By:

Georgia Tech A.R.E.S.

NASA Student Launch 2017

Project Name: KRIOS

October 30, 2016

Georgia Institute of Technology
School of Aerospace Engineering
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1. Introduction

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
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Safety Officer	Vikas Molleti
Team Advisor	Dr. Eric Feron
Team Advisor e-mail	eric.feron@aerospace.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

Table 1.1.1: Team Summary

1.2. Work Breakdown Structure

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.

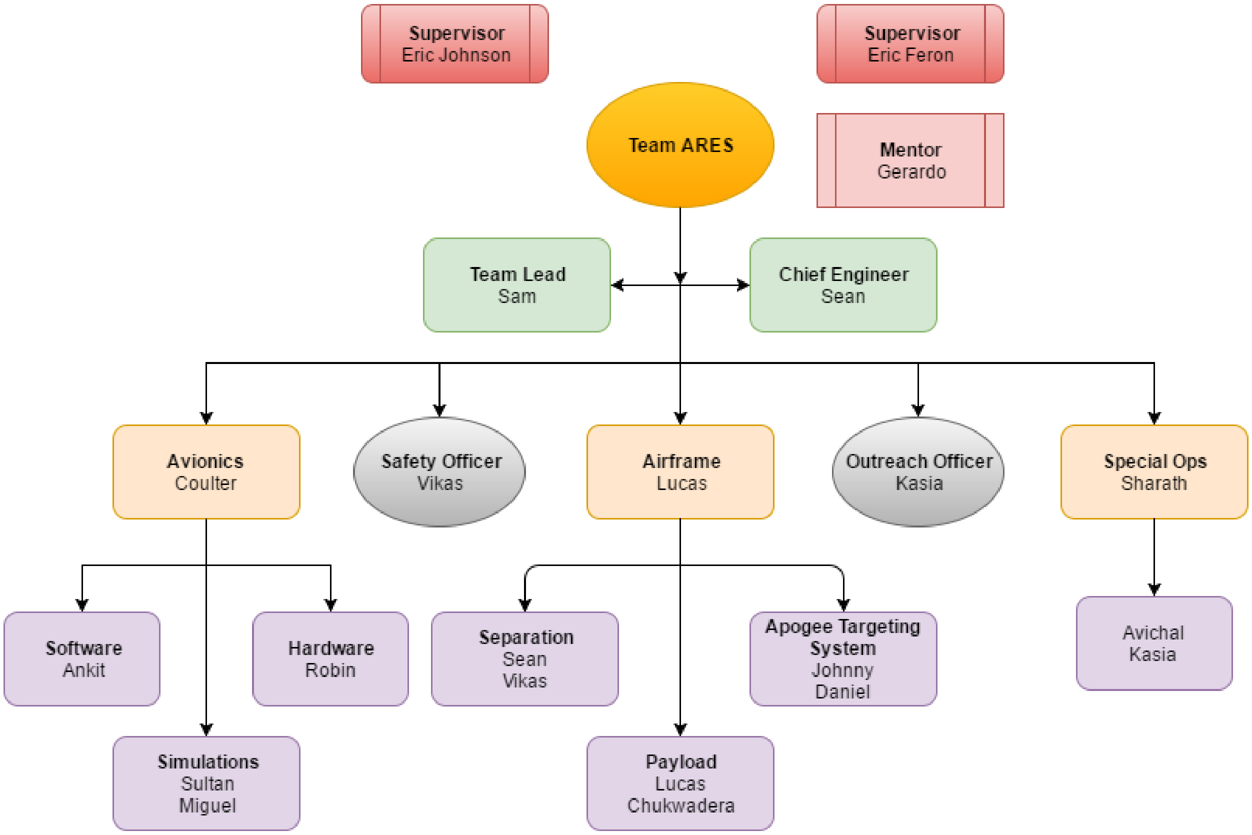


Figure 1.2.1: Team Structure Chart

1.3. Launch Vehicle Summary

The Krios Launch Vehicle is currently dimensioned to be 79 inches in length, with a G12 fiberglass tube of outer diameter 5.5 inches. Having taken all systems into consideration, the rocket is projected to weigh 28 lbs. The launch vehicle's weight includes a 30% mass margin to account for any unexpected masses. Krios is designed to house its StrataloggerCFs, Teensy Microcontroller, Gyro/Accelerometer sensors, and 9V batteries in the avionics bay, which is located in the middle section. In addition to this, the body is comprised of a 6 in long payload section attached to the nosecone, as well as an isolated GPS compartment within the nosecone itself. An Aerotech L1150R rocket motor has been selected to provide the thrust to potentially bring the rocket to an apogee of 5600 ft. The Apogee Targeting System (ATS) and roll-inducing mechanisms will be responsible for creating the drag necessary to achieve an apogee of 5280 ft as outlined in the Student Handbook. Upon reaching apogee, a 25 in drogue parachute will deploy from a compartment between the booster and avionics sections. A main parachute with an 80 in diameter will be deployed when the vehicle falls below 750 ft AGL, to decrease the vertical velocity enough to ensure that the kinetic energy of each independent section of the rocket remains well below 75 ft-lbf.

1.4. Payload Summary:

Krios will have a small Payload section attached to the nosecone that will contain the equipment needed to perform an acoustic experiment by emitting a sound wave from one end of the Payload section to the other. The goal of the experiment is to measure the Sound Pressure Level (SPL) recorded at different altitudes to analyze how changes in air density due to altitude inhibit or enhance the ability of sound waves to travel through space.

1.5. Technical Changes since Proposal

Dimensions

- Body Tube diameter increased from 5 in to 5.5 in due to discovery of sparse resources online to support 5 in frames.
- Coupler lengths decreased from 7 in to 6 in to increase spatial efficiency while retaining necessary structural rigidity to hold sections of rocket together during flight.
- 30% mass margin included to account for mass of adhesives and other potentially unaccounted-for hardware

Motor

- Cesaroni motors no longer considered (no L-class motors being manufactured)
- Aerotech L1150-P motor selected, with L850W-0 in consideration

Flight Control Mechanisms

- Roll-inducing mechanism changed from angling the entire fin surface to using a servo-driven aileron on each fin
- Apogee Targeting System (ATS) has been designed and implemented in the rocket CAD

Materials

- Bulkhead material changed to plywood, was fiberglass

1.6. Payload Changes since Proposal

- Sensors havebeen replaced by a 6 Degrees of Freedom IMU Board
- Firefly Altimeter will be replaced by another Stratologger for dual redundancy to ensure the parachutes are deployed
- Disposable 9V batteries will be the primary form of power

1.7. Project Plan changes

- Outreach after school program to be done at Peachtree Charter Middle School
- Georgia Space Grant Consortium has allocated $2000-$3000 to our project
- Budget for rocket construction fleshed out and expanded accordingly
- Subscale Rocket and Test Flight costs have been incorporated into the budget
- CCTV Camera World is an official sponsor and providing a Go-Pro type camera
- November 19th is secured as our Subscale flight date
- Timeline for October and November has been detailed and laid out in a Gantt Chart

2. Project KRIOS Overview

2.1. Mission Statement

Our mission is to successfully develop an experimental vehicle that integrates multiple disciplines and subsystems in order to fulfill the mission requirements stated in the following section. Krios must not only achieve a precise altitude of 5280 ft, but also perform a controlled roll and gather flight data throughout the full length of the flight. The launch vehicle must successfully launch, reach the correct apogee, deploy the recovery system at the correct altitude, and land without any structural damage. During the ascent of the vehicle, it must actively target the desired altitude using electronic guidance in order to attain the highest level of precision possible. The project also requires an extensive phase of design, manufacturing and testing that will be carried out with the highest safety standards and most efficient procedures as reasonably possible. Every subsystem must be tested and must have proven efficacy before the launch of the vehicle in order to ensure the safety and full functionality of the vehicle.

2.2. Mission Objectives and Mission Success Criteria

Requirement	Design Feature	Verification	Success Criteria
Vehicle altimeter will report an apogee altitude of most nearly 5,280 feet AGL.	Low-mounted electric-controlled fins will be extended and retracted in reaction to altimeter readings to control drag and limit altitude.	Gathering data post-launch from on-board altimeters	ATS directs launch vehicle to accuracy in apogee of 2%
Launch vehicle will be designed to be recoverable and reusable within the day of initial launch.	Vehicle will be constructed of fiberglass to resist fractures and ensure stability.	By inspecting every element of the launch vehicle post recovery	No visible structural damage, and fully functioning systems
Vehicle will require minimal assembly/disassembly time and effort	Modular/flexible assembly construction	Conduct evaluation of time required to assemble/disassemble key components of vehicle	Ability to access components without compromising rocket in any way
The vehicle will complete two rolls and then produce a counter-roll	The roll system will deploy post motor burnout by actuating flaps on the fins to create asymmetrical drag and generate roll.	Gathering data post-launch from the onboard gyroscope and onboard cameras	The roll system completes at least two rolls and produces a counter-roll between time of motor burnout and time at apogee.
The launch vehicle shall have a maximum of four (4) independent sections.	Three (3) sections include: payload/nosecone, avionics, and booster	Observe separated sections during descent	Ensure vehicle separates into 3 sections, each connected via shock cord
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 using one L-class motor	Control installation process	Ensure installation of one single stage motor
The launch vehicle shall stage the deployment of its recovery devices, where a drogue parachute is deployed at apogee and a main parachute is deployed at a much lower altitude.	All recovery systems will be dual-redundant to ensure deployment at a safe altitude	Observe flight data to check for separation and parachute deployment at correct altitudes	Drogue chute should deploy at apogee, and main chute at 750 ft AGL

At landing, the launch vehicle shall have a maximum kinetic energy of 75 ft-lbf.	Main parachute selected by deriving Kinetic Energy for heaviest independent section	Evaluate post-recovery altimeter data to check impact velocity	Velocity before impact < 20 ft/s
The recovery system will contain redundant altimeters, each with their own power supply and dedicated arming switch located on the exterior of the rocket airframe	Install a master key-switch at the rear of the avionics bay to close all circuits simultaneously	Analyze altimeter data post-launch	Ensure all redundant systems are powered and capable
Each detachable section of the vehicle and payload must contain an electronic tracking device and continue transmission to the ground throughout flight and landing.	Will implement and test a GPS system with proper shielding and protection to ensure vehicle tracking	Track each section of vehicle in-flight	Each section of vehicle should sync its position to computer
The vehicle will complete a science experiment	A microphone will be used to analyze how the effects of pressure on the sound signal generated by the altimeter	Gathering data post-launch from the onboard microphones	The relationship between air pressure, height, and their effects on the sound signal is definitively shown.

3. Launch Vehicle

3.1. Overview

Krios (Team A.R.E.S' rocket) is 79 in. in length and has an outside diameter of 5.5in. The rocket is comprised of 3 independent sections; these include the Booster Section, Avionics Bay, and Nosecone Section. The Booster Section houses the motor assembly, roll-inducing mechanisms, and Apogee Targeting System (ATS), in order of location from the bottom end of the rocket. The motor assembly contains the propellant, motor casing, cardboard housing tube, centering rings, and thrust plate necessary to ensure stability and safety of the rocket during ascent. Above the thrust plate there is an additional 12 inches of interior space where the ATS and roll-inducing mechanisms are rigidly secured to the fiberglass tubing. Surrounding the Booster Section are four fiberglass fins. These fins are sized according to the dimensions outlined in Table 3.1.1 below. Attached to each fin is an aileron that can be controlled by the roll-inducing system contained in the Booster Section. The fin sizing process, as well as the roll-inducing mechanism, are explained in greater detail in their respective PDR sections.

Section	Value (in)
Overall Length	79.00
Nosecone	27.00
Booster Section	32.00
Avionics Bay	16.75
Rocket Diameter	5.50
Fin Height	8.50
Fin Root Chord	10.00
Fin Tip Chord	4.00

Table 3.1.1: External Feature Dimensions

Section	Value (in)
Payload Compartment	6.00
ATS Compartment	4.00
Roll Mechanism	4.00
Coupler Length	6.00
Bulkhead Thickness	0.5 / 0.25
Centering Ring Thickness	0.25
Motor Casing Length	20.86
Motor Casing Diameter	2.95

Table 3.1.2 : Internal Feature Dimensions

3.2. Apogee Targeting System (ATS)

3.2.1. System Overview

The Apogee Targeting System (ATS) is a system used to induce a controlled decrease in the apogee of the rocket to the target of 5280 ft. The system uses four tabs which extend out from the body of the rocket on hinges in order to increase the drag on the rocket. This controlled drag will allow for a precise decrease in the apogee to bring the rocket to 5280 ft.

3.2.2. Alternatives and Pros/Cons of Alternatives

Four conceptual designs were created for achieving the tasks of the ATS. The first is the Piston ATS seen in Figure 3.2.1 It features a centralized piston driven system connected via arms and hinges to the tabs as seen. This design would have fast actuation and its centralized design would allow it to make rapid, real time adjustments to the apogee. All four tabs would be actuated by a single solenoid. As a consequence, this solenoid would be quite expensive, have a high power draw, and be very heavy in order to produce the forces necessary to activate the system.

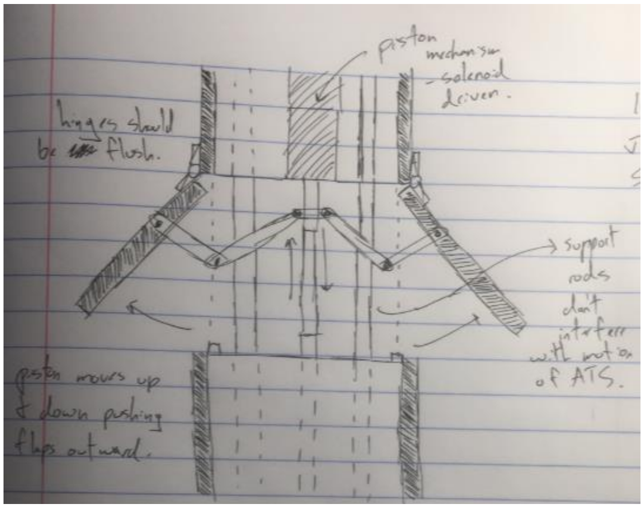


Figure 3.2.1: Piston ATS

The Lead Screw ATS, shown in Figure 3.2.2, uses a motor driven lead screw to adjust the position of a nut which determines the position of the tabs. This design features a minimized and simple part count. The use of the lead screw allows the flaps to be precisely positioned. The drawbacks of this design include very slow actuation, high required torque for the motor, and high friction in the lead screw-to-nut union which could cause seizure.

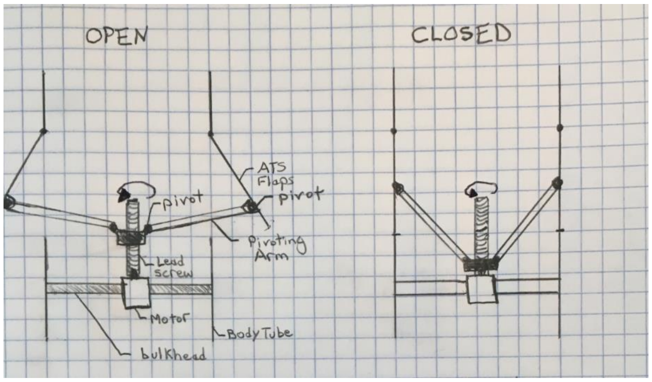


Figure 3.2.2: Lead Screw ATS

The Single Servo ATS, seen in Figure 3.2.3, is a centralized horizontal design powered by a single servo motor. From the closed position, the servo would rotate 90 degrees through opening and then closing the tabs. Then, it would rotate back through those 90 degrees to its home position for a whole cycle. This design uses less vertical space than the others and synchronizes all of the tab extensions. The greatest drawback to this design is that the servo needed to power this system would draw too much power, be too heavy, and be much too expensive.

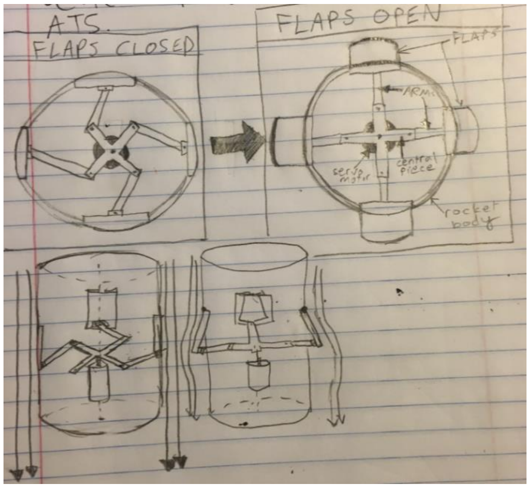


Figure 3.2.3: Single Servo ATS

The fourth and final design is the Quad Servo ATS, shown in Figure 3.2.4. This design uses four Tower Pro MG995 servo motors to rotate the metal rectangular arms and extend the tabs. Since there is a single servo per tab, weaker and less expensive servos can be used. This design is compact, takes up less vertical space, and allows for quick iteration. This design requires that the servos be synchronized though, so that the flaps all open at the same time and to the same length so as to not affect the trajectory of the rocket. The pros and cons of these different systems were considered and compiled in Table 3.2.1.

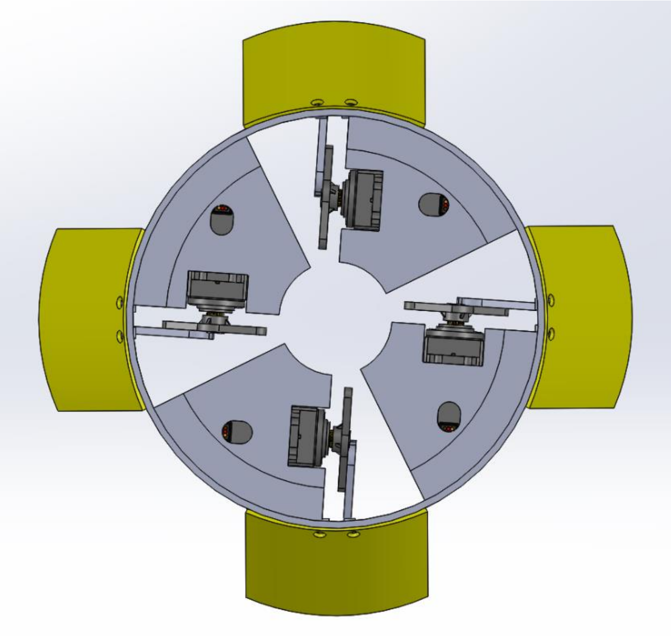


Figure 3.2.4: Quad Servo ATS

Conceptual Design	Pros	Cons
Piston ATS	Fast Actuation	Solenoid would draw a lot of power to hold in open position
	Single actuator	Very expensive actuator
		High power consumption
		Solenoid torque is variable
		Significant use of vertical space
Lead Screw ATS	Motor Driven	Slow
	Single actuator	Slower to actuate (due to lead screw)
	Less expensive actuator	High friction
	Allows for precise control of ATS position	Possibility of seizure
Single Servo ATS	Minimizes part count	High force on linkages
	Fast Actuation	Very expensive actuator
	Single actuator	High power consumption
	Centralized/ axial design	High friction at joints
	Uses less vertical space	Less control
	Combination of the last two years of designs and can build on prior	Need a powerful/strong servo in order to hold all 4 flaps

	experience	
Quad Servo ATS	Can use weaker servos	Must synchronize all four servos
	Less moving parts per flap	Significant friction between metal arm and tab
	Compact and sturdy	
	Allows for quick iteration	

Table 3.2.1: Alternative Design Evaluation

3.2.3. ATS Description and Component Description

The Quad Servo ATS was chosen as the current final design for the system. It consists of four Tower Pro MG995 servo motors, each individually powered by one 9V battery. The servos will each rotate a metal rectangular arm when needed to extend the 3D printed tabs (Figure 3.2.5) and increase drag, thereby decreasing the rocket’s apogee. The rotation of the servos will be determined by a microcontroller and the software’s control algorithm. The arms’ rotations will push the ATS tabs to a maximum extension of forty-five degrees about their hinges as seen in Figure 3.2.6.

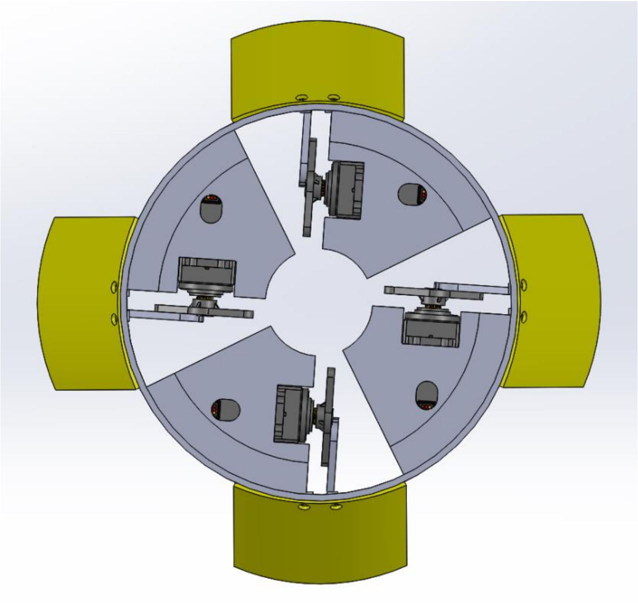


Figure 3.2.5: Quad Servo ATS Top View

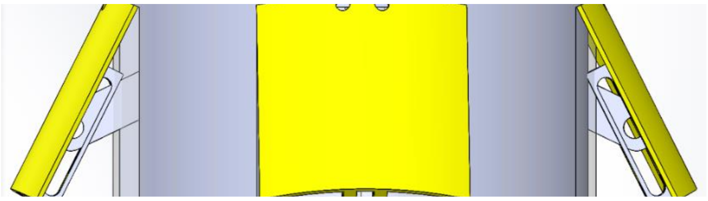


Figure 3.2.6: Quad Servo ATS Side View

3.2.4. ATS Estimated Masses

Part	Material	Mass (g)	Quantity
Alignment Piece	ABS	27.21	1
TowerPro MG-995 Servo	-	32.16	4
Servo Arm	Polyethylene	2.23	4
Servo Mount	ABS	74.87	4
ATS Fuselage	Fiberglass	258.70	1
ATS Fin	Fiberglass	26.62	4
ATS Total Weight	-	873.43	1

3.2.5. ATS Dimensional Drawings

Below are the dimensional drawings of the ATS fin (Figure 3.2.7) and the internal mount for each servo for the ATS system (Figure 3.2.8)

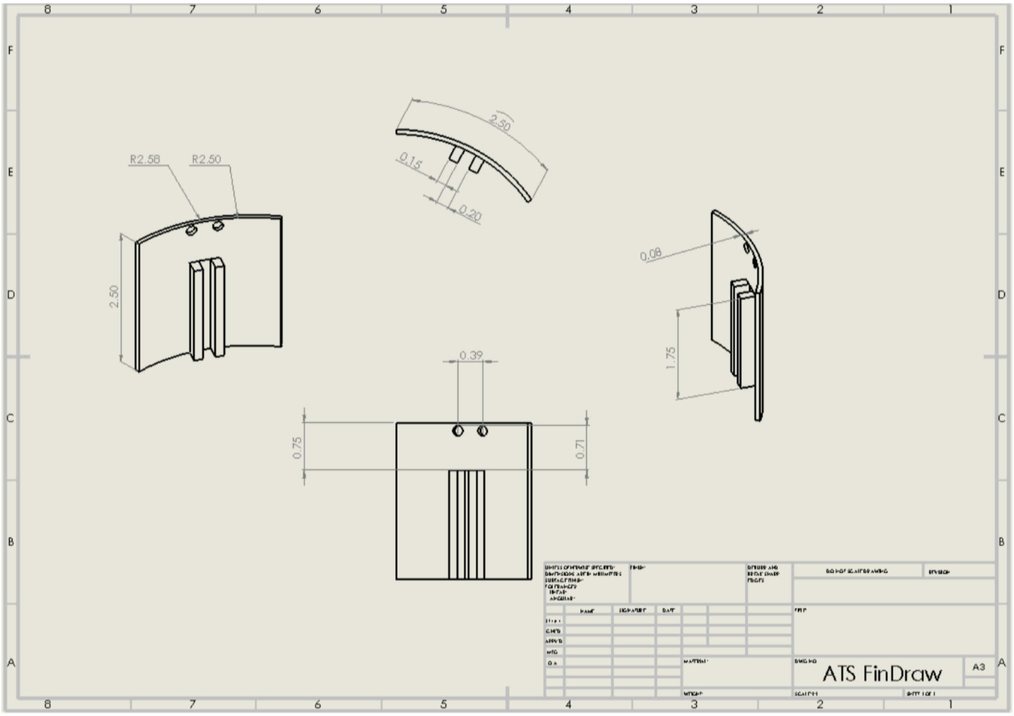


Figure 3.2.7: ATS Fin

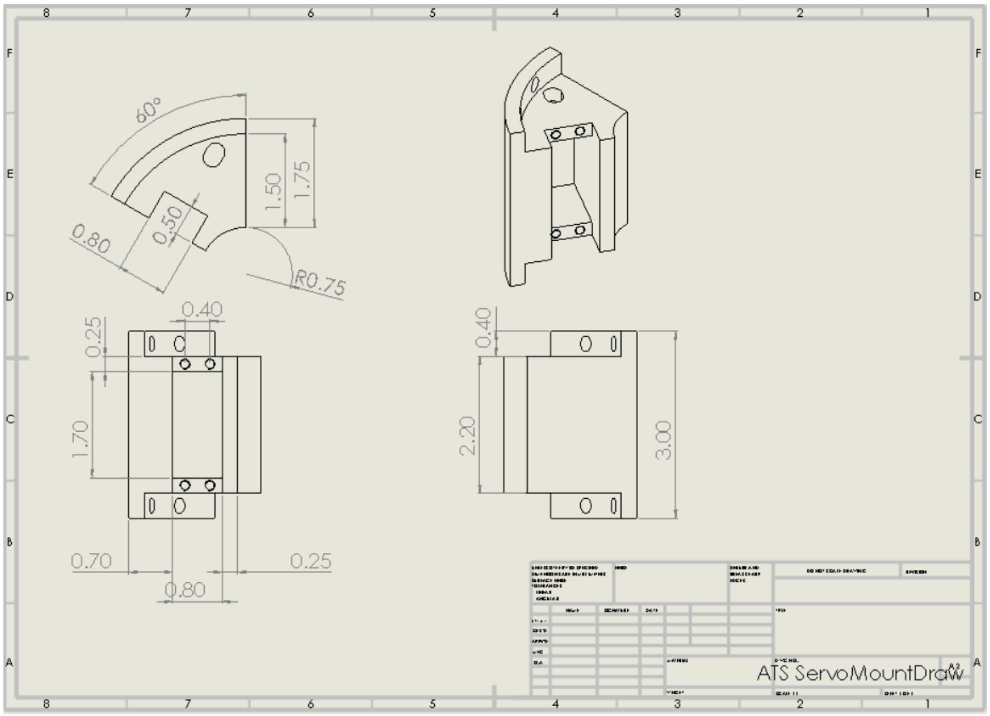


Figure 3.2.8: Servo Mount

3.2.6. ATS Calculations

Based on the design criteria for the ATS, we were able to successfully convert the SolidWorks model to a working mechanical system integrated into the booster section. Components were chosen based on their ability to satisfy the basic force requirements and their feasibility of integration within the 5.5 in body tube. The servo motors were selected based on their holding torque and RPM to withstand the calculated theoretical force on the tabs during flight. Based on our calculations, the servo needs to be able to withstand a torque of 2.90 kg-cm at maximum angle of deployment and at maximum velocity. The servos that we selected were rated at 10 kg-cm, and should be able to withstand applied loads within reasonable deviation. Our sub-scale launch will be used to determine the effectiveness of the launch vehicle design and to give us a base value for the actual launch vehicle apogee.

We determined the necessary strength of the servos by first calculating the force imposed by drag onto the flaps of the ATS at the launch vehicle's maximum velocity, which was found to be roughly 686 ft/s based on OpenRocket simulations. We know the area of the flap is 6 in^2, the air density in Huntsville, AL on the day of the launch is predicted to be roughly 2.3769e-3 slugs/ft^3, and the maximum angle between the launch vehicle and the flap is 45 deg. Combining the formulas for pressure due to wind [1] and force due to pressure [2], while taking the angle of maximum actuation into account, gives us a formula for the drag due to the wind on one of the flaps [3].

$$P = \rho V^2 \text{ [1]}$$

$$P = A \cdot F \text{ [2]}$$

$$F_1 = \rho V^2 A \sin(45) \text{ [3]}$$

The drag imposed by wind at the launch vehicle's maximum velocity was calculated to be roughly 32.96 lbs. With that in mind, we calculated how strong of a force the servo would need to provide to oppose this force by solving for the moment about the hinge (point A) that attaches the ATS fin to the launch vehicle. The length of the servo arm at full actuation is 1.76 in. We denoted the force due to the wind as F_1, the length of the ATS fin (2.5 in.) as L and the pushing force required by the servo as F_2. F_2 was found to be 38.84 lbs. [4], so each servo needs to exert an outward force of at least 38.84 lbs. to successfully manipulate the velocity of the launch vehicle starting immediately after burnout.

$$M_A = F_1(\frac{L}{2}) - 1.76F_2 sin(45) \text{ [4]}$$

Finally, we calculated how much torque each servo would need to provide. We found this by summing the moments about the spinning shaft of the servo, which we denoted as point B. Each servo turns roughly 51.32 deg to actuate the ATS fins to 45 deg. We solved for the servo's moment, X, using formula 5.

$$M_B = X - F_2 A cos(51.32) \text{ [5]}$$

Solving for X equates to 2.52lbs-in or 2.9kg-cm, so each servo needs to provide at least 2.9 kg-cm of torque.

3.3. Recovery System

3.3.1. Introduction

The recovery system will consist of one drogue and one main parachute of 24 in and 80 in respectively. A GPS system is used in order to locate the rocket at the landing site. First, a drogue chute will deploy at apogee to slow the rocket's descent and stabilize its trajectory, limiting the rocket's horizontal drift due to air currents. The drogue chute will be housed beneath the avionics bay as shown in Figure 3.3.1. Once the rocket descends to 750 ft, the main parachute will deploy, slowing the rocket to a safe landing speed and allowing it to remain intact upon impact with the ground. The main parachute will be housed above the avionics bay.

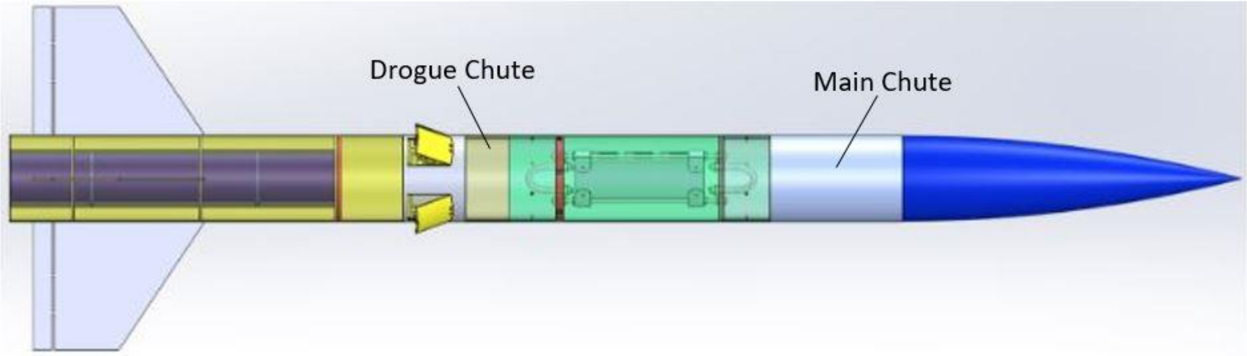


Figure 3.3.1 Parachute Locations

3.3.2 Parachute Description

Both parachutes will be made of rip-stop nylon, to minimize weight while having a strong material resistant to fatigue and tear. Each parachute will be attached to the rocket via shock cords attached to internal bulkheads, which in turn will be secured inside the rocket with a combination of screws and high-quality epoxy glue. Both parachutes will deploy via an explosive black powder charge which will pressurize their chambers, breaking the shear pins and releasing the parachutes. The parachutes will be protected from the explosion with insulative cloth, which will also reduce the risk of premature detonation of the black powder due to static charge on the parachutes.

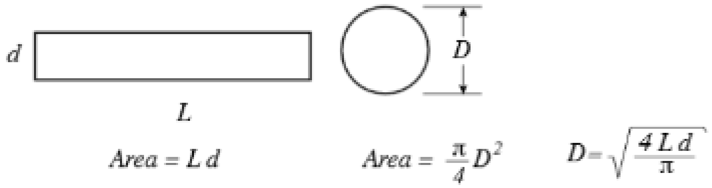
3.3.3. Design Alternatives

The drogue chute and main chute combination design is a standard and well-tested model for high-power rocketry. The only alternative designs featured parachutes of different sizes, and to select the proper sized parachute many OpenRocket simulations were performed. The maximum allowed kinetic energy of any rocket component upon landing is 75 ft-lbf, as stipulated in the competition rules. In order to calculate the maximum landing speed, each section of the rocket had its projected mass estimated. The heaviest section, the booster section, then had its kinetic energy at landing set equal to the maximum allowed energy of landing, allowing the maximum landing velocity (v) to be calculated.

$$(mv^2)/2 = 75\, ft * lbf$$

The result was a maximum landing speed of 20.04 ft/sec. Using OpenRocket, a variety of main parachutes of diameters between 72-85” were simulated, and it was determined that an 80” diameter main parachute would be optimal and land comfortably below the maximum allowable speed, at 13.75 ft/sec. If the main parachute was any larger, the rocket would drift further from the launch site and be heavier than necessary. If it were any smaller, it would run the risk of being damaged upon landing and failing to fulfill the mission requirement of reusability.

3.3.4. Drogue Parachute Packaging Dimensions



Using the above formulas, it was calculated for the drogue parachute to have a diameter of 22.3” if the diameter of the body tube is 5.5”. Even though the calculations result in a parachute of 22.3”, a 24” chute will be used due to ease of access. A larger sized drogue parachute will also help account for weather conditions.

3.3.5. Redundancy

If the recovery system fails to deploy, it will not only destroy the rocket on impact but also present a hazardous situation for personnel and material on the ground. Consequently, redundancy is built into the system. Rather than rely on one main altimeter, a backup altimeter will be included in the system to detonate the explosive charges in the event the main altimeter fails. Using two altimeters will ensure the parachutes deploy and prevent the rocket from crash landing.

3.4. Roll Control System

3.4.1. Roll Description

The roll maneuver of the rocket will occur between the time that burnout occurs and the time that the rocket reaches its apogee. The roll will consist of at least two 360 degree turns, and then the rocket will experience a counter-moment in order to stop rolling. It will then roll back to its initial angular speed prior to the motor burnout. The rolls and counter-rolls will be induced when the ailerons on the fins are angled a predetermined amount; this amount will be determined after testing and analysis.

3.4.2. Roll System: Explanations and Alternatives

The main issues with our chosen design were determining at which angle to actuate the fin, determining the area of the flap, figuring out how long the fin should be actuated, and seeing if the servos themselves could handle the force on the fins. Using a predetermined angle of 5 degrees and a predetermined area of the flap, testing allowed the team to see if the chosen servo could handle the drag force. Testing also enabled the team to determine the length of time for which the fins need to be actuated. The calculations are listed below (Units used in the calculation below are ft, sec, and radians):

The Lift Coefficient for a flat plate is approximately $2\pi\alpha$ where alpha is in radians

$$Cl \approx 2\pi\alpha$$

Below is the equation for lift:

$$L = Cl \cdot \rho \cdot v^2 \cdot A \cdot .5$$

$$L = 2\pi\alpha \cdot \rho \cdot v^2 \cdot A \cdot .5$$

$$\rho_{avg} \approx \frac{2.2743 + 2.0174}{2} \cdot 10^{-3}$$

$$A = 1.843188\ in^2 = .0127999\ ft^2$$

$$L = 2\pi\alpha \cdot 2.14585 \times 10^{-3} \cdot v^2 \cdot .0127999 \cdot .5$$

$$L = 8.62891866428 \times 10^{-5} \cdot \alpha v^2$$

$$v_{avgork} = 287.9031\ ft/sec$$

$$L = 7.153741 \cdot \alpha$$

Assuming the rocket can be simplified as a disc, we then substitute into the following equation to see how angular velocity relates to the torque on the rocket:

$$.5I\omega^2 = \tau\theta$$

$$.5I\omega^2 = \tau\frac{\omega}{2}t$$

$$\omega = \frac{t \cdot \tau}{.5MR^2} = 71.73965t\alpha \cdot 4$$

$$\frac{\theta}{t} = 71.73965t\alpha \cdot 4$$

$$\theta = 71.73965t^2\alpha \cdot 4$$

$$4\pi = 71.73965t^2\alpha \cdot 4$$

Angle of Attack for the fin was predetermined at 5 degrees or .0872665 rad

$$\frac{\pi}{.0872665 * 71.73\ldots} = t^2$$

$$t = .708\ secs$$

This calculation for 2 spins is further corroborated by the OpenRocket Program which gives 3.2337 rolls in .71 seconds when starting with the flaps at an initial angle of attack of 5 degrees. Team ARES's rocket will as such have four fins, each with a movable flap at the rear, to initiate rolls. Given the calculations, the flaps will be deployed for .71 seconds at an angle of 5 degrees to roll at least 2 times. The torque experienced by each individual servo, approximately 30 oz-in, is also well below the 59.7 oz-in max that each servo can handle. This torque was derived from the OpenRocket rotational velocity and the calculations above. In order to perform the counter-roll, the rocket will reverse the direction of the fins until the roll of the rocket matches the final roll of the rocket post motor-burnout. The HS-5085MG Servo will be used, which should be adequate based on the calculations for the necessary torque to directly drive the flap attached to the shaft.

The two main alternatives considered when initially designing the roll system were including a pneumatic system or inserting a flywheel. The pneumatic system would have released pressurized gas out of the rocket in order to induce a spin, but the team decided against it due to the amount of possible errors, additional weight, and safety issues of the complicated system. The flywheel was not chosen because the flywheels that were available to the team for purchase were either built for much larger craft or were too massive for use.

Calculations for Flywheel:

$$(3.134337) * (720\ deg/s)^2 = (1/2) * (Mass\ of\ Flywheel) * (radius^2) * \omega^2$$

$$\omega flywheel = \sqrt{\frac{(3.134337 * 720^2)}{(.5 * 2kg * 5cm * 5cm)}}$$

$$\omega flywheel = \sqrt{\frac{(3.134337 * 720^2)}{(.5 * 2 * .05 * .05)}}\, deg/s$$

$$\omega = 25493.8\ deg/s = 70 * 60 = 4200\ rpm$$

As seen in the calculations above, a 2 Kg. mass flywheel would be necessary to generate enough moment at a low enough rpm that the motor would be able to accelerate in both directions in the short duration of the remaining flight time after motor burnout. This mass would account for nearly 40% of the rocket mass, which is not feasible, especially because this could introduce gyroscopic precession into the system if the rocket is not perfectly vertical at all times. Additionally, there was not much data available for flywheel use in hobby sized craft and rough calculations suggested that a flywheel would not be able to accelerate in one direction and then reverse directions fast enough to meet the post motor burnout requirements.

3.4.3. Roll Dimensional Drawings and Component Description

The roll system consists of four fins, four servos, and 4 control surfaces under the four main fins, which are shown in Figures 3.4.1, 3.4.2, and 3.4.3 below, with dimensions given in Table 3.4.1. The servo that will be used for this project is the HS-5085MG Servo; it has 60 oz.-in. of torque and requires 4.8-6.0 volts for operation. The servos will be directly modulating a control surface next to the main fins. This control surface will redirect the flow of air in order to generate a moment about the center axis of the rocket. The servos will be modulated in real time using a programmable Teensy microcontroller and instrumentation system. This system will monitor the gyroscopic and acceleration sensors in order to determine motor burnout and roll rate, and it will in turn allow for the rocket to achieve two rotations and stabilization. The control surfaces be attached to a rod in front of the surface, and this rod will be directly driven by the servo motor. The rod will be secured by installing it through rings extending from the fin above the control surface. This is done to ensure the control surface will be stable, while preventing any excessive moments on the servo. The servo will be secured to the inner tube and centering rings of the rocket by a 3-D printed housing, allowing easy access by sliding out the inner tube from the rocket.

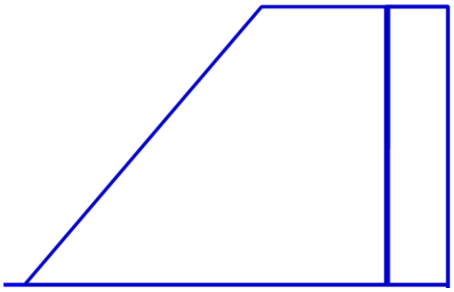


Figure 3.4.1: Fin and Flap

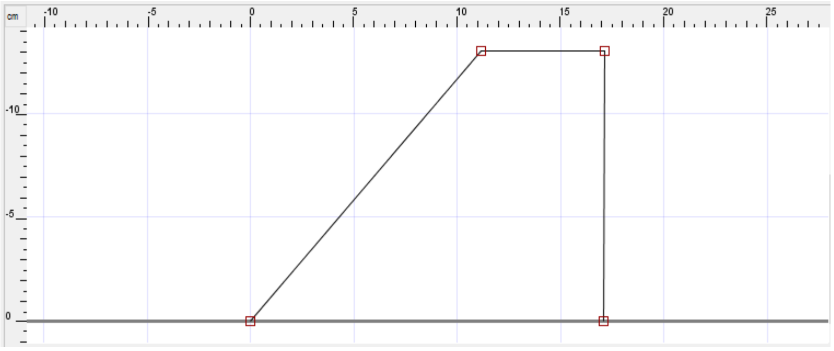


Figure 3.4.2. OpenRocket Fin Diagram (cm)

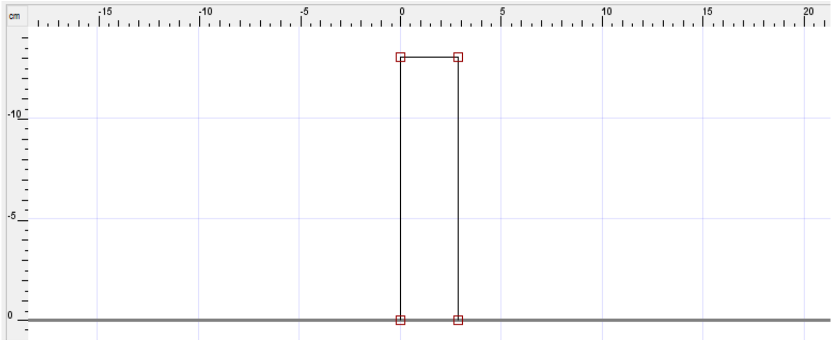


Figure 3.4.3. OpenRocket Flap Diagram (cm)

Dimension	Length (in)
Fin root chord	7.87
Fin tip chord (including aileron)	3.50
Fin semispan	6.56
Length of fin mid-chord line	5.55
Distance between fin root leading edge and fin tip leading edge parallel to body	4.37
Aileron chord - the bottom portion of fin that is capable of actuation	1.14

Table 3.4.1: Fin Dimensions

3.5. Launch Vehicle Performance Analysis

Using the OpenRocket software, Team A.R.E.S created a model of Krios that accurately represents the dimensions and mass distributions of the rocket and its subsystems. Accuracy in this process was achieved by coordinating with the sub-teams responsible for the different subsystems and having each one verify its system’s size, mass, and location along the frame of the rocket. These included the Avionics Bay, ATS system, Roll-Inducing Mechanism, Motor Assembly, and Payload sections.

After finalizing the completed model, the team used it to run simulations and generate plots reflecting different performance aspects of the vehicle. The following sections will display the results and analysis of Stability, Propulsion, Motion, Recovery, and Roll during flight.

3.5.1. Stability, CP, and CG

The student handbook for the 2016/2017 Student Launch competition provides a requirement that the rocket must have a Stability Margin of at least 2 cal when it clears the launch rod. Our CP, CG, and Stability Margin values were all obtained using the OpenRocket software, after having created an accurate model of the rocket, Krios, and its mass distribution. Krios has a 5.5 in outer diameter, which means that a stability margin of 1 cal would mean that the distance between the CP and CG is 1 times the diameter, or 5.5 in. After creating the model, the airframe and special operations teams collaborated to decide on a fin sizing that would move the center of pressure at least 11 in away from the CG, which is defined by the placement of masses along the body of the rocket.

The final design has the CP at 64.275 in and the CG at 52.492 in from the tip of the nosecone, putting the difference between the two at 11.783 in. This distance, when divided by the diameter, give a stability margin of 2.14 cal.

As a final check, team ARES used the OpenRocket software to generate a simulation of the Stability Margin, CP, and CG versus time as Krios advanced along its flight path (Figure 3.5.1). By extracting the data computed, it was found that, using a launch rail of 8 ft, Krios would have a stability margin of 2.0891 cal at the moment it cleared the launch rod, thus proving its compliance with the requirements set forth in the student handbook (Table 3.5.1). The following page calculates the CP manually using the Barrowman equations.

Field	Value
Time to Rod Clearance	0.29433 s
Center of Pressure (CP)	64.535 in
Center of Gravity (CG)	52.915 in

Stability Margin Caliber	2.0891 cal

Table 3.5.1 Extracted Data at Rod Clearance

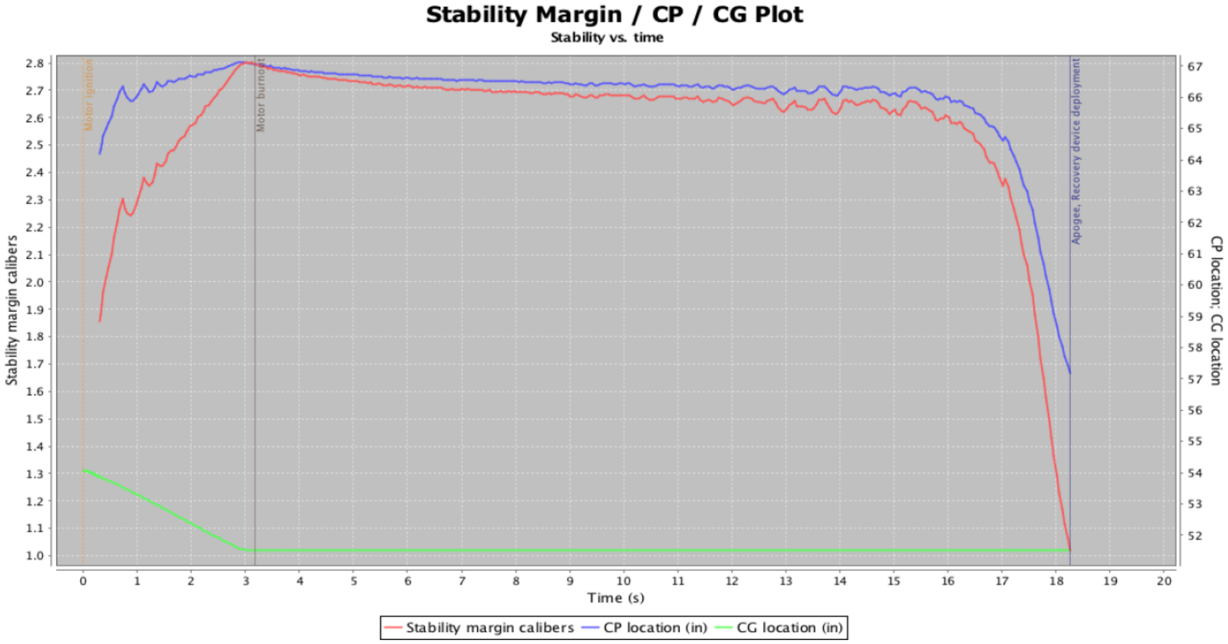
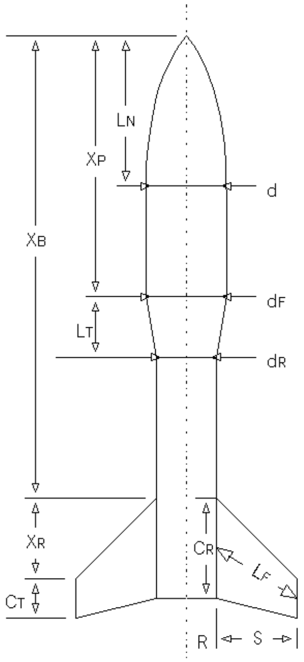


Figure 3.5.1: Stability Simulations

Barrowman Equations for Stability



L_N	=	length of nose
d	=	diameter at base of nose
d_F	=	diameter at front of transition
d_R	=	diameter at rear of transition
L_T	=	length of transition
X_P	=	distance from tip of nose to front of transition
C_R	=	fin root chord
C_T	=	fin tip chord
S	=	fin semispan
L_F	=	length of fin mid-chord line
R	=	radius of body at aft end
X_R	=	distance between fin root leading edge and fin tip leading edge parallel to body
X_B	=	distance from nose tip to fin root chord leading edge
N	=	number of fins

Nosecone Terms

For Ogive: $X_N = 0.466 L_N$

Equation for CP

$$\bar{X} = \frac{(C_N)_N X_N + (C_N)_T X_T + (C_N)_F X_F}{(C_N)_R}$$

Fin Terms

$$(C_N)_F = \left[1 + \frac{R}{S+R}\right]\left[\frac{4N\left(\frac{S}{d}\right)^2}{1 + \sqrt{1 + \left(\frac{2L_F}{C_R + C_T}\right)^2}}\right]$$

$$X_F = X_B + \frac{X_R}{3}\frac{(C_R + 2C_T)}{(C_R + C_T)} + \frac{1}{6}\left[(C_R + C_T) - \frac{(C_R C_T)}{(C_R + C_T)}\right]$$

Conical Transition Terms

$$(C_N)_T = 2\left[\left(\frac{d_R}{d}\right)^2 - \left(\frac{d_F}{d}\right)^2\right]$$

$$X_T = X_P + \frac{L_T}{3}\left[1 + \frac{1 - \frac{d_F}{d_R}}{1 - \left(\frac{d_F}{d_R}\right)^2}\right]$$

Variable		Value
L_N	=	21.75 in
d	=	5.5 in
d_F	=	5.5 in
d_R	=	5.5 in
L_T	=	0 in
X_P	=	0 in
C_R	=	7.87 in
C_T	=	3.50 in
S	=	5.12 in
L_F	=	5.55 in
R	=	2.25 in
X_R	=	4.37 in
X_B	=	66.5 in
N	=	4 fins

Explanation of Results:

Using the dimensions assigned to the rocket, it is possible to fill out the table of coefficients to use in the equations.

After solving, the Barrowman equations estimate a CP of **64.91 in** from the tip of the nosecone. If we compare this estimate to the CP predicted by OpenRocket, given identical geometry, the difference between the two is: **66.4 in** (OpenRocket) - 64.91 in (Barrowman) = 1.49 in of difference.

These results show that the Barrowman estimate has a **2.24% error** relative to the CP evaluated by OpenRocket (see Stability simulations). A possible explanation for this error is that OpenRocket may simulate a wind tunnel test and integrate the pressures across the entire airframe, while the Barrowman Equations use simplifying assumptions to provide estimates.

Table 3.5.1: Dimensions

3.5.2. Nose Cone

The part selected for use is a 5.5 in OD Fiberglass nosecone that has a 4:1 ratio of length to diameter, putting the length at 21.75 in. This nosecone was chosen to have an Ogive shape to allow for more room to include the GPS system inside the cone itself. A 5.25 in shoulder provides enough space to mount the Payload, which merely comprises of an acoustic transmitter/sensor pair, as well as a microcontroller to read the Sound Pressure Level (SPL) from the sensor several times per second as the rocket rapidly changes altitude.

3.5.3. Motor Selection

Currently the final motor choice for rocket is a Aerotech L1150R. This motor was compared with the Aerotech L850W and chosen because it will provide a larger average thrust of 1,100.49 N (L1150R) as compared to 786.67 N (L850W) for a shorter period of time 3.17 s (L1150R) as compared to 4.7 s (L850W) (as shown in Figure 3.5.2 and Table 3.5.2). The higher thrust will provide more power for the rocket to climb altitude at a faster rate. This thrust does not need to be exerted for too long as the rocket will exceed the mission altitude. The total impulse this motor will produce is 3488.55 Ns which is enough to power the rocket to the mission specified altitude. The comparison of both motor options are shown below.

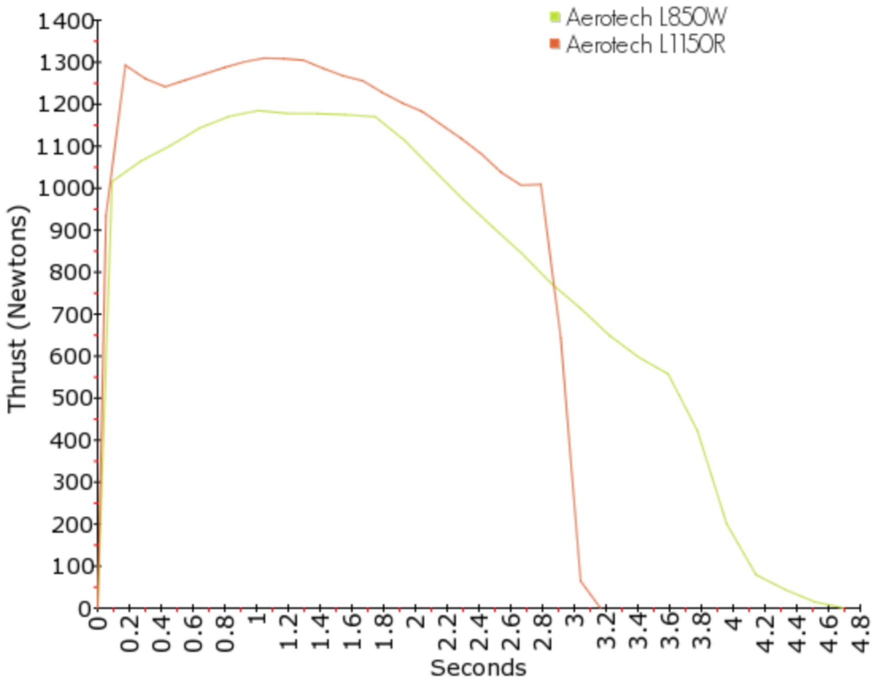


Figure 3.5.2: Motor comparisons of thrust v time

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

Table 3.5.2: Thrust calculations (Motor comparisons)

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.

3.5.4. Booster Section

At the head of the booster section, the motor tube is capped with a 0.25 in thick thrust plate, secured across multiple surfaces to the motor tube as well as the body tube via epoxy and option L-bracket installation. A U-bolt runs through the thrust plate, providing a point of attachment for Recovery System components. The entirety of the booster section is designed to slide into the main rocket body tube as a single component, including the fins and motor. Once positioned inside the body tube, the assembly may be secured via the L-bracket points. This design allows for rapid access to the booster section in the event that modification or repair is necessary.

3.5.5. Kinetic Energy at Landing

The kinetic energy at landing can be approximated for each rocket section by the following formula:

$$KE = (1/2)mv^2$$

The value for the landing velocity is based on OpenRocket simulations, which is 13.75ft/sec. Table 3.5.3 shows the landing kinetic energy for each rocket section.

Body Section	Weight (lbs)	Kinetic Energy (lbf-ft)
Nose Cone /Payload	3.721	10.93
Avionics Bay	4.292	12.261
Motor/ATS/Fins	15.41	45.27

Table 3.5.3: Landing Mass Distributions

3.5.6. Altitude Predictions

Mission Performance Predictions

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.

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

Table 3.5.4: Flight Simulation Conditions

Flight profiles

Figure 3.5.3 below shows the calculated flight profile of the Krios rocket with the AeroTech L1150-P using the flight conditions from Table 3.5.4. Velocity, altitude and acceleration were plotted as a function of time. 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.

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	

Table 3.5.5: Readings at Major Launch Events

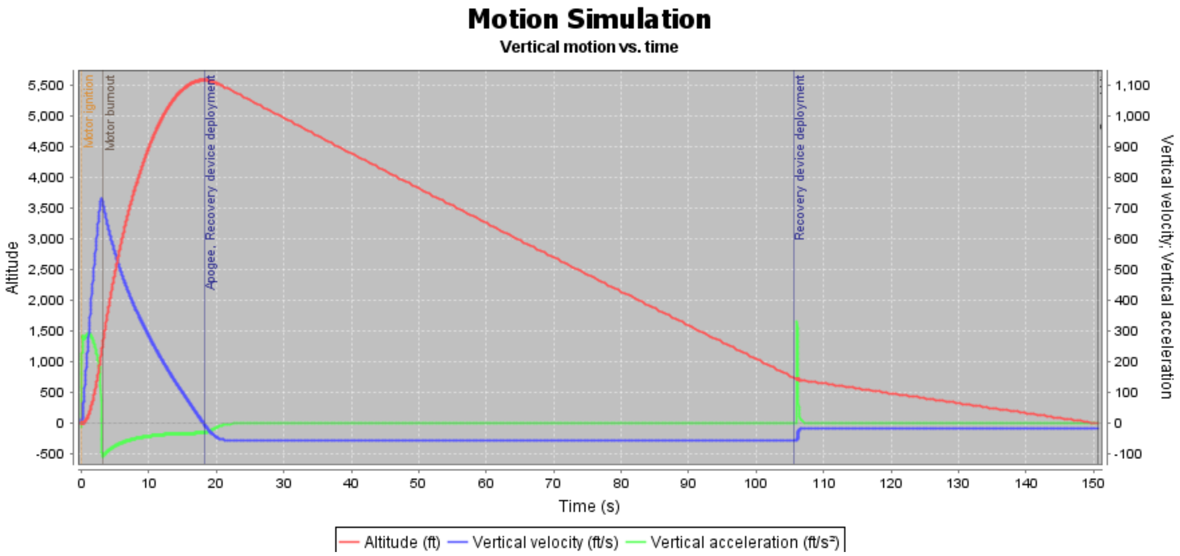


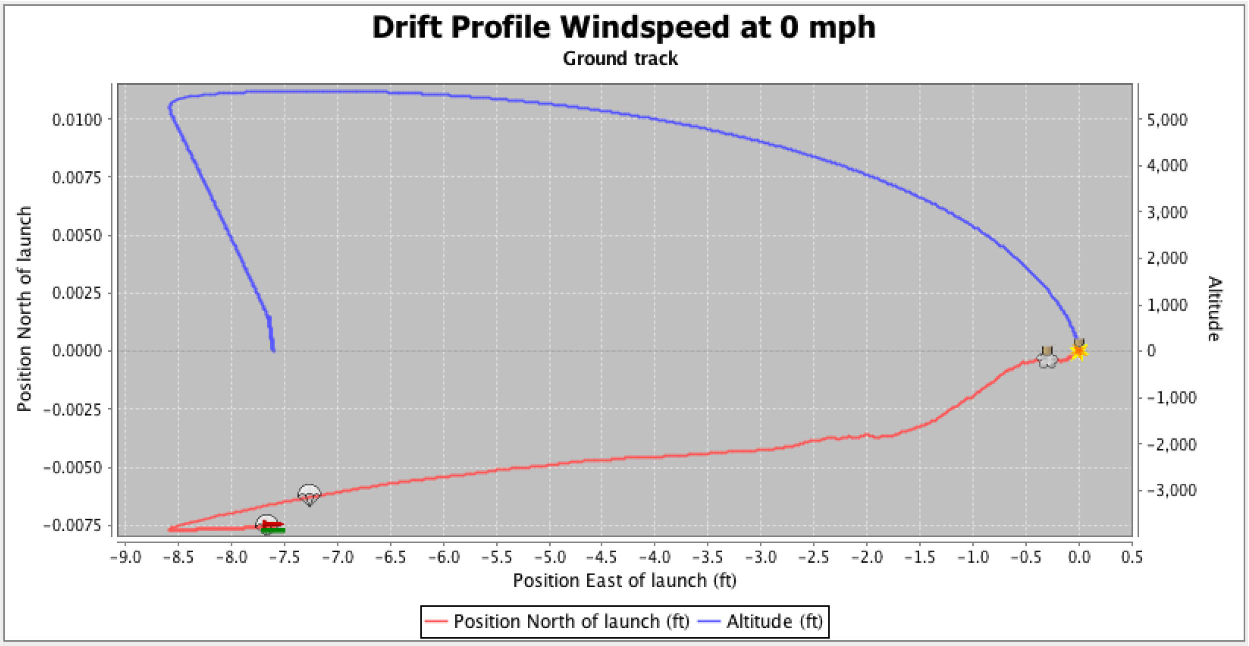
Figure 3.5.3: Flight profile with AeroTech L1150-P

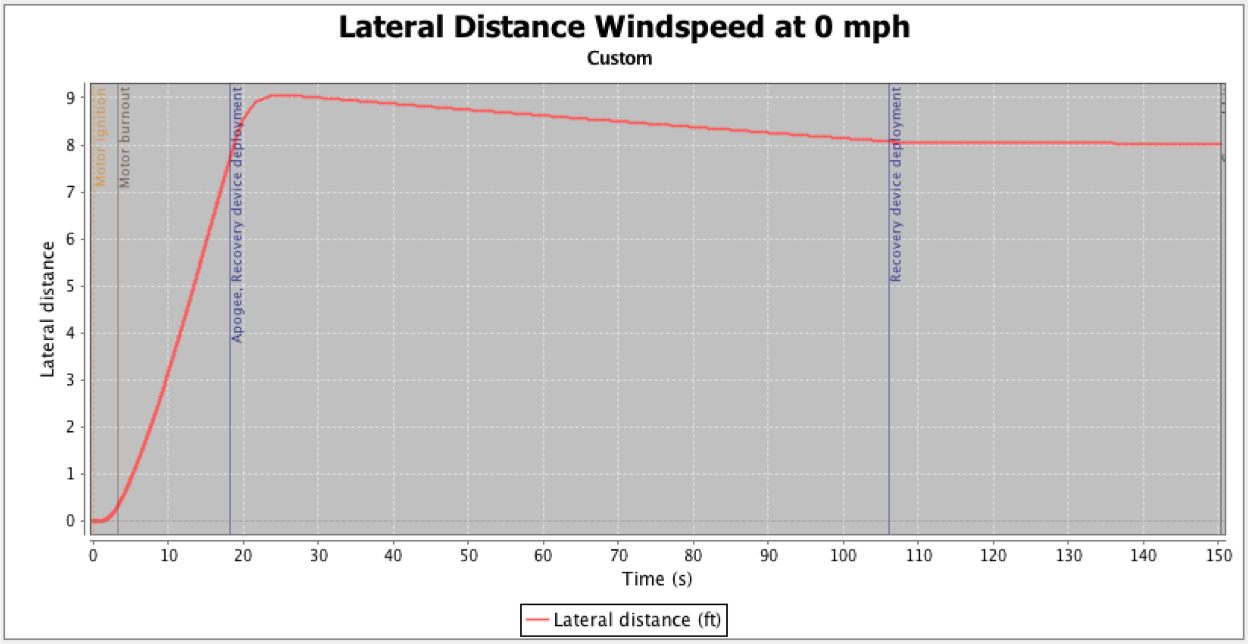
Altitude Predictions

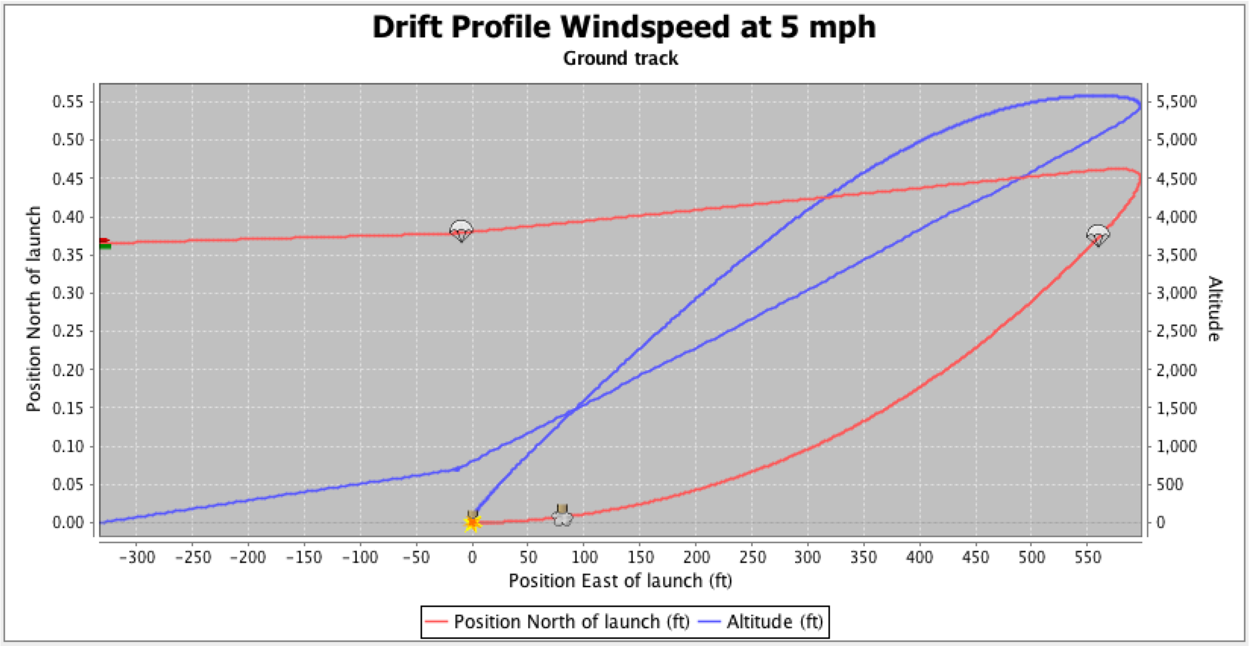
The apogee of this rocket has been simulated to be 5582 ft. (0 mph wind speed). Though this is around 202 ft above the target altitude of 5280 ft., this will not be a problem as we want the rocket to overshoot the target altitude rather than undershoot it. When flying the rocket, the ATS system will activate to create drag and lower the apogee of the rocket to be precisely 5280 ft.

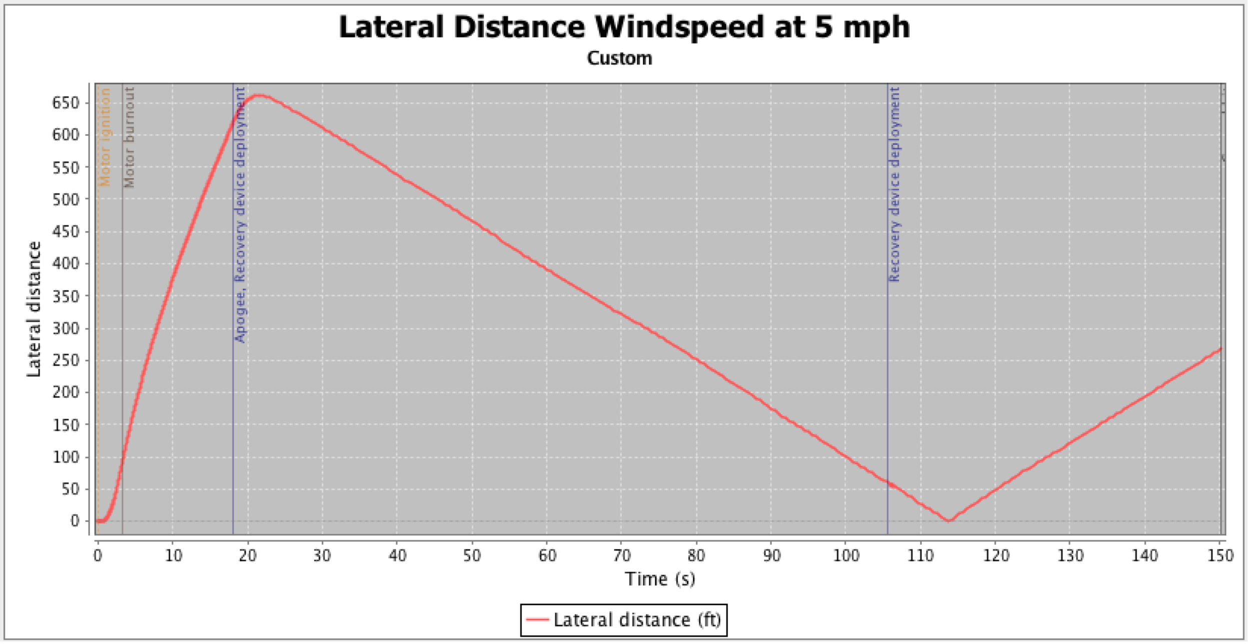
Drift Profiles

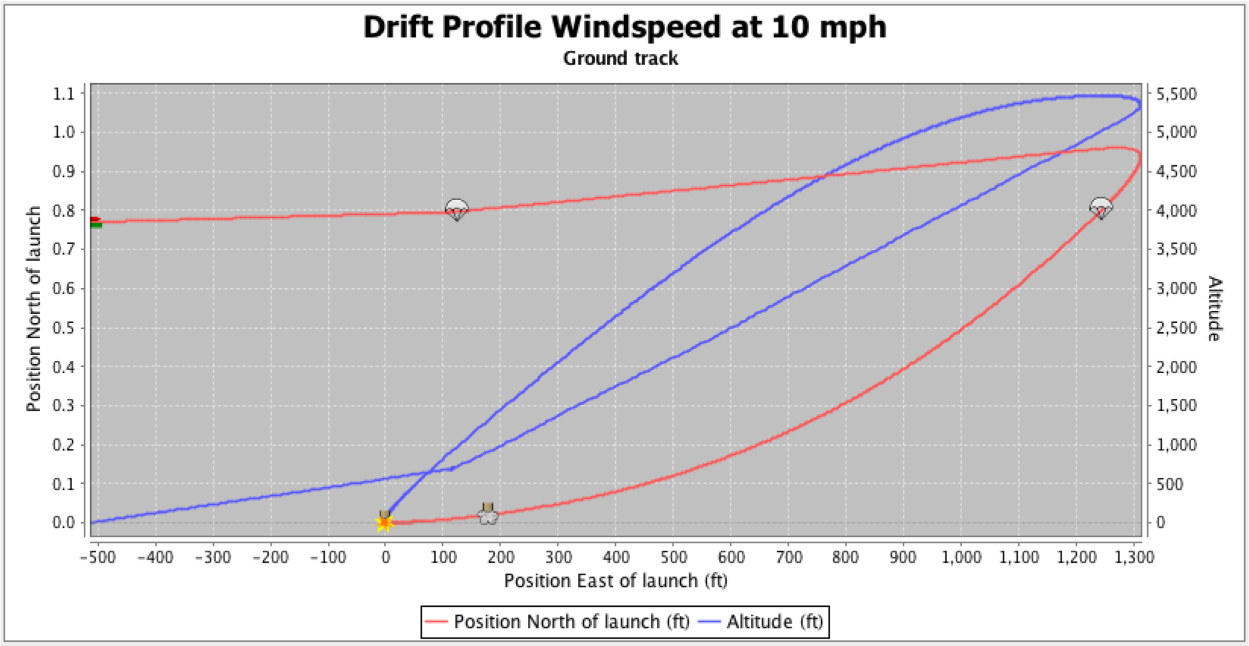
The following figures, all considered a part of Figure 3.5.4, show the drift profiles and lateral distance traveled by the rocket in simulations with average wind speeds set at 0, 5, 10, 15, and 20 mph.

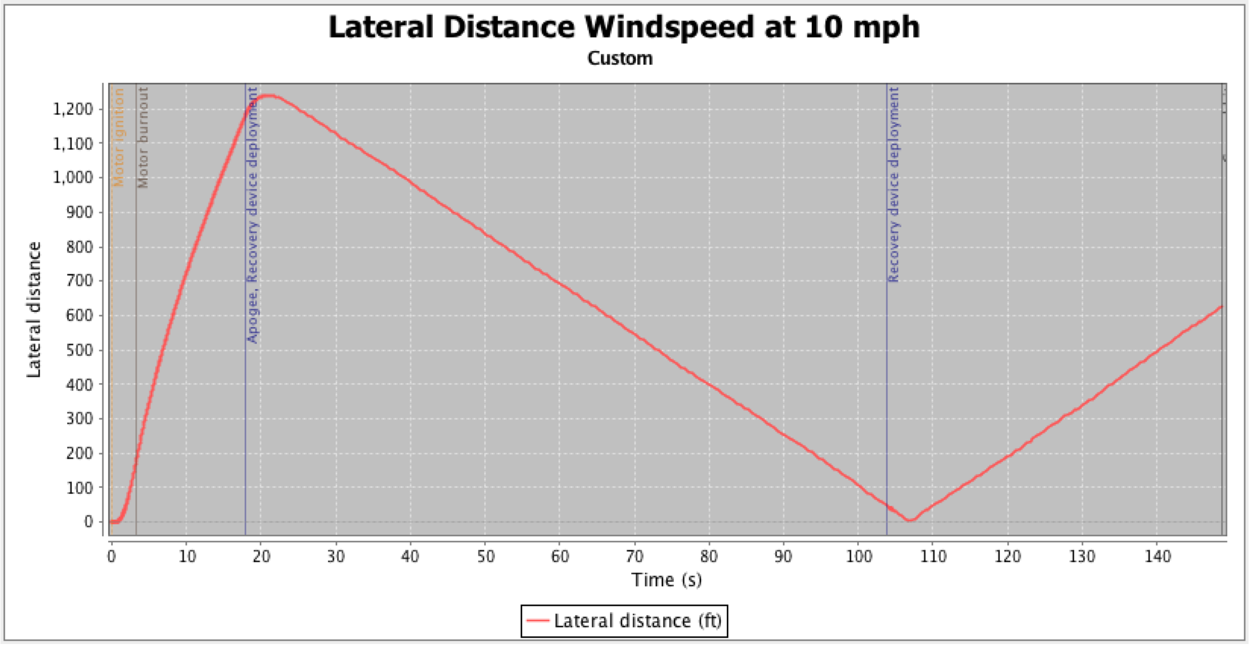

Drift Profile Windspeed at 0 mph
Ground track
Position North of launch
0.0100
0.0075
0.0050
0.0025
0.0000
−0.0025
−0.0050
−0.0075
Altitude
5,000
4,000
3,000
2,000
1,000
0
−1,000
−2,000
−3,000
−9.0 −8.5 −8.0 −7.5 −7.0 −6.5 −6.0 −5.5 −5.0 −4.5 −4.0 −3.5 −3.0 −2.5 −2.0 −1.5 −1.0 −0.5 0.0 0.5
Position East of launch (ft)
Position North of launch (ft)
Altitude (ft)

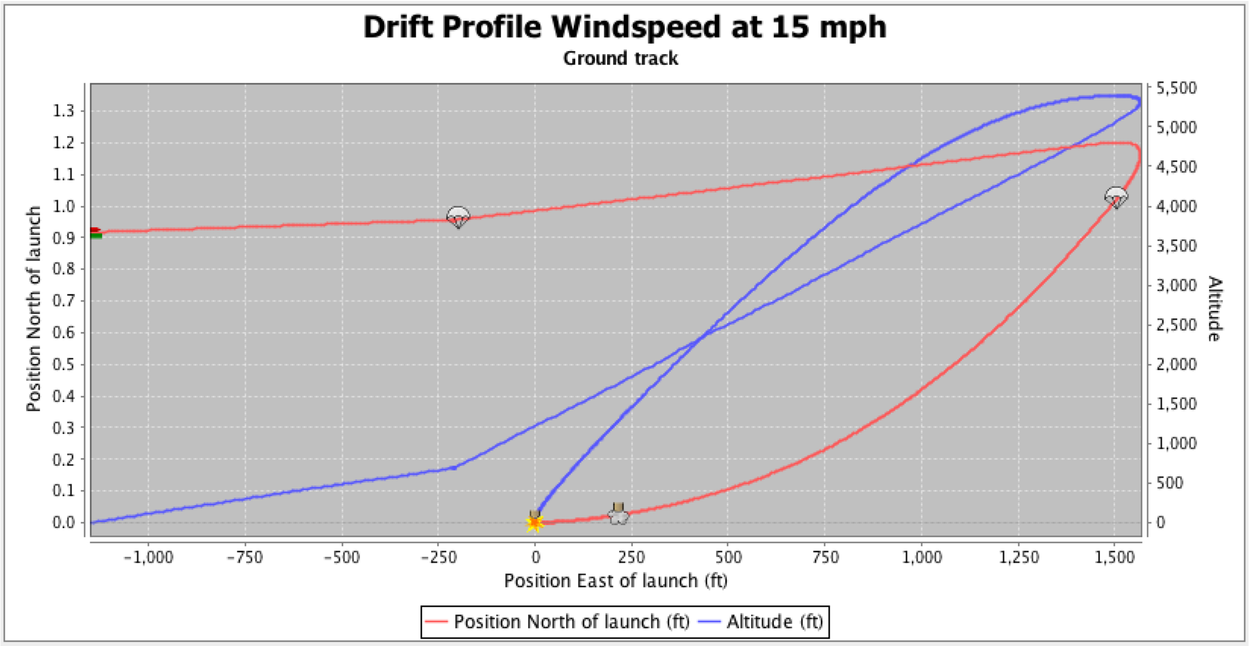

Lateral Distance Windspeed at 0 mph
Custom
Lateral distance
0 1 2 3 4 5 6 7 8 9
Motor ignition
Motor burnout
Apogee, Recovery device deployment
Recovery device deployment
0 10 20 30 40 50 60 70 80 90 100 110 120 130 140 150
Time (s)
Lateral distance (ft)

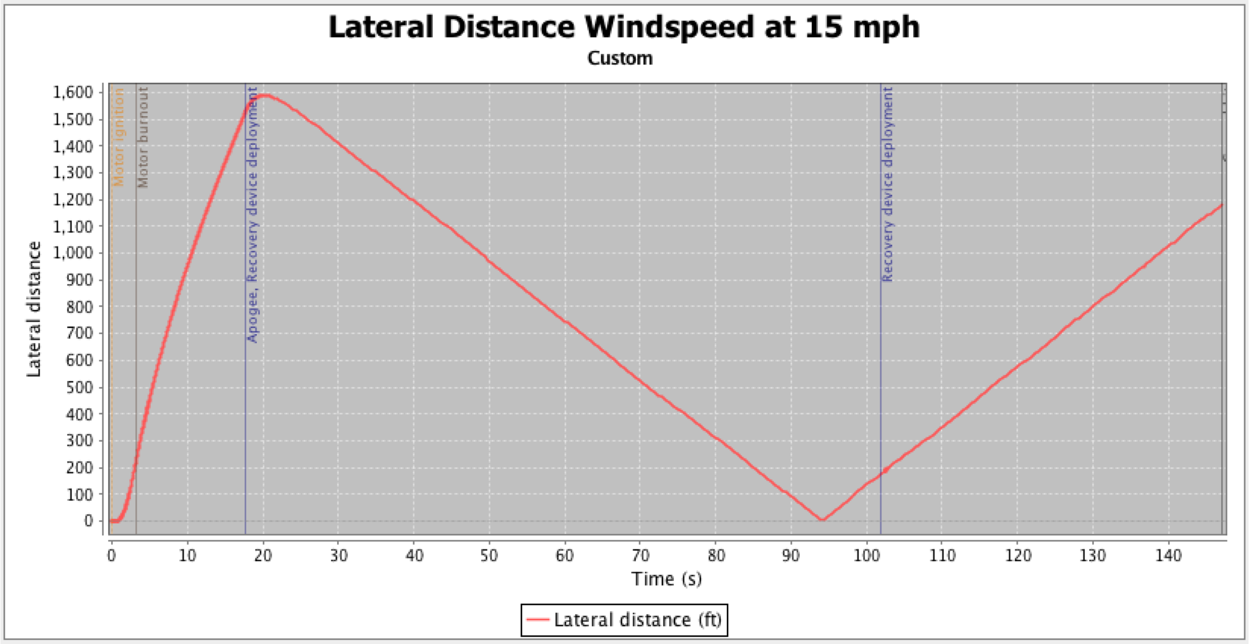

Drift Profile Windspeed at 5 mph
Ground track
Position North of launch
0.55
0.50
0.45
0.40
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00
Altitude
5,500
5,000
4,500
4,000
3,500
3,000
2,500
2,000
1,500
1,000
500
0
-300
-250
-200
-150
-100
-50
0
50
100
150
200
250
300
350
400
450
500
550
Position East of launch (ft)
Position North of launch (ft)
Altitude (ft)


Lateral Distance Windspeed at 5 mph
Custom
Lateral distance
650
600
550
500
450
400
350
300
250
200
150
100
50
0
Motor ignition
Motor burnout
Apogee, Recovery device deployment
Recovery device deployment
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
Time (s)
Lateral distance (ft)


Drift Profile Windspeed at 10 mph
Ground track
Position North of launch
1.1
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
Altitude
5,500
5,000
4,500
4,000
3,500
3,000
2,500
2,000
1,500
1,000
500
0
-500
-400
-300
-200
-100
0
100
200
300
400
500
600
700
800
900
1,000
1,100
1,200
1,300
Position East of launch (ft)
Position North of launch (ft)
Altitude (ft)


Lateral Distance Windspeed at 10 mph
Custom
Lateral distance
1,200
1,100
1,000
900
800
700
600
500
400
300
200
100
0
Motor ignition
Motor burnout
Apogee, Recovery device deployment
Recovery device deployment
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
Time (s)
Lateral distance (ft)


Drift Profile Windspeed at 15 mph
Ground track
Position North of launch
1.3
1.2
1.1
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
Altitude
5,500
5,000
4,500
4,000
3,500
3,000
2,500
2,000
1,500
1,000
500
0
-1,000
-750
-500
-250
0
250
500
750
1,000
1,250
1,500
Position East of launch (ft)
Position North of launch (ft)
Altitude (ft)


Lateral Distance Windspeed at 15 mph
Custom
Lateral distance
1,600
1,500
1,400
1,300
1,200
1,100
1,000
900
800
700
600
500
400
300
200
100
0
Motor ignition
Motor burnout
Apogee, Recovery device deployment
Recovery device deployment
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
Time (s)
Lateral distance (ft)

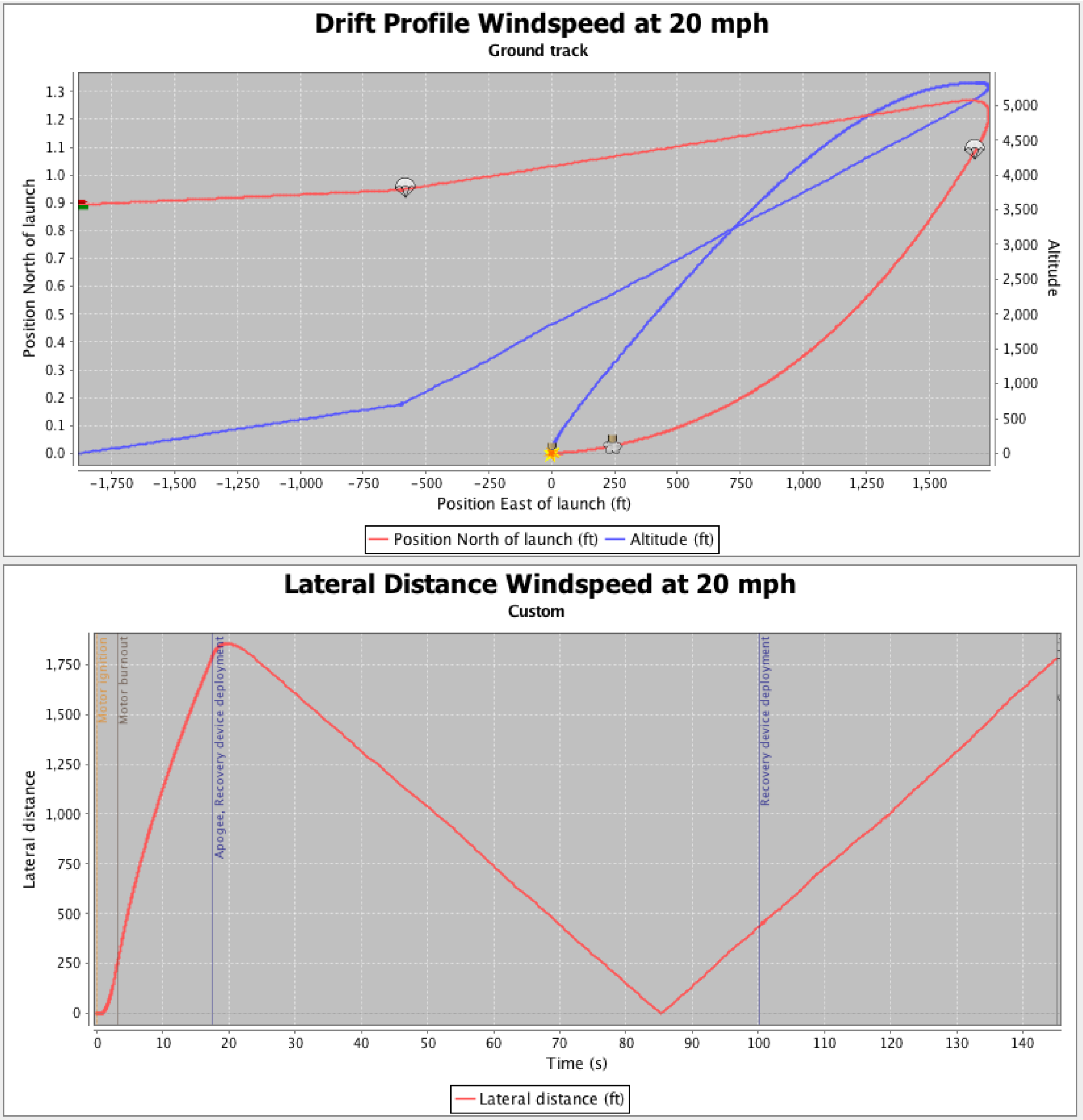


Figure 3.5.4: Drift Profiles in Various Windspeeds

3.5.7. Fabrication and Materials

3.5.7.1. Fins

The fins will be manufactured using a water jet cutter provided by the Georgia Tech Invention Studio. Using a water jet cutter will allow an accurate model of the fin to be made; however, because G10 Fiberglass is layered, the layers risk peeling off due to the high pressure from the water jet cutter. Water jet pressures can be lowered to mitigate this issue. To eliminate this problem, after the water jet cutting process has been completed, the fiberglass layers that have peeled off will be epoxied on and placed under weights in order to reform the original shape.

3.5.7.2. Avionics Bay

The avionics bay consists of two different materials: G10 fiberglass and 0.25in plywood boards. These two materials require different manufacturing methods to ensure that their structural integrity isn't affected. For the plywood boards, the conventional method for altering the dimensions of the board is using a high powered laser cutter for precise and safe manufacturing. In addition, it is important to note that any drilling or screwing into plywood risks damaging its structural integrity, as its layers can separate and splinter. As for the fiberglass tubes, the most convenient method of altering its shape is through the use of powered saws. This, however produces significant amounts of hazardous fiberglass dust, so it is important to take this into account and ensure the appropriate safety equipment is used by every individual present during the time of manufacturing. As for the holes that secure the Avionics Bay in place, a conventional drill will be used while still accounting for the same safety hazards as previously discussed. These methods ensure there will be little deformation or delamination, and that cuts will be precise for the manufacture of each component. Epoxy will ensure that the plywood bulk plates on each side of the avionics bay are secured to the body tube.

3.5.7.3. Booster Section

A large majority of the booster section can be created using conventional manufacturing tools. Laser cutters will be sufficient to create the centering rings, while a waterjet cutter or CNC router will be employed in order to cut the thrust plate. Any cardboard tubing, such as the motor tube, can be cut using power tools. L-brackets will be bought rather than manufactured and subsequently attached via nuts and bolts. All components not secured via fasteners will be fixed in place by epoxy (i.e. centering rings to the motor tube).

3.5.7.4. ATS

The ATS tabs will be cut directly from another segment of 5.5 in fiberglass tubing to ensure their correct radius and to keep a consistent material used along the airframe.
The triangular hinge piece will attach to the tab by screws or bolts as well as the hinge. A small hole will be cut in the fiberglass body tube in order to fit the hinge of the ATS tab.

3.5.8. Future Testing and Analysis

The following are potential tests that are going to be performed on the launch vehicle:
1. Perform Wind Tunnel Test to obtain experimental Cd for comparison with test flight
2. Perform Wind Tunnel Test to obtain ATS Cd
3. Perform Wind Tunnel Test to measure moment induced on airframe due to roll-inducing flaps
4. Perform FEA Analysis on Thrust Plate
5. Use strain gauges to determine flutter and vibrations on fins
6. Perform ATS Ground Test to acquire Torque Data
7. Data from Subscale Flight will be used to adjust simulations and design accordingly

3.6. Mass Breakdown

The weight of the various rocket components is a key aspect of any design. The table and figure below show the mass distribution of the rocket by each subsystem, and they clearly show that the airframe takes up the most resources, which is acceptable. The fully-fueled motor comes in second, but by a wide margin, and then the recovery and avionics systems both take up minimal weight. In total, the rocket weighs just under 28 pounds at launch.

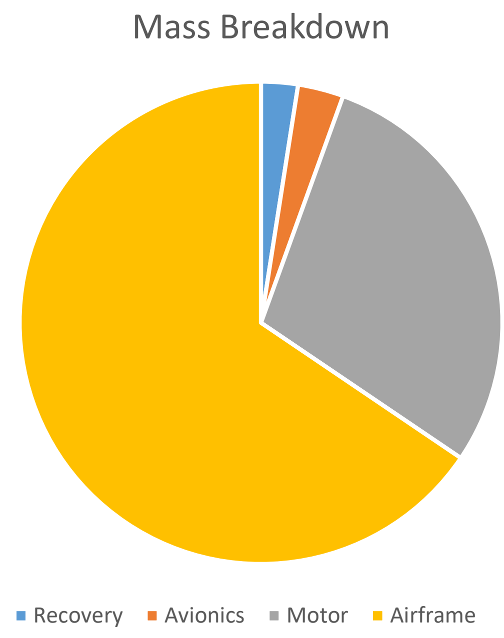


Figure 3.6.1: Mass Breakdown by System

System	Mass (lbs)
Recovery	0.69
Avionics	0.857
Motor	8.098
Airframe	18.332
Total	27.977

Table 3.6.1: Mass Breakdown

4. Flight Systems (Electronics and Payload)

4.1. Objective

The flight system of the rocket will have three primary responsibilities: automating the recovery, braking, and rolling of the rocket. A successful recovery will deploy the drogue chute at peak apogee followed by the main at 750 ft. The braking and rolling control has slightly more room for error, but the objective is to gradually slow the rocket so that its peak apogee is approximately 5280 ft. A successful rolling motion will include two complete spins on the ascent followed by inducing a counter moment to stop the roll. Additionally, a successful payload will provide some insightful footage of the rocket's flight path.

4.2. Success Criteria

The success of the launch vehicle will be defined in two ways: minimum and maximum. The minimum success criteria will be accomplished if the requirements are accomplished with no fatal flaws. Maximum success criteria will be met if everything goes according to plan and each sub-system performs optimally. Maximum success will additionally include collecting diagnostic data for the launch vehicle so that design feedback is available for creating the most effective launch vehicle design. The current success criteria of the avionics system are included in the table below (Table 4.2.1).

Requirement	*Design Feature to Satisfy Requirement*	*Requirement Verification*	*Success Criteria*
The vehicle shall not exceed an apogee of 5,280 ft.	Drag from the ATS system	Subscale flight test	Apogee within 2% of target
The vehicle successfully performs two rotations around the roll axis and induces a counter rolling motion.	Rolling will be activated by rotating servo motors attached to fins that are controlled by the Teensy	Subscale flight test	The vehicle will halt all rolling motion for the remainder of launch vehicle ascent

	microcontroller		
The data of the vehicle’s flight will be recorded.	Sensors will save data into Teensy microcontroller	Subscale flight test	The data will be recovered and readable after flight

Table 4.2.1: Mission Success Criteria for Flight System

4.3. Payload Explanation

The main experiment conducted by KRIOS will be measuring the Sound Pressure Level of the atmosphere recorded at different altitudes. This information will be recorded and analyzed to determine how changes in air density due to altitude inhibit or enhance the ability of sound waves to travel through air. The device will work by emitting a sound wave from one end of the Payload section to the other and taking data of the SPL values.

The following figure shows the main embedded components of the avionics system: The StratoLoggerCF altimeter (left) and the Teensy 3.2 microcontroller (right).

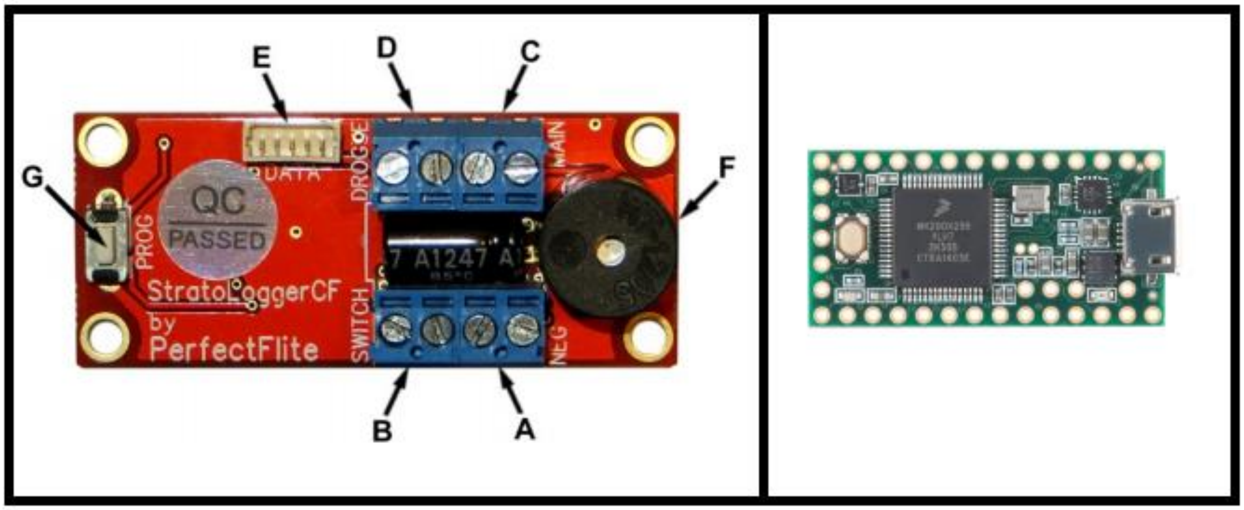


Figure 4.3.1: StratloggerCf altimeter (right) and Teensy microcontroller (left)

The Perfectflite StratloggerCF altimeter (Figure 4.3.1) is capable of measuring altitude through the use of a barometric pressure sensor. It will act as the main component of the recovery system and will report the official peak apogee of the rocket. Two Stratologger CF altimeters will both be powered independently and connected to the main and drogue chutes in order to provide dual redundancy and further ensure parachute deployment. One of the Stratologger's will be used to report real time data and determine the rocket's projected apogee in order to perform in-flight calculations that, in turn, activate the ATS braking. The accelerometer and gyroscope data will be used to induce rolling maneuvers and ensure rocket stability. The Teensy 3.2 microcontroller (Figure 4.3.1), equipped with 3 serial ports, will handle all in flight data implementation and servo motor control.

The StratoLoggerCF altimeter additionally has the ability to deploy parachutes by ejecting a large output current at the desired height. The StratoLoggerCF is industry quality, robust, and is easily programmed through the Perfectflite DataCap application. The StratoLoggerCF was selected carefully in order to ensure a successful recovery system as well as an accurate max apogee reading. A gyro sensor provides a reading of radial velocity, which will be crucial for calculating the in-flight roll maneuvers of the rocket. An accelerometer is also useful for rolling calculations as well as determining the rocket's 3-D orientation which help to ensure rocket stability. A 6 degrees of freedom IMU embedded chip will account for these two components. The teensy microcontroller was chosen for its cost effectiveness, lightweight design, and variety of I/O pins. It is also compatible with the simplified C-variant Arduino language. We don't foresee the system calling for a more powerful microcontroller, but the MBED ARM microcontroller is an option should that occur. The MBED would be programmed using C++. The current and speculative components of the avionics system are included in the table below (Table 4.3.1).

Component	Description	Voltage rating
PerfectFlite StratoLoggerCF altimeter	Will be used as the main component of the rocket's recovery system. It reports and records the rocket's apogee and deploys chutes at the desired height.	4 - 16V
Teensy 3.2 microcontroller	Will be programmed to read in sensor data and activate motor control appropriately	3.3V

ADXL345 accelerometer	Triple axis accelerometer used for rolling calculations. Part of 6 DoF IMU.	3.3V
ITG-3200 gyro	Gyro sensor returns radial velocity used for rolling calculations. Part of the 6 DoF IMU.	3.3V
E-Flite 721 camera	Camera to record in-flight footage and show rolling maneuver	3.7V
Sparkfun Logic Level Converter	Used to convert switch between 3.3V and 5V for individual components	H: 5V L: 3.3V
MBED ARM microcontroller	Backup microcontroller should the teensy not suffice our needs. Programmed in C++	4.5 - 9V

Table 4.3.1: Electrical Components and Descriptions

4.4. Preliminary Interface Between Payload and Launch Vehicle

The Avionics bay will house the components responsible for the rocket's recovery, ATS, rolling, and data collection systems. Conductive leads will protrude out from the avionics bay to connect to the motors and parachute charges that control the rocket. Interface details on the components of the avionics system are outlined in the following sections.

4.4.1. StratoLoggerCF Altimeter

The StratoLoggerCF altimeter records flight data at a rate of 20 samples per second and is able to do so for flights of up to 18 minutes in duration that can be stored for later use. The altimeter reports the rocket's peak altitude and maximum velocity after flight via a sequence of beeps. It draws a current of 1.5 mA to function and can output up to 5 A for up to 1 second (although this will vary slightly depending on the voltage of the battery connected to it). During launch, two outputs are provided for deploying a small chute at apogee to minimize drift and a larger chute closer to the ground to slow down the rocket. Main chute deployment altitude is adjustable between 100 feet and 9,999 feet. The altimeter also includes a Data I/O connector which allows real-time altimeter data to be sent to the onboard teensy microcontroller. Table 4.4.1 lists the different ports of StratoLoggerCF and briefly describes the functionality of each.

Port	*Name*	*Description*
A	Battery	Connect a 9V battery here
B	Power Switch	Connect a power switch here
C	Main Ejection Output	Connect to match for deployment
D	Drogue Ejection Output	Connect to match for deployment
E	Data I/O Connector	Connect to flight computer for real-time data transfer
F	Beeper	Audibly reports setting via a series of beeps
G	Preset Program Button	Not used.

Table 4.4.1: Altimeter Port Details (from figure 4.3.1)

A basic block diagram of the StratoLoggerCF and its connections with regards to the recovery system is found below in figure 4.4.1. Again, each StratoLoggerCF will powered independently and connected to the main and drogue deployment charges.

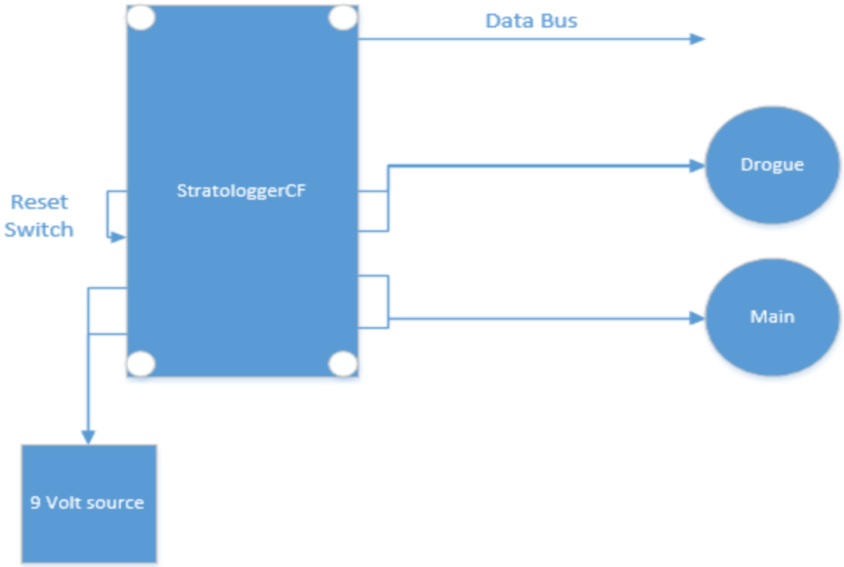


Figure 4.4.1: Block diagram of freestanding recovery system

As for the altitude specifications of the device, it will function up to an altitude of 100,000 ft above MSL, with decreasing altitude reading resolution the higher up the rocket goes. Anywhere below 38,000 ft above MSL the readings' resolution will have an uncertainty of ±1 ft. Seeing as the formal launch of the rocket will take place in Huntsville, AL which has an altitude of 600 ft above MSL, and that the rocket will be designed to be placed 5,280 ft AGL, the range of the rocket can safely be assumed to fall within this range. In addition, an uncertainty of ±0.05% must be further added to the overall error analysis of the StratoLoggerCF due to uncertainty during calibration.

4.4.3. Inertial Measurement Unit

The IMU will be used to measure the velocity of the rocket, which will be later used to calculate the in-flight roll maneuvers of the rocket and this measurement is done using gyroscope. The accelerometer, on the other hand, is also useful for roll calculations as well as determining the rocket's 3-D orientation. The data from the sensors are sent through the I2C port.

The accelerometer ADXL345 will provide acceleration data and, combined with the GPS module, provide rotation and position data for the launch vehicle trajectory. Three axis capabilities will implicitly define velocity, position, and rotational motion. The ADXL345 accelerometer can record up to ±16G. The ADXL345 is capable of entering a “standby” mode for periods of inactivity, an advantage for periods of inactivity during setup and preparation to launch.

The gyroscope ITG-3200 MEMS will measure the angular velocity, that will be useful to calculate the roll induction of the rocket. Unlike accelerometers gyros are not affected by gravity. The three axes capabilities of rotation will implicitly define roll, pitch, and yaw.

4.4.4. Teensy 3.2

Teensy has a 32 bit processor, which will be used to run computations to store correct values and use those values to make flight adjustments. It is equipped with 3 serial ports, which will handle all data implementation and, in turn, servo motor control. Teensy will be programmed using a C variant in Arduino IDE with Teensyduino add-on. It also has the ability to provide system voltage of 3.3V to other devices at up to 100mA. The heart of the avionics is the teensy microcontroller. Data that is collected from StratoLoggerCF Altimeter and IMU will be used to feed information into the controller, store it, make calculations based on the stored values, and activate the fin system of the rocket accordingly. The altimeter will send the data to teensy via tx and rx serial connections, while the IMU (accelerometer and gyroscope) will send the data through an I2C port. A block diagram schematic of this system is shown below (figure 4.4.1).

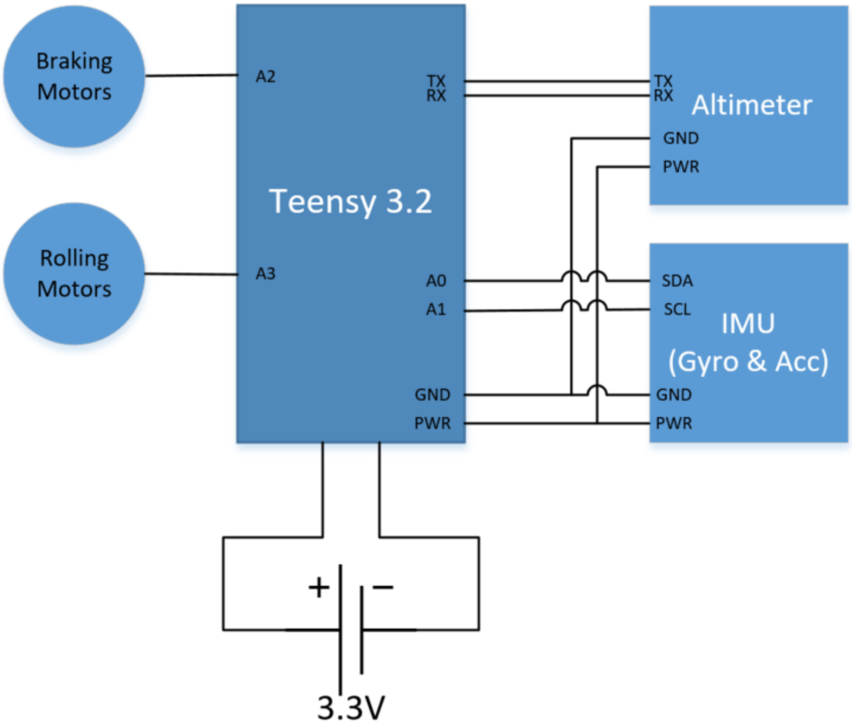


Figure 4.4.1: Block diagram of Motor Control System

4.4.5. Precision of Instrumentation

Component	**Voltage Rating**	**Current Rating**	**Precision**
StratoLoggerCF altimeter	4V-16V	1.5mA	< 38,000 ft MSL (±1 ft.) Additional for calibration (±0.05%)
Teensy 3.2	3.3V	185mA	32-bit ARM Cortex microprocessor resolution
ADXL345 accelerometer	3.6V	145uA	10-bit resolution
ITG-3200 gyro	3.3V	6.5mA	14.375 LSB per °/sec Additional for full-scale range (±2000°/sec)
Logic Level Converter	3.3V-5V	0.22A	NA

Table 4.4.1: Precision of Instrumentation

4.6. Payload Structure

The payload, consisting of only of the experiment used to measure Sound Pressure Level propagation through different air densities, will be designed similarly to the avionics bay. Housed in the shoulder of the nosecone, the payload will rest on a ¼ in sheet of plywood that will be secured on both ends by bulk plates. These will like between the nosecone and the avionics section, as well as between the shoulder and the curved section of the nosecone. Bolts running across this gap will hold the plywood sheet in the center of the tube and prevent any motion.

4.7. Altimeter Info/Testing

The StratoLoggerCF altimeters will be tested using a vacuum sealed pressure chamber to simulate barometric altitude change. LED lights paired with step-down resistors will be used to simulate the parachute deployment charges. The mock flight data information will be extracted and analyzed using a serial-to-USB adapter and the PerfectFlite DataCap software to confirm that both altimeters function as anticipated. These tests are crucial for ensuring a successful subscale launch.

4.8. GPS

The GPS will be the telemetry system's main electrical component. We will use an Eggfinder GPS tracker to send NMEA data to stream the rocket's position as it launches and lands. The module transmits data in the 900 MHz license-free ISM band at 100mW. The module sends packets in 9600 baud, 8 bits, and no parity. The GPS module will be placed in the nosecone of the rocket, such that it can be slid in and out with ease. Appropriate shielding will be placed to prevent any unwanted interference from altering GPS data.

4.9. Power

In order to ensure a cost effective, safe, and durable power system for the rocket's electronics, disposable Duracell 9V batteries will be used. One will be used to power each altimeter, one for the Teensy, and two connected in parallel for the servo motor in order to double the capacitance.

5. Safety

5.1. Overview

Team A.R.E.S. is dedicated to maintaining safe operating conditions for all team members and anyone involved in competition activities. Under the tutelage of the Safety Officer, Vikas Molleti, Team A.R.E.S. will undergo rigorous safety briefings to ensure the integrity and safety of the entire team and equipment is ensured. During manufacturing, fabrication, and testing of rocket vehicle, it is important to identify the hazards of the environment, and how following safety procedures and protocols can prevent accident and injury to oneself or damage to competition hardware. When working with construction equipment, Team A.R.E.S. members are instructed to work in minimum team sizes of two. This ensures that one team member would be available to provide immediate assistance or quickly get help should an incident occur while using the equipment. The Invention Studio, where team members use the necessary equipment for manufacturing and fabrication, is equipped with first aid kits, fire extinguishers, safety glasses, and expert supervision for the use of all equipment. All individuals using the equipment in the studio also need training by a certified by an instructor there.

During physical testing of the rocket structure, and during ejection charge testing, team members will wear safety glasses, have a first aid kit and fire extinguisher on hand, and have licensed safety officials present. In order to use the machines, all team members have been briefed on the proper protocols and procedures of using the lab machines. Risk identification and mitigation techniques are used to assess the dangers of tools and activities to personnel, and how they may create safe operating conditions. To that end, Table XX lists the procedure to identify what hazards and risks may exist and how to minimize the chances of occurrence.

Step Name	***Step Definition***
1. Hazard Identification	Team will collectively brainstorm to identify any possible hazards that the team may encounter.
2. Risk and Hazard Assessment	Team will determine the severity and probability of consequences in even the hazard is encountered. Steps to approach each hazard will also be reviewed.
3. Risk Control and Elimination	After the hazard has been identified and assessed, a plan will be put in place to ensure the hazard will be mitigated.
4. Reviewing Assessments	The entire process will be repeated for any new hazards or existing hazard that needs to be updated.

Table 5.1.1: Safety Steps

Hazard	***Severity***	***Likelihood***	***Mitigation & Control***
Batteries Explode	Burns, skin and eye irritation	Low	Wear safety glasses and gloves when handling. Make sure no shorts exist in circuits using batteries. If battery gets too hot, stop its use and disconnect it from any circuits. Check for battery corrosion.
Black Powder	Explosions, burns, skin and eye irritation	Medium	Wear safety glasses, gloves when handling black powder. Be careful when pouring black powder. Operate in a static-free environment
Dremel	Cuts and scrapes	Medium	Only operate tools with supervision of teammates. Use tools in an appropriate manner. Wear safety glasses to prevent debris from getting into eyes.
Power Tools	Cuts, punctures, and scrapes	Medium	Only operate power tools with supervision of teammates. Use tools in

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

Table 5.1.2: List of Hazards, Risks, and Mitigations

5.2. Launch Vehicle Safety

Table 5.2.1 lists the possible failure modes and respective failure prevention procedures that the Launch Vehicle may encounter during testing.

Potential Failure	***Effects of Failure***	***Failure Prevention***
Apogee Targeting System (ATS)	Vehicle will not reach target altitude	Test ATS using subscale launch vehicles
Roll System	Vehicle will spin out of control and crash land, damage to vehicle, unable to be reusable, hazardous to personnel	Test roll induction of fins using subscale launch vehicles
Body structure buckling on takeoff	Launch failure, damage to launch vehicle, unable to be reused, flying shrapnel towards personnel	Test structure to withstand expected forces at launch with a factor of safety. Have properly sized couplers connecting sections.
Drogue separation	Main parachute will deploy at high speed and may rip or disconnect from vehicle, launch vehicle may become ballistic	Perform ground test and flight test.
Fins	Fins could fall off, causing unstable flight. Fins break or disconnect from launch vehicle, unable to be classified as reusable	Test fin at attachment points using expected forces to ensure strength of attachment method. Do not have fins with sharp pointed edges, ensure parachute is large enough to minimize impact kinetic energy, test fin at attachment points using expected forces to ensure strength of attachment.

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

Table 5.2.1: Failure Modes and Prevention

5.3 Environmental Concerns

The same methodology to identify and assess risks for vehicle and payload safety will be used to identify hazards for constructing various flight and testing components. A Material Safety Data Sheet (MSDS) is on hand for all materials used in the construction of components, and team members have been briefed on best practices for creating a safe workplace. Additionally, all old motors and unused materials will be disposed of in a safe manner, taking all the necessary precautions.

6. Project Plan

6.1. Verification Plan and Team Derived Requirements

See Table 2.2.1 in section 2.2 for the verification plan of each requirement, including team derived requirements found at the bottom of the table.

6.2. Budget

The projected budget of Team ARES for the 2016-2017 competition year is $5450, with Table 6.2.1 showing the breakdown between 5 categories: Launch Vehicle, Avionics, Outreach, Travel, and Test Flights. Figure 6.2.1 shows the percentage distribution of the categories, and Table 6.2.1 shows the budget of each category. Table 6.2.2 shows the full line item budget for each category.

Section	Cost
Launch Vehicle	$2100
Avionics	$550
Outreach	$800
Travel	$800
Test Flights	$1200
Total	**$5450**

Table 6.2.1. Budget

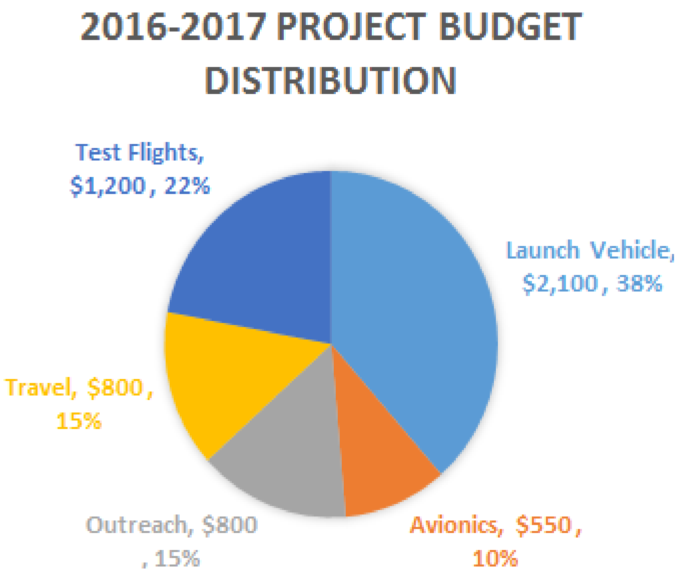


Figure 6.2.1 Budget Breakdown

Category	***Component***	***Price Ea***	***Quantity***	***Price Total***
Airframe	5.5" 4:1 Ogive Nosecone	$84.95	1	$84.95
	5.5" Body Tube	$100.00	2	$200.00
	G12 5.5" Coupler	$63.70	1	$63.70
	G10 Sheet for Fins	$27.00	4	$108.00
Hardware	2-56 X 1/4" Shear Pins	$3.10	1	$3.10
	12-24 Steel Locknut	$8.41	1	$8.41
	12-24 Stainless Threaded Rod	$3.92	1	$3.92
	Rail Buttons	$7.00	1	$7.00
	Servos	$19.95	8	$159.60
	10-32 7/16" Countersunk Screw	$9.35	1	$9.35
	3/8-16 2" ID U-Bolt	$1.46	4	$5.84
Propulsion	G10 75mm Centering Ring	$17.96	1	$17.96
	6061-T6 5.5" - 75MM THRUST PLATE	$59.21	1	$59.21
	Motor: L1150R	$159.99	1	$159.99
	Motor Casing	$385.20	1	$385.20
Recovery	84" FRUITY CHUTES: IRIS ULTRA	$295.58	1	$295.58
	24" FRUITY CHUTES: DROGUE	$63.70	1	$63.70
	3/4" X 25FT Shock Cord	$28.89	2	$57.78
				$0.00
Adhesives	1/4lb FIXIT® EPOXY CLAY	$12.55	1	$12.55
	2-Pint G5000 ROCKETPOXY	$38.25	1	$38.25
Misc Structure	1/4in x 6in x 3ft Oak Board	$6.83	1	$6.83
	G10 5.5" Body Tube Bulkead	$8.56	5	$42.80
	G10 5.5" Coupler Bulkead	$8.56	1	$8.56
Avionics	PerfectFlite StratoLoggerCF	54.95	2	$109.95
	Perfectflite firefly	24.95	1	$24.95
	teensy 3.2	19.95	2	$39.90
	Data tranfer cable	24.95	1	$24.95
	6 DoF IMU	39.95	1	$39.95
	E-Flite 721 camera	44.99	1	$44.99
	Eggfinder GPS		1	$50
	Sensors/circuit elements	50	N/A	$50
	tools/cables	100	N/A	$100
	Batteries	100	N/A	$100
Misc	Replacement Materials	200	N/A	$200.00
	Test Flight Motors	400		$300.00

Roll Induction	Servos	40	4	160
	Fiberglass	26	1	26
	Shafts & Gears	50	1	50
	Shipping & Handling	30	1	30
Subscale	Total Estimate	700	1	$700
Outreach				
	Estes Viking Rocket Bulk Packed 12 Multi-Colored*	63.99	5	$319.95
	Estes A8-3 Engines Bulk Pack (24)	56.32	3	$168.96
	Stickers (Promotional Material, Feron suggested it)	111 (300 stickers)	1	$111
	Posters** (Promotional Material)	$1 per ft^2	30	$30
	Pens (Promotional Material)	$0.62	250	$155
Travel				$900
Total				$5,482.88

Table 6.2.2

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 they have estimated they can allocate us between two and three thousand dollars. We plan for Orbital ATK to cover our travel budget, and CCTV Camera World has agreed to give us a camera that will be put on the rocket for flight data and publicity material. We hope to extend relations with other companies for further sponsorship. 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 Space Grant Consortium has offered to assist in connecting us with corporate sponsors. Table 6.3.1 shows our projected funding, which exceeds our cost estimates by 8%, giving appropriate room for unanticipated costs. 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. Georgia Tech has also offered us a room in the Engineering Science and Materials Building to use for construction, storage, and meeting space.

Sponsor	*Contribution*	*Date*
2015-2016 Unused Funds	$388	--
Georgia Space Grant Consortium	$2,000-$3000	Oct 2016
Alumni Donations	(est.) $200	Dec 2015
Corporate Donations	(est.) $3,000	Jan 2017
Orbital ATK Travel Stipend	(est.) $400	Apr 2017
Total	$6500	

Table 6.3.1. Projected Sponsorship

6.4. Current Sponsors

Table 6.4.1 lists the current sponsors of Team ARES and their contributions.

Sponsor	*Contribution*
Georgia Space Grant Consortium	$2000-$3000
CCTV Camera World	Camera to be housed in the rocket

Table 6.4.1. Current Sponsorship

6.5. Timeline

In order to meet the deadlines given by NASA and the internal deadlines created by Team ARES (Table 6.5.1), we have created a Gantt Chart (Appendix A) to more easily visualize the timeline of our project, and broke down each task into smaller tasks with completion dates (Appendix A). This task breakdown allows us to more easily see if we're on track to task completion while making it easier for every team member to understand their assignments and due dates.

7. Education Engagement Plan and Status

7.1. Overview

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 middle and high school students and educators. Team A.R.E.S. will have an outreach request form on their webpage for Educators to request presentations or hands-on activities for their classroom. The team plans to particularly encourage requests from schools in disadvantaged areas of Atlanta, with the goal of encouraging students there to seek careers in STEM fields.

7.2. Eagles at GT

Team ARES, for the next two semesters, will be partnering with Eagles at GT, a Boy Scouts of America sub-organization run by Georgia Tech students who are Boy Scouts or who are interested in boy scouting. Eagles at GT are planning multiple Merit Badge Clinics at which Team ARES will teach hands-on, STEM-related merit badges. Some of Team ARES's potential merit badges include the Space Exploration Merit Badge, the Engineering Merit Badge, the Astronomy Merit Badge, and the Model Design & Building Merit Badge. The event targets boys who are ages 10 to 17 years old and are located in the metro-Atlanta area.

7.3. CEISMC GT

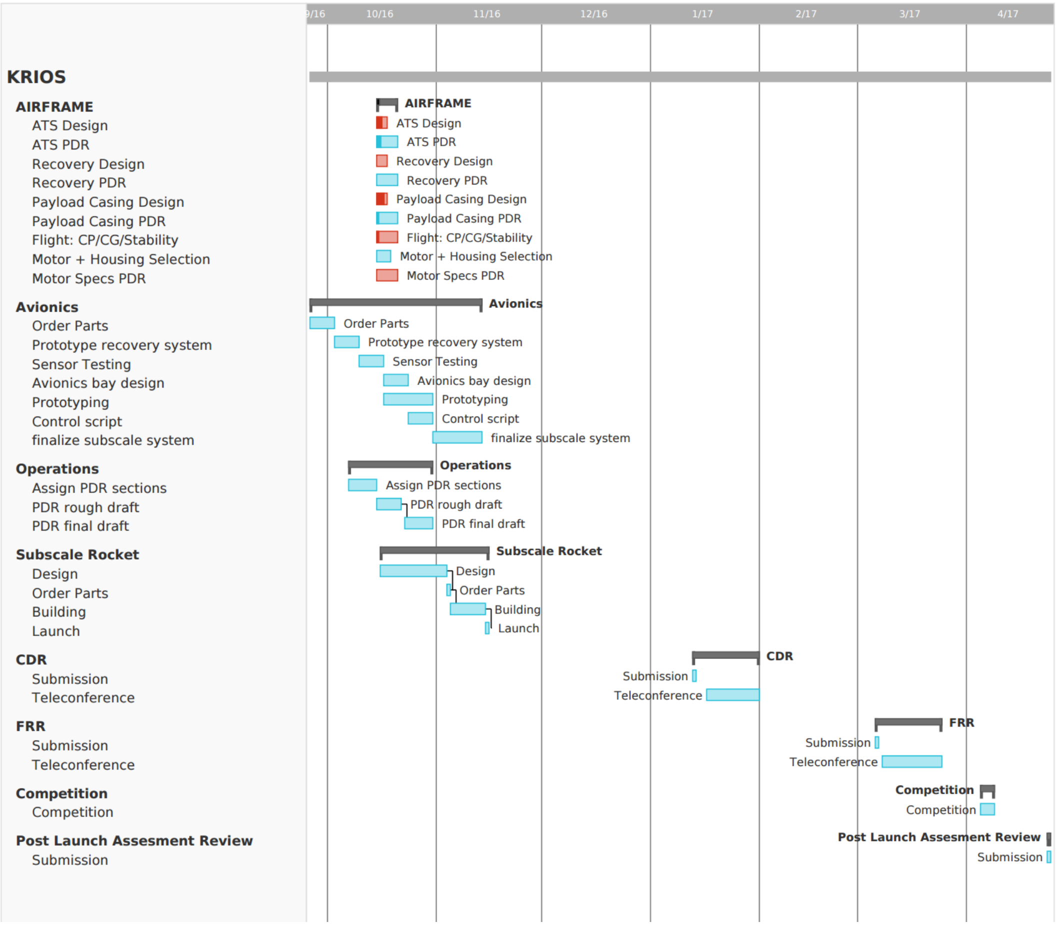
The Center for Education Integrating Science, Mathematics, and Computing (CEISMC) is a partnership uniting the Georgia Institute of Technology with educational groups, schools, corporations, and opinion leaders throughout the state of Georgia. Team ARES is dedicated to the enhancement of STEM education and will look forward to partnering with CEISMC and their events in the near future.

7.4. Peachtree Charter Middle School

Team ARES has run an after school program at Frederick Douglass High School for the past two years, teaching students the basics of rocketry and allowing them to design and build their own rockets. Aaron Campbell, the engineering teacher that has helped organizing this event with us, has moved to Peachtree Charter Middle School, and Team ARES has communicated with him and intends to continue the same program at Peachtree.

Appendix

A. Gantt Chart and Timeline



Gantt Chart

Task	Start Date	End Date
Airframe	10/15/2016	10/20/2016
ATS Design	10/15/2016	10/17/2016
ATS PDR	10/15/2016	10/20/2016
Recovery Design	10/15/2016	10/17/2016
Recovery PDR	10/15/2016	10/20/2016
Payload Casing Design	10/15/2016	10/17/2016
Payload Casing PDR	10/15/2016	10/20/2016
Flight: CP/CG/Stability	10/15/2016	10/20/2016
Motor + Housing Selection	10/15/2016	10/18/2016
Motor Specs PDR	10/15/2016	10/20/2016

Avionics	9/26/2016	11/13/2016
Order Parts	9/26/2016	10/2/2016
Prototype recovery system	10/3/2016	10/9/2016
Sensor Testing	10/10/2016	10/16/2016
Avionics bay design	10/17/2016	10/23/2016
Prototyping	10/17/2016	10/30/2016
Control script	10/24/2016	10/30/2016
finalize subscale system	10/31/2016	11/13/2016
Operations	10/7/2016	10/30/2016
Assign PDR sections	10/7/2016	10/14/2016
PDR rough draft	10/15/2016	10/21/2016
PDR final draft	10/23/2016	10/30/2016
Subscale Rocket	10/16/2016	11/15/2016
Design	10/16/2016	11/3/2016
Order Parts	11/4/2016	11/4/2016
Building	11/5/2016	11/14/2016
Launch	11/15/2016	11/15/2016
CDR	1/13/2017	1/31/2017
Submission	1/13/2017	1/13/2017
Teleconference	1/17/2017	1/31/2017
FRR	3/6/2017	3/24/2017
Submission	3/6/2017	3/6/2017
Teleconference	3/8/2017	3/24/2017
Competition	4/5/2017	4/8/2017
Post Launch Assessment Review	4/24/2017	4/24/2017
Submission	4/24/2017	4/24/2017

Project Plan Timeline