By:

Georgia Tech A.R.E.S.

NASA Student Launch 2017

Project Name: KRIOS

September 30, 2016

Georgia Institute of Technology

School of Aerospace Engineering

270 Ferst Drive, Atlanta GA 30332 - 0150

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1. Introduction

1.1. School Information

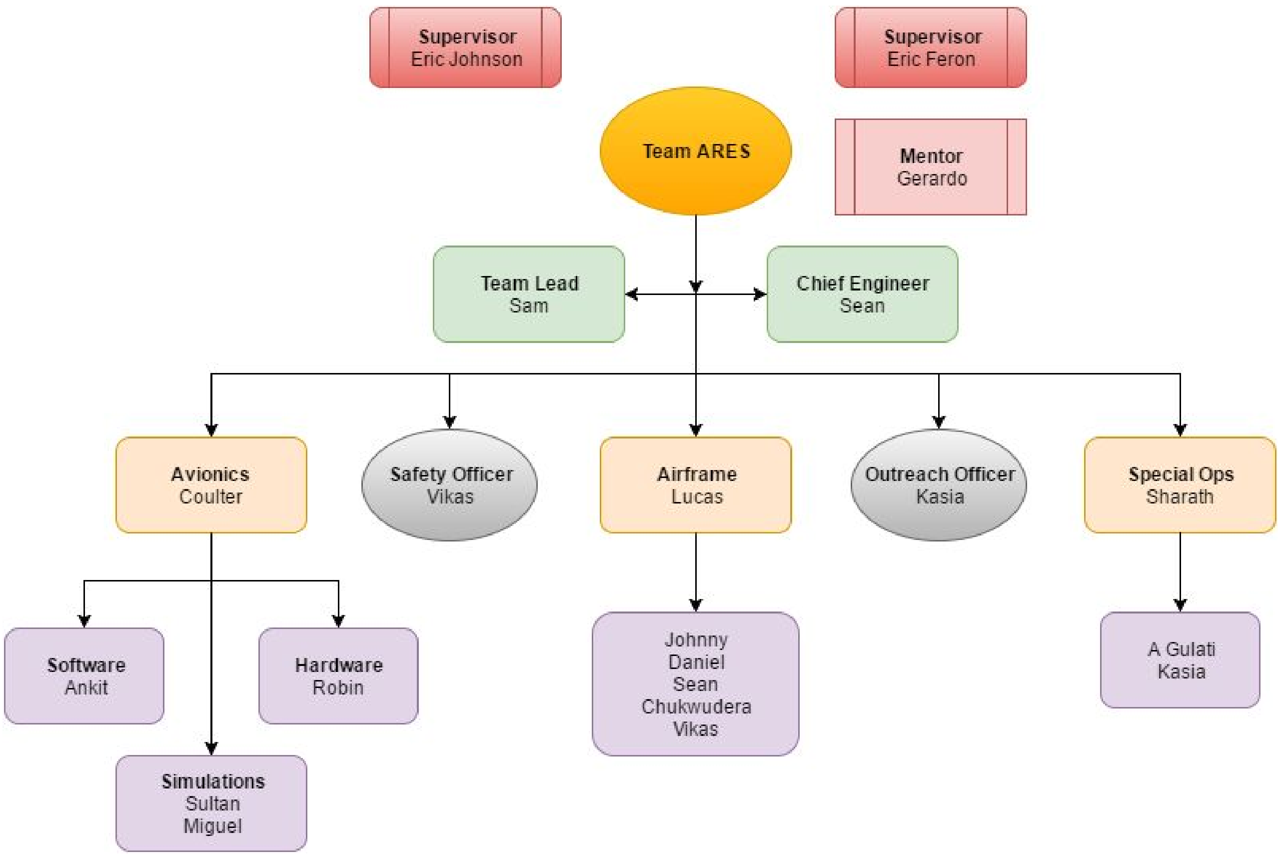
Table 1.1.1: Team Summary

Team Summary	
School Name	Georgia Institute of Technology
Mailing Address	270 Ferst Drive, Atlanta GA 30332 - 0150
Team Name	Team A.R.E.S. (Autonomous Rocket Equipment System)
Project Title	Mile High Club
Rocket Name	Krios
Project Lead	Sam Rapoport
Project Lead e-mail	srapoport3@gatech.edu
Safety Officer	Vikas Molleti
Team Advisor	Dr. Eric Feron
Team Advisor e-mail	feron@gatech.edu
NAR Section	Primary: Southern Area Launch Vehiclery (SoAR) #571
NAR Contact, Number & Certification Level	Gerardo Mora NAR Number: 98543 Certification Level: Level 2 Certified for HPR by NAR

1.2. Student Participation

Team Autonomous Rocket Equipment System (A.R.E.S.) is composed of sixteen students studying various fields of engineering. Our team is composed of less than 50% Foreign Nationals (FN) per NASA competition requirements. To work more effectively, the team is broken down into groups that focus on special tasks. Each sub-team has a lead supported by several specialized task groups. Team memberships were selected based on each individual's area of expertise and personal interest. Figure 1.2.1 shows the work breakdown structure of Team ARES.

Figure 1.2.1: Team Structure Chart



1.3. Facilities and Equipment

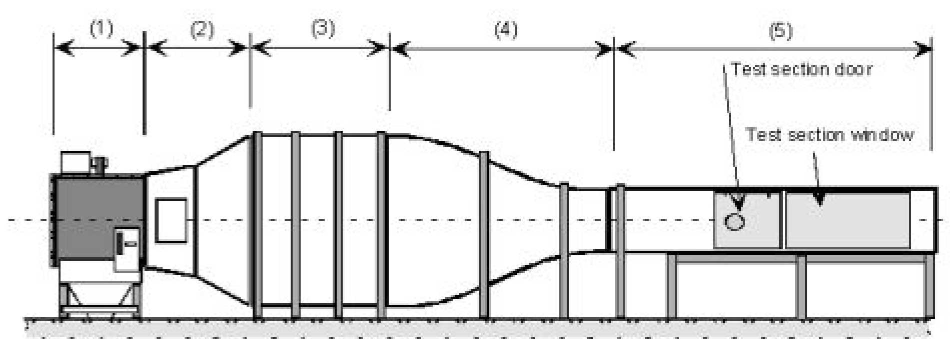
This section will list all the available facilities, software and equipment accessible to Team A.R.E.S in the design and testing of Project KRIOS.

1.3.1. Facilities

In order to manufacture the launch vehicle, the Georgia Tech Invention Studio has tremendous capabilities for enabling a NASA SL team to construct innovative and creative projects. Team A.R.E.S. will have access to the Invention Studio from 10AM-5PM, Monday through Friday under the supervision of a Graduate Lab Instructor (GLI), or Undergraduate Lab Instructor (ULI). The Invention Studio is equipped with the following machinery:

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

Figure 1.3.1: Wind Tunnel



Team A.R.E.S will utilize an open-circuit, Low Speed Aerocontrols Wind Tunnel, which will be available for use under the supervision of a graduate student from 9AM-6PM, Monday through Friday (Figure 1.3.1). This will enable Team A.R.E.S. 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, force-strain stands, high-speed, multi-channel 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.

Additionally, in order to participate in video-teleconferences and off-campus communications, Team A.R.E.S has access to Cisco Video-Teleconferencing equipment (CTS 1000), as well as POLYCOM HDX video teleconferencing capabilities with T3 broadband connection through the Georgia Tech Vertically Integrated Projects (VIP) program. Team A.R.E.S. will maintain a dedicated website which will include project documentation, current team information, team pictures, and other relevant information. Team A.R.E.S will comply with all aspects of the Architectural and Transportation Barriers Compliance Board Electronic and Information Technology (EIT) Accessibility Standards (36 CFR Part 1194) Subpart B-Technical Standards.

1.3.2. Software

All the members of Team A.R.E.S will have ongoing access to all the industry-standard engineering software packages on campus and personal computers, such as:

- OpenRocket
- NX7, Abaqus(FEA)
- SolidWorks, AutoCAD (FEA and CAD)
- MATLAB, Simulink
- Autocoders(control algorithms)
- COSMOL(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 Student Launch Team at Georgia Tech consists of three subteams: Airframe, Avionics, and Special Operations. These sub teams will work together and implement a safety plan that considers all aspects of the team's designs and practices in construction and launch. In order to assure quality, the team's technical knowledge and the experience of graduate students, faculty advisors, and NAR mentors will be used. The safety plan used for this project will include how to utilize proper safety precautions such as protective equipment when operating hazardous material or equipment. Team A.R.E.S. and NAR personnel involved will enforce all safety codes and precautions in compliance with NAR high power safety code regarding the rocket operation, rocket flight, rocket materials, and launch site activities.

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 Team 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 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. Wind tunnel testing will also be used to evaluate the effects aerodynamic forces on the design of the rocket. 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

Gerardo Mora, our 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 run by Gerardo Mora, 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) in charge will ensure that all requirements on the safety checklist are met. The 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, NFPA1127" 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, Gerardo Mora, 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.

2.7 Safety Agreement Signatures

2016 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.

1.6.1. 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.

1.6.2. 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.

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

Name	Signature	Date
Vikas Molleti		9/29/16
Samuel Rapsport		9/29/16
Lucas Muller		9/29/16
Sultan Imran Hashmi		9/29/16
Sean Fitzpatrick		9/29/16
Johnny Sockwell		9/29/16
Chukwudera Mojekwu		9/29/16
Daniel Davis		9/29/16
Ankit Khanal		9/29/2016
Katherine Kwasniak		09/29/2016
Miguel Calleja		09/29/2016
Robin Lam		9/29/2016
Avichal Gulati		9/29/2016
ERIC FERON		9/29/2016
Eric Johnson		9/29/2016
Sharath Yalla		9/29/2016

3. Technical Design

3.1. Dimensions

The dimensions of the launch vehicle were specifically determined in order to achieve the mission requirements detailed in the previous section, to accommodate the various systems efficiently and effectively, and maintain a high stability margin to ensure the success of the mission. The dimensions are specified below in Table 3.1.1.

Table 3.1.1: Length Breakdown

Name of Part	Size			Mass
	ID	OD	Length	
Nose cone		Ogive	18in	15.4 oz
Body tube	5in	5.15in	70in	89.5oz
Engine block	3.75in	4in	19.5in	32 oz
Roll-inducing Controls	4.461in	4.5in	5in	8 oz
Parachute		80in	0.984in	33.7oz
Main chute		24in	0.984in	2.17 oz
Payload Retention System	4.461in	4.5in	6in	48 oz
Fins	Thickness:	0.125in		48.1 oz
ATS	Thickness:	0.118in		0.163 oz

The height dimensions for the systems that are categorized as inner components of the launch system are detailed below in Table 3.1.2.

Table 3.1.2: Length Breakdown Cont.

Parameter	Value
Payload Bay	6.2 in
Avionics Bay	11 in
ATS	4.2 in
Motor Casing	19.5 in
Couplers	7 in
Bulkheads & Centering Rings (Thickness)	0.25 in

3.2. Materials

Table 3.2.1: Materials Table

Component	**Material Options**	**Final Selection**
Airframe Tube	Phenolic/Fiberglass/Carbon Fiber	G12 Fiberglass
Nose Cone	Carbon Fiber/Fiberglass/foam/wood	G12 Fiberglass
Fins	Foam Core/Fiberglass/Plywood	G12 Fiberglass
Centering Rings	Fibre/Plywood	G10 Fiberglass
Bulkheads	Fibre/Plywood	G10 Fiberglass

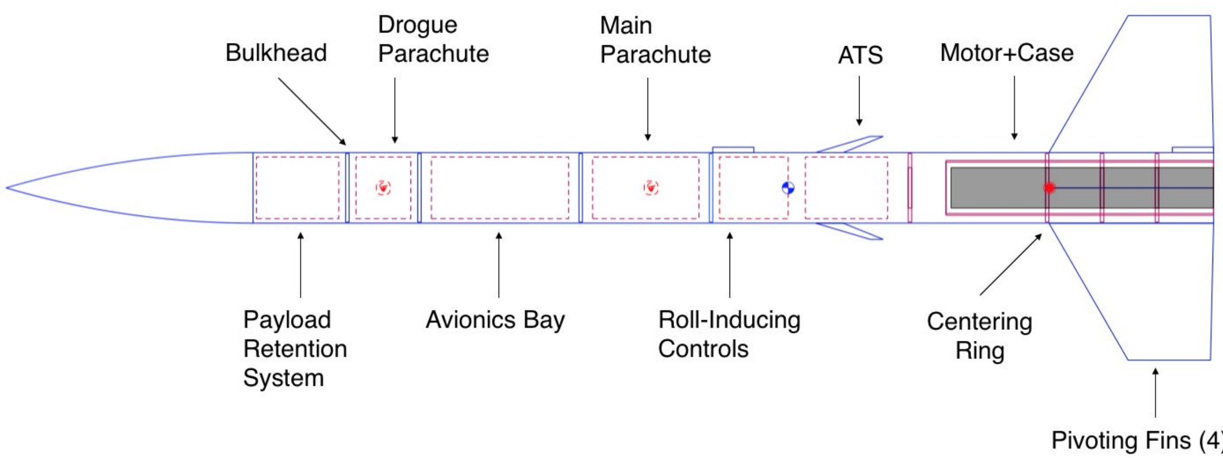
The main structural component of any rocket is the airframe or body tube. Due to the compressive pressure forces and horizontal shear stresses created by the flow of air around the rocket, this component needs to be designed with a strong material. We considered the use of Phenolic (resin coated paper), Fiberglass (fiber-reinforced plastic), and Carbon Fiber (woven carbon filament), whose densities are 1.07g/cm^3, 1.52g/cm^3, and 1.6g/cm^3 respectively. The rocket will feature a 5" ID G12 Fiberglass tube, as it is the best compromise between material price and specific strength. G12 Fiberglass is strong enough to endure through multiple flights and landings and would thus be an optimal choice to further the mission goal of reusability. It will also allow our team test-launching opportunities. Similar options were available for the Nose Cone. Again, G12 Fiberglass presented a suitable compromise of price and strength. Furthermore, the material consistency allows us to securely bond the Nose Cone to the Airframe tube.

G10 Fiberglass was chosen for the fins and bulkheads due to its high ultimate yield stress and ductility, which allows the fins to maintain structural rigidity during flight without compromising the ability to absorb landing impact without shattering. Although plywood is cheaper and easier to machine, it has a lower specific strength and will not bind to the Fiberglass body tube as well as the G10 Fiberglass.

3.3. Construction

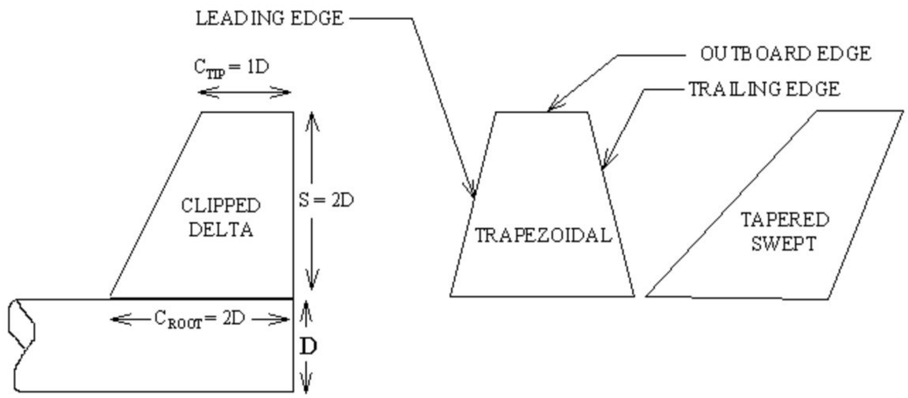
The general vehicle layout is shown in Figure 3.3.1. As shown, the launch vehicle will consist of three physically independent sections that are connected with smaller diameter tube segments which are attached to the intermediate section. The design, from aft to front, includes the booster and control section, avionics section, and the payload retention section. The components distributed on the inside are labeled in Figure 3.3.1, with the exception of relatively smaller components such as bulkheads, U-bolts, and shock-cords.

Figure 3.3.1: General Layout of Rocket Components



The clipped delta fin platform is an ideal shape for the fins (Figure 3.3.2 above). The fins are large enough to stabilize all rockets adequately if certain design formulas are followed. The clipped delta fin also generates little drag. Once the general shape of the fins is produced, it must be sanded down to create a symmetrical airfoil. This will reduce drag due to the fact that the fins perform most efficiently at the tips where airflow is smooth due to it being outside the turbulent region caused by air flowing over the nose cone.

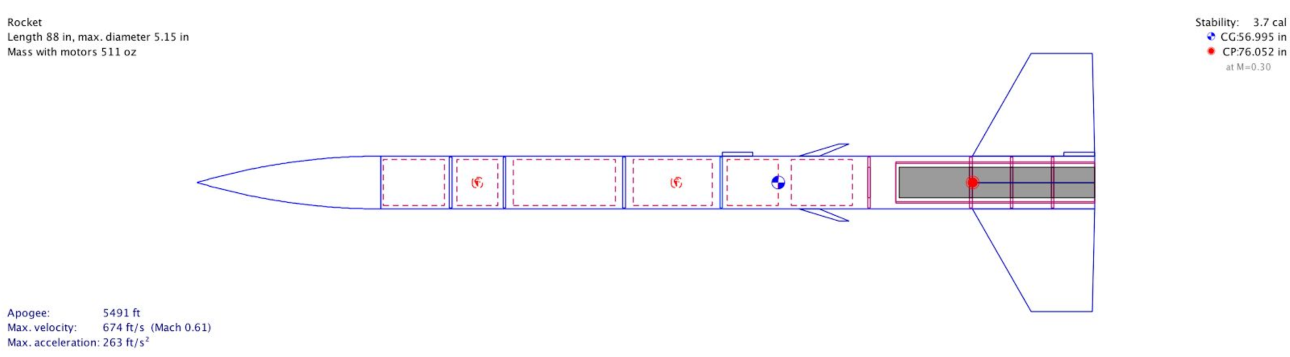
Figure 3.3.2: Fin Configurations



Src: http://www.nakka-rocketry.net/fins.html

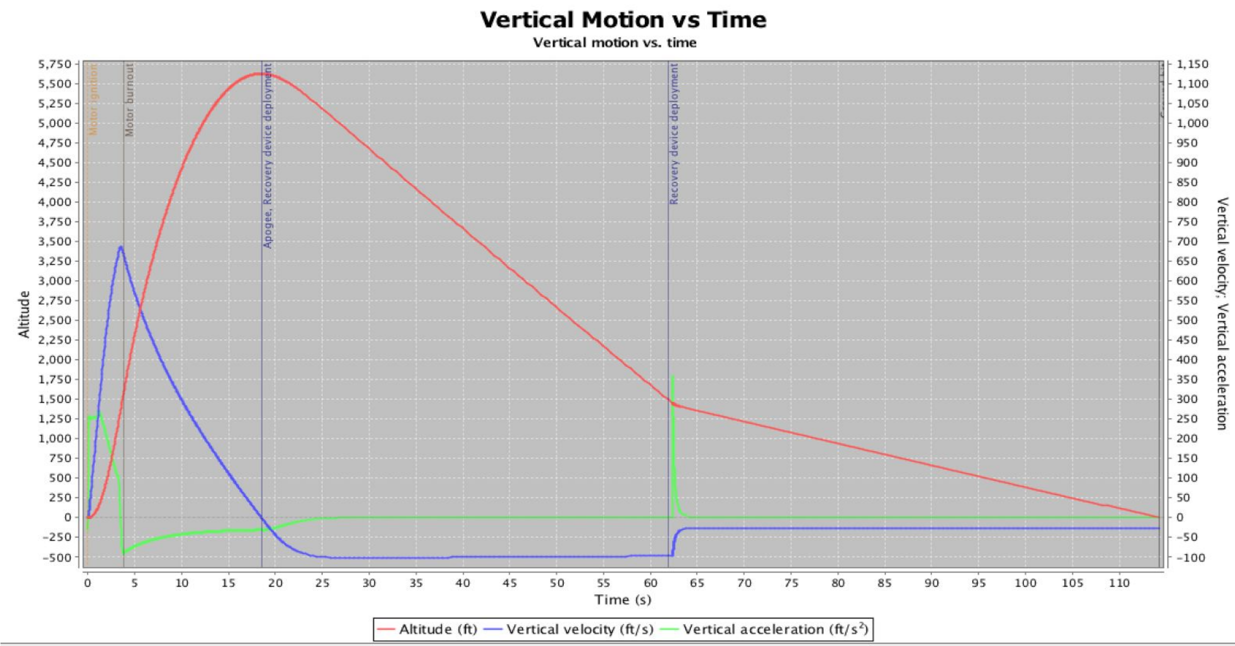
A configuration of four such clipped delta fins, as opposed to the option of three, has been considered for its potential to increase stability. The driving factor behind the desire for the increased stability is the decision to implement a variable Apogee Targeting System which may lead to an increasingly complex tendency toward instability. This four-fin choice is estimated to increase stability by slightly over 50%. Other benefits include increased design symmetry and reduced associated manufacturing costs and material required per fin, allowing for lower cost replacement fins. The Figure below, extracted directly from OpenRocket, depicts the estimated locations of the center of gravity and the center of pressure. It also derives the stability given the previous estimates..

Figure 3.3.3: Open Rocket Model



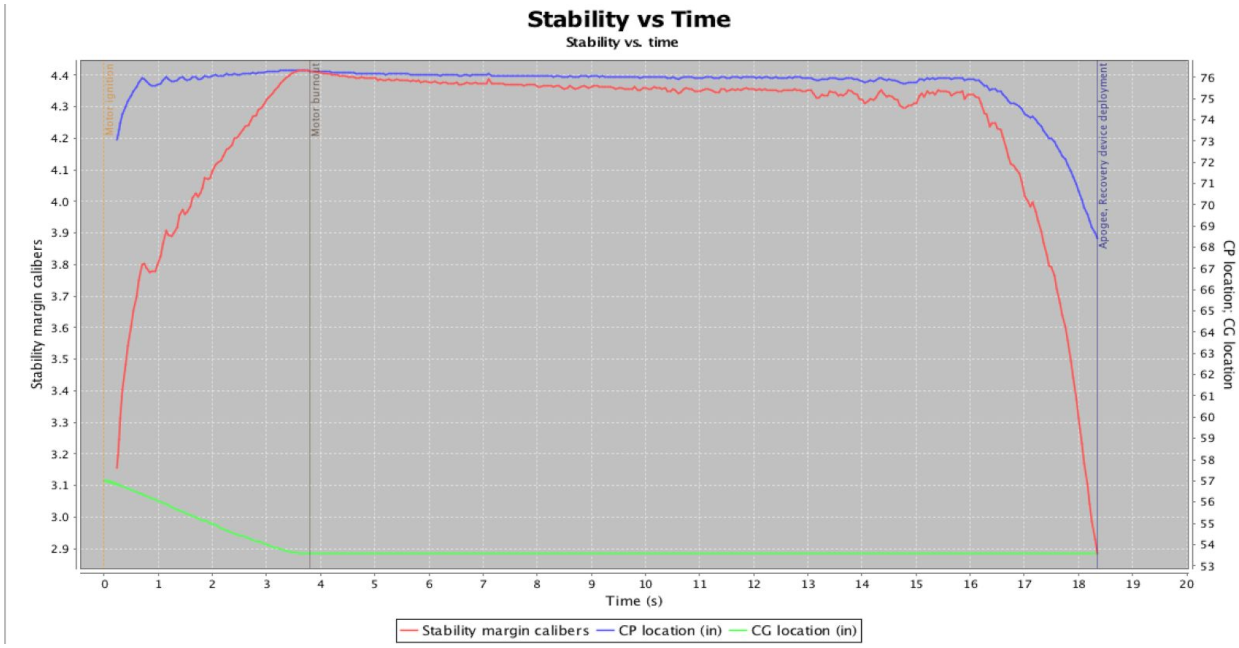
3.4. Altitude and Calculations

Figure 3.4.1: Altitude Projection



After burnout the apogee targeting system will adjust the drag on the rocket. Further experimentation and simulation will be carried out to quantify the effect of this system on the apogee. Figure 3.4.1 demonstrates that the rocket reaches apogee at approximately 19s where the apogee is projected to be 5,491 ft (without assistance from the ATS). At apogee, the ejection charges for the drogue parachute will activate. Deployment of the main parachute will occur between 1500 and 1000 ft AGL to further decelerate the rocket so that the impact force is below 75 ft-lbf and to prevent considerable amount of horizontal displacement occurring from wind gusts and air currents.

Figure 3.4.2: Stability Projection



Ultimately, the launch vehicle's mission is to reach an apogee of 1 mile (5,280 feet / 1,610 meters), as precisely as possible. Several performance parameters are implicit in this objective: most importantly, a controlled ascent and a survivable descent velocity (such that the ground impact does not compromise any component's structural integrity). Given the Student Launch competition's mission requirements, the success of the launch vehicle's performance can be quantified by the difference between its intended apogee and its actual, experimentally measured apogee. The majority of this final apogee will be determined by thrust, a factor of the motor's performance that is selected for the launch.

3.5. Parachute Design

The main parachute will be housed below the avionics section while the drogue parachute will be located just above the avionics section (using the nose cone as reference location). All chutes are made of ripstop nylon to support the weight of the rocket. The chutes will be protected by an insulating material to prevent the ignition of the nylon due to the explosive charges that will induce rocket separation during descent. The parachutes are secured to the rocket with the by a shock-cord that is attached to U-bolts secured to the bulkheads and centering rings. Through simulations on OpenRocket software, it was determined that the most effective sizes for the parachutes are an 80” diameter for the main parachute and a 24” diameter parachute for the drogue parachute. Parachutes were sized such that the impact kinetic energy of each independent section is below 75 ft-lbf.

At apogee (5280 ft), the ejection charges for the drogue parachute will activate. The drogue parachute will be deployed to slow and stabilize descent and reduce downrange drift, allowing for payload and main parachute deployment. Deployment of the main parachute will occur between 1500 ft and 1000 ft, further decelerating the rocket so that the impact kinetic energy is below 75 ft-lbf. The main parachute will also serve to prevent a considerable amount of horizontal displacement that occurs as a result of wind gusts and drift.

Table 3.5.1: Parachute Specifications

Parachute	Description	Cd	Carrying capacity	Cost
Main	CERT-3 Large 80’’	1.6	16.2 - 35 lb	$145.00
Drogue	CERT-3 Drogue 24”	1.6	2.2 lb	$63.70

3.6. Motor

Given the Student Launch competition’s mission requirements, the success of the launch vehicle’s performance can be quantified by the difference between its intended apogee and its experimentally measured apogee. In the motor selection process, performance and affordability are the highest priorities for the engineering team. The limited initial funds forces certain tradeoffs to be made. In terms of performance, the team selected a motor that would overshoot the mission requirement of a 1-mile apogee. This intentional overshooting is made viable by the vehicle's Apogee Targeting System, which will increase the drag force on the vehicle, thus acting directly against the motor's performance and allowing the vehicle to reach its intended apogee far more accurately.

To select a motor, a model of the rocket was created in Openrocket. Three potential motors were chosen initially: the Cesaroni L990, L995, and L952W-P. Openrocket was used to simulate the apogee, max velocity, and max acceleration of the rocket with each motor choice. The L990 gives a projected apogee of 4381 ft, a max velocity of 592 ft/s, and a max acceleration of 356 ft/s2. The L995 gives a projected apogee of 5641 ft, a max velocity of 686 ft/s, and a max acceleration of 356 ft/s2. The L995 gives a projected apogee of 5641 ft, a max velocity of 686 ft/s, and a max acceleration of 268 ft/s2. The L952W-P gives a projected apogee of 7843 ft, a max velocity of 762 ft/s, and a max acceleration of 186 ft/s2. The final motor choice for Krios is a Cesaroni L995. The L995 motor has the necessary thrust to potentially overshoot the target altitude of 5280 ft so the Apogee Targeting System can be activated to automatically slow down the rocket and achieve the desired apogee. The following Table 3.6.1 outlines the specifications and dimensions of the motor.

Table 3.6.1

MOTOR NAME	Cesaroni L995
DIAMETER	75.0 mm
LENGTH	48.6 cm
PROP WEIGHT	1.9125 kg
TOTAL WEIGHT	3.591 kg
AVG THRUST	996.5 N
MAX THRUST	1404.5 N
TOTAL IMPULSE	3618.0 Ns
BURN TIME	3.6 s

3.7. Payload

The payload of the rocket will be housed primarily in the avionics bay and mostly encompasses the components of the avionics system. Additionally, the Krios will contain a camera to record in-flight footage and two parachute deployments: one drogue and one main.

3.8. Launch Vehicle Requirements

Table 3.8.1: Launch Vehicle Requirements

Requirement	***Design Feature to Satisfy Requirement***
The vehicle will deliver the payload at its apogee altitude of 5,280 feet above ground level (AGL).	Engineering payload integrated into rocket frame.
Vehicle altimeter will report an apogee altitude of most nearly 5,280 feet AGL.	Control surfaces mounted to fins will provide air resistance. Control surfaces will be dynamically controlled throughout flight to optimize apogee altitude.
Recovery electronics shall be powered by commercially available batteries.	Hobby grade Li-Po (Lithium Polymer) batteries will be utilized.
Launch vehicle will be designed to be recoverable and reusable within the day of initial launch.	Vehicle will be designed in a modular manner. Sections can be quickly reassembled or damaged components substituted with spares.
The launch vehicle shall have a maximum of four (4) independent sections.	Two (2) sections: nose-cone, and main body section which includes motor and payload.
The vehicle will be limited to a single stage, solid motor propulsion system, delivering an impulse of no more than 5,120 Newton-seconds.	Design utilizes one motor
Vehicle will be prepared within 4 hours of FAA waiver opening.	Simple-to-assemble Design

Launch vehicle shall be capable of remaining launch ready for 1 hour on launch pad without loss of functionality.	Vehicle will incorporate battery of sufficient capacity to power rocket for minimum of 1 hour and duration of flight.
Vehicle shall be capable of being launched via 12 volt DC firing system.	Vehicle will utilize a solid rocket motor capable of igniting under 12 volt system.
Vehicle will require no external circuitry or ground support, other than provided by Range Services.	Vehicle will be designed with a battery and microcontroller capable of self sufficient operation.
Vehicle will utilize commercially available solid propellent systems.	Appropriate hobby grade engine will be chosen.
Pressure vehicles shall be approved by RSO.	No pressure vessels will be utilized.
Vehicle shall have minimum static stability margin of 2.0 at point of rail exit.	Vehicle will incorporate stabilizing fins and appropriate rail exit speed to achieve static stability of at least 2.0.
Launch vehicle shall accelerate to minimum velocity of 52 fps at rail exit.	Appropriate motor size will be chosen.
Teams shall launch scale rocket prior to CDR	Scale rocket shall be constructed and tested. An altimeter will be included.
Teams shall test full scale rocket prior to FRR	Full scale rocket shall be launched and recovered before FRR.
Any structural protuberance on rocket shall be located aft of burnout center of gravity.	Fins shall be positioned aft of burnout center of gravity.
Vehicle Prohibitions	Vehicle will not utilize prohibited design elements listed in section 1.19 of student handbook.
Launch vehicle shall stage deployment of recovery devices.	Vehicle will be equipped with a drogue parachute that opens near apogee and main parachute that opens at a lower altitude. Deployment shall be controlled via altimeter.

Team must perform successful ground ejection of recovery system.	Team will deploy drogue chute and main parachute in a dry ground test.
At landing, independent sections of vehicle will have a max kinetic energy of 75 ft-lbf	Parachute shall be sized accordingly.
Recovery system electric circuits shall be independent of payload electronics.	Rocket shall use a separate microcontroller to coordinate recovery procedure.
Recovery system shall use redundant altimeters.	Commercially available redundant altimeters shall be incorporated.
Motor ejection is not a permissible form of recovery system deployment.	Motor shall remain firmly installed in rocket for duration of flight and recovery procedure.
Each altimeter shall be armed with a dedicated arming switch accessible from exterior of rocket airframe when rocket is in launch configuration on launchpad.	Altimeter shall be positioned in appropriate location on airframe.
Each altimeter shall have a dedicated power supply.	Appropriate altimeters with integrated batteries shall be utilized.
Removable shear pins shall be used for parachute compartments.	Recovery system components shall be installed and retained using shear pins.
An electronic tracking device shall be installed in launch vehicle and shall transmit position of vehicle to a ground receiver.	An electronic transponder shall be installed in the launch vehicle.
Recovery system electronics shall not be adversely affected by other on board electronic devices during flight.	Recovery system electronics shall remain separated from on board electronic devices during flight.
Each team shall choose one design experiment	A.R.E.S. shall choose and implement Option 2: Roll Induction and Counter Roll
Additional experiments.	No additional experiments shall be flown.
Additional experiment documentation.	No additional experiments shall be flown.

Team shall design system capable of controlling launch vehicle roll post motor burnout.	Team shall design rocket with control surfaces on fins that shall induce moment to control roll during coast stage of flight. Control surfaces shall be modulated by microcontroller.
Systems shall induce at least two rotations around roll axis of launch vehicle.	Control surfaces shall be appropriately engaged until two rotations have been completed.
After system induces two rotations, it must induce a counter rolling moment to halt all rolling motion for remainder of vehicle ascent.	Control surfaces shall be modulated by microcontroller and gyroscope to stabilize rotation about roll axis of launch vehicle.
Teams shall provide proof of controlled roll and successful counter roll.	Onboard gyroscope data and camera footage shall be recorded during flight and made available to scoring personnel for review.
Teams shall not intentionally design launch vehicle with fixed geometry capable of inducing passive roll.	Launch vehicle will only utilize actuated control surfaces to achieve roll and counter roll. Actuated surfaces will be designed to have no contribution to moment about roll axis of launch vehicle until activated.
Teams shall only use mechanical devices for rolling procedures.	Launch vehicle will utilize only control surfaces to alter the aerodynamic properties of vehicle and induce moment about roll axis.

3.9. Challenges and Solutions

There were several key challenges that our team faced. For our structures team this included reaching the target apogee given the payload and avionics components. Given the added complexity coming from the versatile fins, the structures team had to find innovative ways of packing and placing all of the critical components and wiring. In order to solve this and other problems the structures team will do extensive testing by using various CAA(Computer Aided

Analysis) tools including OpenRocket, AVL, XFoil, and Catia. The team will also be performing significant wind tunnel testing to ensure that the rocket reaches the apogee in an ideal fashion.

In order to address the issue of positioning the components in an effective manner, the structures team also decided to compartmentalize each group of components. For the avionics team the main challenges lie in designing and programming robust systems that are able to obtain accurate height readings, ensure correct parachute height deployment, as well as work with the fin design to make sure that the fins perform both the roll and braking maneuvers correctly. In order to solve these problems, the avionics team will program a reliable kalman filter. For the fin team, the primary challenge is to make sure that fins are at the right angle for each speed, height, and rotation required as well as finding and testing proper fins. This will involve a significant amount of theoretical calculation and wind-tunnel testing.

4. Avionics

4.1. Avionics Overview

The avionics system of the Krios will have three primary responsibilities: ensuring a safe recovery, activating the braking system, and controlling Roll Induction during the flight ascent. The main components of the Avionics system will be a PerfectFlite StratologgerCF altimeter, a Teensy 3.2 microcontroller, and the various input sensors it connects to. Additionally, the Avionics portion of the rocket will require a reliable, sufficient, and robust power supply. All of this will be ideally housed in the avionics bay located in the upper portion of the Krios (figure 3.3.1).

4.2. Recovery System

The rocket's recovery will be entirely controlled by the PerfectFlite StratologgerCF altimeter. Like most altimeters, the StratologgerCF is capable of measuring apogee of the rocket by detecting the change in air pressure around it. This model has some other features as well and can act as the trigger for parachute deployment through the use of an electric match that sets off a small, controlled black powder charge. Therefore, the StratologgerCF will be independent from the rest of the avionics system and will be used to record the official peak apogee and deploy the chutes at the desired altitudes. The Stratologger will first deploy a small drogue shoot shortly after peak apogee is reached. At somewhere between nine hundred and five hundred feet, the main shoot will be deployed in order to reduce drifting. This value will likely be adjusted over time and tested at preliminary launches. An additional, smaller Perfectflite altimeter will be used in tandem with the Teensy to provide real-time flight data.

4.3. Apogee Targeting System (ATS)

The physical foundations of Krios's braking system is a fin system that exposes horizontal surface area and creates a drag force on the rocket. In order to activate this force, the Teensy microcontroller will be involved heavily. The controller will be taking inputs from both an altimeter and an accelerometer at a sampling rate of twenty samples per second and use these values to predict the peak apogee of the rocket. If the predicted apogee is above our desired height, the rocket will deploy the air braking fins and recalculate the rocket's trajectory until it becomes optimal. The more sensors we can utilize for this calculation, the more accurate it is likely to be with the implementation of a common filter that predicts the rocket's flight trajectory. Two instruments that will definitely be incorporated are a triple-axis accelerometer and the PerfectFlite firefly altimeter.

4.4. Roll Induction

Similar to the ATS braking, the rocket's rolling maneuvers will be activated by rotating servo motors attached to fins that are controlled by the Teensy microcontroller. However, the input data from a gyro sensor will be the primary variable in rolling calculations because it records its measurements in angular velocity (rad/s). This measurement of angular velocity will be used in calculations to ensure that rocket rolls twice and then induces a counter roll. Additionally, the payload camera will confirm the rolling maneuvers of our rocket and allow the team to see what may need improvement.

4.5. Power

The Stratologger altimeter and Teensy microcontroller will most likely be powered by a single 9V disposable battery. These batteries provide a sufficient amount of power, are inexpensive, and are able to withstand the heat and pressure that may accumulate within the rocket tube. Additionally, the mechanical system for the rocket's fins will require a slightly larger power source that will be activated by the microcontroller through the use of an N-Channel power mosfet. In the event that a substantially large amount of power is required, an INR rechargeable battery will be used due to its ability to output a high current while retaining some degree of capacitance.

5. Outreach

5.1. Educational Engagement

One of the most valuable aspects of the 2016-2017 Georgia Tech Team A.R.E.S. mission 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). 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.

5.2. Community Support

In order to gain support from the community, Team A.R.E.S. will pursue advertising opportunities through personal contact with companies and alumni as well as through on-campus events. In addition to this, Team A.R.E.S will manage and produce content for the Team's personal website and Facebook page, and the Team will be featured in a Technique article in the future to increase campus-wide awareness of the Team.

The Team also will hopefully receive partial funding from the Space Grant Consortium, and the Team will be in close contact with Georgia Tech's Ramblin' Rocket Club in order to stimulate collaboration and to enhance the team's knowledge of rocketry and access to rocket engines.

5.3. Educational Outreach

The goal of Georgia Tech's outreach program is to promote interest in the Science, Technology, Engineering, and Mathematics (STEM) fields. Team A.R.E.S. intends to conduct various outreach programs targeting students from all grade levels ranging from Kindergarten to 12th grade. Team A.R.E.S. 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.

5.4. Eagles at GT

Eagles at GT is a club that brings together members of the Boy Scouts of America organization who have earned the highest rank in scouting: the Eagle rank. Within the next semester, Eagles at GT is organizing a STEM merit badge day where they teach STEM-related merit badges; however, the Space Exploration merit badge is not on their list of merit badges offered. Team A.R.E.S.'s goal is to collaborate with Eagles at GT to be able to teach the Space Exploration merit badge, which intricately explores rockets and the physics behind them. The projected amount of Boy Scouts taking this merit badge is 40-70 scouts, and their ages would range from 11 to 17 years old.

5.5. Georgia Tech NSBE

The Georgia Tech chapter of the National Society of Black Engineers (NSBE) is one of the largest student-governed organizations at Georgia Tech. NSBE's mission is to increase the number of culturally responsible black engineers who excel academically, succeed professionally and positively impact the community. Team A.R.E.S. plans to engage the chapter throughout the year, coordinating with them on high-profile engineering outreach-related events to further both organizations' outreach goals.

6. Project Plan

6.1. Timeline

The Krios project is driven by the design deadlines set forth by the NASA SL Program office. These deadlines are listed in Table 6.1.1.

Table 6.1.1

Deadline	***Date***
Proposal	30 SEPT
Web Presence Established	31 OCT
PDR Documentation	31 OCT
PDR Teleconference	2-18 NOV
CDR Documentation	13 JAN
CDR Teleconference	17-31 JAN
FRR Documentation	6 MAR
FRR Teleconference	8-24 MAR
Competition	5-8 APR
PLAR Documentation	24 APR

To meet these deadlines, sufficient planning and foresight must be employed. In addition to the deadlines set by the NASA SL program office, we have set our own preliminary deadlines, which can be found below in Table 6.1.2.

Table 6.1.2

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

6.2. Project Budget

In order to ensure proper funding for the rocket and our outreach activities, the ARES team has reached out to multiple sponsors to receive proper funding. Figure 6.2.1 shows our current budget estimate for this 2016-2017 competition.

Figure 6.2.1: Total Budget

Item	***Cost***
Gas cost	80
Hotel Stay for competition	960
Small Scale Rocket	375
Rocket Materials	750.5
Control Mechanisms	826.15
Outreach	784.91
Avionics	660
Total	4436.56

6.3. 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 we have applied to the Georgia Tech Student Foundation to cover our outreach budget. We are discussing with Orbital ATK to potentially provide a travel stipend to cover our expenses for competition travel. We have also been in contact with a company willing to give us a free go-pro type camera and hope to establish and maintain more extensive relationships with other corporate sponsors. More specifically, we intend to reach out to companies A.R.E.S. members have interned with, local Atlanta companies, and established invested aerospace companies such as Orbital ATK, SpaceX, Lockheed, Boeing, etc. while also reaching out to Georgia Tech Aerospace alumni who could connect us more directly to companies. The Georgia Tech Rambling Rocket Club has generously offered the use of some of their tools, storage space, and facilitating the purchase of rocket motors.

6.4. Sustainability Plan

Recognizing the experience and hands on practice that the NASA SL competition offers, the Georgia Tech Team A.R.E.S. has worked with the institute to offer Student Launch as a vertically integrated project within the VIP program. 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 team A.R.E.S. as a lasting and beneficial experience for students. Financially, we hope to develop a more established relationship with the Georgia Space Grant Consortium for consistent funding.

7. Appendix A

HIGH POWER ROCKET SAFETY CODE

EFFECTIVE AUGUST 2012

(NAR. "High Power Rocket Safety CodeEffective August 2012." ***National Association of Rocketry***. N.p., Aug. 2012. Web. 26 Sept. 2016.)

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-s ec, 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.

_Table 7.1: Minimum Distance Table

Installed Total Impulse (Newton-Seconds)	Equivalent High Power Motor Type	Minimum Diameter of Cleared Area (ft.)	Minimum Personnel Distance (ft.)	Minimum Personnel Distance (Complex Rocket) (ft.)
0 - 320.00	H or smaller	50	100	200
320.01 - 640.00	I	50	100	200
640.01 - 1,280.00	J	50	100	200

1,280.01 - 2,560.00	K	75	200	300
2,560.01 - 5,120.00	L	100	300	500
5,120.01 - 10,240.00	M	125	500	1000
10,240.01 - 20,480.00	N	125	1000	1500
20,480.01 - 40,960.00	O	125	1500	2000