SO) is required to attend all launches and will ensure that all requirements on the safety and launch checklists are met. The launch site safety checklist and briefing will include details of compliance with federal, state, and local laws regarding motor handling and unmanned rocket launches, specifically, Federal Aviation Regulations 14 CFR, Subchapter F, Part 101, Subpart C; Amateur Rockets, Code of Federal Regulation 27 Part 55: Commerce in Explosives; and fire prevention, NFPA 1127 "Code for High Power Rocket Motors." The SO will brief all team members on the protocols necessary for pre-launch safety by covering the hazards for the launch and the rules placed by the local NAR section. Launches will take place at NAR sponsored launch events, one being the Huntsville Area Rocketry which will regulate the competition launch.

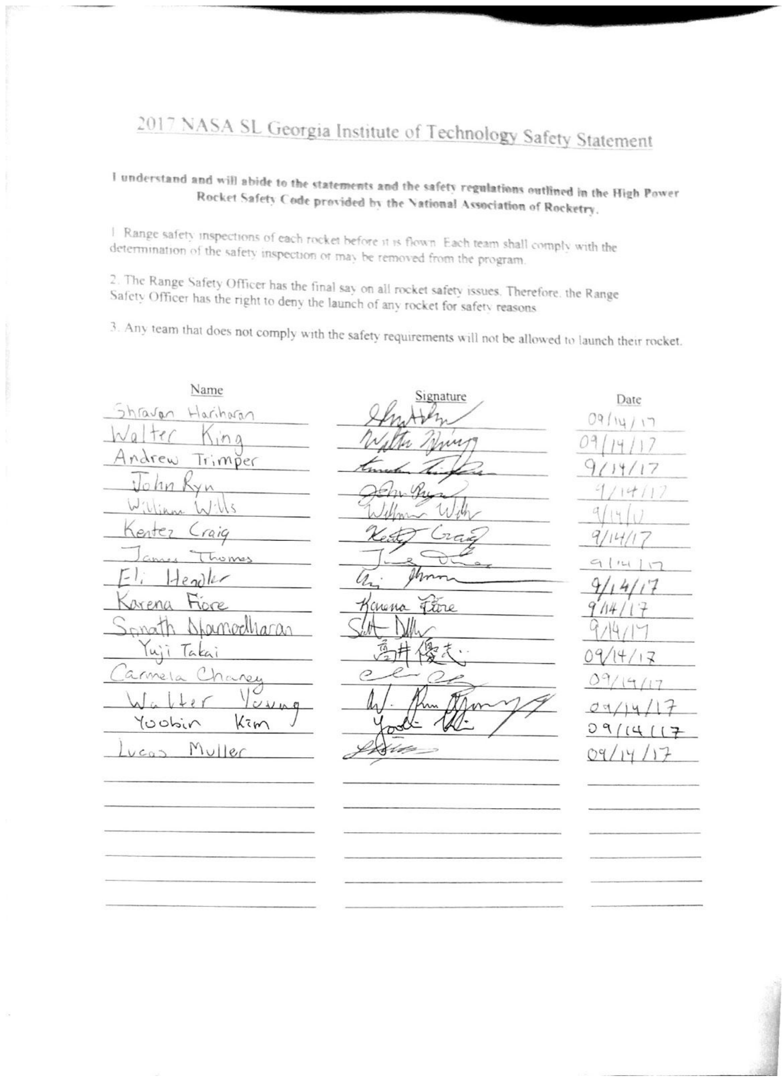
2.6. High Power Rocket Certification

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

2.7. Safety Agreement Signatures

Figure 2.7.1 below displays the safety agreement with signatures of team members.



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	[illegible]	09/14/17
Walter King	Walter King	09/14/17
Andrew Trimper	[illegible]	9/14/17
John Ryn	[illegible]	9/14/17
William Wills	[illegible]	9/14/17
Kentez Craig	[illegible]	9/14/17
James Thomas	[illegible]	9/14/17
Eli Hendler	[illegible]	9/14/17
Karena Fiore	Karena Fiore	9/14/17
Sanath Dhamodharan	[illegible]	9/14/17
Yuji Takai	[illegible]	09/14/17
Carmela Chaney	[illegible]	09/14/17
Walter Young	[illegible]	09/14/17
Yoobin Kim	[illegible]	09/14/17
Lucas Muller	[illegible]	09/14/17

Figure 2.7.1: Team Safety Agreement

3. Selected Challenge

A large component of the team's rocket design for this year's competition cycle will be dependent on the specific experimental challenge chosen. Therefore, it became necessary to weigh the pros and cons of all three challenges, in order to choose the one that best fit this year's team structure, skills, and interests.

3.1. Target Detection

In this challenge, "teams will design an onboard camera system capable of identifying and differentiating between 3 randomly placed targets." Table 3.1.1 shows the pros and cons of this challenge, as identified by members of both the Vehicle and Avionics subteams.

Table 3.1.1: Target Detection

Pros	Weight	Cons	Weight
Could potentially require no mechanical work besides camera mounting	3	Needs good programmers to process images real time	3
Would not fail if any other system fails	2	Could potentially require a complicated mechanical/electrical/software mechanism to rotate camera	3
Would allow vehicle team to focus more efforts on the design of the rocket, thereby increasing reliability and performance of remaining systems	4	Less work for vehicle team, which has far more members available than avionics team	3

3.2. Deployable Rover

In this challenge, "teams will design a custom rover that will deploy from the internal structure of the launch vehicle." Table 3.2.1 shows the pros and cons of this challenge, as identified by members of both the Vehicle and Avionics subteams.

Table 3.2.1: Deployable Rover

Pros	Weight	Cons	Weight
Easy involvement for new members	2	Remote trigger is a source of potential fail	1
Easy to distribute tasks - electronics hardware, circuit design, software, frame, vehicle	4	Rover adds an additional stage to the rocket	3
Completely separate system, does not depend on success of other rocket systems (except rocket diving into the earth)	3	Additional mechanical complexity to rocket	3
More mechanically-driven than other challenges	2	If parachutes fail, rover most likely cannot deploy	2
Less reliant on a single electronic component like the other challenges are	4	Deployment complex due to orientation of rocket upon falling	1
		If rocket falls into tree, rover fails	2
		Deployment of sections by black powder charge presents possibility to damage rover electronics/mechanisms	2

3.3. Landing coordinates via triangulation

In this challenge, "teams will design an optical range finding system to determine launch vehicle landing coordinates within a grid provided by the NASA SL office." Table 3.3.1 shows the pros and cons of this challenge, as identified by members of both the Vehicle and Avionics subteams.

Table 3.3.1: Landing Coordinates via Triangulation

Pros	Weight	Cons	Weight
A lot of conceptual work that coursework would help with (geometry, diff-eq)	3	Mostly all software, no mechanical work involved	3
		Very complex software that all hinges on the functioning of a single system (camera)	3
		Would fail if parachutes fail	2

3.4. Selected Challenge

Based on the pros and cons from team brainstorming, the general team consensus was that Experiment 2, the deployable rover, best fit the team's composition and skills. As a majority of the team members are on the vehicle team and possess strong mechanical skills, the rover challenge would involve a majority of the team, without adding an extra burden.

4. Technical Design

4.1. Dimensions

Due to having a current stock of two Aerotech L1150 motors (the same ones we used last year), the rocket for this year will be designed with a similar weight target. The OpenRocket model for our vehicle last year (shown below) ended up being 102 inches in length and approximately 34 pounds in mass.

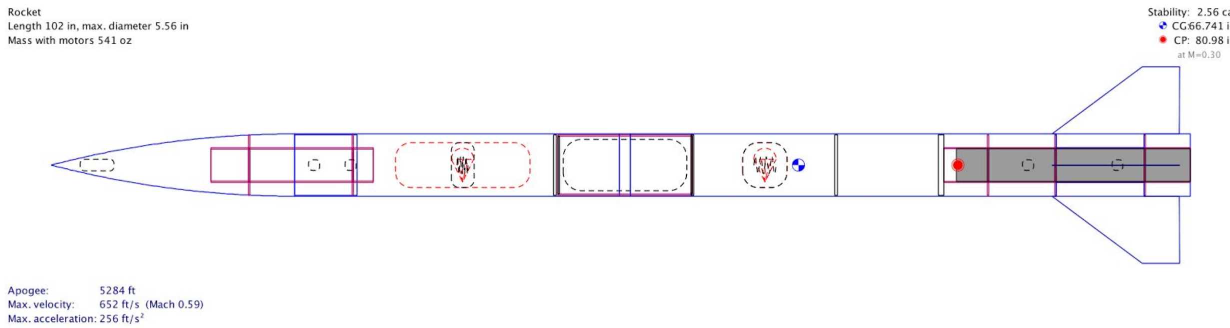


Figure 4.1.1: OpenRocket Model from 2016-2017 Competition

The overall rocket dimensions for this years' vehicle will be similar. However, due to the new challenges we are aiming to accomplish, the subsystems contained within the rocket will affect its center of gravity and overall weight, so the dimensions are subject to change. As opposed to last year's rocket, which attempted the controller roll challenge, this year we are taking on the proposed Rover challenge. As a result, the subsystem of highest mass is being moved from the bottom of the rocket to the top, just below the nose cone.

Additionally, we are going to be producing a system capable of manipulating in-flight drag. Aptly labeled the Apogee Targeting System, this mechanism will be located near the vehicle center of pressure, and will actuate control surfaces that induce a controlled amount of drag on the rocket to bring its apogee to a precise value.

4.1.1. Stability

Definition of stability in rockets

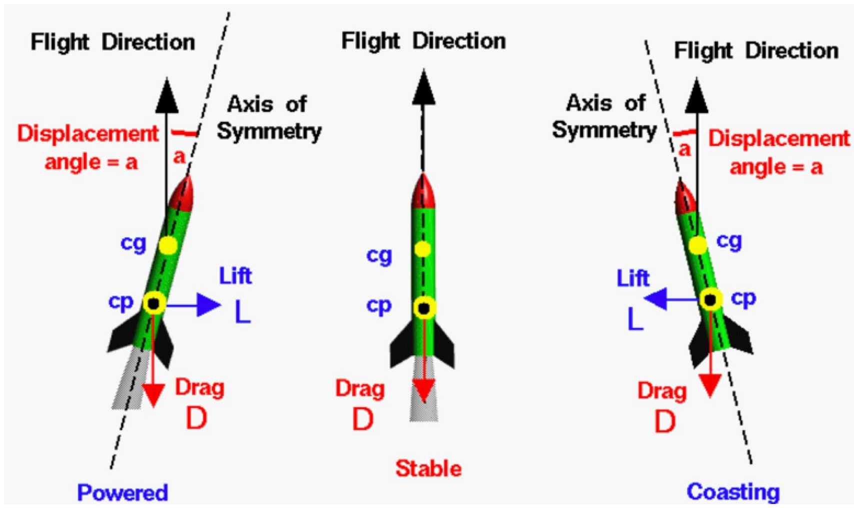


Figure 4.1.2: Stability of rocket
https://spaceflightsystems.grc.nasa.gov/education/rocket/rktstab.html

When a wind or turbulence is applied to a rocket, the rocket flies with an angle of attack (AOA) and lift and drag forces are applied at the center-of-pressure (CP). If the CP is below the center-of-gravity (CG), then the torque generated by the aerodynamic forces about CG will move the nose back towards the flight direction. In this case, the aerodynamic forces are called restoring force and the rocket is said to be stable. On the other hand, if the CP is above the CG, then the torque generated by the aerodynamic forces will amplify the deviation of the nose's direction from the flight direction. The rocket is said to be unstable in this scenario. Thus, for a rocket to be stable, the CP must be located below CG.

Center-of-Pressure (CP) and its relationship with CG to impact stability

CP[2] is the point on the rocket where all the aerodynamic forces are said to be balanced.

Case 1: CP is below CG

The torque generated by the lift and drag forces about the CG will restore the nose's direction to the flight direction. In the case of the powered rocket in Figure 1, the aerodynamic forces will

induce a counterclockwise torque that will tilt the nose towards the left such that the nose will point towards the flight direction eventually. The rocket is stable in this case.
As the distance between CP and CG decreases, the torque created by the aerodynamic forces will decrease, making the rocket's ability to restore to its initial condition, i.e. stability, decline.

Case 2: CP is above CG

The torque generated by the aerodynamic forces about CG will deviate the nose direction more away from the flight direction. If the locations of CG and CP are switched for the powered rocket in Figure 1, the induced torque will be acting in the clockwise direction, making the nose farther away from the flight direction. The rocket is unstable in this case.
As the distance between CP and CG decreases, this instability will decrease since the destabilizing torque is lowered.

Impact of Length/Diameter on stability with regards to CP and CG

Other than the forces acting on the nose and fins, there is a lift acting on the tube when the rocket is flying with an AOA. If the tube is uniform from the top to the bottom (constant cross section) the lift force applied to it is located in the center of the tube.

As the length of the rocket increases (i.e. as the length/diameter ratio increases), the force on the tube will shift to a higher location. In order to cancel out the torques about CP generated by the forces on the nose, tube, and fins, the CP will move to a higher location i.e. closer to CG. At a certain length of the tube, the CP will become above the CG, making the rocket unstable. Thus, the greater the length/diameter ratio is, the lower the the stability of the rocket is since the CP moves closer towards the CG.

Changing stability and ideal range

Increasing the stability requires the CP and CG to be moved farther apart from each other assuming that CP is below CG. This means that either the CG has to be shifted to a higher location, or CP to be moved a lower point. There are several methods to do so.

1. Addition of weight on the nose cone will make the upper part of rocket to be heavier thus shifting the CG to a higher point.
2. Using fins with larger area will generate greater lift force at the fins, shifting the CP to a lower point.
3. Extending the fins rearwards will also lower the CP
4. Making the fin thicker generates more lift and drag forces, moving the CP rearward. However, at a certain point, the thickness causes the airflow to transition from laminar to turbulent flow, reducing lift significantly, and thus shifting CP frontwards. In addition, the addition of drag accompanied with the increased thickness will reduce the apogee height that the rocket can achieve. On the other hand, if the fin is made thinner, the drag is reduced so the achievable altitude will increase, while compensating the stability since CP moves frontwards. Moreover, if the fin is too thin, it is possible that the fin breaks during the flight by external cause.

The NASA handbook requires the rocket to have a "minimum static stability margin of 2.0 at the point of rail exit." The static margin measures "how stable" the rocket is: it is a ratio of the distance between the CG and CP to the body tube diameter. A rocket is defined to be overstable if the static stability margin is above 2.0. An overstable rocket will gradually travel horizontally with wind, decreasing the apogee height. Thus, our team should aim the static stability margin as close as possible to the requirement of 2.0.

4.2. Materials

4.2.1. Material breakdown chart

Table 4.2.1: Material Breakdown Table

Material	Description	Density (kg/m^3)	Young's Modulus (GPa)	Shear Strength (MPa)	Compressive Strength (MPa)	Flammability
Balsa (longitudinal HD)	Tropical, light wood used in model building, packaging, and insulation	240 - 300	7.2 - 8.8	4.5 - 5.6	18 - 26	High
Balsa (transverse HD)	Tropical, light wood used in model building, packaging, and insulation	240 - 300	0.23 - 0.28	13.5 - 16.8	1 - 1.45	High
Balsa (longitudinal LD)	Tropical, light wood used in model building, packaging, and insulation	120 - 140	2.8 - 3.4	2.2 - 2.7	6.2 - 9.5	High
Balsa (transverse LD)	Tropical, light wood used in model building, packaging, and insulation	120 - 140	0.09 - 0.11	6.6 - 8.1	0.5 - 0.85	High
ABS	Thermoplastic commonly used in 3D printing/molding	1020 - 1080	2 - 2.9		35.9 - 69	High
ABS (15% carbon fiber)	Thermoplastic commonly used in 3D printing/molding	1100 - 1140	10.3	52 - 62.9	109 - 120	High
Basswood (longitudinal)	Hardwood	370 - 460	10 - 12.2	6.1 - 7.5	29.4 - 35.9	High
Basswood (transverse)	Hardwood	370 - 460	0.43 - 0.48	18.4 - 22.4	2.3 - 2.81	High
Carbon Fiber (PEEK)	Used as resin for aerospace app.	1420 - 1440	20.7 - 25		172 - 240	Self - Extinguishing
PC (30% glass fiber)		1400 - 1430	8.62	9.65	124 - 138	Self - Extinguishing
G12CR Fiberglass		1810	21 - 24	152	448	Low
G10/Fr-4 Fiberglass		1850	21 - 24	152	448	Flame - retardant
Polyurethane Foam	Used as impact pads, insulation, packaging	75 - 85	.00033 - .0004	0.0125 - 0.015	0.025 - 0.03	Self - Extinguishing
Phenolic	Used in heat shields	62.7 - 65.3	.000489 - .00123	1.05 - 1.16	3.87 - 4.27	Self - Extinguishing

4.2.2. Material Selections for Major Components

Table 4.2.2: Part Materials Selection Chart

	Desired Qualities	Selected Material	Alternatives
Nosecone	Should not impede RF signals, lightweight, high compressive strength	G12CR Fiberglass	G10/Fr-4 Fiberglass, ABS (15% Carbon fiber), Carbon Fiber (PEEK), PC (30% glass fiber)
Airframe Tube	Very high compressive strength, lightweight though not as important, fire-resistant	G10/Fr-4 Fiberglass	G12 Fiberglass, ABS (15% Carbon fiber), Carbon Fiber (PEEK), PC (30% glass fiber)
Fins	light, high shear and compressive strength	G10/Fr-4 Fiberglass	G12 Fiberglass, ABS (15% Carbon fiber), Carbon Fiber (PEEK), Basswood(transverse)
Centering Rings	High compressive strength	G10/Fr-4 Fiberglass	G12 Fiberglass, ABS (15% Carbon fiber), Carbon Fiber (PEEK), PC(30% glass fiber)
Bulkheads	High compressive strength	G10/Fr-4 Fiberglass	G12 Fiberglass, ABS (15% Carbon fiber), Carbon Fiber (PEEK), PC(30% glass fiber)

4.3. Construction

4.3.1. How to machine the materials listed in the section above

Table 4.3.1: Machining Methods / Safety

Material	Machine(s) Used	Location of machine(s)	Safety Concerns	Safety equipment required (for material handling)
G10 Fiberglass	Mill, Waterjet,Hand tools (Dremel, sandpaper,etc.)	SCC, Invention Studio, ESM	Inhalation, Skin irritation, Vision damage	Respirator, Long sleeves, Safety goggles, Gloves, Two people required
Wood	CNC Laser, Band saw, Table saw, Miter saw, Hand tools (hacksaw, sandpaper, etc.)	Invention Studio, G-5, ESM 303	Splinters resulting in skin irritation	Gloves, Safety glasses
Aluminum	Mill, Waterjet, Belt sander, Chop saw, Band saw	SCC, Invention Studio	Small chips can cause skin irritation	Gloves, Safety glasses
ABS/PLA	3D printer	Invention Studio, AE Makerspace	Toxic concentrated fumes, Heat of recently extruded material	Gloves, Well Ventilated area
Brass	Mill, Waterjet, Tap and Die	SCC, Invention Studio, ESM, G-5	Small chips can cause skin irritation	Gloves, Safety glasses
Steel	Mill, Waterjet, Belt sander, Chop saw, Band saw	SCC, Invention Studio	Spark generation can cause fires, Small chips can irritate skin	Gloves, Safety glasses, Area free of easily flammable materials

4.3.2. Campus Machining Facilities

Georgia Tech Invention Studio

The Invention Studio is a student-run makerspace available to all Georgia Tech students. Use of the studio is free. This includes access to the Metal Room, Wood Room, Waterjet/Laser Room, 3D Printer and Electronics Room, and the Montgomery Machining Mall. The rooms have built in circulation that allow us to machine the hazardous composites common in model rocketry. Two of the members on our team have after-hours access to this makerspace, which allows us to conduct the hazardous machining operations without jeopardizing the safety of other people nearby.

A full list of tools contained in the different rooms of the studio are shown below:

Metal Shop*	Wood Room	Electrolounge*	3D Printer Room
Bandsaw*	CNC Router*	Circuit Mill*	UP! Mini 3D Printer
Drill Press*	Miter Saw*	Oscilloscope*	UP! Mini 2 3D Printer*
Sheet Metal Brake*	Bandsaw*	Soldering Tools*	Afinia 3D Printer
Tube Bender*	Scroll Saw	Logic Analyzer*	MakerBot Z18 3D Printer*
Grinders*	Wood Lathe*	LCR Meter*	Formlab 1+ 3D Printer*
Kiln*	Drill Press*	Circuit Diagnostic Tools*	Hyrel System 30 3D Printer*
Sheet Metal Shear*	Cutting Tools*	IR Thermometer*	Autodesk Ember 3D Printer*
Belt Sander*	Sanders*	Electronics Microscope*	David 3D Scanner*
Bench Grinder*	Table Saw*	Xbox Kinect*	Faro Edge ScanArm*
Metal Chop Saw*	Planer*	Oculus Rift DK2*	Vinyl Cutter
Slip Roller*	Handheld Power Tools*	Misc. Electronics Consumables*	
Anvil			
Arbor Press*			
Spot Welder*			
English Wheel*			
Tumblers*			
Misc. Metalworking Tools*			

Capstone Room*
Dimension uPrint 3D Printer*
Dimension bst 768 3D Printer*
Dimension sst 1200es 3D Printer*
mcor iris 3D Printer*
Objet Eden 250 3D Printer*
Sewing Machine*
Vacuum Former*

Waterjet Room*
OMAX Waterjet
Trotec Laser Cutters
Base bath*

Figure 4.3.1: Tools Contained in Different Sections of Invention Studio

Student Competition Center (SCC):

The SCC is home to all of Georgia Tech's automotive competition teams, as well as several robotics research labs. With its extensive machining resources, the SCC is an excellent place for prototyping and performing large machining tasks. In this workshop, you can find large milling machines (CNC and manual), metal lathes, band saws, and other large-scale metal manufacturing tools. There is also a waterjet and several industrial sized 3D printers available for use. For more information go to http://scc.gatech.edu/.

Aero Makerspace

The AE Makerspace, like the Invention Studio, is a rapid prototyping workshop run by students and Georgia Tech faculty. The student-run space houses several laser cutters, CNC foam cutter, and an array of hand tools for delicate work. There is also a composites workshop. Equipped with vacuum bagging tools and pumps this section of the AMS is built for handling hazardous composite materials like those we will be using for this competition. Lastly, there is a professionally staffed metal machine shop in another section of the studio that houses CNC lathes, CNC mills, wire EDM, welders, a waterjet, and a CNC router. One of our members is staffs the AMS, giving us full access at any time of day. For more information, go to https://www.ae.gatech.edu/aero-maker-space.

BME Design Shop

The BME shop is a small, but well-stocked machining room. In here one has access to full a CNC mill, manual mill, metal lathe, laser cutter, vacuum former, and various hand tools. This workshop also has the highest quality 3D-printers available to Georgia Tech students for free use: the Ultimaker 2. One of our members is employed there, and thus has full access to the space. For more information, go to https://bme.gatech.edu/bme/bme-design-shop/

4.3.3. Inventory

Table 4.3.2: Inventory of Materials

Item	Dimensions (Inches)	#	Material
Plywood stock	0.25 x 12 x 24	7	Birch
	0.125 x 12 x 24	1	Birch
Fiberglass stock	0.125 x 23.75 x 23.75	2	?Green?
	0.25 x 6 x 4.25	1	G10
Metal Stock	1 x 1.5 x 2.25	1	Aluminum
Tubing	34 x 3	3	Cardboard
	24 x 0.5	2	PVC SCH40
	19 x 0.5	1	PVC SCH40
	10 x 2	1	PVC SCH40
	1.625 x 2	2	PVC SCH40 End Caps
	36 x 0.4375	1	Aluminum
	20 x 0.5	1	Steel
	178.625 x 0.3125	1	Clear Vinyl
	28.75 x 5.5	1	Fiberglass body tube
	60 x 5.5	2	Fiberglass body tube
	12 x 5.25	1	Fiberglass coupler tube
Rod	36 x 0.25	2	Steel (Threaded)
	24 x 0.25	5	Steel (Threaded)
	12 x 0.375	1	Steel (Threaded)
	36 x 0.25	1	Brass
	23.875 x 0.125	1	Aluminum
	34 x 0.375	1	Fiberglass
	19 x 0.25	1	Steel (square toothed)
Centering Rings	OD: 5.375, ID: 3.125 Thickness: 0.125	2	Fiberglass
	OD: 5.5 ID: 2.875 Thickness: 0.1875	1	Plywood
Bulk Heads	0.125 x 5.1875	6	Fiberglass

	0.25 x 5.375	2	Fiberglass
	0.125 x 5.375	7	Fiberglass
	0.25 x 5.25	1	Plywood
Adhesives & Solvents	Jug	1	150 Thick Epoxy Resin
	Bottle	1	4:1 Epoxy Hardener
	120 oz	1	Mineral Spirits
	16 oz	2	Mineral Oil
Shock Cord	16’20”	1	Yellow Kevlar
	20’	1	Red Stitched (Nylon?)
	14’	1	Red Stitched (Nylon?)
	12’	1	Red Stitched (Nylon?)
Misc.	2 oz	1	Carbon Fiber Flakes
	1.7 oz	1	Fiberglass Dust
	133.518 x 0.25	1	Steel Cable
	36 x 3	1	Foam Insulation
	102.5 x 2	1	Velcro
	0.125 x 5.125	1	ABS Ring Gear
	150ft x 30	1	Kraft Brown Paper

4.4. Altitude and Calculations

The current performance predictions are based on assumptions that the launch vehicle will weigh approximately 28 lbs at launch including the motor, which has been decided to be the AeroTech L1150-P. Currently all the flight condition simulations are run in OpenRocket. However, we are currently creating a code in MATLAB that will enable us to make a better prediction, and once finalized, the mission performance will be updated to reflect the effects of the ATS on the apogee of the vehicle. Table 3.5.4 shows the assumption made when the simulation was run.

Table 4.4.1: OpenRocket Environmental Conditions

Condition	Value
Altitude	500 ft
Wind speed	variable
Temperature	57.217 F
Latitude	28.61°
Pressure	995.38 mBar

Using OpenRocket simulations the following was concluded: Apogee occurs at approximately 18s. At apogee, the ejection charge for the drogue chute will fire, slowing the descent rate to 54 fps. Deployment of the main chute will occur around 707 ft above the ground level to further decelerate the launch vehicle to approximately 17 fps. The entire flight duration is estimated to be 150s. The following tables detail the time, altitude, velocity, acceleration and drag at certain events during the course of the launch.

Table 4.4.2: OpenRocket Simulation Results

Event	Time(s)	Altitude (ft)	Total velocity (ft/s)	Total acceleration (ft/s²)	Drag force (N)	Drag coefficient
Ignition	0	0	0	10.682	0	0.65516
Lift Off	0.06	0.10422	5.8164	203.95	0.023013	0.63631
Launch rod disengaged	0.29	8.0174	65.979	277.95	2.2494	0.53934
Burnout	3.2126	1343.1	711.9	106.17	258.37	0.60269
Apogee	18.163	5582.1	20.11	30.568	0.30249	0.596951
Drogue Chute	18.216	5581.9	26.534	32.249	23.28	
Main Parachute	106.23	707.88	54.167	0.37287	112.21	
Ground Impact	150.27	-4.3134	16.036	1.4428	112.94	

4.5. Recovery System

4.5.1. Recovery System Function Tree

Figure 4.5.1: Function Tree

4.5.2. Recovery System Solution Table

Table 4.5.1: Solution Matrix

4.5.3. Parachute Shapes and Materials

Table 4.5.2: Parachute Type Breakdown

Shape	Pros	Cons
Triangle	Shortest drop time (lowest drag per radius)	
Square	Cheapest, simplest design	Not very efficient Allows a considerable amount of sway during descent
Round	Very stable in descent Highest drag per radius	

Table 4.5.3: Parachute Material Breakdown

Material	Pros	Cons
Polythene		Low quality Tend to burn or tear easily
Nylon / ripstop nylon	Durable Widely available Cheap Good wind resistance Good elasticity Lightweight	
¼ mil Aluminized Polyester	Thin Highly visible	
Silk	Light Thin Strong Easy to fold and pack Fire resistant	For military silk: poor visibility
Kevlar	Extra strength recovery insurance Heat and flame resistant	May be expensive
Terylene	Strong Heat resistant	

4.5.4. Parachute Sizing

The handbook requires that the rocket descends with a kinetic energy less than 75 ft-lbf.

$$KE = \frac{1}{2} * m * V^2$$

$$V_{max} = \sqrt{\frac{2 * KE}{m}} = \sqrt{\frac{2*75\,ft\,lbf}{m}}$$

This means that the descent velocity is dependent on the mass of the rocket. Main and drogue parachutes will chosen for material lightness, strength, and the ability to stay below the maximum descent velocity. There are two methods that can be used for choosing the size of the parachutes.

Method 1: Rule of Thumb

Table 4.5.4: Parachute Sizing by Rule of Thumb

Main Chute	Drogue Chute
0 – 2 oz. 12″	Rockets 12″ and shorter – use streamer recovery or an 8″ chute.
3 – 8 oz. 18″	Rockets 12″ to 18″ tall – use a 12″ chute.
9 -15 oz. 24″	Rockets 18″ to 24″ tall – use a 12″ or 18″ chute.
16 – 23 oz. 30″	Rockets 24″ and taller – use a 18″ or 24″ chute.
24 – 35 oz. 36″	
36 – 47 oz. 42″	

This method is not very accurate and is highly dependent on the coefficient of drag of the parachute, which is driven by its shape and material.

Method 2: Calculations Based on Shape

Maximum descent rate is determined by the strength of the main chute which in turn determines the size of the drogue chute. If this method is chosen to determine the size of the parachutes, these calculations will be simulated in OpenRocket and analyzed before a decision is made.

Procedure for Picking Drogue Chute Size

- Run computer simulations to get baseline information
    - Look at decent rate of drogue chute
        1. Falling too slow: decrease diameter of drogue chute
        2. Falling too fast: increase diameter of drogue chute
- Find the equivalent surface area as the lateral area of the largest section of the rocket
    - Diameter of a surface with equivalent area is found using the following equations:

For example, to find the parachute area for round rockets:

- S: area of parachute
- g: acceleration due to gravity (9.81 m/s2)
- m: mass of rocket in grams (with empty engine)
- ρ: density of air at sea level (1225 g/m3)
- C_d: coefficient of drag (estimated at 0.75 for a round canopy)
- V: descent velocity chosen

$$S = \frac{2*g*m}{\rho*C_d*V^2}$$

4.5.5. Additional Recover Mechanisms

Shock Cord

The shock cord connects the nose cone and the airframe together after the rocket separates. The shock cord withstands the force of the nosecone separating, and it must endure the force of the parachute opening and decelerating the rocket.

Typically, rubber or Kevlar is used for a shock cord. Kevlar can absorb more energy than rubber before permanently deforming and breaking. Kevlar has a spring constant about 200 times greater than typical elastic. Therefore, Kevlar can withstand much higher forces, and is less likely to break compared to elastic. However, the total amount of force a Kevlar shock cord can withstand is often limited by the shock cord anchor. For the force absorbed by the shock cord, the cord applies the same force onto the anchors. Kevlar will deform much less than elastic because of the larger spring constant. Modeling the shock cord as an ideal spring, energy absorbed by the displacement is proportional to the square of displacement.

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

$$F = k\Delta x$$

Energy and force are a linear function of the spring constant. Energy as a function of displacement is quadratic, whereas force is linear. Using elastic would decrease the amount of force that that the anchors have to absorb. Essentially, the more the shock cord displaces, the more energy the shock cord absorbs, and the less force placed on the structure of the rocket. Additionally, elastic cords would be easier to replace and work with than Teflon shock cords.

The force the shock cord can withstand increases as the length of the shock cord increases. The force applied onto the shock cord must be less than the force the cord can withstand before breaking. The length of the shock cord depends on the material selected and their spring constants. If the diameter or spring constant of the cord increases, the amount of energy the cord can absorb will also increase.

Ejection Charges

The ejection charge is designed to break apart the nose cone and airframe, and deploy the parachute. A black powder explosive is most commonly used to deploy the recovery system. The powder is ignited after the main engine stalls, and the powder is ignited. The expansion of hot gas creates a pressure that ejects the nose cone and parachute system.

The amount of ejection charge needed depends on the pressure needed to eject the nose cone, the volume of the module housing the ejection charge, and the temperature of the air. Modelling the explosion as an ideal gas, the number of moles needed are will be proportional as follows:

$$moles = \frac{pressure * volume}{gas\ constant * temperature}$$

When working with ejection charges additional precautions must be taken. There should be a thermal barrier between the parachute and the ejection charge. The explosion creates heat which can damage the parachute, and it can prevent proper parachute deployment. To create this barrier, two common potential options are using fire retardant wadding or a wire mesh to catch the flaming particles. Additionally, when testing the ejection charge systems, closed toed shoes, safety glasses, and hearing protection should be worn.

4.6. Motor

The motor choice for our rocket is an Aerotech L1150R. This selection is made primarily for budgetary reasons, as we have two in our inventory that were unused last year. The total impulse this motor will produce is 3488.55 Ns which is enough to power the rocket to the mission specified altitude. The other motor we had in consideration was the Aerotech L850W. A desired characteristic of the flight path is that the burn time be minimized to allow the Apogee Targeting System as much time as possible to manipulate the predicted apogee of the rocket to exactly 1 mile AGL. The comparison of out top two choices is shown below.

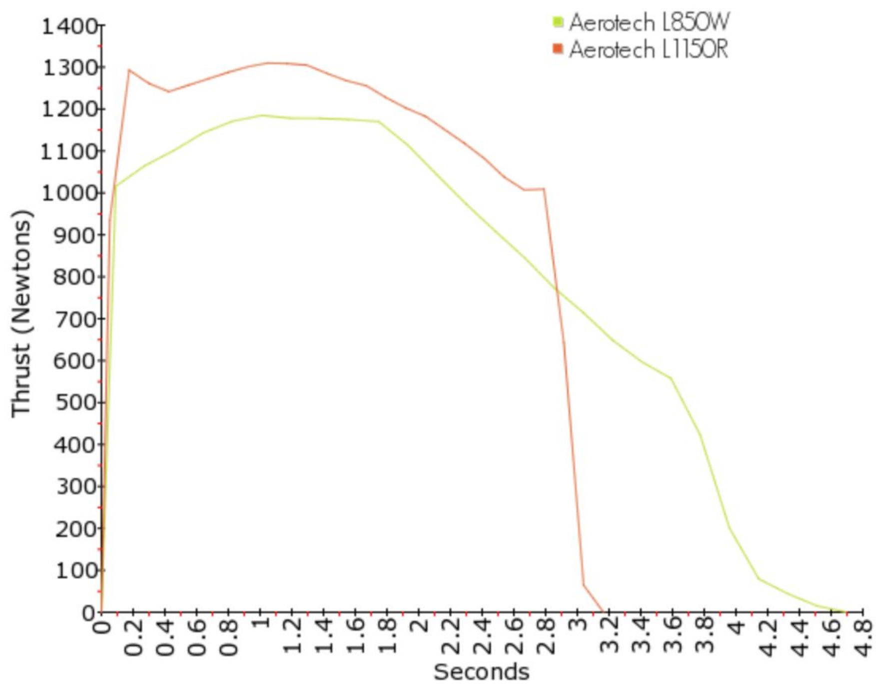


Figure 4.6.1: Motor comparisons of thrust v time

Table 4.6.2: Thrust calculations (Motor comparisons)

Performance	Aerotech L1150R	Aerotech L850W
Average Thrust:	786.67 N	1,100.49 N
Peak Thrust:	1,184.80 N	1,309.71 N
Total Impulse:	3694.98 Ns	3488.55 Ns
Thrust Duration:	4.70 s	3.17 s

The motor weighs 3673.60 g and will be housed in the motor section. The motor has a diameter of 2.24 in, which is smaller than the rocket diameter. Consequently, it will be held in place by centering rings in the motor housing.

4.7. Rover Subsystem

4.7.1. Rover Requirements

The rover must successfully complete the following 4 steps in order to complete the Rover Challenge:

1. The rover must remain safe during rocket launch and flight
2. The rover must deploy from the rocket
3. The rover must move at least 5 feet away from the rocket in any direction
4. The rover must deploy foldable solar panels

The following sections describe the team-specific rover function requirements, as well as proposed solutions to these requirements.

4.7.2. Function Tree

The function tree below details the specific challenges of the rover experiment, that need to be addressed for a successful deployment.

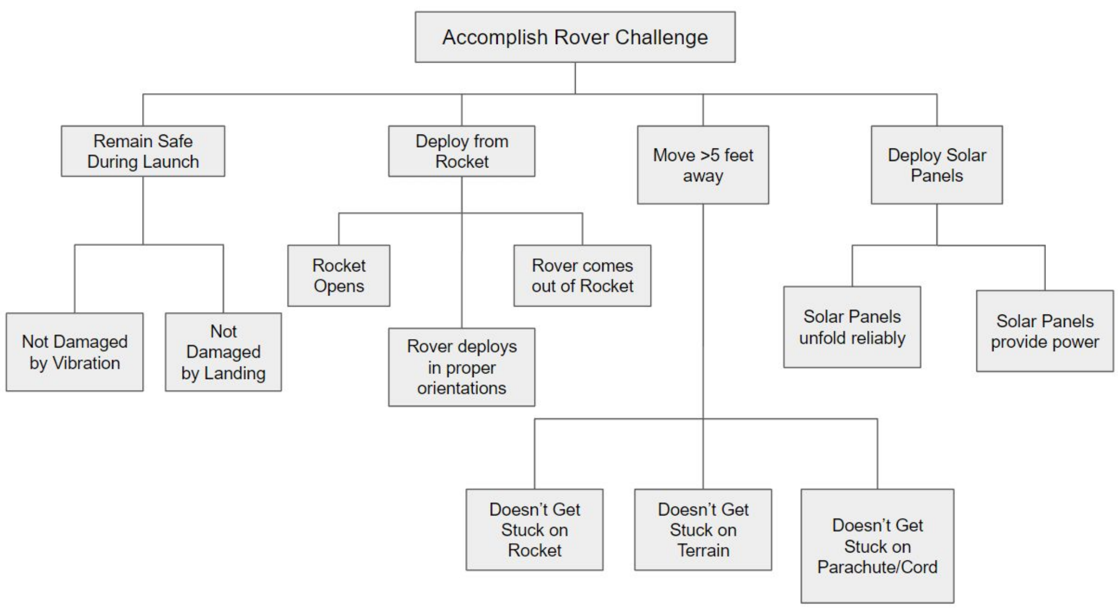


Figure 4.7.1: Function tree

4.7.3. Solution Table

The following table details possible solutions to each of the problems described in the function tree.

Table 4.7.1: Solution table to perceived problem areas

	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	Distance sensor to detect where the walls of the rocket are

			move wheels 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

4.7.4. Design Sketches

The following sketches are detailed descriptions of certain feasible solutions, taken from the solution table shown above. These sketches are preliminary, and will be developed more prior to prototype fabrication.

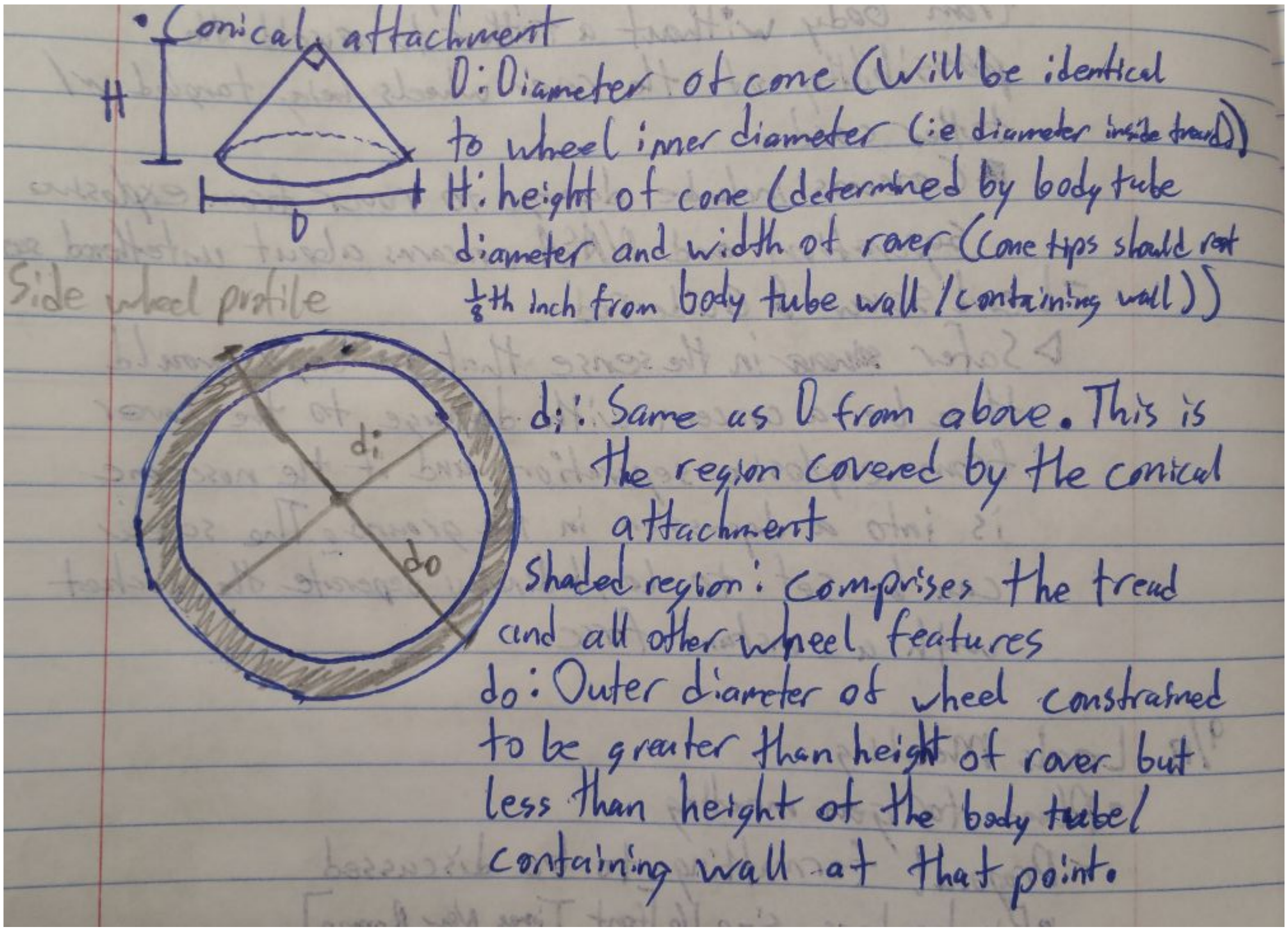


Figure 4.7.2: Wheel vs. Cone size

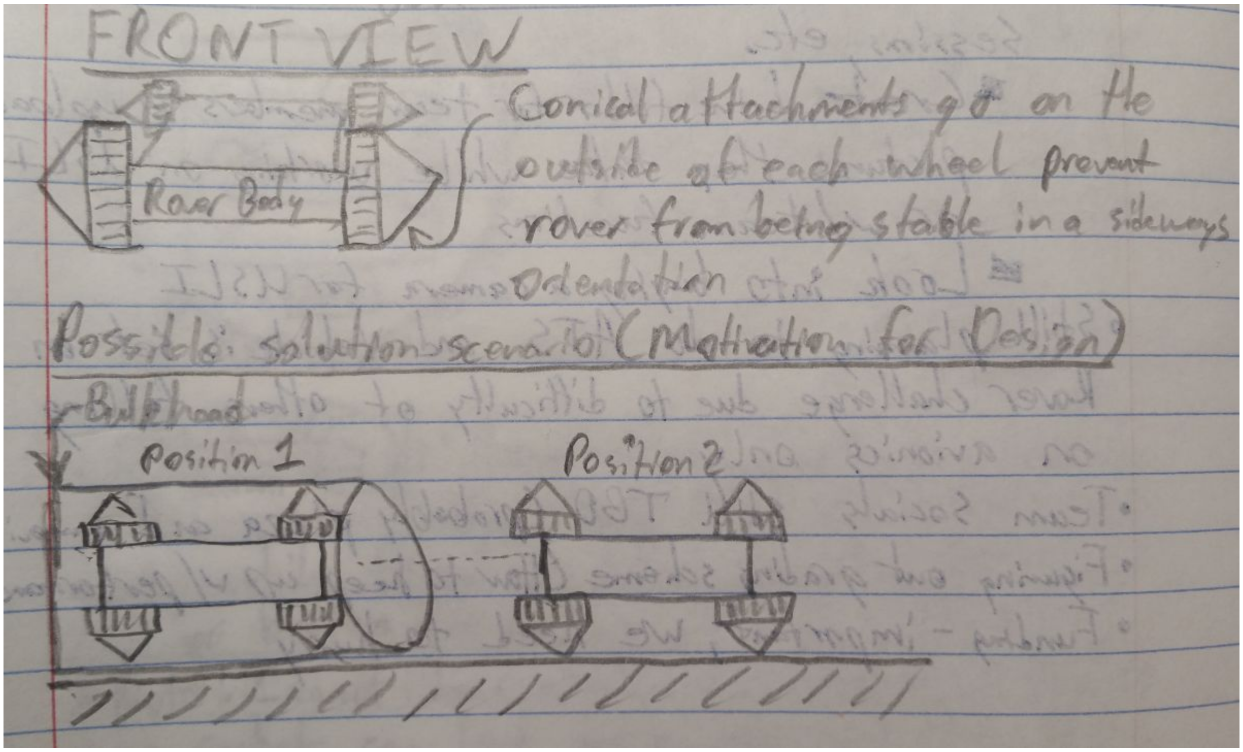


Figure 4.7.3: Reasoning behind adding the cones to the wheels

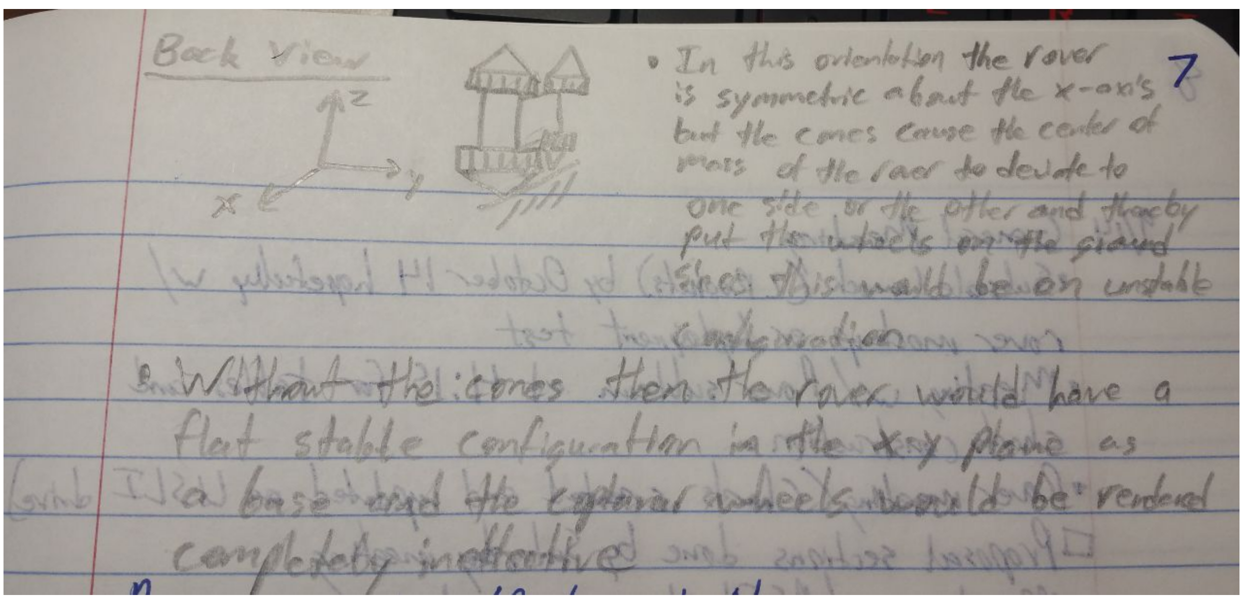


Figure 4.7.4: Axial explanation of the benefits of a rover design with conical wheel caps

An analysis of possible failure scenarios for the rover subsystem of the vehicle was conducted. This analysis consisted of many days of team and individual brainstorming on possible issues that could arise in the vehicle as they pertained to the proper functioning of the rover subsystem. One of the scenarios consisted of the possibility that the vehicle could come to rest in a configuration that put the rover oriented at an angle normal to the horizon (as seen in Figures 4.7.3 and 4.7.4). In said configuration there is a chance that the large diameter of wheel chosen in order to allow the rover the ability to drive in the top or bottom side up configuration, could prove detrimental. The detriment arises from the fact that the large diameter wheel would generate a base upon which the rover could come to rest. Coming to rest in such a configuration with the load placed on the wheel hub rather than the tread would render the rover immobile.

The simplest way to prevent the rover from coming to rest in its only immobile configuration by design, is to add conical caps over the wheel hub on each of the four wheels. These caps would render the wheel hub down configuration very unstable as any deviation in the slightest of the center of gravity of the rover would cause the entire machine to rotate into a mobile configuration. The caps could easily be manufactured by 3D printing or they could be purchased depending on the size of wheel chosen. The important specifications for the caps shown in Figure 4.7.2 are the cap diameter and cap height. The cap diameter should match the diameter of the wheel hub which is defined as the point at which the tread surface stops (cap diameter labeled as d_i and D in Figure 4.7.2). This important distinction ensures that the cap will not get in the way of any needed traction surfaces for motion. The cap height should be as large as possible, in the effort to minimize the room the rover has to move around in its containment section during flight. Suggested spacing would set the height as an eighth of an inch from the tip of the cone to the container walls. The reduction in free space would help in vibration dampening efforts by reducing the distance the machine can move from side to side. Less open space would also aid in deployment since there would be less of a chance that the rover could twist in its containment section and become stuck at an angle that would be difficult for it to autonomously extricate itself from.

4.7.5. Criteria for Evaluation

These 6 characteristics will be used as the criteria to decide which solutions are better than others.

1. Reliability (whether or not the solution will fulfill its intended purpose)
2. Ease of Construction (whether the solution is too complex to construct/feasibility)
3. Estimated Mass
4. Estimated Cost
5. Avionics Workload (how much work the solution will require out of the Avionics subteam)
6. Durability (will the solution last)

4.8. Apogee Targeting System (ATS)

4.8.1. Function Tree

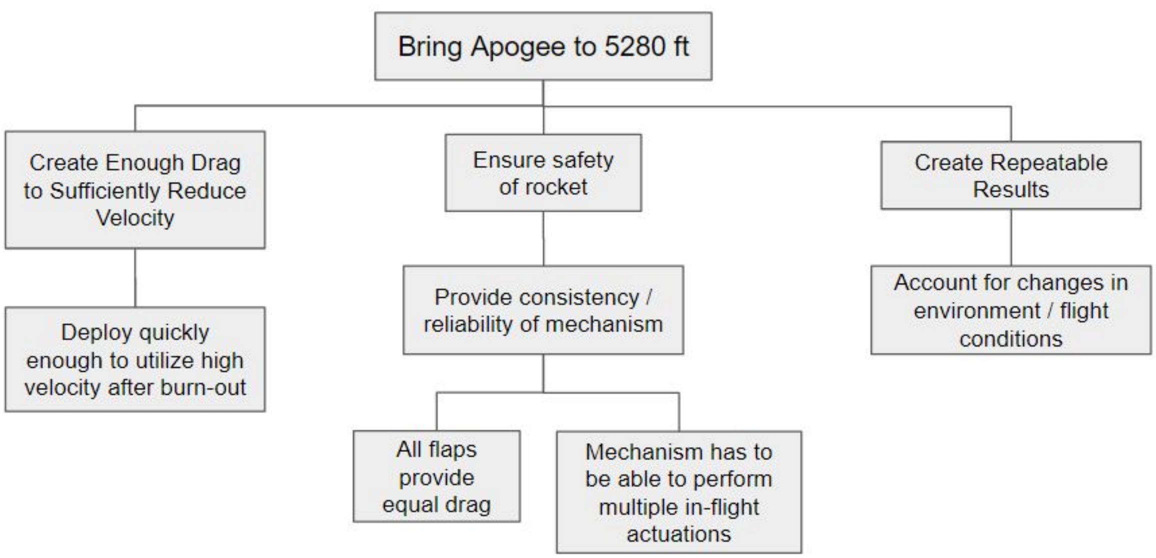


Figure 4.8.1: ATS Function Tree

4.8.2. Solution Table

Table 4.8.1: 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		

4.8.3. Conceptual Designs / Computations

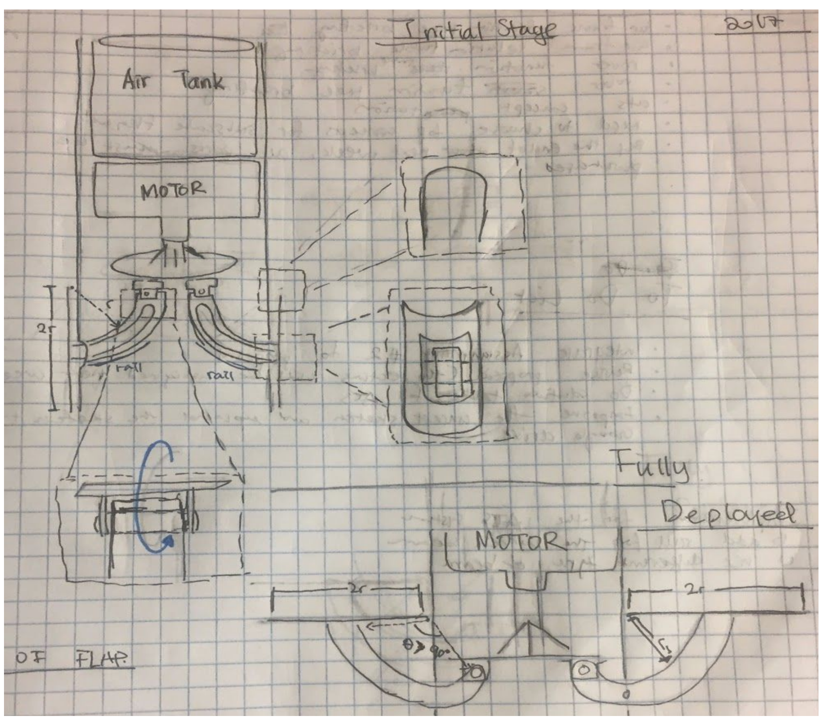


Figure 4.8.2: ATS Hinging Concept Using Single Actuator

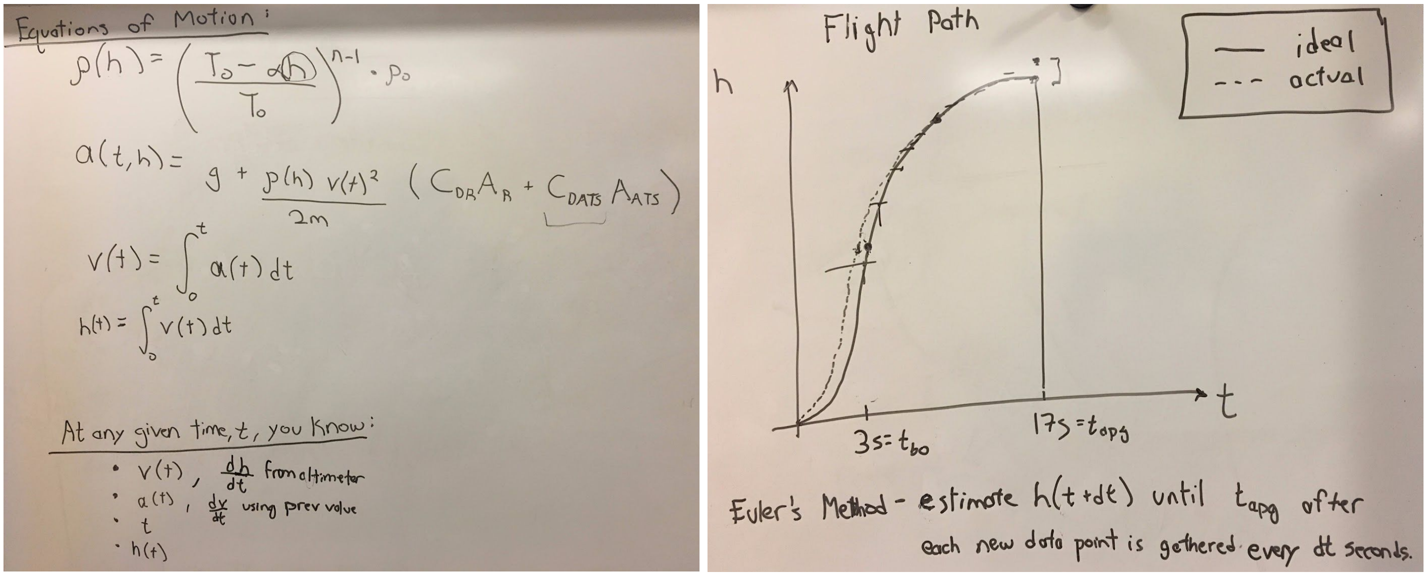


Figure 4.8.3/4: Equations of Motion to Describe Flight, and Graphical Representation of Flight Path

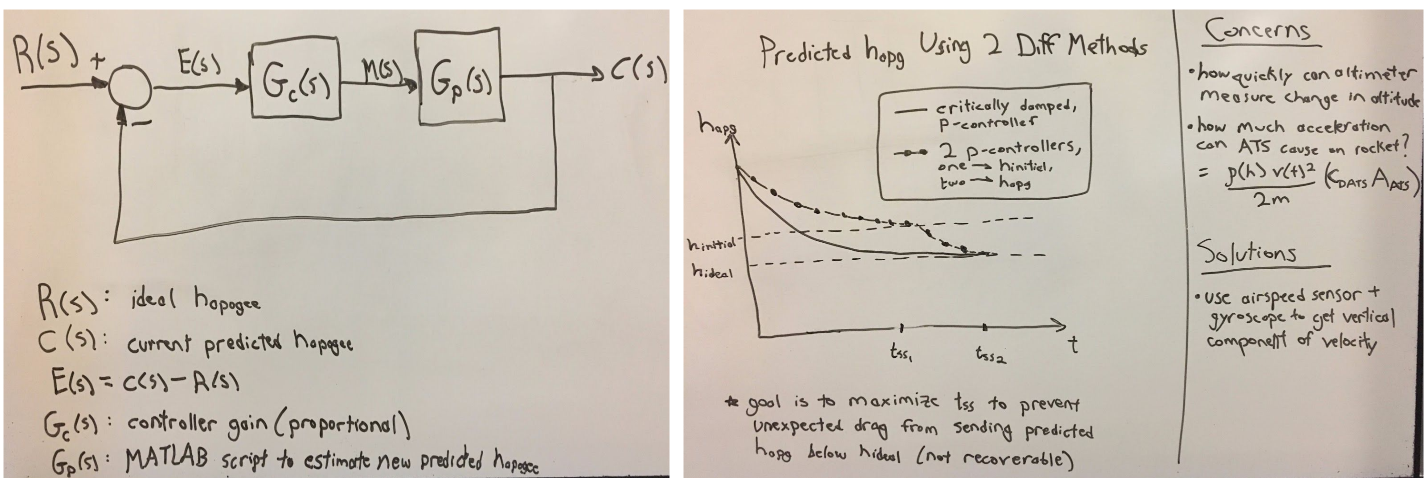


Figure 4.8.5/6: ATS as Dynamic System, and Plot Showing Predicted Apogee Throughout Flight

4.9. Launch Vehicle Requirements

4.9.1. Rover Requirements

In order for the rover launch and deployment to be a success, the launch vehicle needs to accommodate the rover in terms of space, a functional deployment system, and vibration dampening to protect the rover from launch forces.

First, the rover must fit inside the outer tubing of the rocket and must be surrounded on each side by a wall so that the rover will not move around the body of the rocket.

In terms of deployment, the rover can be deployed via multiple methods. One method would be to use a blast of compressed air to expel the rover out of the body of the rocket. Another would be to have the rover autonomously drive itself out of the rocket. Two other possible methods that are being considered is to have the rover be pushed out by a lead screw mechanism or be released by a pin as the rocket opens.

In order to protect the rover from vibrations during launch and landing, a system will be incorporated into the rocket and rover that will help dampen the vibration felt by the rover. Two methods were proposed: 1. The rover will be sized to take up as much space as possible inside the rocket to limit the amount of vibration or oscillations felt by the rover. 2. Attach springs to rover to reduce shaking.

5. Avionics

5.1. Overview

The avionics system of the rocket will have three objectives: ensuring a safe recovery, controlling the rocket’s braking system, and facilitating the completion of the selected challenge. Three subsystems will be implemented to achieve these objectives: the Recovery System, the Apogee Targeting System(ATS), and the Challenge System. Each of these subsystems, with the exception of the Challenge System, will be housed within a centralized avionics bay in the upper portion of the rocket.

5.2 Recovery System

The following altimeters were considered. 9 features were compared among 6 altimeters to determine the best altimeter to use for the rocket: price, range, accelerometer specifications, data accuracy, data collection rate, dual deployment support, flight storage capacity, and existence of additional features.

Table 5.2.1 Considered Altimeters and Respective Specifications

	Raven 3	**Parrot**	**Jolly Logic Altimeter 2**	**StratoLoggerCF with Dual Deployment**	**TeleMetrum**	**TeleMega**
Price (USD)	155.00	159.00	69.95	54.95	321.00	428.00
Range (ft)	30000 at 2.5 ft resolution 100000 at 5 ft resolution	30000 at 2.5 ft resolution 100000 at 5 ft resolution	29500	100000	101706.04	101706.04
Accelerometer	400 Hz axial acceleromet er, +/- 70 Gs, 200 Hz lateral acceleromet er, +/- 35 Gs, and a 250 G single-axis acceleromet er available as an option	200 Hz acceleromete r, +/- 70 Gs axial, and a +/- 35 Gs lateral, or a 250 G single-axis acceleromete r	250 Hz 3-axis, 24g accelerometer	None	1-axis 105-g accelerometer for motor characterizatio n	1-axis 105-g accelerometer for motor characterizatio n, 3-axis 16-g accelerometer for gyro calibration
Accuracy	± 0.3% Data Accuracy	± 0.3% Data Accuracy	measurement precision <1ft	0.1% Data Accuracy	20cm at sea level	20cm at sea level
Data Collection Rate	20Hz	50Hz	25 Hz	20Hz		
Dual Deployment Support	4 deployment outputs	3 deployment outputs	None	2 deployment outputs	2 deployment outputs	6 deployment outputs
Flight Data Storage Capacity	45 minutes of flight data	25 minutes of flight data	100 flights	288 minutes of flight data	8MB of onboard storage	

Additional Features	20 Hz high-precision temperature sensor	50 Hz high-precision temperature sensor		Built-in voltmeter reports battery voltage on powerup	Integrated GPS receiver, 70cm ham-band transceiver for telemetry	3-axis magnetic sensor,3-axis 2000 deg/sec gyros, On-board, integrated GPS receiver, 70cm ham-band transceiver
Disadvantages	High Cost	High Cost, short flight data storage capacity	ABS casing prevents integration of alitmeter to rocket, no dual deployment	No accelerometer	Very high cost	Very high cost
Advantages		High Data Collection Rates	Low Cost, high accuracy	Low Cost, relatively good accuracy	Has integrated GPS and telemetry, high accuracy	Has gyroscope, GPS, and many other components, high accuracy, many deployment outputs

Overall, the best altimeter to use performance and price-wise is the Jolly Logic Altimeter 2, but since it cannot be incorporated into the rocket system due to the ABS casing that surrounds its electronics, the Jolly Logic cannot be used on the rocket. The TeleMetrum and TeleMega have the best specifications and features, but their prices are well over the team's budget, and thus, were not considered. After comparing the altimeters above, assessing the team's budget and inventory, the team decided to use the StratoLoggerCF with dual deployment because of its cheap price and availability. Currently, the team has 2 StratoLoggers in inventory. Thus, the team determined it would best to save money and use the ones that are in inventory. However, this would mean that the team has to purchase an accelerometer, gyroscope, and a GPS since the StratoLoggerCF does not have these features. These components would allow the avionics system to measure the acceleration, angular velocity, and position of the rocket during flight.

Four GPS brands were compared and considered to be used on the rocket: Beeline, Real Flight, Altus Metrum, and eggfinder. The products' sizes, ranges, weights, additional required materials (extra antennas, radios, etc. required to use product), and prices were compared. All products except for the TeleMetrum are purely GPS devices. The TeleMetrum also includes an altimeter and accelerometer.

Table 5.2.2 Considered GPS and Respective Specifications

	Beeline		**Real Flight**			
	BRB 70cm	**BRB 900**	**GPS-1**	**GPS-2**	**TeleGPS**	**Eggtimer (TRS)**
Tranceiver Weight	55g		276g		18g	25g
Min. tube size that GPS can fit through	38mm	38mm	54mm	54mm	29mm	38mm
Frequency	440MHz	900MHz	900MHz	900MHz	440MHz	900MHz
Relative Range (Using BRB 70cm HP as baseline reference)	40%	26%	27%	27%	40%	8000ft
HAM license	required	none	none	none	required	none
Bi-Directional	no	no	yes	yes	no	
Antenna	removable	removable	removable	removable	fixed	removable
Battery	on-board	on-board	separate	separate	separate	separate
Pyro Channels	no	no	no	yes	no	yes
Flight Computer	no	no	no	no	no	yes
Transceiver price	$215–260	$200	$300	$500	$200	$90
Receiver antenna	with radio	available	included	included	user-supplied	Eggfinder RX or LCD Kit
Receiver radio	user-supplied	available	available	available	available	Included in kit
Computer	no	no	no	optional	required	required
Price of Transceiver and Receiver	No Receiver - User supplied antenna and radio w/ APRS	$330–400	$550–600		$350–400 User supplied antenna and computer	$115 User supplied computer

Among the GPS products shown above, the TeleMetrum has the best specifications in terms of performance. It has a compact size, high range, and also has a built-in altimeter and accelerometer. Based on price, however, the Big Red Bee 70cm GPS, has the best value among the 6 GPS devices. With the cheapest price, the BRB 70cm GPS has adequate range and an on-board battery. Only disadvantage would be the additional antenna and radio that is required to use the product.

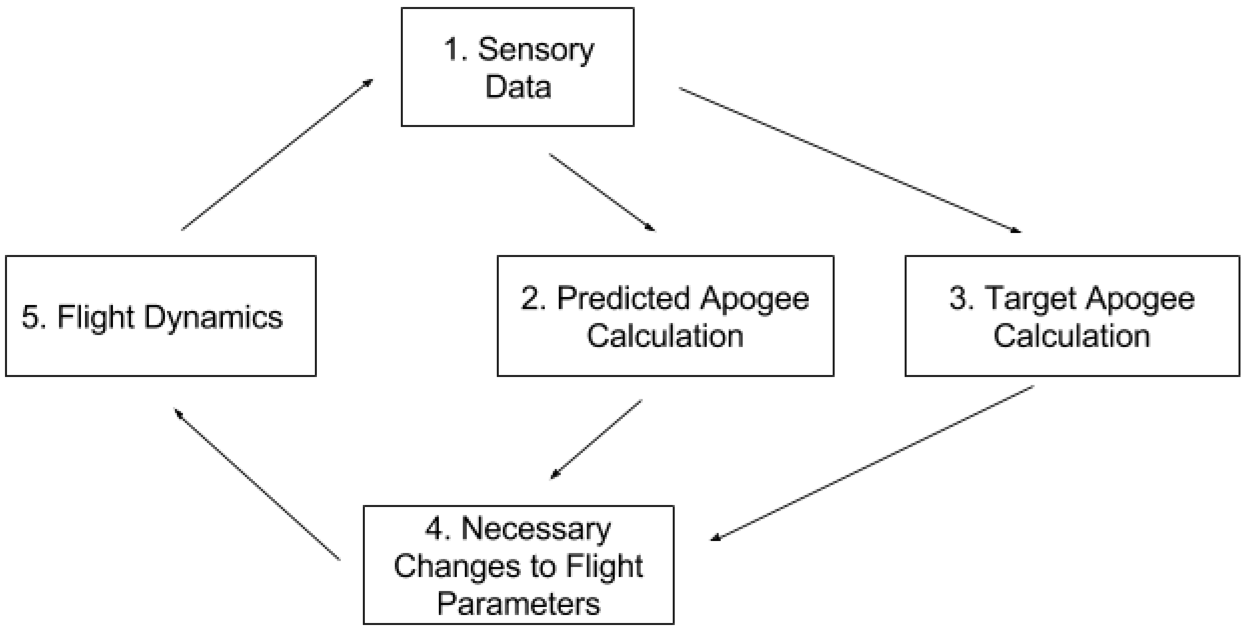
However, all 6 GPS products are very expensive, most of them being in the $300 range. Therefore, due to a limited budget, the team will use either the eggfinder or build a GPS telemetry system from scratch using a microcontroller, gps receiver, and a radio modem (which will most likely use APRS protocol).With a GPS antenna priced around $20-$50, the cost of building one will definitely be cheaper than purchasing many of the pre-built GPS. However, a very large amount of time would have to be spent designing and building a GPS telemetry system.

5.3 Apogee Targeting System (ATS)

5.3.1. Overview

The goal of the *Apogee Targeting System (ATS)* is to provide a mechanism for mid-flight adjustment of predicted apogee in order to better achieve the target apogee of one mile. In short, this will entail the repeated processing of data retrieved from altitude, speed, and rotational sensors to measure the expected apogee and in return adjust the dynamics of the rocket such that the rocket's expected apogee aligns with the predefined target apogee.

The rocket dynamics the ATS will adapt mid-flight are the forces on the rocket along coaxial direction (thrust and drag). Because the rockets flown in USLI use solid rocket engines, we cannot change the thrust magnitude, and are thus limited to adjusting the drag of the rocket. Because it will be impossible to raise expected apogee mid-flight without modifying the thrust of the engine, we aim to use an engine that will, in an ideal case, slightly overshoot the target apogee, requiring only a minimal increase in drag to slow the rocket and lower the predicted apogee to the target. The below diagram outlines the sections of the ATS.



5.3.2. Sensory Data

Various flight parameters will be necessary for apogee calculations; generally the more data acquired, the more accurate the calculations (at the cost of additional resources and circuitry). An altimeter, airspeed sensor, and gyroscope will be the ideal sensor suite, as these three sensors would provide redundancy in the case of a sensor's failure. It may be possible to use only altimeter output (manually calculating the upwards velocity over time) at the cost of accuracy. The sensory output will need to be connected/soldered to the microcontroller or processing unit that will be performing the calculations.

5.3.3. Apogee Calculations

The calculations will likely be performed on a microcontroller that will read in sensory data, evolve the equations of motion, and output signals to the motors that will induce drag.

For simplicity an Arduino board will likely be used for the subscale launch. The full-scale launch will migrate to an embedded circuit coded in C++ for performance, reliability and greater control.

5.3.4. Necessary Changes to Flight Parameters

After calculating the necessary parameters for target apogee, the correct change in flight dynamics will be calculated. The results will be sent to servos via the microcontroller.

5.3.5. Flight Dynamics

A group of servos will receive signals from the microcontroller. The current mechanism for inducing drag is a collection of panels that will be extended away from the body of the rocket to increase surface area against the air in front of the rocket and therefore increase drag. To simplify the calculations, the surfaces will likely extend through slits perpendicular to the axis of the rocket. This system is outlined in section 4.8.

5.4. Power

Each avionics system on the rocket will be powered by a battery. No two systems will share a battery and each system will have an independent arming keyswitch accessible from the exterior of the rocket when the rocket is in launch configuration. This compartmentalization will reduce the likelihood of a failure in one system inducing a failure in another system, thus ensuring maximum reliability of the vehicle as a whole. An appropriate battery for each system will be selected based on three criteria (1) the continuous current output that the battery can provide, (2) the energy density of the battery, and (3) the availability of the battery.

Secondary(rechargeable) batteries will be used for the ATS system and for the (challenge system). Secondary batteries are preferable in this application as they will allow for many ground-based test cycles without requiring the purchase of numerous expendable batteries. All readily available secondary battery types were considered. Energy densities were obtained from “Battery University” (http://batteryuniversity.com/learn/archive/whats_the_best_battery). Safety information was obtained from “Battery Solutions” (https://www.batterysolutions.com/recycling-information/battery-types/).

Table 5.4.1 Battery Properties

Battery Type	Energy Density (Wh/kg)	Safety
Lead Acid	30-50	toxic, spillable depending on type
Lithium Ion	110-160	non-toxic, non-spillable
Lithium Polymer	100-130	non-toxic, non-spillable
NiCd	45-80	toxic, non-spillable
NiMH	60-120	non-toxic, non-spillable

Either Lithium Ion or Lithium Polymer batteries will be used to power the ATS and the (challenge system) due to their high energy density and large number of commercially available pack configurations.

To determine the correct lithium batteries for the ATS and (challenge system), the continuous current draw for each system will be calculated. Current spikes, for instance when the ATS is active, will also be considered in order to prevent brown-outs. A battery will be chosen to power each system that possesses a capacity and C rating that allows it to provide in excess of the maximum current draw required by that system. The continuous current a battery(or cell) can provide is equal to its capacity multiplied by its C rating. Where voltage regulators are utilized, it will be ensured that their current output is also in excess of the maximum current draw the device they are powering.

Each Perfectflite Stratologger altimeter onboard the rocket will be powered by one nine-volt, primary(non-rechargeable), alkaline battery, as specified by the manufacture of the altimeter. Adhering to the recommendation of the manufacturer is the best way to ensure the product operates as intended. Additionally, nine volt alkaline batteries are easy to come by, have a high energy density, and are non-toxic and non-spillable.

Additionally, the capacities of all batteries will be selected such that the vehicle can remain launch-ready and on standby for a minimum of two hours. The runtime achievable with a given battery and system will be calculated by dividing the capacity of the battery by the average current draw of the system.

6. Design Process

The rocket will be a large and complex machine with a vast number of parts that depend on one another in order to function correctly. The interdependent nature of these many factors is why it is so important to plan a design process that emphasizes clarity, communication, and documentation. Setting and following rules for the extensive design process maximizes our chance of success by avoiding common design pitfalls such as miscommunication and poor planning.

6.1. Design Groups

As per the team's general structure, the Vehicle subteam is primarily responsible for the physical design and construction of the rocket. To accomplish this, the subteam is divided into smaller groups: Airframe, ATS, and Rover. Each group will begin the process of designing its respective component by creating a function tree; a diagram that shows all the functions that must be completed. Groups then brainstorm as many ideas as possible for how to complete these functions. These ideas are organized into a solution table in no particular order. Some ideas may be highly unrealistic, but it is still important to document them, as they may help facilitate creativity. The most realistic options for each function will be sketched and developed and discussed, then evaluated using an evaluation matrix. This chart involves determining evaluation criteria such as complexity, reliability, and ease of construction, then assigning each criteria an importance level. Design options are scored on each criteria. Each score is then multiplied by the importance level. Summing these results for each option results in a final score. Based on these scores and a great deal of discussion, each group will decide which ideas to move forward with. Some ideas may be prototyped for ground testing or even for subscale launch. Between the evaluation chart, group discussion, and the performance of prototypes, each group will decide on a final design option for each function. The design process is already underway. Examples of a function tree and solution table, as well as some preliminary design sketches, can be seen in Section 4.6.

Table 6.1.1

Design Charts	
Chart	Purpose
Function Tree	Describes necessary functions
Solution Table	Lists possible solutions to necessary functions
Evaluation Matrix	Scores potential solutions based on weighted criteria

6.2. CAD Process

As design progresses, CAD models will become increasingly important and detailed. Proper management of these files is essential. CAD will be done in Solidworks 2017, which is provided to students by Georgia Tech. Version control will be managed by a free software called GrabCAD. Every time changes to a part are saved, GrabCAD creates a new version of the part, which is then shared with the rest of the team. GrabCAD's most useful features are listed in the table below.

Table 6.2.1

GrabCAD Features
Ability to include notes with each new version that describe changes made and reasons why
Rolling back to previous versions if necessary
Visually comparing different versions of the same part or assembly side by side
Locking parts while making changes to avoid team members overwriting each other's work
View parts online without opening CAD software
Share comments on parts

Any major design changes should be discussed at Vehicle subteam meetings in order to keep everyone on the same page and avoid miscommunication. It is the role of the Systems subteam to monitor the CAD files. This includes making sure that all versions have adequate notes, all parts are fully defined, and all assemblies build without errors. In addition, Systems subteam members will regularly check in with each group as well as with the Avionics subteam to ensure that no design has conflicts with another part of the rocket.

6.3. Revision and Approval

Once as group decides that a CAD model is complete, it must be presented to the whole team. Any team member will be able to contribute feedback and share ideas as to how the design could be approved. Afterward, any major changes must be approved by the Vehicle, Avionics, and Systems leads as well as the Chief Engineer. Before construction of the rocket can begin, each group will write assembly instructions for their components. This will greatly aid the building and assembly process and help avoid mistakes such as gluing something on too early and then needing to remove it. The subscale rocket as well as any other prototypes will be good practice for writing and following these assembly instructions.

7. Outreach

7.1. Educational Engagement

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.

7.2. Community Outreach

In order to gain support from the community, GIT LIT will pursue advertising opportunities through personal contact with companies and alumni as well as through on-campus events. In addition to this, the team will manage and produce content for an official website and Facebook page, to increase social media presence.

On campus, the team plans to collaborate heavily with the Ramblin' Rocket Club, which provides members the resources and guidance necessary to construct high power rockets for NAR certifications. Through this collaboration, the team hopes to reach out to more interested members of the Georgia Tech community, as well as attend more launches and events geared towards the general high power rocketry community.

7.3. Educational Outreach

The goal of Georgia Tech's outreach program is to promote interest in the Science, Technology, Engineering, and Mathematics (STEM) fields. GIT LIT intends to conduct various outreach programs targeting students from all grade levels ranging from Kindergarten to 12th grade. GIT LIT will be planning multiple events over two semesters that will be geared respectively towards certain age groups. The team plans to particularly engage in outreach with schools that are located in disadvantaged areas of Atlanta, with the goal of encouraging students there to seek careers in STEM fields.

7.3.1. Middle School Outreach Program

One such program that has proved successful in the past is an after-school rocketry program with a local Atlanta middle school. Each semester, members of the team make weekly trips to the school, which is in an impoverished neighborhood without a strong STEM influence. Through this program, which introduces the students to the basics of rocketry, the team hopes to foster an interest in STEM in the community. In addition to this continuing middle school program, the team also participates in local science fairs and festivals, to engage with the larger Atlanta community.

7.3.2. 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 other merit badges as well, 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.

7.3.3. 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.

8. Project Plan

8.1. Timeline

Figure 8.1.1 Team Timeline Chart

The team's timeline is based primarily off of the deadlines and dates provided in the 2018 NSL Handbook, which are summarized in Table 7.1.1. In addition to those deadlines, the team has implemented additional benchmarks by which certain technical or logistical tasks must be completed, in order to remain on schedule. These additional milestones, shown in Table 7.1.2, are managed using Zoho, an online task management tool. This tool allows team leadership to track individual, low-level tasks, as well as high-level team goals.

These tasks break down the concrete deadlines provided in the handbook (Table 7.1.1) into more manageable, discrete milestones. For example, as shown in Figure XXXXXX, The major tasks leading up to the PDR Report submission are:

- Completion of Leadership-provided Assignments, which distribute sections of the report across the team members

- Securement of additional funding to support prototyping and subscale construction
- Progression through the design process of the main sub-systems and airframe
- Construction of two variants of a subscale to allow for testing of different systems during the subscale launch

Table 8.1.1 NSL Deadlines

Deadline	***Date***
Proposal	20 SEPT 2017
Web Presence Established	03 NOV 2017
PDR Documentation	03 NOV 2017
PDR Teleconference	06-29 NOV 2017
CDR Documentation	12 JAN 2018
CDR Teleconference	16-31 JAN 2018
FRR Documentation	05 MAR 2018
FRR Teleconference	06-22 MAR 2018
Competition	04-07 APR 2018
PLAR Documentation	27 APR 2018

Table 8.1.2 Team Specific Deadlines

Subteam	***Deliverable***	***Date***
Airframe	Finalized Parts List - Subscale	18 SEPT
	Internal Design Review	22 SEPT
	Finalized Parts List Full-scale	15 OCT
	Structural Testing – Fins, Bulkheads, Airbrakes	20 OCT
	Recovery System Testing	6 NOV
	Subscale & Full Scale Design Review	8 NOV
	Subscale Launch	19 NOV
	Full Scale Construction	20 NOV
	Recovery System Testing	3 DEC
	Airbrake Wind tunnel Testing	3 DEC
	Full Scale Design Review	5 JAN
	Full Scale Test Launch	15 FEB
	Competition	5-8 APR
Avionics	Finalized Parts List	10 OCT
	Avionics Bay Construction - Subscale	18 OCT
	Finished Software - Airbrakes	16 NOV
	Testing - GPS, Altimeters, and sensors	21 NOV
	Avionics Bay Construction – Full Scale	12 FEB
	Full Scale Integration Testing	13 FEB
	Full Scale Launch	15 FEB
	Competition	5-8 APR
Operations	Secure All of Budget Funding	6 NOV
	Set up Outreach Events for the rest of the life cycle	20 NOV
	Secure transportation and housing for competition	20 JAN
	Competition	5-8 APR

8.2. Project Plan Budget

Based on team spending from prior years, the team has created a preliminary budget estimate for the 2017-2018 competition years, which is shown in Table 7.2.1. However, this budget estimate is likely to change based on the materials and resources used by the team

Table 8.2.1 Budget Estimate

Item	*Cost ($)*
Gas cost	80.00
Hotel Stay for competition	960.00
Small Scale Rocket	375.00
Rocket Materials	750.50
Control Mechanisms	826.15
Outreach	784.91
Avionics	66.00
Total	4436.56

8.3. Funding Plan

GIT LIT is working closely with the Georgia Space Grant Consortium to receive most of the rocket material budget, as done in the past. In addition, the team has applied to the Georgia Tech Student Foundation for additional outreach funding. The team also hopes to expand and create a network with corporate sponsors. More specifically, we intend to reach out to companies that team members have interned with, local Atlanta companies, and established invested aerospace companies, such as Orbital ATK, SpaceX, Lockheed, Boeing, etc. Another possible source of funding is the massive network of Georgia Tech alumni, who may be able to help the team secure funding from corporate sources. The Georgia Tech Ramblin' Rocket Club has generously offered the use of some of their tools, storage space, and aid in facilitating the purchase of rocket motors.

8.4. 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 6.1 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.