By:

Georgia Tech A.R.E.S.

NASA Student Launch 2017

Project Name: KRIOS

January 13th, 2017

Georgia Institute of Technology

School of Aerospace Engineering

270 Ferst Drive, Atlanta GA 30332 - 0150

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1. Introduction

1.1. Team Summary

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	samrapoport3@gmail.com
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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 Vehicle (SoAR) #571
NAR Contact, Number & Certification Level	Gerardo Mora gmora3@gatech.edu NAR Number: 98543 Certification Level: Level 2 Certified for HPR by NAR

1.2. Work Breakdown Structure

Team Autonomous Rocket Equipment System (A.R.E.S.) is composed of 22 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.

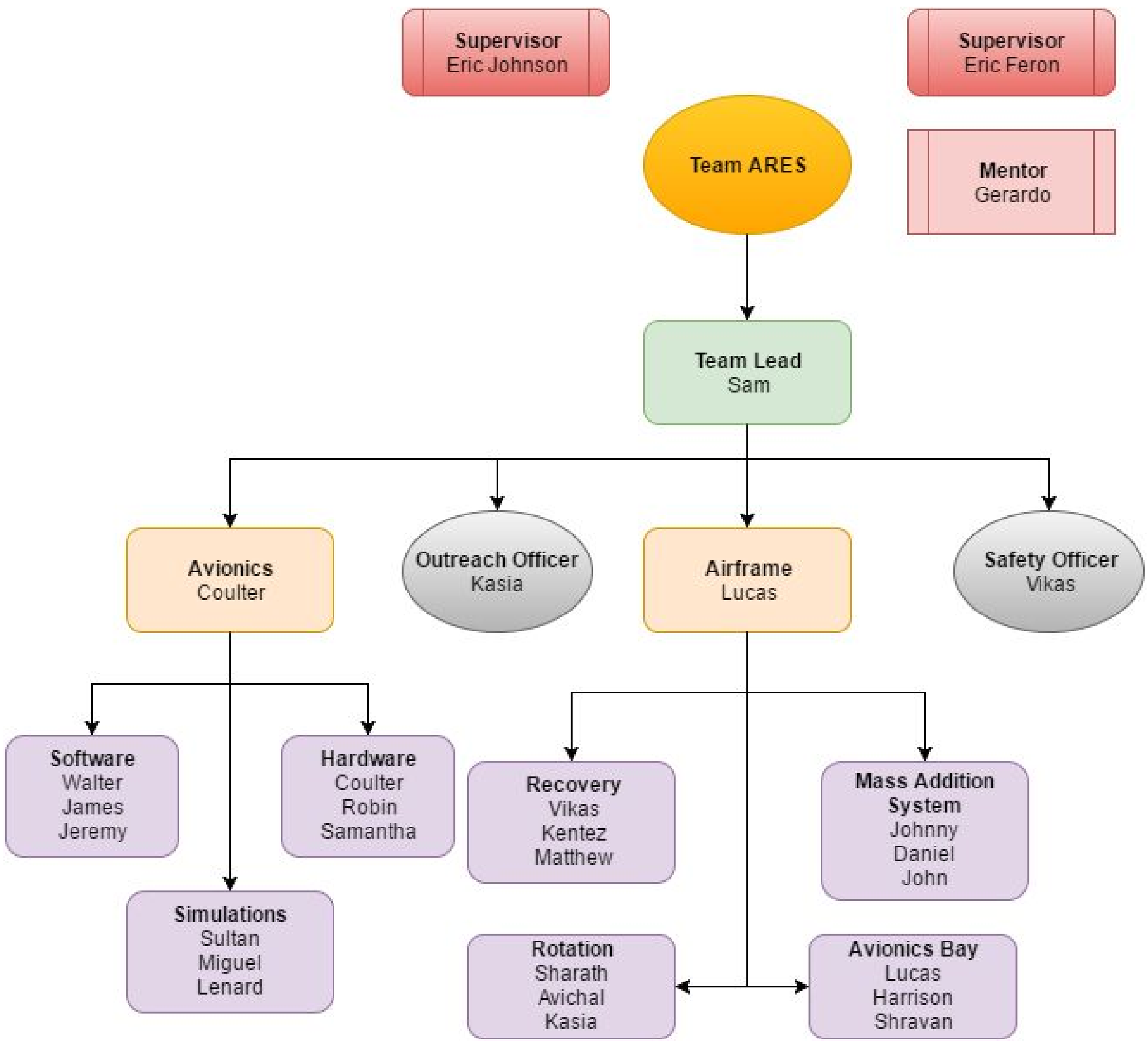


Figure 1.1.1: Team Structure

1.3. Launch Vehicle Summary

The Krios Launch Vehicle will be 102 inches in length, with a 5.5 inch diameter, G12 fiberglass tube. Before launching, its fully loaded weight is projected to be 545 oz. The launch vehicle's weight includes a 30% mass margin to account for any unexpected masses. Krios is designed to house its StrataloggerCFs, Pixhawk microcontroller, and 9V batteries in the avionics bay, which is located in the middle section of the rocket. The GPS unit will be located in a separate bay located in the nosecone and will be easily accessible between flights. The Aerotech L1150R rocket motor has remained as the motor of choice, despite the rocket's projected weight increasing over what was predicted in the CDR. This is largely due to the loss of the Apogee Targeting System from this design. The rocket's predicted apogee of 5297 ft is derived from its weight now rather than from what a drag inducing mechanism will bring it to. Upon reaching apogee, a 45 in drogue parachute will deploy from a compartment between the booster and avionics sections. A main parachute with a 120 in diameter will be deployed when the vehicle falls below 750 ft AGL in order 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. Avionics Summary

The Recovery System and the Roll Control System, comprised of the Pixhawk autopilot with varied attachments, will be the primary referenced payload components aboard the Krios. Each are autonomous flight systems designed to ensure a successful flight under the criteria of challenge 2 in the USLI student launch handbook. The flight systems of the rocket will have two primary responsibilities: automating the recovery, and controlling the roll of the rocket. A successful recovery system will deploy the drogue chute at peak apogee followed by the main roughly 800 ft with dual redundant deployment. The rolling maneuvers of the rocket will be autonomously controlled based on a closed-loop system that compares the calculated radial velocity with the obtained radial velocity from sensor data, and actuates the motors varied and accordingly. A successful roll controller will precisely perform two complete spins on the ascent followed by inducing an articulated counter moment to stop the roll.

1.5. Structural Changes Since PDR

There have been a few significant changes to the designs submitted with the PDR. One of the most prominent is the removeall of our Apogee Targeting System, to be replaced with a simpler but effective Mass Addition System. This internal mechanism, which would have deployed four “flaps” from the booster section to induce drag on the rocket, would have allowed us to precisely control the actual apogee of the rocket. It is worth mentioning that the design for the system was significantly expanded and refined since the submission of the PDR. However, there were drawbacks to the design that, ultimately, led to its removal. For one, it required several high-weight components (DC motor, lead screws, metal brackets, extra 9V batteries). It also proved to be a challenge that the programming team was not prepared to address. Thirdly, the system would be slow to deploy leading to lag times between actuation and results, causing inaccuracies and complex programming issues, along with structural issues of cutting large empty spaces in the airframe.

In addition to this, changes were made to the sizing of the body of the rocket, based on the results that were witnessed at our subscale launch. One of the main changes involved a redesign of the avionics bay. In the subscale design, the avionics bay was a tube that had an epoxied bulkhead at one end, and a removeable one at the other end. The issue we encountered was that wiring the bay to the key switches and epoxied bulkhead buried deep inside the tube were incredibly laborious tasks due to the minimal access that was built into the design. For this reason, the new design allows both bulkheads to be removed, thus significantly increasing the access that people assembling the avionics bay will have.

The last major change made to the structure of the rocket concerns the length of the tube compartments containing the parachutes. During our subscale flights it was observed that on both launches there were issues with the deployment of the parachutes. It was speculated that this occurred for two reasons: 1. The couplers were too short, and thus the parachutes were being packed too tight. 2. The direction of the separation explosions would push the parachutes deeper into the couplers, thus compacting them further rather than expelling them outward. For these reasons, the coupler lengths have been resized to include a 30% volume margin over what the listed packing volumes are. Furthermore, the separation charges are being moved to the side of the tube opposite where the shear pins are located, to try to force the parachutes out with each separation event rather than push them further into the rocket.

1.6. Payload Changes Since PDR

The suggestion was made by a distinguished mentor to use an all-encompassing Pixhawk auto-pilot developer board as opposed to a custom built embedded system in order to diminish build time and room for logical error. The Pixhawk contains the same sensors and capabilities as the original motor control system design and adds more. Therefore, to allow the team to focus more on controller design, the previous modular, embedded system design will be replaced entirely by the Pixhawk autopilot devboard. The recovery system of the rocket remains untouched and will be controlled by tandem StratologgerCF altimeters. Additionally, no air brake control system will be implemented on the full scale rocket; only roll control. The team decided the two systems would cause interference with one another that would be difficult to compensate for, and the function of the ATS can be achieved through precise mass measurements and modeling.

1.7. Project Plan Changes

Due to burn bans and all other launches occurring during times our school was not in session, our subscale launch has been delayed to January 14th. This has pushed back our CDR submission in order to include subscale launch data in our report. Concrete plans have been made to lead a merit badge clinic and campus tour for a local troop, and communication to arrange after-school rocket classes at a local middle school has been furthered. Funding has been secured through our Aerospace Department, and further outreach events may be planned through the department. A room in the Aerospace building has been allocated to us, allowing a permanent meeting and construction location for our team.

2. Project KRIOS Overview

2.1. Mission Statement

To maintain a sustainable team dedicated to the gaining of knowledge through the designing, building, and launching of reusable launch vehicles with innovative payloads in accordance with the NASA University Student Launch Initiative Guidelines. Project KRIOS specifically will launch a rocket reaching as close to an apogee of 5280 ft as possible, induce a roll of at least 2 rotations with counter roll, and further community enthusiasm for STEM and rocketry.

2.2. Mission Objectives and Mission Success Criteria

Table 2.2.1. Mission Objectives

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	Modular/flexible assembly construction	Conduct evaluation of time required to	Ability to access components without

assembly/disassembly time and effort		assemble/disassemble key components of vehicle	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: 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	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

parachute is deployed at apogee and a main parachute is deployed at a much lower altitude.			
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

3. Launch Vehicle

3.1. Overview

3.1.1. Rocket Requirements and Specifications

Our team designed a rocket to address the challenge of inducing a moment and counter-moment in-flight to make the rocket achieve 2 full rotations, and then return it to its original rotational position. The rocket is built to perform this task during ascent, and then activate its recovery systems during its descent to safely land such that all data from flight may be recovered. The overall, physical specifications are listed the table below.

Table 3.1.1: Overall Specifications

Dimensions	Mass	CG Location	CP Location	Est. Apogee	Max Vel
102 in length 5.56 in diam	545 oz	68.615 in	82.346 in	5298 ft	0.5767 mach

The rocket is comprised of 3 different sections. A list of the sections, their dimensions, and the internal systems/mechanisms contained within each section is included in Table 2.2.3 below.

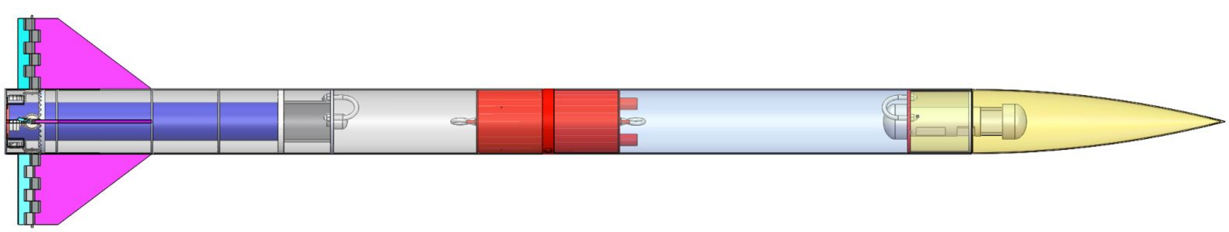


Figure 3.1.1: Full Rocket CAD

Table 3.1.2 - Main Components in Each Section

Sections	Internal Systems	Length	Estimated Mass
Booster	Fin + Roll Mechanism Booster Assembly **W**eight **A**ddition **T**ransmission **S**ystem (WATES) Drogue Recovery System	43.63 in	338 oz (loaded motor)
Avionics	Avionics Bay	12 in	53.4 oz
Nosecone	Main Recovery System GPS Bay CG Adjustment Bay	57.75 in	153.6 oz

3.1.2. Assembly of Sections

Figures 3.1.2 and 3.1.3 depict the places of separation along the rocket. Shear pins will be located on the side of the Avionics Bay that is closest to the Booster Section. They will also be placed on the shoulder of the Nosecone. The reason for this set up is largely due to the nature of the deployment of the parachutes. One of the setbacks we had during subscale launches was that the parachutes would sometimes become stuck inside the tubes even during separation, and it was suspected that the blast was compressing them into the tube. It is important to note that the Avionics Bay is not epoxied to the tube shown attached to it in Figure 3.1.3, but rather has rivets holding the two pieces together. While this will prevent shearing of the two parts, it allows for easy separation when using tools on the ground. This is important as it will significantly improve the ease of assembling the wiring within the avionics bay.

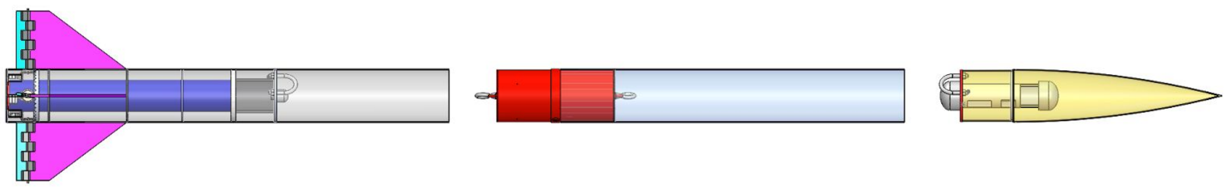


Figure 3.1.2. Figure Showing Separation of Sections

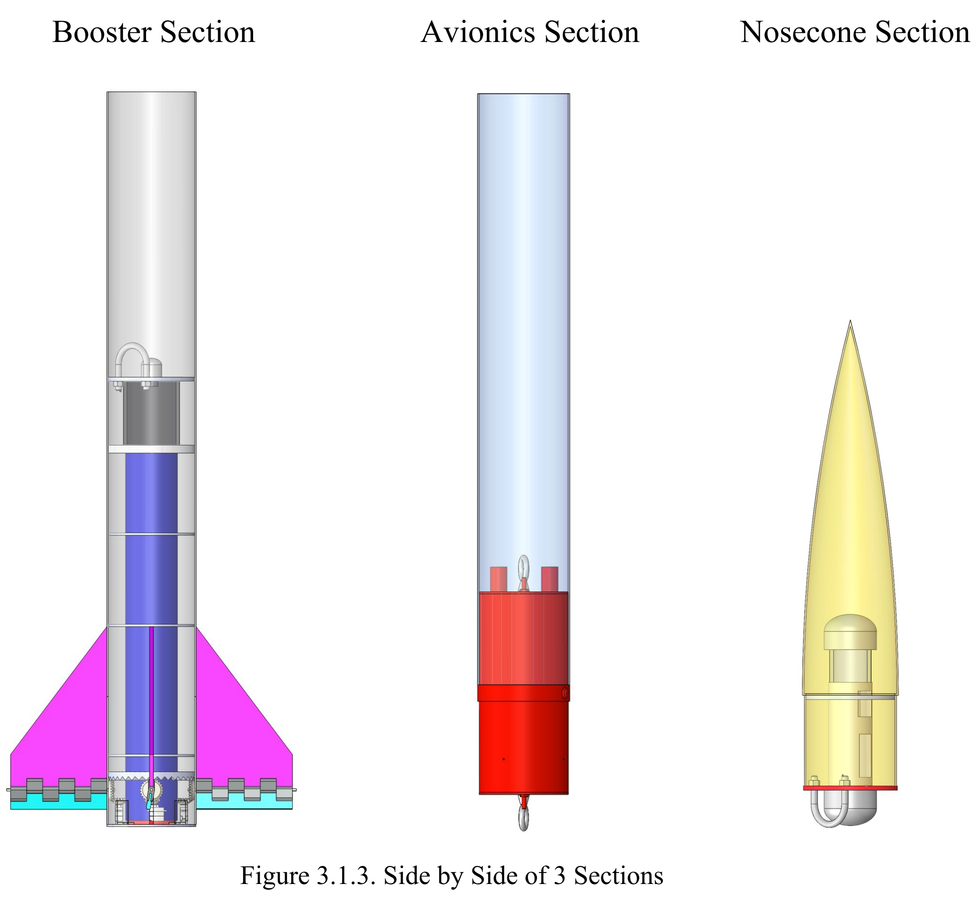


Figure 3.1.3. Side by Side of 3 Sections

3.2. Roll Control System

3.2.1. Overview: 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.

3.2.2. 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

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

$$t = .708\ secs$$

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.

3.2.3. 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 3.2.1, 3.2.2, and 3.2.3 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 Pixhawk devboard. 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 3D printed housing, allowing easy access by sliding out the inner tube from the rocket.

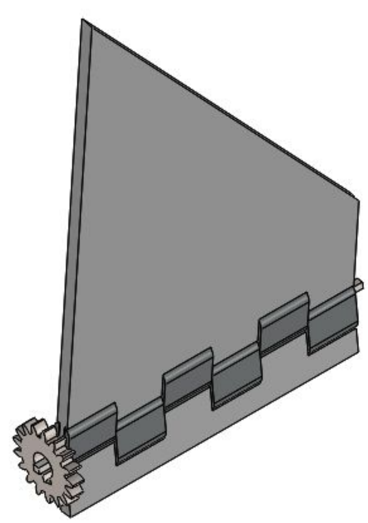


Figure 3.2.1 - Rocket Fin & Flap Mechanism

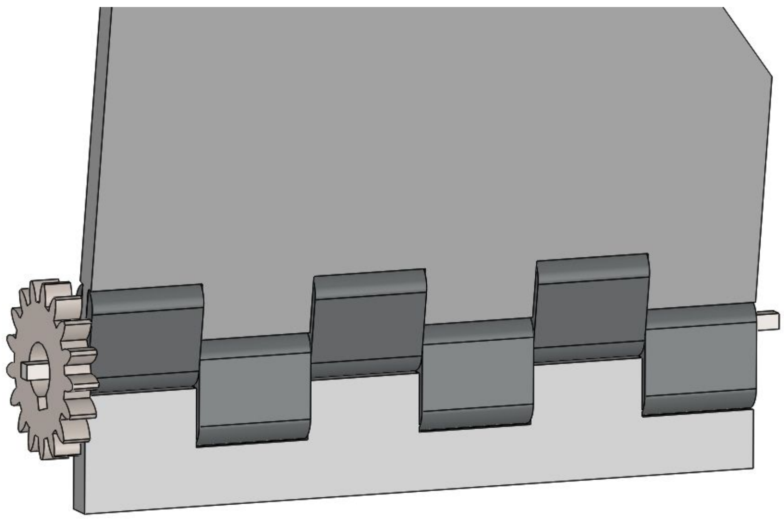


Figure 3.2.2 - Hinge Mechanism

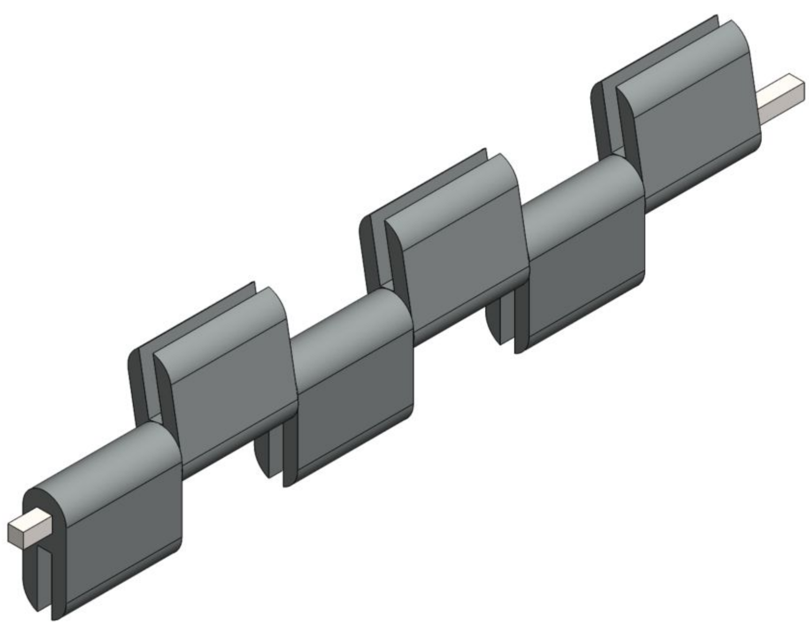


Figure 3.2.3 Hinge Assembly

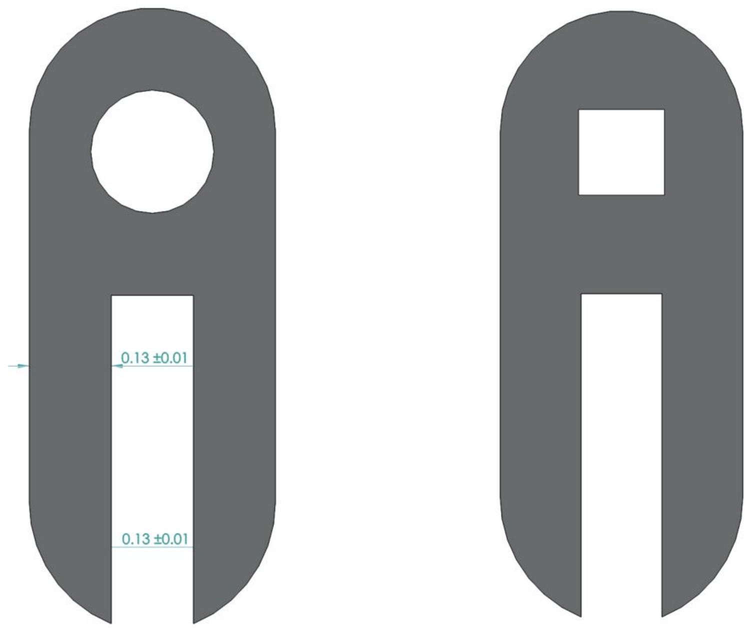


Figure 3.2.4 Fin Bracket (left), Rotating Flap Bracket (right)

3.2.4. Design Meets All Requirements with Acceptable Risk Levels

The launch vehicle is to be outfitted with 4 adjustable fins attached to the end of 4 stationary fins. The main purpose of these is to induce a roll in the launch vehicle. However, this presents a pressing issue that the failure of this mechanism would result in a catastrophic crash. Therefore it is imperative that the design be designed with enough safeguards such that when the launch vehicle is subject to aerodynamic loads on the variable fins, all fins shall maintain the same orientation. This will be accomplished with large gear ring that will constrain all the variable fins to the same orientation. The design will solve the issue of a single servo failure, effectively adding parity to the design.

The fins will be manufactured from fiberglass and the hinge mechanism will be constructed from a high strength steel. This will prevent fractures in the variable fin assembly. In order to prevent slip of the rotating fin on the drive shaft, the shaft will be machined into a square shape. This design will ensure that force transfer is efficient and there will be reduced risk of fin slip on the shaft. Additionally, the drive shaft will place its weight on the rocket frame thereby removing direct stresses applied to the servo motor directly. This will reduce the likeliness for failure due to servo motor burnout.

The failure mode of this assembly has now been limited to failures that would be catastrophic, but impossible to prevent without using significantly more expensive materials or weight. Therefore, the risk in this design has been minimized to as low as possible given the budget, manufacturing, and rule constraints.

3.2.5. Fin Shape and Style

The fins were designed and tested in OpenRocket software at the beginning of the semester; once an OpenRocket model of the entire rocket was created, differently shaped fins were added to the model and tested using the software's test flight simulator. After assessing all the fins, the design that provided the most lift and allowed for the most stable roll was chosen for the final rocket, and it is shown above in the previous section. The fins' main two purposes are to stabilize the rocket and to initialize a precise roll post-motor-burnout, and the design shown fulfills these tasks without as many errors as the other designs.

The fins' dimensions are shown below in Table 3.2.1. Each fin has two components – a stationary component and movable component (the flap). The stationary component will be attached firmly to the rocket using epoxy, and the movable component will be stationary for each launch but will be moved via a hinge mechanism, shown previously in Figure 3.2.3. The fins will be comprised of a fiberglass material; fiberglass is very strong and tends not to deform. Fiberglass is also more easily obtainable by Team ARES. The trapezoidal shape of the main fin will be easy to manufacture, and the flap is rectangular due to the simplicity of its addition to the bottom of the triangular fin. This way, the flap can be attached in a straightforward manner with little possibility of breaking.

Table 3.2.1: Fin Dimensions

Dimension	Length (in)
Fin root chord	10
Fin tip chord	4.5
Fin semispan	5.25
Length of fin mid-chord line	5.55
Distance between fin root leading edge and fin tip leading edge parallel to body	4.5
Aileron chord - the bottom portion of fin that is capable of actuation	1
Fin thickness	.25

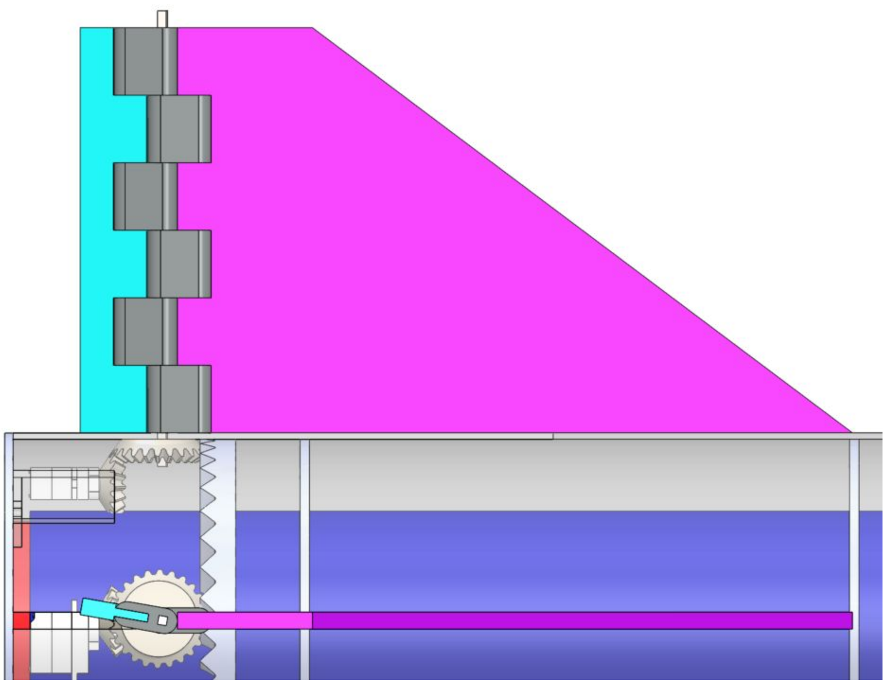


Figure 3.2.5 - System on Rocket

All of these components will either be purchased online, or manufactured from bulk material using our campus machine shops. Table 3.2.3 provides additional details on this topic.

Table 3.2.2. Component Breakdown

Component	Material	Manufacturing Method
Small Gears	6061 T6 Aluminum	N/A → Purchased
Large Ring Gear	6061 T6 Aluminum	Waterjet
Fin	G10 Fiberglass	Waterjet + Mill
Rotary Flap	G10 Fiberglass	Waterjet + Mill
Hinges	6061 T6 Aluminum	Waterjet
Square Shaft	Carbon Steel	N/A → purchased
Shaft-Servo Interface	ABS Plastic	3D printed

3.3. Booster Assembly

3.3.1. System Description

The Booster assembly exists to center the motor within the Booster section of the rocket, and to ensure that it is prevented from shooting up into the body of the rocket, or from falling out of it. This design includes 3 Fiberglass Centering rings, each ⅛” in thickness. They are spaced such that the fins will have a slot in the middle of them to fit over the lowest centering ring. At the top of the assembly is a 0.5” Plywood Thrust Plate, which serves to prevent the motor from moving up relative to the airframe.

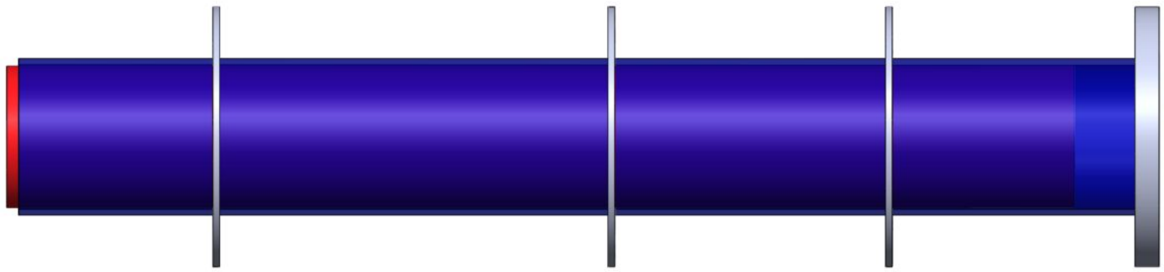


Figure 3.3.1. - Booster ASSY CAD

3.3.2. System Manufacturing and Assembly

Both the centering rings and the thrust plate will be cut from sheets of stock fiberglass using our campus Omax Waterjet machine. To assemble, the thrust plate will first be place at the end of the tube and centered. A epoxied fillet between the cardboard tube and the thrust plate will be made, though it will not be a structurally significant joint. The 3 centering rings will be moved over the tube and epoxied to the positions desired. Epoxy lining will be place inside the 5.5” Tube where the centering rings and thrust plate will end up. Once the booster section is slid in, a significant epoxy fillet will be made from the other end of the 5.5” Tube, thus preventing the thrust plate from have any vertical freedom of motion.

3.3.3. Load Analysis on Thrust Plate

By taking a model of the thrust plate (with the correct material), a simulation can be run in solidworks to determine whether the stresses exerted on the place exceed its Yield Strength. A few assumptions have to be made when creating the simulation.

Assumptions:

1. The outer surface of the bulkhead is fixed geometry, meaning the epoxy guarantees it will not fail before the wood does
2. The motor acts on the center of the plate with a contact area of 1” dia circle

3. The max force created by the motor on the thrust plate is 1310 N, as pulled from the motor's data sheet

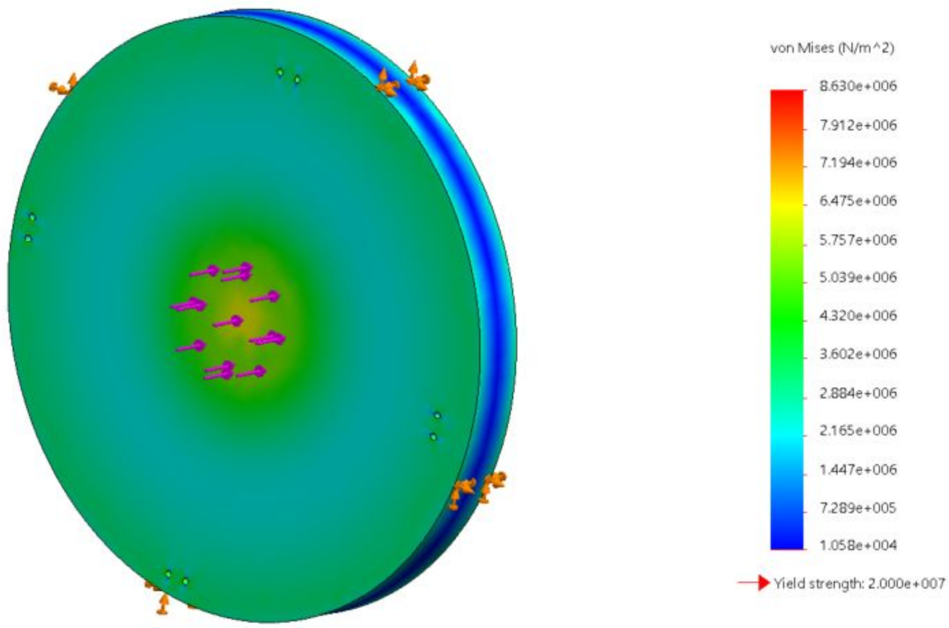


Figure 3.3.2. - Load Analysis on Thrust Plate

Results:

It is clear to see that, considering a material Yield Stress of 2e7 N/m^2, the maximum stress generated by the motor is only about 8.63e6. This is significantly lower than the Yield Stress so there it be said that a 0.5" Plywood thrust plate is more than sufficient to hold the motor.

3.4. Weight Addition Transmission Equipment System

3.4.1. System Description

The WATES was created as a way to accurately achieve an apogee of 5280ft with a lighter, simpler, more robust, time-independent system with less possible failure points. To reach target apogee, a motor with predicted apogee above 5280ft would be chosen in combination with a calculated mass would be secured in a compartment directly above the Thrust Plate. This mass would be calculated so that the new apogee would be close to 5280ft, using Openrocket, other simulations, and comparison to real flight data from the subscale flights and full-scale test flights.

3.4.2. System Assembly

The compartment, as shown in Figure 3.4.1 in an exploded view, shows the 4 components to the system: A 3” dia PVC pipe, a bulkhead that fits in the 5.5” tube, and a smaller, threaded pvc pipe + cap. To assemble it, the 3” pipe is first epoxied to the Thrust Plate. Then, the bulkhead can be epoxied to the other end of the tube, as well as epoxied to the outer airframe tube. This bulkhead will need to be pre-assembled with a U-bolt as it is involved in the Drogue recovery system. Once epoxied, the small pvc pipe can be epoxied into the small hole in the bulkhead. Screwing on the pvc end cap provides a temporary seal to the compartment.

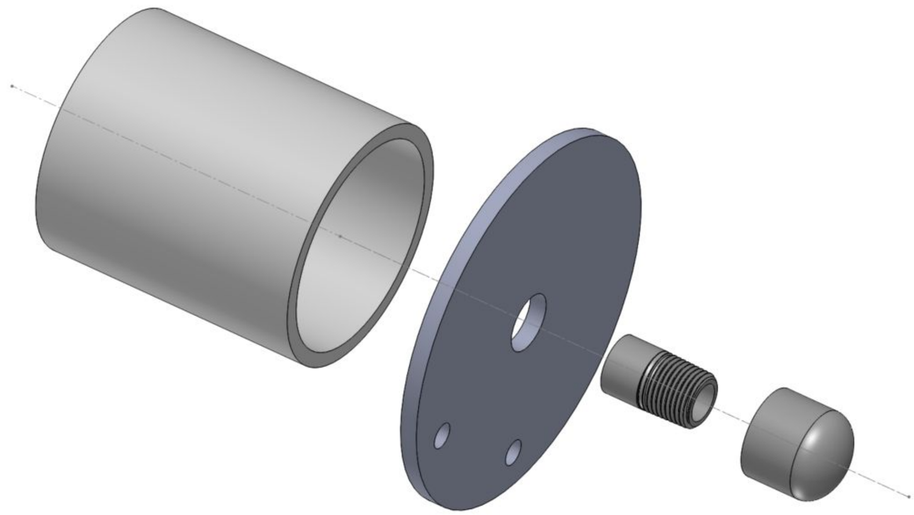


Figure 3.4.1 - Exploded View of MAS

To get a better sense of how the system looks on the rocket, see Figure 3.4.2 below. On the far left you can see the 0.5” Thrust plate, and just to the right of it is where the assembly from 3.4.1 lies. To add mass to the compartment, the pvc end cap can be screwed off, allowing for the user to pour a pre-defined mass of sand into the smaller, 0.5” pvc pipe. Once poured, the cap can be screwed back on and the compartment is set.

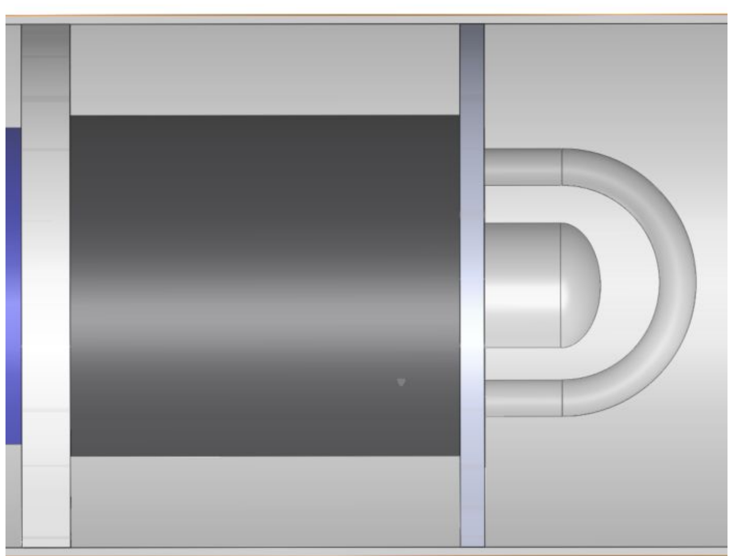


Figure 3.4.2 - WATES Assembled Inside Rocket

3.4.3. Reasoning for choosing WATES over Apogee Targeting System

One reason we forewent the ATS system was due to the turbulence and break in flow that the drag inducing flaps would cause. After running ANSYS simulations, the flow disruption caused by the ATS would be significant and would cause separated flow for the bottom fins, creating instability and reducing the effectiveness of the Roll Induction System. Another reason is the actuation speed of the motor controlling the ATS flaps would be slower than necessary to induce drag using an autonomous system. The delay in activating the motor combined with the requirement of frequent data sampling an autonomous system would need to accurately control the flaps to achieve proper apogee would lead to an ineffective system unless there was a very large amount of testing and flight data to produce refined models. The large amount of time and resources it would take to make this system effective, along with a larger amount of possible failure points, led us to choose the WATES system which is simpler, safer, less resource intensive, and more reliable.

3.5. Drogue Recovery System

3.5.1. System Description

Our chosen drogue parachute is a 45” Ripstop Nylon Top Flight Parachute. Using a packing volume reference sheet (http://www.b2rocketry.com/PDF%20files /SkyAngle%20Packed%20Length.pdf) it was determined that for our 5.5” airframe, the packing volume would be <6” in height. By then adding an extra 3.5” on each side of the parachute, we can comfortable fit the 16 ft of shock cord as well.

3.5.2. System Assembly

A CAD of the system can be seen below (Figure 3.5.1). The orange cylinder represents the volume that will be occupied by the Parachute. On the right is the beginning of the Avionics Bay, which is shown to have a large eye bolt protruding from the bulkhead. On the far left is the end of the WATES compartment. A U-bolt is used here due to the center of the bulkhead being occupied by the PVC end cap. There will be approximately 10 ft of shock cord on the left, and 5 ft to the right of the Parachute.

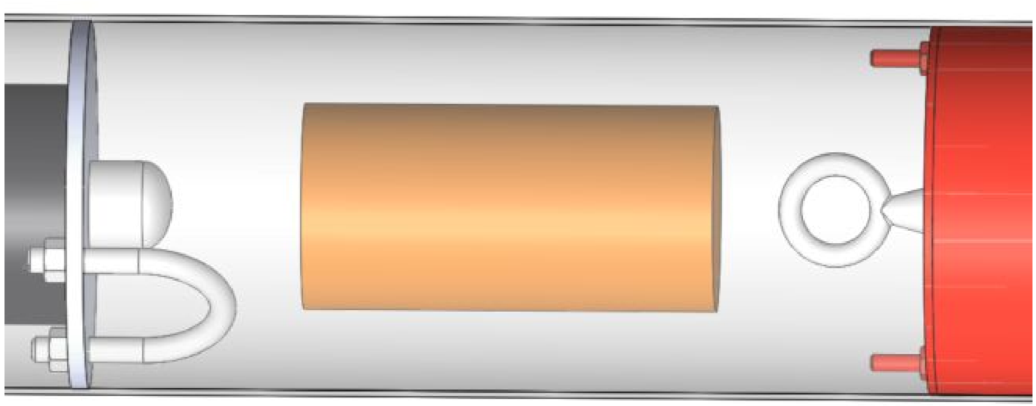


Figure 3.5.1. - Representation of Drogue Chute Inside Rocket

3.5.3. Description of Separation

In our subscale launch we tried to put blast caps on the ends of the avionics bay, such that the parachutes were pushed into their respective rocket sections during the blast. However, we found that the pressure of the explosion was compacting them deep down into their tubes, thus creating too much friction with the wall of the tube to ever get pulled out. For this reason we will try used capsules that are wired from the avionics bay, and routed down such that the sit right above the WATES system and just below the parachute (use Figure 3.5.1 for reference). This would ensure that this compacting of the parachute would not occur.

3.6. Avionics Bay

3.6.1 System Description

The purpose of the Avionics Bay (A-Bay) is to contain, protect, and enable the function of all avionics components. Additionally, it serves as a separator between the main and drogue parachutes. Avionics are mounted to a sled inside of the bay. The A-Bay is sealed on both ends to protect the electronics from hot ejection gases. The fiberglass structure shields the avionics from any impacts experienced during flight. A hole in the A-Bay enables the avionics to measure the barometric pressure of the atmosphere surrounding the vehicle.

3.6.2 System Assembly

The Avionics Bay (A-Bay) is housed inside of a 12in section of fiberglass coupler tube. Avionics components are mounted onto a 8.75in by 3.75in plywood sled contained in the coupler. Two 14in long threaded rods are attached along the length of the sled, so that the extend out of the coupler. On the aft end of the A-Bay, the rails run through and are attached to a fiberglass cap. This cap is formed by connecting together two concentric disks: one with the same outer diameter as the coupler, and one with the same inner diameter as the coupler. A second cap, which is free, is slid of the rails at the top of the A-bay. This cap is secured by nuts placed over the threaded rail. When the nuts are tightened, both caps are pulled against the edge of the coupler, forming a seal.

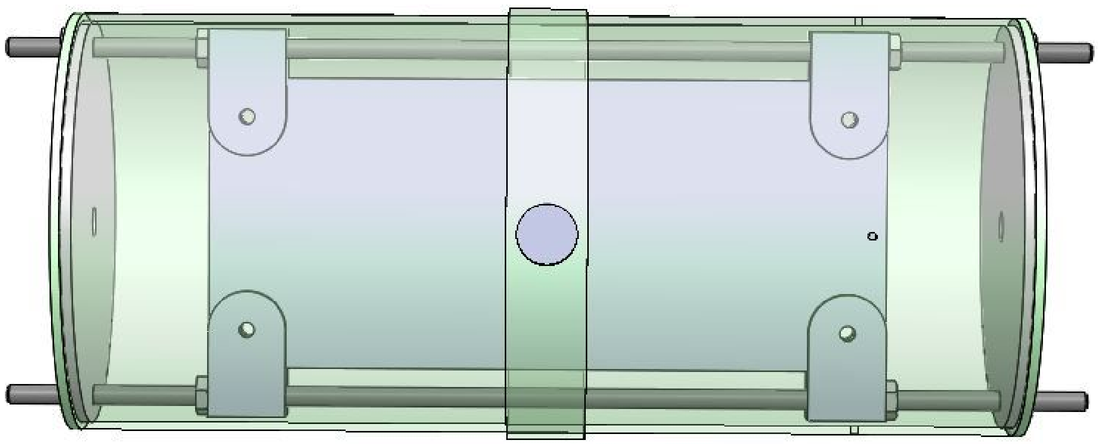


Figure 3.6.1 - Top View of Empty Avionics Bay

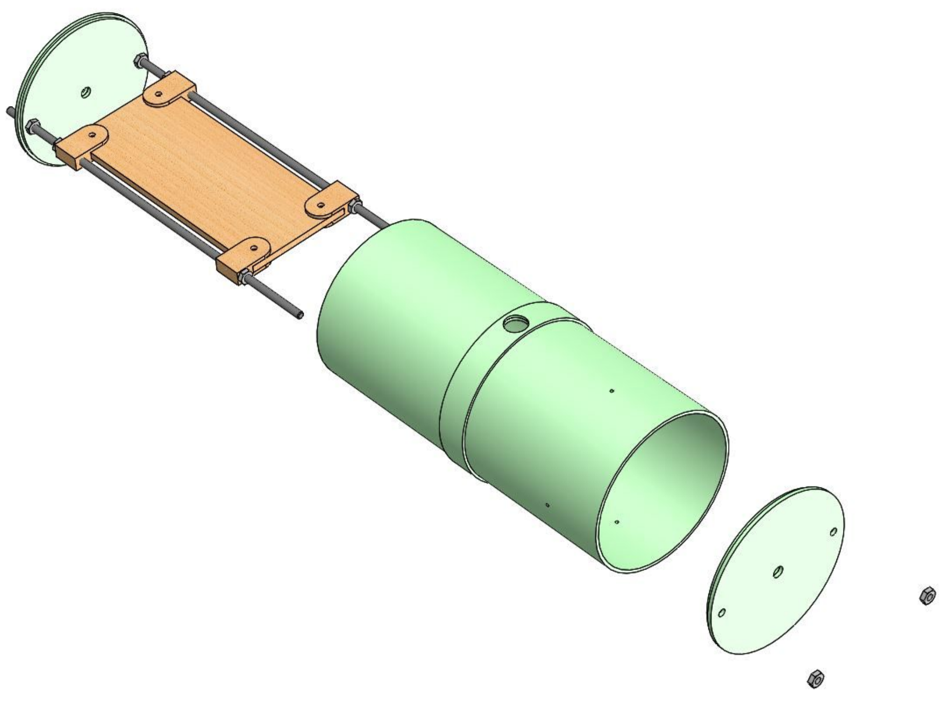


Figure 3.6.2 - Exploded View

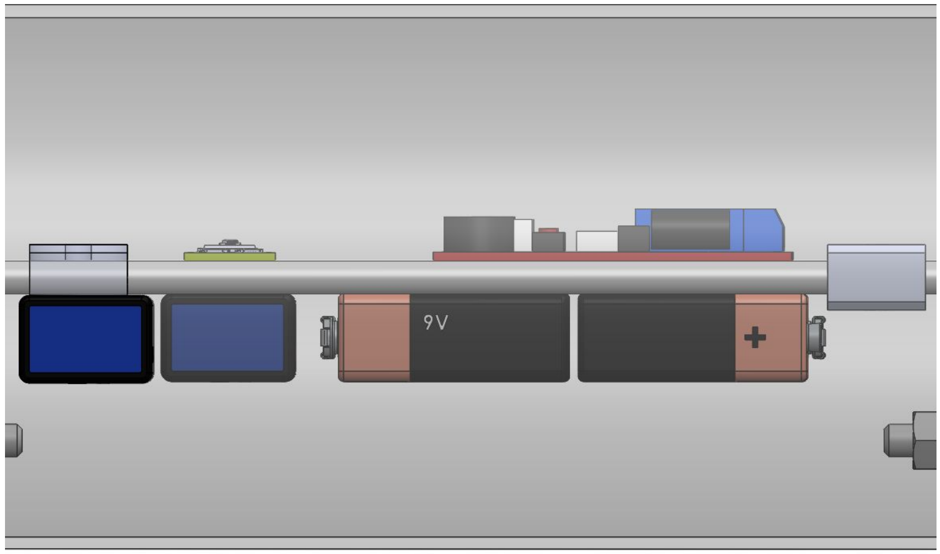


Figure 3.6.3 - Tray With Mounted Hardware

3.7. Main Recovery System

3.7.1. System Description

Just above the avionics bay, before the nosecone, is the main parachute bay. To ensure that each section of the rocket lands with less than 75lb-ft of Kinetic Energy, a 120” TFP Parachute has been chosen. This will ensure that our landing velocity falls below 15 ft/s. The calculations are shown below:

According to OpenRocket, the vehicle will touchdown with a velocity of 18.9ft/s. The most massive section of the vehicle upon touchdown will be the booster section, with a weight of 208oz. First convert this weight into a mass.

$$208oz * \frac{1lbf}{16oz} * \frac{1slug}{32.17lbf} = .404\ slugs$$

Now kinetic energy may be calculated using the equation:

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

$$E_k = \frac{1}{2} * .404\ slugs * (18.9\ ft/s)^2$$

$$E_k = 72.2\ lb \cdot ft$$

3.7.2. System Assembly

Like with the drogue parachute, the main parachute is located between two, epoxied, .25” Fiberglass bulkheads, thus ensuring that the force of deployment does not create stresses that exceed the surement methods of the recovery system. Figure 3.7.1 is provided below to show how the forces of deployment do not exceed the Yield Stress of the Fiberglass bulkheads.

3.7.3. Description of Separation

Unlike the Drogue System, deployment of the main parachute will occur via conventionally placed blast caps on the end of the avionics bay. This will minimize the chances of the parachute from being compacted by the force of the charges, and thus being prevented from getting pull out and fully deploying. A load analysis verifying that the pressures creating during separation are not beyond what the bulkheads can handle is shown below.

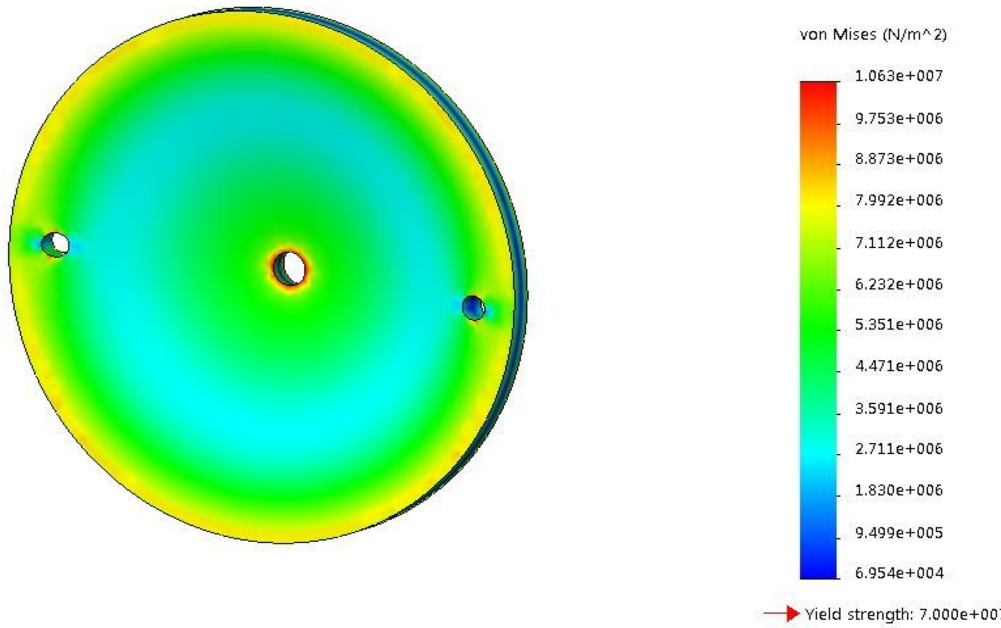


Figure 3.7.1 - Load Analysis on Bulkhead

3.8. GPS Bay

3.8.1. System Overview

The GPS Bay is a small assembly located in the nosecone of the rocket. It exists to allow the GPS unit to operate in conditions that are not prone to electrical interference, such as in the avionics bay. It also has its own 9v power supply, making it a completely separate system from those in the avionics bay. The most important aspects of this design are ensuring that the GPS unit is placed in a safe environment with low risk of a mechanical failure. Figure 3.8.1 shows its precise location along the upper section of the rocket.

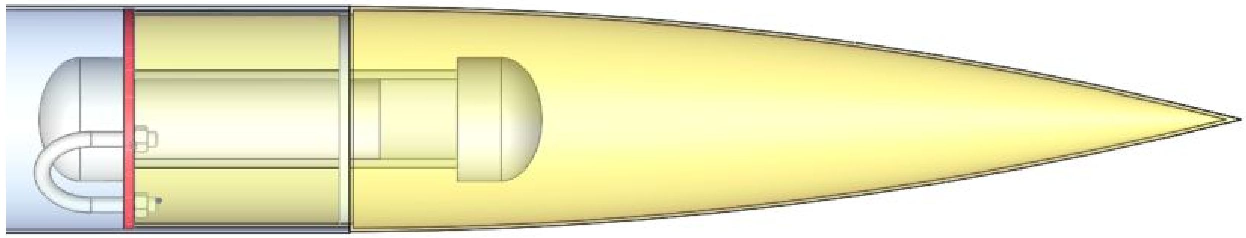


Figure 3.8.1 GPS Bay on Rocket

3.8.2. System Assembly

Figure 3.8.2 shows an exploded view of the system. Like with the WATES compartment, this system is design using PVC hardware. The capsule itself, which is just a 2.5" PVC pipe with threaded ends, is sealed at one end first by screwing on an end cap. Then, the GPS and 9V units can be placed inside the rigid foam structure that has been precut with their profiles, such that they can sit within the cylinder of foam and not protrude. This foam assembly is then slide into the tube such that the entire assembly can be sealed.

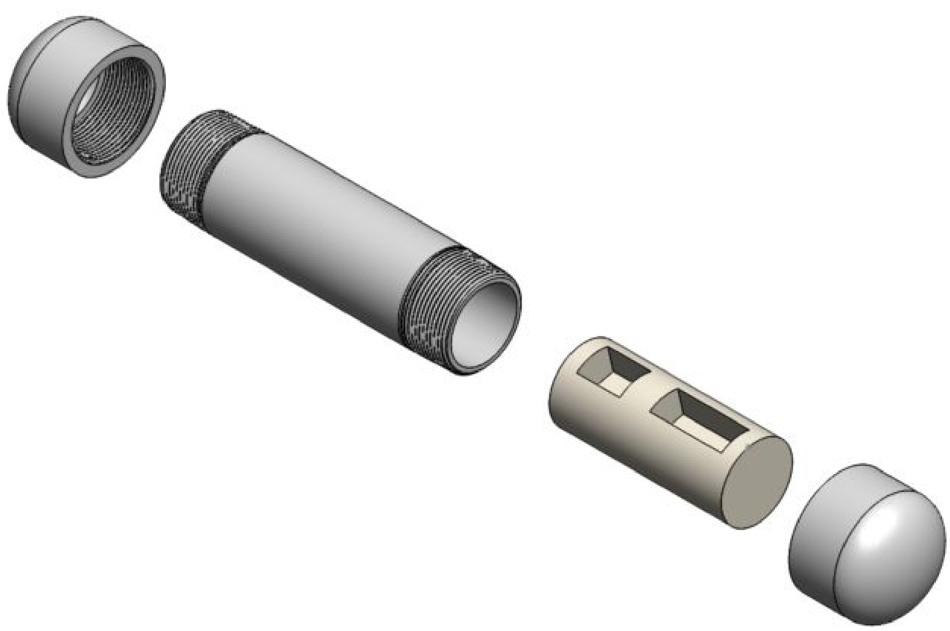


Figure 3.8.2 Exploded GPS Capsule

In terms of assembling the capsule onto the rocket, if we refer back to Figure 3.8.1, we can see a more clear image of what the final product should look like. There is an epoxied centering ring in the shoulder of the nosecone, and another ring in the 5.5" tube just to the left of the shoulder. This centering ring is secured by the clamping force that the threaded cap provides. The Capsule will be mounted to these centering rings prior to their securement inside the rocket. This mean that, like the booster section, the capsule + centering ring assembly will be slide into the rocket and be epoxied such that it will be one rigid, unchangeable assembly located within the nosecone as shown. The only removable pieces to the assembly are the end cap on the left, and the bulkhead which it holds in place. The end cap will be unscrewed whenever the GPS unit needs to be removed or replaced.

3.9. CG Adjustment Bay

The CG Adjustment Bay refers to a sub-section within the GPS bay. If you refer back to Figure 3.8.1 and look closely, you will notice that the foam cylinder does not occupy all of the space inside the PVC pipe. That extra space exists so that iron masses can be added to move the CG. This would be significant if, after production of the rocket, the CG is slightly lower than was calculated. An extra pound of mass that far up along the rocket could move the CG by a couple inches.

3.10. Recovery System

3.10.1. Final System Design

The recovery system has not changed since the preliminary design review. The primary component of the rocket's recovery system, the Perfectflite StratloggerCF altimeter is capable of measuring altitude through the use of a barometric pressure sensor. The StratoLogger altimeter additionally has the ability to deploy parachutes by ejecting a large output current at the desired height. Two of these will act as the sole electrical components of the recovery system. They will both be powered independently and connected to both the main and drogue chutes in order to ensure dual redundant chute employment. Additionally, one altimeter is set to blow its charges at a delay of one second. As seen in figure 3.10.1, the StratoLogger CF is an industry standard model rocketry altimeter. Through its robust and easily modifiable design, it provides a desired reliability for the recovery system of the rocket.. The stratologger altimeter was carefully selected in order to ensure successful recovery: the subscale launch confirmed that it can be both trustworthy and reliable.

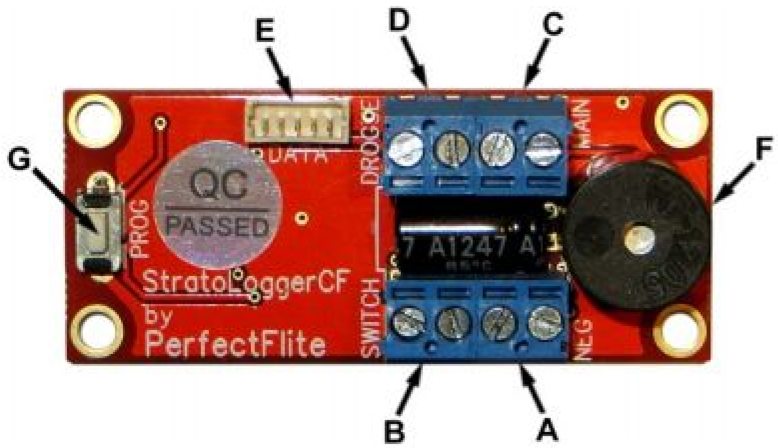


Figure 3.10.1: The StratologgerCF altimeters with connection labels (for reference)

3.10.2. Parachute and Attachment Hardware

The recovery system will consist of one drogue and one main parachute of 120” and 45” 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 above the avionics bay. 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 below the avionics bay. 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 700 ft and 800 ft, further decelerating the rocket so that the impact kinetic energy is below 75 ft-lbf. The main parachute will also prevent a considerable amount of horizontal displacement that occurs as a result of wind gusts and drift.

Figure 3.10.2: Location of parachutes in rocket

Both parachutes will be fabricated from rip-stop nylon in order to support the weight of the launch vehicle. Parachutes will be secured in their individual sections using an insulated material to prevent the ignition of the nylon due to explosive charges that will separate the different sections of the rocket sections during descent deployed from the blasting caps that are attached to 0.25 in bulkheads which seal the avionics bay from the rest of the rocket's compartments. The parachutes will be attached and secured to the rocket via the shock-cords which are connected to U-bolts installed onto the respective bulkheads/centering rings insulating each section of the rocket from pressurization.

Rather than relying 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.

3.10.3. Electrical Components and Redundancy

As noted in section 3.10.1, the two stratologger altimeter will be the sole electrical components of the recovery system. The reason for this is to ensure that the recovery of the rocket is completely independent of the flight control system system and minimize risk to ensure successful recovery.   The tandem altimeters, each with an independent 9V power supply and their own drogue and main chute deployment charges create a dual redundant system. If one altimeter were to fail, the other would be able to recover the rocket. One altimeter is set to have a delayed drogue and main charge firing so that both blasts will not fire at the same time, which could potentially damage the rocket. Figure 3.10.3 below depicts the StratologgerCF wiring path and illustrates the dual redundant system.

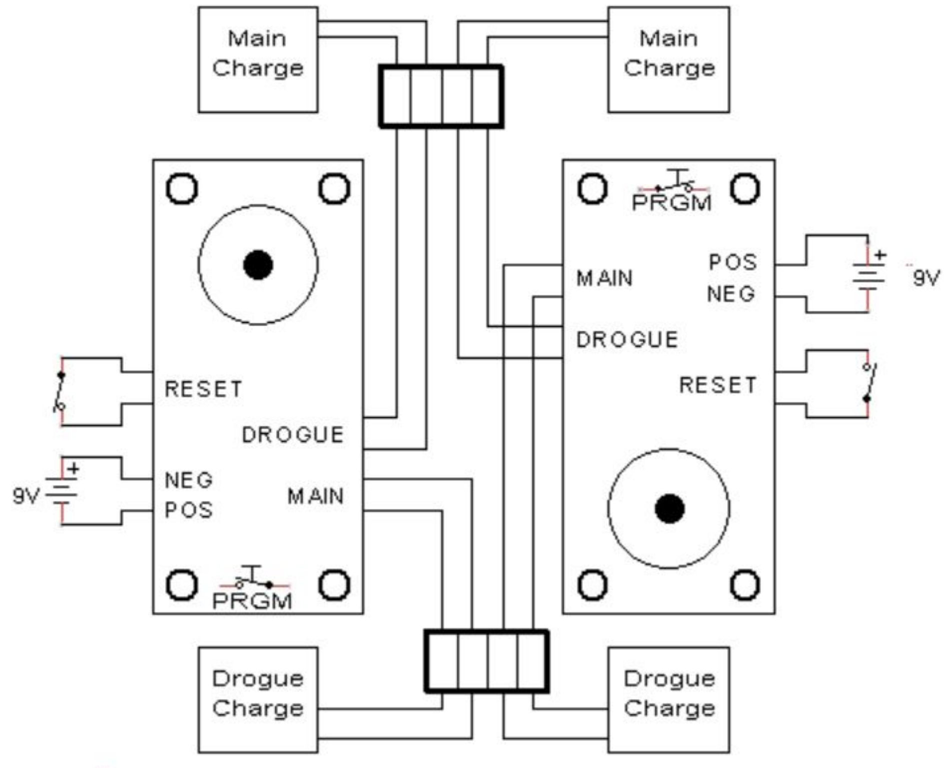


Figure 3.10.3: Dual Redundant System

3.10.4 Operating frequency and locating tracker

The rocket will have live GPS capabilities through the implementation of the Eggfinder GPS system; comprised of the RX Receiver module, connected to a ground station, and a TX transmitter module, embedded into the nosecone of the rocket. The two will communicate through 900 MHz ISM band signals. 100 mW will enable roughly 10,000 feet of lossless communication: enough for the purposes of the task at hand. The eggfinder will satisfy the competition requirement of live tracking capabilities and allow the team to know the exact latitude and longitude of the rocket throughout the flight, and, more importantly, to find the rocket upon recovery.

3.11. Launch Vehicle Performance Analysis

3.11.1. Sufficient Motor Mounting and Retention

The motor mount in the Krios rocket consists of 4 main parts – centering rings, an inner tube, a thrust plate, and a motor retention plate. There are three fiberglass centering rings epoxied into place within the rocket's outer frame, and these rings hold the cardboard inner tube and keep it centered.The motor is inserted into the motor casing, which is then slid into the inner tube. The fiberglass thrust plate is located at the top of the motor within the rocket tube. The thrust plate is also epoxied into place above the motor, and it prevents the rocket motor from shooting into the rocket when it is ignited. At the bottom of the main tube is an aluminum plate with a screw on cap system to prevent the motor from sliding out before, mid, or after flight by gravity.

The inner tube secured by fiberglass centering rings will make sure the motor stays aligned and straight in the rocket, the thrust plate prevents the motor from moving forward in the rocket, and the retention plate screwed into the main tube of the rocket will prevent the motor from falling out. Below is an image of the motor tube inserted between the three center rings; there will be a main body tube that goes around the center rings. The retention plate will be attached to the motor and the center ring on the right of the image, and the thrust plate will be located at the top of the motor (leftmost part of the image).

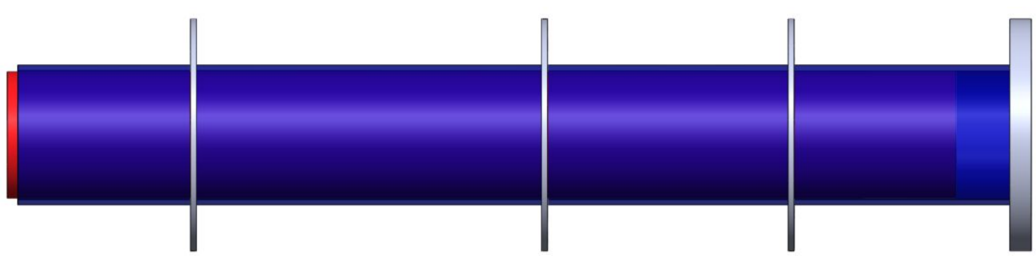


Figure 3.11.1 Motor and Center Rings

3.12. 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 over 34 pounds at launch.

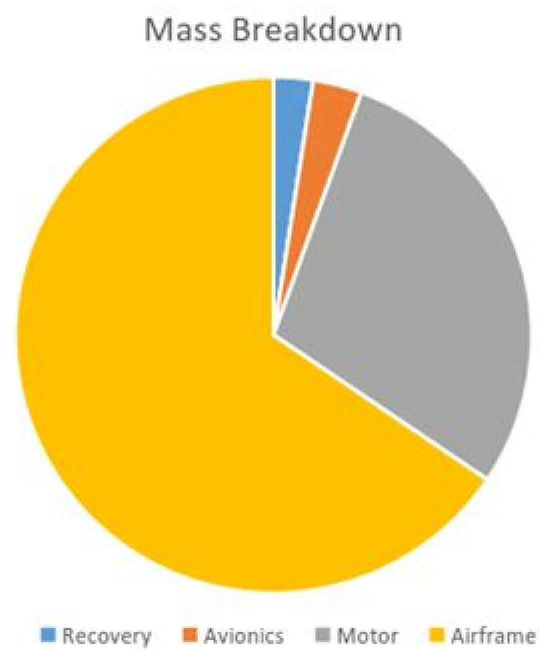


Figure 3.12.1: Mass Breakdown by System

Table 3.12.1 Rocket Mass Distribution

Booster Section Total: 334 oz		Avionics Section Total: 53.4 oz		Nosecone Section Total: 157.6 oz	
Components	Mass (oz)	Components	Mass (oz)	Components	Mass (oz)
Motor Tube	5.73	5.5” Tube	1.69	Nosecone	17
Centering rings	8.12	Coupler Tube	22	Centering rings	4.18
Bulkhead	6.07	Avionics Eqpt	18	GPS PVC Tube	4.47
Thrust Plate	12.1	Bulkheads	11.68	GPS Package	4
MAS	50.9	-	-	5.5” Tube	60.8
Fins	23.4	-	-	CG Adjustment	17
Drogue Chute	6	-	-	Main Chute	45
Shock Cord	5.61	-	-	Shock Cord	5.61
5.5” Tube	73.7	-	-	-	-
Fin-Spin Mech	8	-	-	-	-
Loaded Motor	130	-	-	-	-

3.13. Subscale Flight Results

3.13.1. Subscale Flight Simulation

A simulation of the subscale rocket was conducted using forecasted conditions for the day of the launch, which are described in Table 3.13.1.

Table 3.13.1: Flight Simulation Conditions

Condition	Value
Altitude	500 ft
Wind speed	4 mph S

Temperature	71 F
Latitude	28.61°
Pressure	1029.80 mBar

Figure 3.14.1 below shows the calculated flight profile of the subscale rocket using the flight conditions from Table 3.14.1. Velocity, altitude and acceleration were plotted as a function of time. Apogee occurs at approximately 14s. At apogee, the ejection charge for the drogue chute will fire, slowing the descent rate to 21 fps. Deployment of the main chute will occur around 739 ft above the ground level to further decelerate the launch vehicle to approximately 11 fps. The entire flight duration is estimated to be 192s. Table 3.14.2. contains the details of the time, altitude, velocity, acceleration and drag at certain events during the course of the launch.

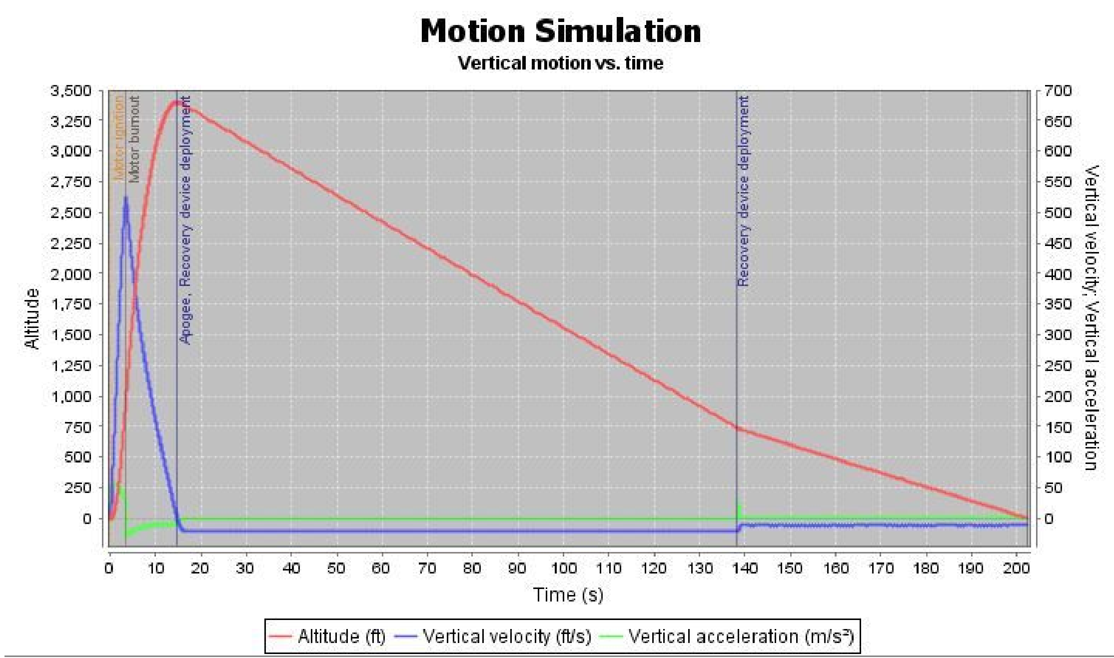


Figure 3.7.1. Subscale Motion Simulation

Table 3.13.2: Simulated Flight Data

Event	Time(s)	Altitude (ft)	Total velocity (ft/s)	Total acceleration (ft/s²)	Drag force (N)	Drag coefficient
Ignition	0	0	0	11.107	0	0.54471
Lift Off	0.06	0.08619	4.3167	133.51	0.001611	0.5442
Launch rod disengaged	0..35	8.0287	50.803	166.2	0.91531	0.52818
Burnout	3.5216	978.08	514.45	92.911	69.084	0.56572
Apogee	14.271	3172.6	64.4	32.243	2.0324	0.52898
Drogue Chute	14.276	3172.6	96.007	612.73	678.63	
Main Parachute	127.88	739.49	21.486	4.2476	36.53	
Ground Impact	192.91	-4.243	11.182	4.3493	34.256	

The simulated apogee of the testbed vehicle is 3388 ft. (0 mph wind speed). 3388 ft is ample altitude to test the functionality of all testbed components. Figure 3.13.2 and Figure 3.13.3 show the drift profiles and lateral distance traveled by the rocket in simulations with average wind speeds set to 5 mph.

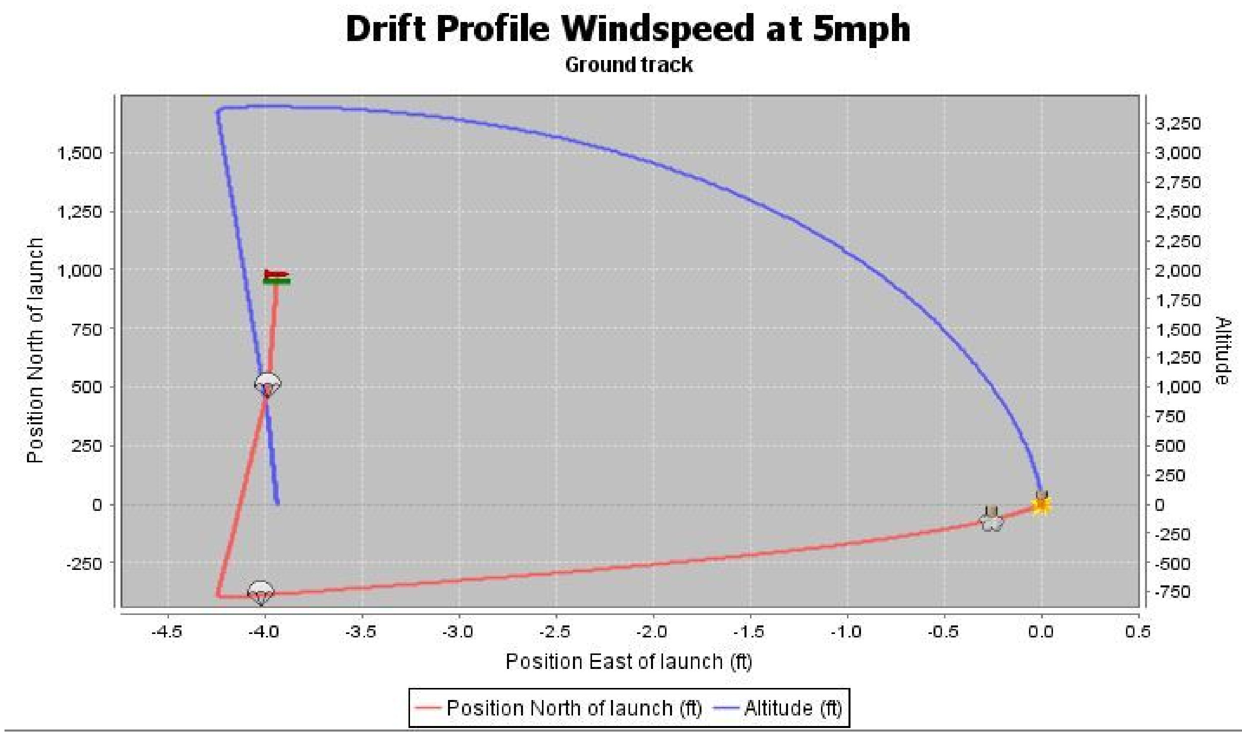


Figure 3.13.2. Drift Profile Windspeed at 5 mph

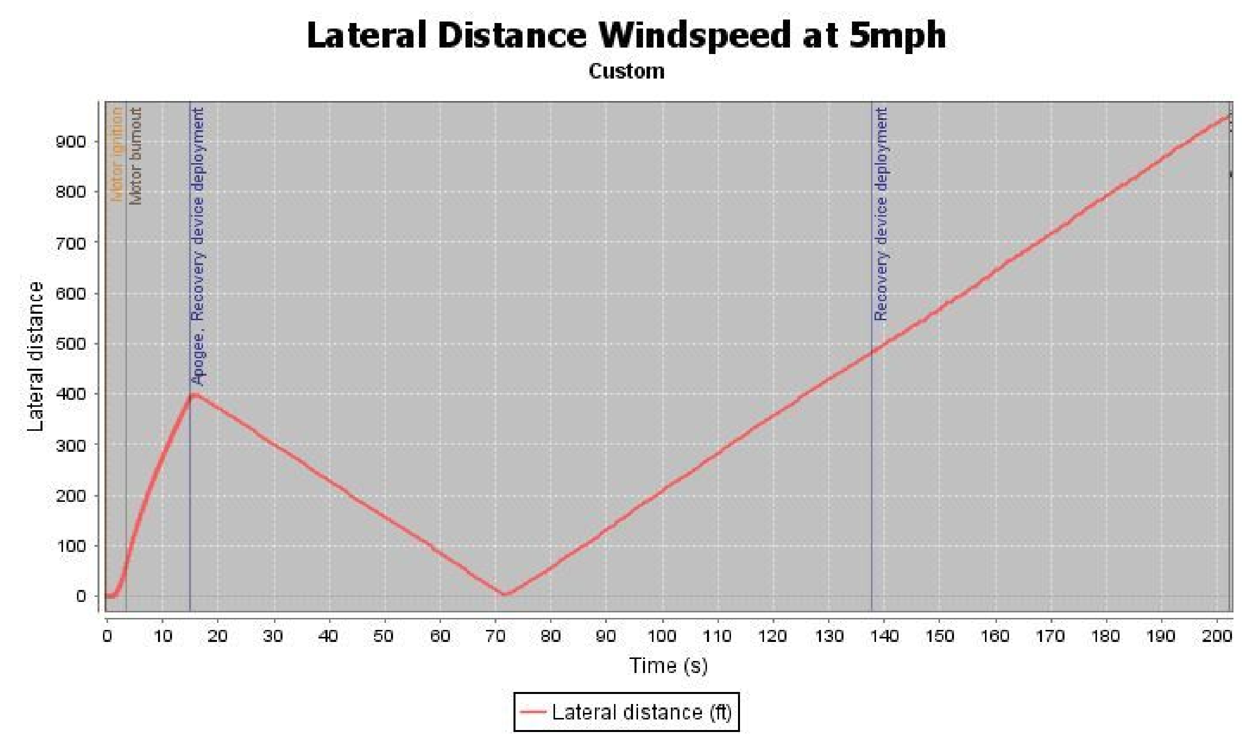


Figure 3.13.3. Lateral Distance Windspeed at 5 mph

3.13.2. Scaling Factors

-What was Constant and What Changed

The main sizing difference is that the subscale rocket outer diameter is 4 inches, while the full scale is 5.5in. This was done because the systems in the subscale are simpler, requiring less servos and electronics that take up interior space, allowing a smaller diameter. Because less interior space was needed, the length of the rocket was also scaled down to reduce structural weight from 102in to 67in. Due to design changes against the ATS design, we didn't test it in favor of testing the WATES system. A mass of 250g was added to the subscale at the bottom of the nosecone, estimating to lower the apogee by 200 ft and experimentally lowered the apogee by 30 ft.The roll induction mechanism was also simplified from an autonomous system to a fixed setup, with a flight having no roll inducing flaps, and another flight with flaps set at a fixed small angle to induce roll. This ended up not being implemented due to the fact that we only had 2 Cessaroni J380 motors (with no possibility to procure more) and decided that the WATES system was more important to test and receive flight data from. These systems demonstrate the fundamental principles of the full scale systems, while still being simple enough to manufacture and cost efficient. The fin size is slightly smaller to give the rocket an appropriate stability margin due to the altered rocket length and motor.

3.13.3. Flight Analysis

For the subscale launch, we utilized two Stratologger altimeters to obtain flight data at 0.05 second intervals. Altimeter 1 (hereby referred to as 'Alt1'), has no apogee delay and deploys the main parachute at 800 ft. Altimeter 2 (hereby referred to as 'Alt2'), has a one second apogee delay and deploys the main parachute at 750 ft. Two launches were carried out for the subscale rocket (namely 'Flight 1' and 'Flight 2'). 'Flight 1' had an extra mass of 250g added below the nose-cone to test the WATES. The figures below show the flight data acquired from the two altimeters.

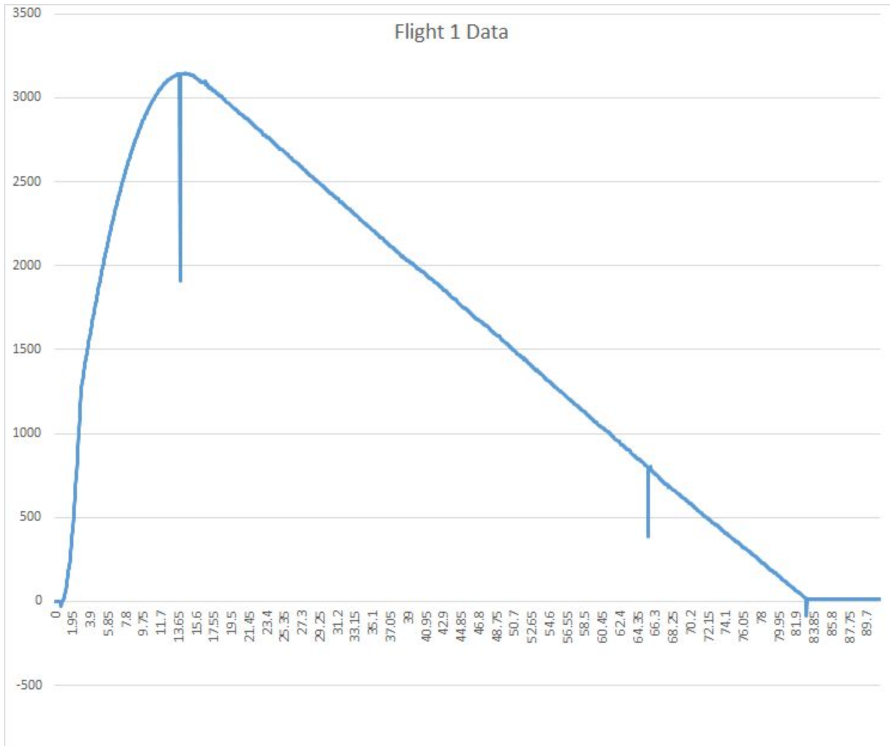


Figure 3.13.4. Flight 1 Data

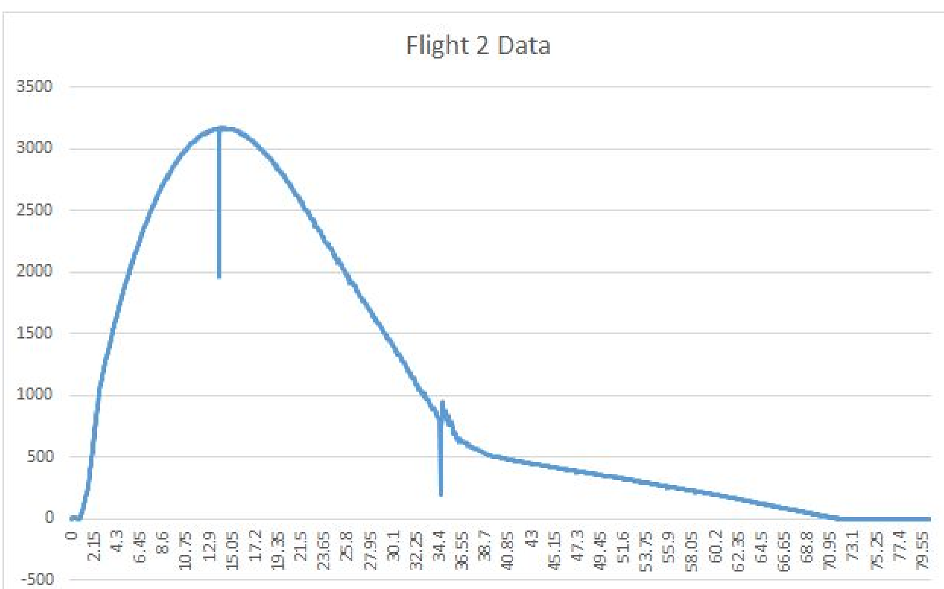


Figure 3.13.5. Flight 2 Data

For flight 1, the apogee occurs at 3145 ft at 14.35s. For flight 2, the apogee is 3166 ft, which occurs at 14.05s. The minimal difference in the results of Flights 1 & 2 shows how the WATES is effective.

3.13.4. Impact on Full Scale Design

One result of our subscale rocket design is a complete redesign of our avionics bay. Our previous avionics bay required a lot of working with tedious screws and wires a foot or two deep in the section, making it very difficult to access, along with a lot of wire excess and tangling that led to multiple poor connections. A new avionics bay was created that allowed both more accessibility and robustness. The WATES system has now had a proof of concept with fairly successful results, justifying its replacement of the ATS system.Very large key switches inconvenienced the avionics bay assembly largely, so smaller ones will be used for the full scale. In the dual redundancy recovery system, the main chute charges will be set to deploy 50ft apart from each other in addition to the 1s delay on the drogue chute charges to prevent the possibility of both charges exploding simultaneously and over-pressurizing the coupler sections. We also switched the main parachute location to be above the avionics bay and the drogue parachute to be below the avionics bay.

3.14. Mission Performance Predictions

3.14.1. Flight Profile Simulations

Figure 3.14.1 below shows the calculated flight profile of the Krios rocket with the AeroTech L1150-P using the flight conditions from Table 3.14.2. Velocity, altitude and acceleration were plotted as a function of time. Apogee occurs at approximately 18.3s. At apogee, the ejection charge for the drogue chute will fire, slowing the descent rate to 20.2 fps. Deployment of the main chute will occur around 711 ft above the ground level to decelerate the rocket again when it is falling at around 59 fps. The entire flight duration is estimated to be 165s. The following tables detail the time, altitude, velocity, acceleration and drag at certain events during the course of the launch.

Table 3.14.1 Full Scale Simulation Data

Event	Time(s)	Altitude (ft)	Total velocity (ft/s)	Total acceleration (ft/s²)	Drag force (N)	Drag coefficient
Ignition	0	0	0	13.368	0	0.59769
Lift Off	0.06	0.086	4.8864	174.37	0.0148	0.57316
Launch rod disengaged	0.21825	3.413	39.28	241.98	0.727	0.4485
Burnout	3.1759	1149.5	637.93	74.457	172.48	0.49114
Apogee	18.326	5289.9	14.43	31.77	0.044	0.50164
Drogue Chute	18.38	5289.8	20.225	31.96	13.512	
Main Parachute	94.851	711.23	58.77	0.23589	131.2	
Ground Impact	165.03	-2.1046	10.867	6.53	153.62	

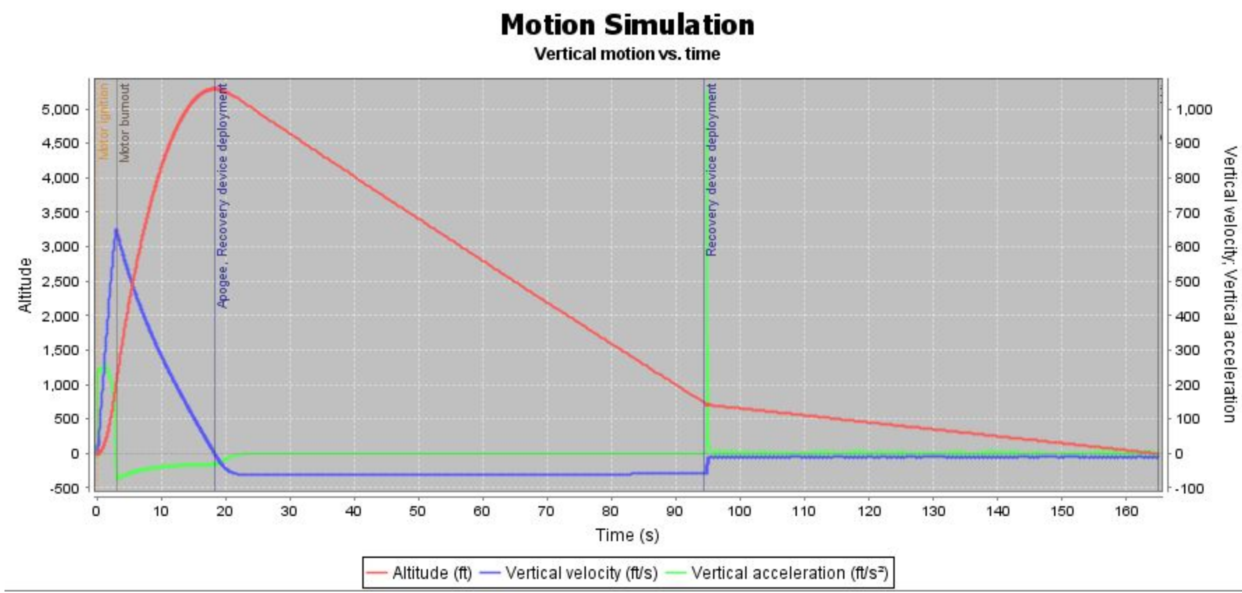


Figure 3.14.1 Full Scale Simulation

Table 3.14.2 Flight Conditions

Condition	Value
Altitude	500 ft
Wind speed	10 mph S
Temperature	60 F
Latitude	28.61°
Pressure	1029.80 mBar

3.14.2. Stability and Centers of Gravity/Pressure

The table 3.14.3 below shows the stability, centre of pressure and centre of gravity of the rocket. In the following Figure 3.14.2, the locations of CP and CG are shown in the image, CP is the red dot, CG the blue dot.

Table 3.14.3 Stability, CP, CG

Variable	Value
Stability	2.6 cal
Centre of Gravity	67.887 in
Centre of Pressure	82.346 in

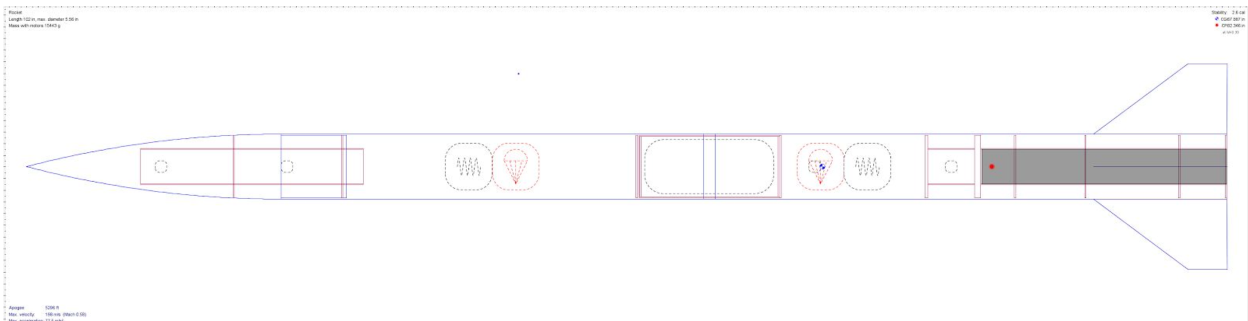


Figure 3.14.2 CG and CP Locations

3.14.3. Kinetic Energy of Sections at Landing

Using a 120” main parachute and 45” drogue parachute, the rocket will land at 19ft/s

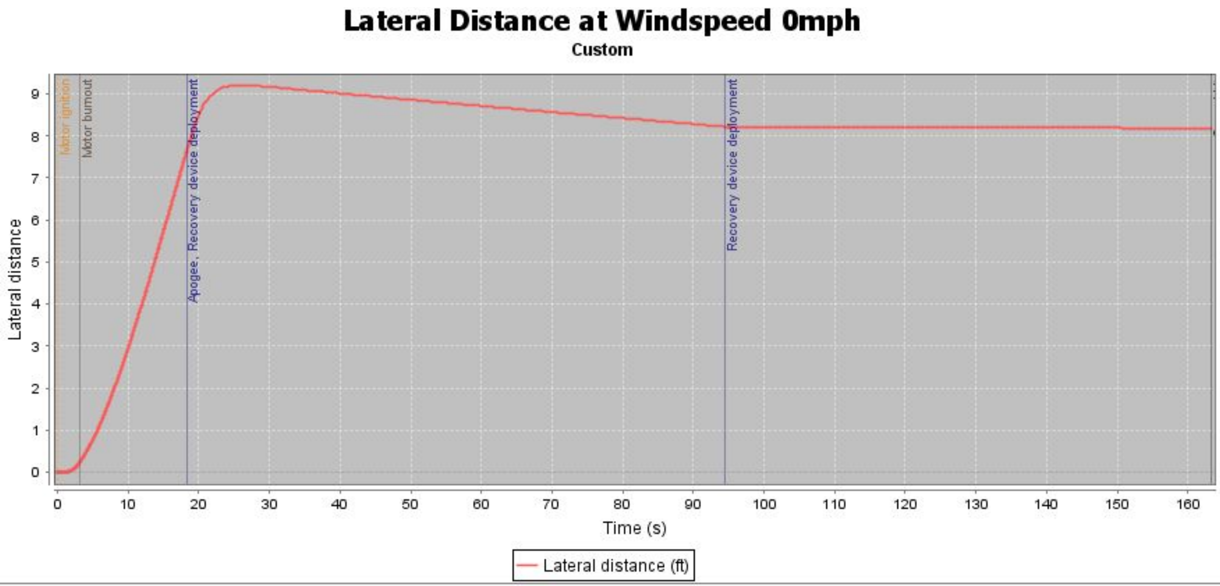
KE= $.5*m*v^2$

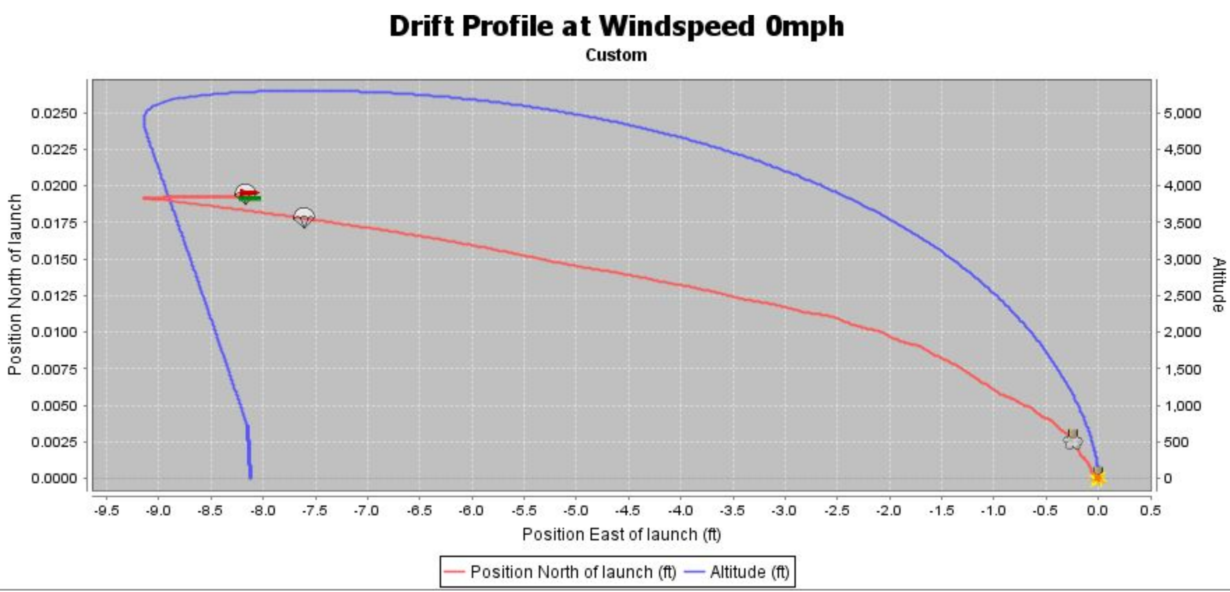
75ft-lbf >= $.5*m_{section}*(19ft/s)^2$

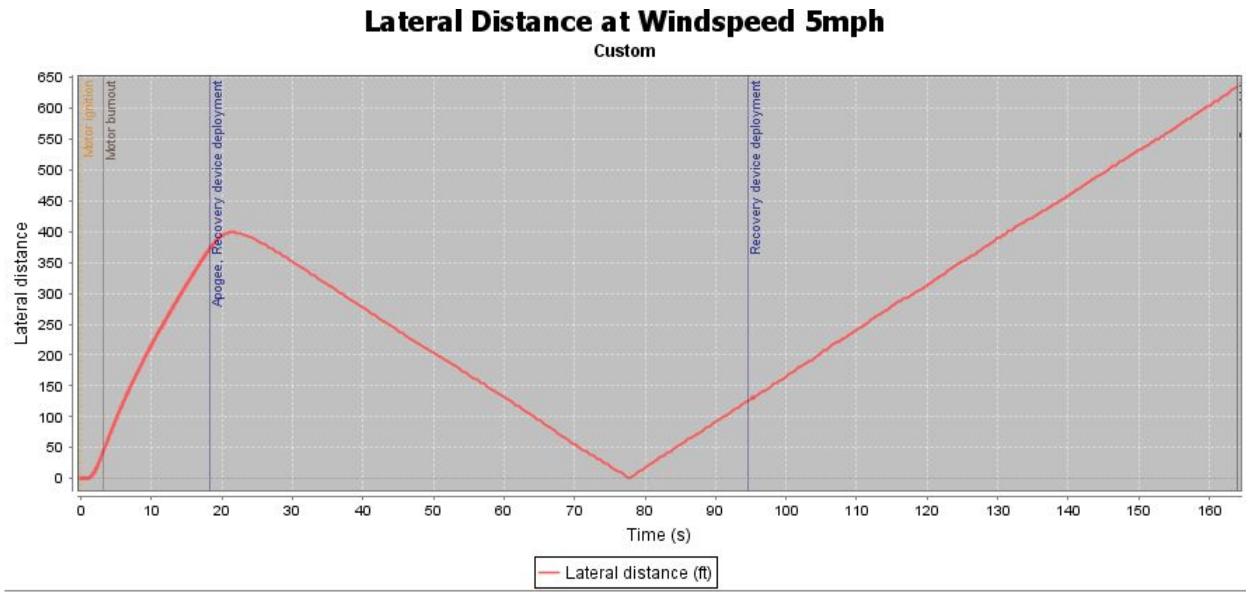
Table 3.14.4. Kinetic Energy of Sections

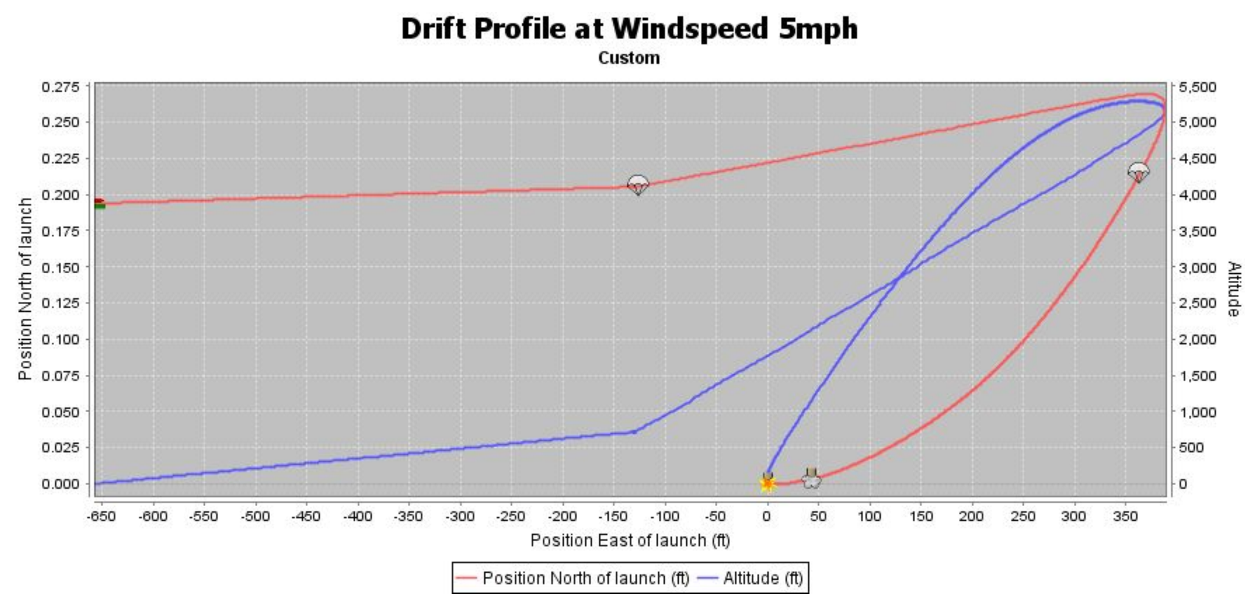
Section	Mass(lbm)	Kinetic Energy(ft-lbf)
Booster	13.125	74.0332
Avionics	7.38	41.62781
Nosecone	6.68	37.67938

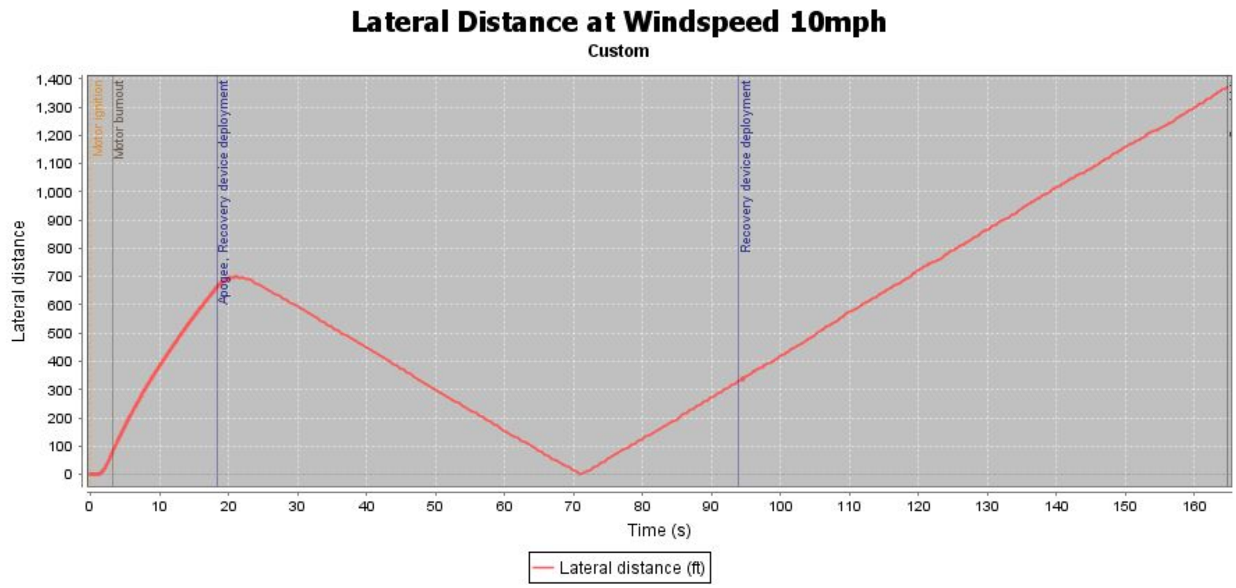
3.14.4. Drift Profiles

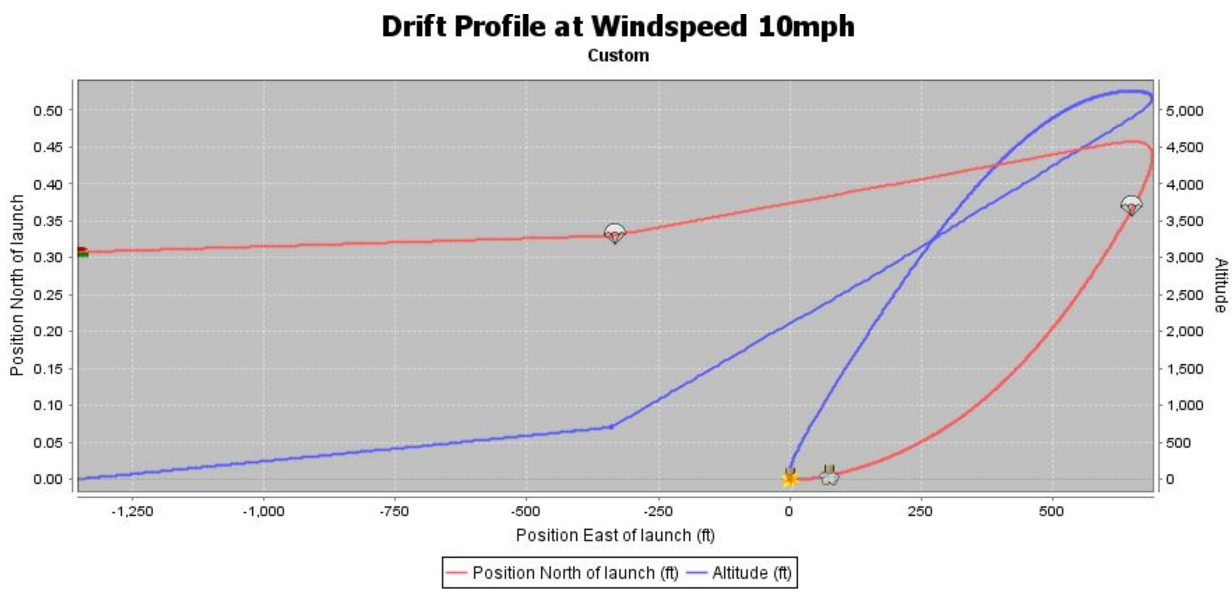




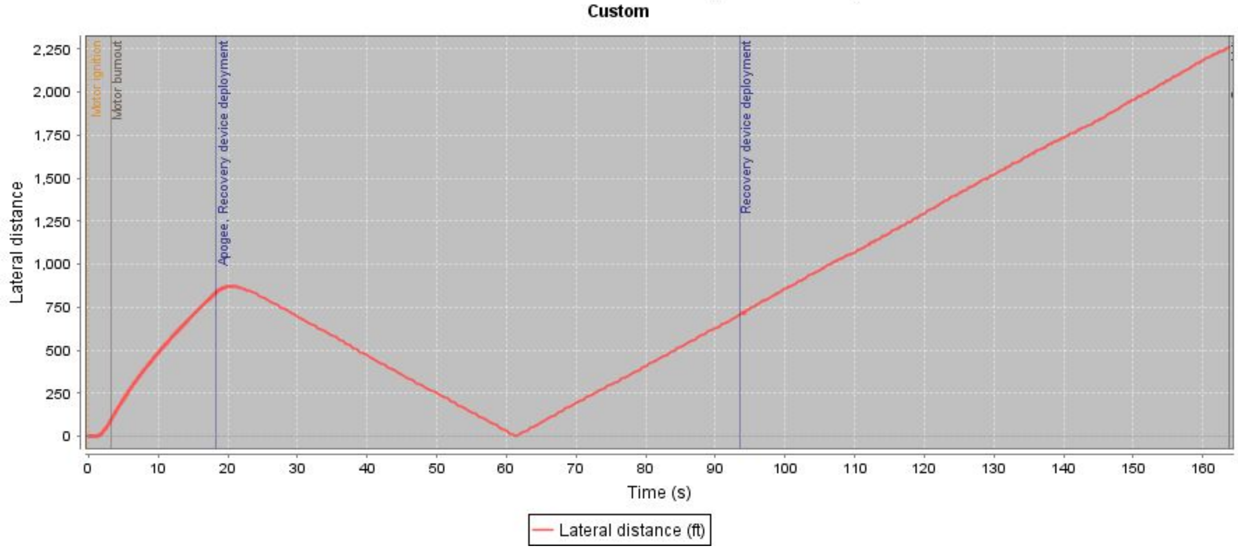

Lateral Distance at Windspeed 5mph
Custom
Motor ignition
Motor burnout
Apogee, Recovery device deployment
Recovery device deployment
Lateral distance
Time (s)
Lateral distance (ft)


Drift Profile at Windspeed 5mph
Custom
Position North of launch
Altitude
Position East of launch (ft)
Position North of launch (ft)
Altitude (ft)

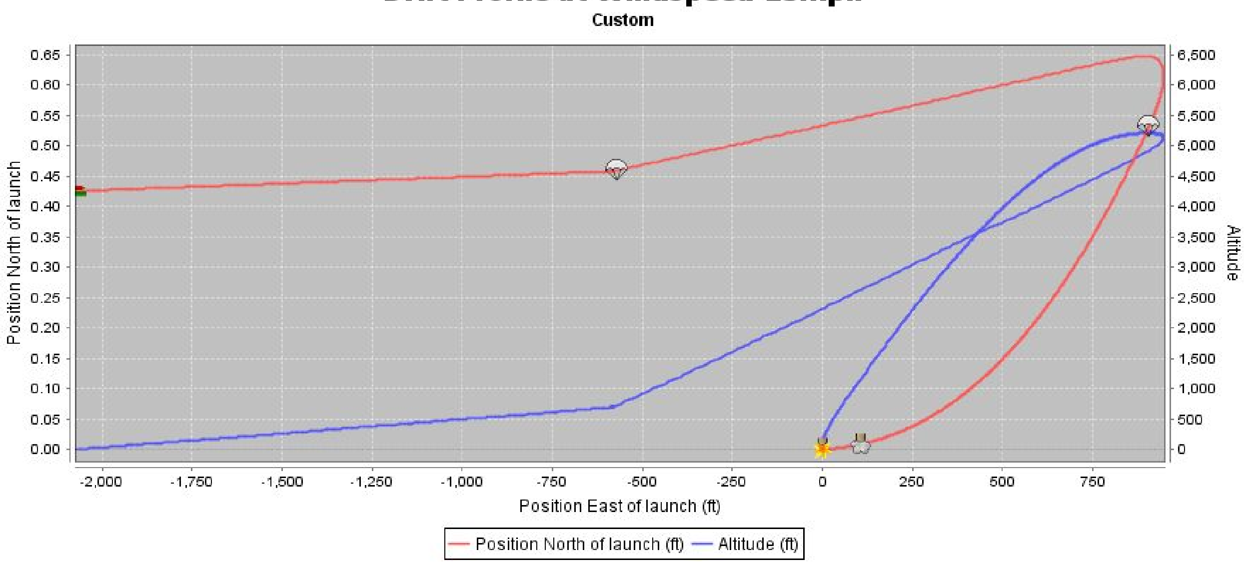

Lateral Distance at Windspeed 10mph
Custom
Motor ignition
Motor burnout
Apogee, Recovery device deployment
Recovery device deployment
Lateral distance
Time (s)
Lateral distance (ft)

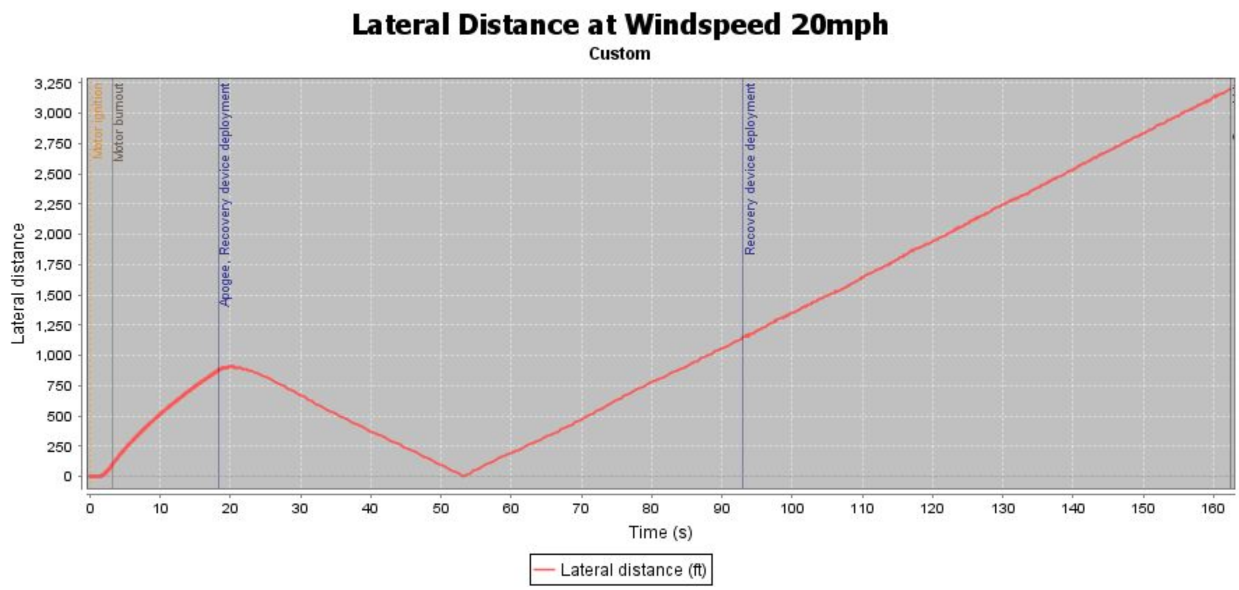

Drift Profile at Windspeed 10mph
Custom
Position North of launch
Altitude
Position East of launch (ft)
Position North of launch (ft)
Altitude (ft)

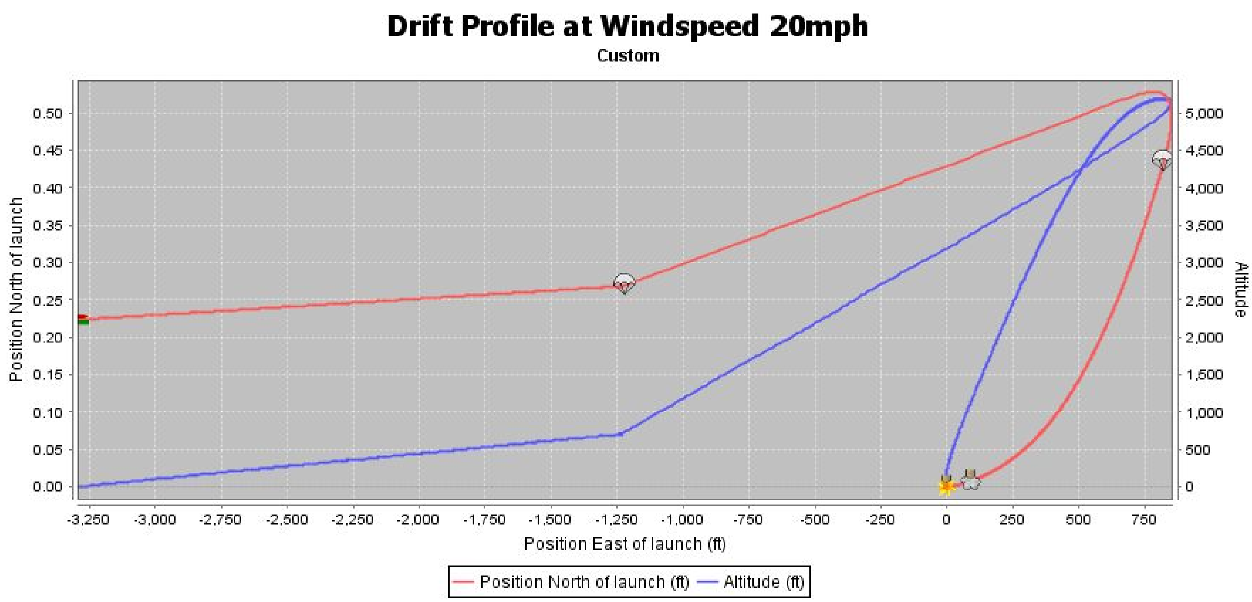
Lateral Distance at Windspeed 15mph



Drift Profile at Windspeed 15mph







4. Flight Systems (Electronics and Payload)

4.1. Overall Design

As stated previously, the embedded system flight controller design will be replaced entirely by the Pixhawk autopilot devboard. The Pixhawk is equipped with 9DOF MEMS as well as 14 specialized PWM outputs, making it more capable than the previous design while leaving less opportunity for failure. The only external connections made to the Pixhawk will include a reset switch, power source, air speed sensor, the eggfinder GPS receiver, and four servo controllers located at the bottom of the rocket. The pixhawk, figure 4.1.1, is widely used to automate quadcopters, but can easily be adapted to suit our needs for the challenge. It is fully programmable in C++ and ensures both a robust and effective hardware design.

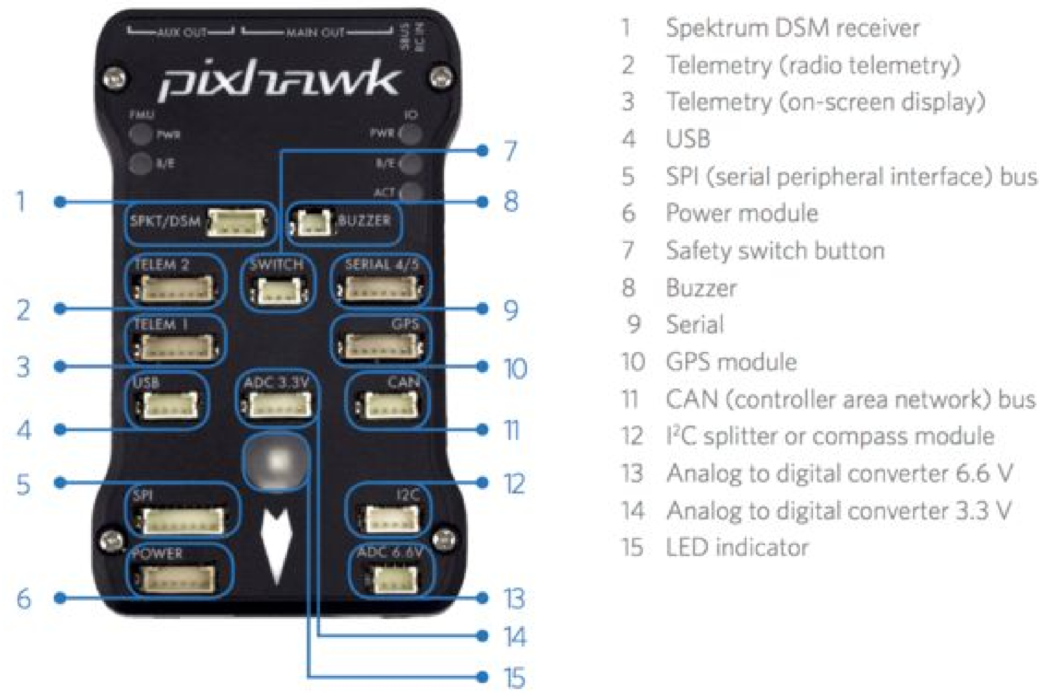


Figure 4.1.1 Pixhawk autopilot flight controller

4.2. Design Specification

The pixhawk will be powered using a regulated 5V source and will have connections running out of the Avionics bay in order to connect to the Eggfinder GPS transmitter and the four servo motors. The GPS system will be housed in the nose cone of the rocket, and the servo motors located above the thrust plate. Separable and mountable power pole connections will be used to allow the connections to stand until the rocket tubes separated for recovery, where they will be blown apart. After peak apogee is reached, the pixhawk will have no need any connection with the GPS or motor system of the rocket.

4.2.1. Interaction between Payload Components

Most of the elements needed for the rocket's motor actuation system are already built into the pixhawk devboard. 3-axis Gyroscope, Accelerometer, and Magnetometer are all included and will be utilized for rolling calculations. The calculations will also take into account the GPS location of the rocket for further accuracy. The GPS will be connected through the GPS pin serial connection on the board. The rocket's air speed will be estimated through readings from both the onboard barometric pressure sensor as well as an external air speed sensor, connected to the serial ut on the pixhawk. All sensor data will be polled through the use of a kalman filter in order to normalize error from noise and provide more accurate, stable positional readings. The servo motors will be actuated depending on the sensor data results and how they compare to our ideal, calculated flight path at the specified instance in time in time. The servo motors are connected to the pixhawk's 14 pwm_out servo rail. An external power source is additionally required to power the motors. Everything used in the rocket's motor actuation system will be completely independent from the rocket's recovery.

4.2.2. Interaction between Payload and Launch Vehicle

The pixhawk autopilot system directly powers the servo motors that actuate fins to induce a rolling moment. The various sensors found on the pixhawk devboard are additionally used in flight calculations to predict the rocket's projected apogee and roll distance relative to the starting point. Most of the payload components are found in the avionics bay of the rocket with lead wires coming out of each bulkhead to interact with external components. These connections include: chute connections from the altimeters (8 total connections), GPS connection (4-pin connector), and servo connections (8 total). The connections leading to the GPS and servo motors will need to be installed with durability and assembly in mind. The wires connected to these devices will have to withstand the blast on the recovery and separate accordingly. Therefore, powerpole connections will be used to ensure a sturdy connection that can also be broken with a significant force. Any wires that line the rocket tube will have protective conduit lining to ensure reusability. According to the voltages supplied in table 4.2.1, the servo rail will be powered by a Nickel Metal Hydride or LiPo battery, and the pixhawk by a regulated 9V DC source.

Table 4.2.1

	Normal Operation Maximum Ratings	Absolute Maximum Ratings
Power module input	4.8V - 5.4V	4.1V - 5.7V, 0V - 20V undamaged
Servo rail input	4.8V - 5.4V	4.1V - 5.7V, 0V - 20V
USB power input	4.8V - 5.4V	4.1V - 5.7V, 0V - 6V

Figure 4.2.1

4.3. Software and Data Transfer/Control Overview

The mission flight software will be written in C++ and flashed onto the pixhawk through the linux command line. The project will be organized modularly in github and composed of different libraries and custom built classes. The information obtained from the pixhawk will be stored onto a micro sd card and analyzed predominantly in Matlab.

4.4. Simulink Design Overview

This is the general form of our simulink model. This Simulink model aim to help us first simulate the program and help us to design the motor we want and need. Also, this simulink allow us to design the controller for this system.

Here is the General Simulink model for the design:

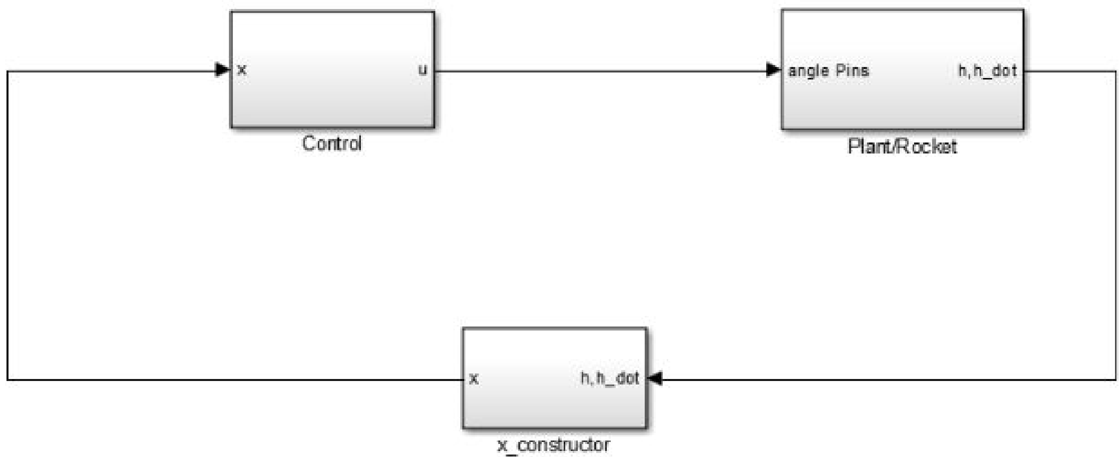


Figure 4.4.1. Simulink Model

In this section, we are going to present the Rocket block. We have implemented a Simulink model for the equations of the rocket. Briefly, we have: weight, engine thrust, plates drag, and rocket drag acting on the rocket. So, we created these forces, summed them (with the adequate projection) and then thanks to Newton's second law we know that this net sum equals the mass of the rocket times its acceleration.

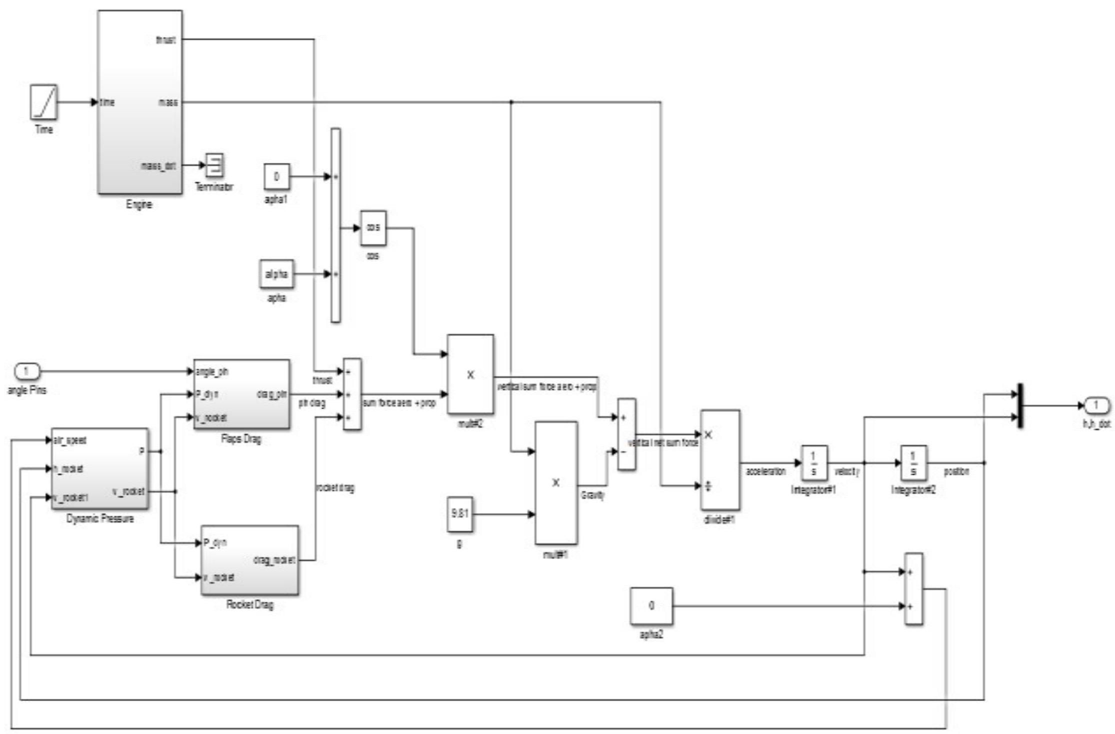


Figure 4.2.2. Simulink Model for Rocket Block

In this diagram, we modeled the engine by computing a function depending only on the time. From this function we are then able to compute the mass ejected by the motor since launch and the thrust level. Please find the Simulink model of the motor below:

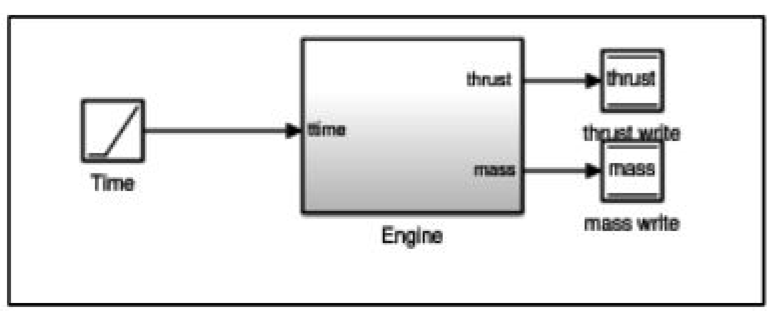


Figure 4.4.3. Simulink Model of Motor

4.5. Controller Design Overview

The controller will be based on a closed system feedback loop that compares the ideal, calculated roll location at a particular instance t in time to the position obtained from sensor polling. Sensor noise will be accounted for through the implementation of a kalman filter. Modeling the response of the the rocket's rotation moment when deploying flaps at specific angles given a fixed airspeed is process that will need to be simulated in a wind tunnel. This value completes the loop by applying a calculated fin actuation such that the the projected rocket position tracks the calculated values. Figure 4.5.1 shows the feedback system logic for the purposes of our controller.

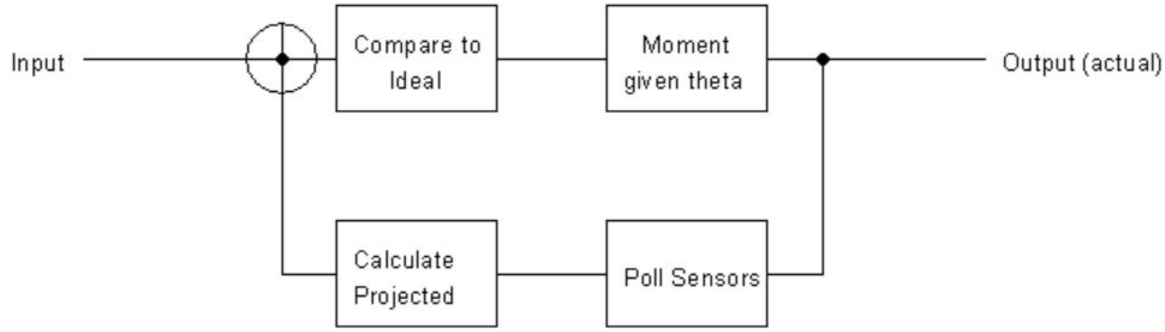


Figure 4.5.1 Control system block diagram and logic flow

5. Safety

5.1. Overview: Personnel Hazard Analysis

The following table entails the information on the general risks that the team may experience while constructing the rocket. The table goes through the severity, likelihood, and prevention methods for each hazard.

Table 5.1.1. Safety Risks

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.
Black Powder	Explosions, burns, skin and eye irritation	Medium	Wear safety glasses, gloves when handling black powder. Be careful when pouring black powder. Operate in a static-free environment.
Dremel	Cuts and scrapes	Medium	Only operate tools with supervision of teammates. Use tools in appropriate manner. Wear safety glasses to prevent debris from getting into eyes.
Power Tools	Cuts, punctures, and scrapes	Medium	Only operate power tools with supervision of teammates. Use tools in appropriate manner. Wear safety

			glasses to prevent debris from getting into eyes.
Epoxy/Glue	Toxic fumes, skin and eye irritation	High	Wear gloves, nitrile for epoxy, face masks, and safety glasses. Work in well ventilated area.
Exacto/Craft Knives	Cuts, serious/fatal injury	Medium	Only use knives with teammate supervision. Only use tools in appropriate manner. Do not cut in the direction towards oneself.
Fire	Burns, serious/fatal injury	Low	Keep a fire extinguisher nearby. If an object becomes too hot, or does start a fire, remove power (if applicable) and be prepared to use the fire extinguisher.
Hammers	Bruises, serious/fatal injury	Medium	Be aware of where you are swinging the hammer, so that it does not hit yourself, others, or could bounce and hit someone.
Hand Saws	Cuts, serious/fatal injury	Medium	Only use saws with teammate supervision. Only use tools in appropriate manner. Wear safety glasses to prevent debris from getting in eyes.
Waterjet Cutter	Cuts, serious/fatal injury, flying debris	Low	Only operate under supervision of Undergraduate/Graduate Learning Instructors, and with other teammates.

			Follow proper operating procedures, wear safety glasses.
Improper dress during construction	Cuts, serious/fatal injury	High	Wear closed toed shoes, tie back long hair, do not wear baggy clothing.
Power Supply	Electrocution, serious/fatal injury	Medium	Only operate power supply with teammate supervision. Turn off power supply when working with circuitry.

5.2. Failure Modes and Effects Analysis

The following table entails the potential failure modes that may be experienced by the Launch Vehicle team and the prevention method for each failure mode.

Table 5.2.2. Failure Mode

Potential Failure	***Effects of Failure***	***Mitigation and Control***
Apogee Targeting System (ATS)	Vehicle will not reach target altitude	Test ATS using subscale launch vehicles
Body structure buckling on takeoff	Launch failure, damage to launch vehicle, unable to be reused, flying shrapnel towards personnel/crown	Test structure to withstand expected forces at launch with a factor of safety. Have proper sized couplers connecting sections.
Drogue separation	Main parachute will deploy at high speed and may rip or disconnect from vehicle,	Perform ground test and flight test.

	launch vehicle may become ballistic	
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.
Ignition failure	Failure to launch	Follow proper procedures when attaching igniter
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 veracity 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 veracity 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

5.3. Environmental Concerns

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

5.4. Final Assembly and Launch Procedures

Table 5.4.1. Pre-Launch Procedures

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

Table 5.4.2. Launch Procedures

LAUNCH		
Checklist	**Performer**	**Inspector**
Prepare Payload Bay		
Ensure the batteries and switches are properly connected to the altimeters.		
Ensure the batteries, power supply, switches, data recorders, and pressure sensors are properly wired.		
Install and secure new batteries into the battery holders.		
Insert the altimeter and payload into the payload bay.		
After connecting the appropriate wires, verify that the payload powers are turned on and working properly. If the payload power does not work, check the wiring schematics. Turn off payload power afterwards.		
Arm the altimeters to verify the jumper settings. Check the battery voltage and continuity once the altimeters have been armed.		

Disarm the altimeters afterwards.		
Assemble Charges		
Test e-match resistance and make sure it is within specifications.		
Remove protective cover from e-match.		
Measure the required amount of black powder that was determined during testing.		
Place e-match on tape with the sticky side facing up.		
Pour the black powder over the e-match and seal the tape.		
Retest the e-match resistance.		
Check Altimeters (Figure 1 for configurations)		
Ensure altimeters have been properly disarmed.		
Connect charges to the ejection wells/altimeter bay.		
Turn on altimeters and verify continuity. Disarm altimeters afterwards.		
ALTIMETER 1		
ALTIMETER 2		
Pack Parachutes		
Connect drogue shock cord to booster section and altimeter.		
Fold excess shock cord so it does not tangle.		
Add Nomex cloth to ensure only the Kevlar shock cord is exposed to ejection charge.		
Insert altimeter bay into drogue section and secure with shear pins.		

Pack main chute.		
Attach main shock cord to payload bay.		
Assemble Motor		
Follow manufacturer's instruction.		
Use the necessary safety equipment needed such as gloves and safety glasses.		
Be careful not to get any grease on propellant or delay grain.		
Do not install the igniter until at launch pad.		
Install motor in launch vehicle.		
Secure motor retention system.		
Final Preparation		
Turn on payload via a switch and start stopwatches.		
Install skin.		
Inspect the launch vehicle. Verify the CG in order to make sure it is in safe range. Add nose weight if necessary.		
Bring launch vehicle to the range safety officer (RSO) table for inspection.		
Bring launch vehicle to pad, install on pad, and verify that it can move freely.		
Install igniter in launch vehicle.		
Touch igniter clips together to make sure they will not fire igniter when connected.		
Make sure clips are not shorted to each other or blast deflector.		
Arm altimeters via switches and wait for continuity check for both.		

Connect shock cord to nose cone, install nose cone, and secure with shear pins.		
Launch		
Stop the stopwatches and record time from arming payload and launch.		
Watch flight so launch vehicle sections do not get lost.		

Table 5.4.3. Post-Launch Procedures

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

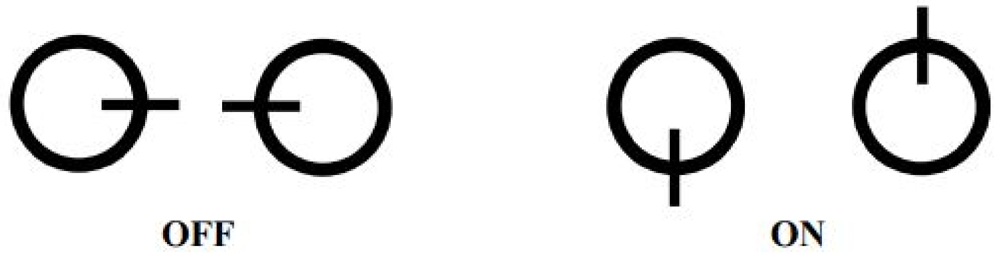


Figure 5.4.1. Altimeter On/Off Configurations.

Table 5.4.4. Launch Preparation

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

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

	Turn on altimeters to verify continuity
	Disarm altimeters
Pack Parachutes	
	Connect drogue shock cord to booster section and body section
	Attach drogue parachute to drogue shock cord
	Pack drogue parachute
	Fold excess shock cord so it does not tangle
	Attach Nomex cloth to shock cord so it will enclose and shield the parachute while exposing only the Kevlar shock cord to ejection charge
	Insert cellulose wadding into drogue parachute bay between ejection charges and parachute
	Insert drogue parachute and shock cord into drogue parachute bay
	Insert booster section into lower body section, and secure with shear pins
	Attach main parachute shock cord to upper body section and lower payload parachute bay
	Attach main parachute to main parachute shock cord
	Pack main parachute
	Fold excess shock cord so it does not tangle

	Attach Nomex cloth to shock cord so it will enclose and shield the parachute while exposing only the Kevlar shock cord to ejection charge
	Insert cellulose wadding into main parachute bay between ejection charges and parachute
	Insert main parachute and shock cord into main parachute bay and
	Insert upper body section into the lower section of the payload parachute bay, and secure with shear pins
	Attach payload parachute shock cord to payload section
	Attach parachute to the end of the payload parachute shock cord
	Pack payload section parachute
	Fold excess shock cord so it does not tangle
	Attach Nomex cloth to shock cord so it will enclose and shield the parachute while exposing only the Kevlar shock cord to ejection charge
	Insert cellulose wadding into upper payload parachute bay between ejection charges and parachute
	Insert drogue parachute and shock cord into upper payload parachute bay
	Insert payload section into payload parachute bay and secure with shear pins
Assemble motor	

	Follow manufacturer's instructions
	Do not get grease on propellant grains or delay grain
	Do not install igniter
	Install Motor in launch vehicle
	Secure motor retention system
Launch Vehicle Prep	
	Inspect launch vehicle, check CG and make sure it is within specified range
	Bring launch vehicle to Range Safety Officer(RSO) for inspection
	Touch igniter clips together to make sure they will not fire the igniter when connected
	Connect igniter clips to motor igniter
Launch	
	Watch flight so launch vehicle sections do not get lost
Post Launch Payload/Vehicle Recovery	
	Recover Payload Section and tethered Body/Booster Section
	Disarm Altimeters if there are unfired charges
	Disassemble launch vehicle, clean motor case, other parts, and inspect for damage
	Record altimeter data

6. Project Plan

6.1. Testing

6.1.1. Tests required

Roll control testing needs to be done to ensure the servos have enough torque to induce roll at necessary speeds under large aerodynamic forces, and the fiberglass fins are not damaged by the loads on them. The roll system will be put into a wind tunnel to ensure the system will be able to perform in flight

ANSYS will be done on the model of the rocket to determine the aerodynamics, drag, and effectiveness of the roll system.

Ejection charge tests will be done to determine empirically the amount of black powder needed to consistently separate the sections while preventing any damage from occurring

Thrust plate load testing will be done to ensure the thrust plate will withstand the forces placed on it from the motor.

6.1.2. Test Objective, Success Criteria, Testing Variable and Methodology

The objective for the roll control wind tunnel testing is to ensure the fin flaps enact a controlled spin in flight conditions at an appropriate rotation speed, and are capable of being deployed. Success will be considered if the flaps can be angled and manipulated in strong wind and if they produce forces measured to be consistent with the desired roll speed. The testing variable will be the force on the flaps, and will be measured with strain gauges attached to the flaps.

The objective of ANSYS will be similar to the wind tunnel tests, mathematically verifying the proper forces on the fins, and also estimating drag and aerodynamics of the rocket.

The objective of the ejection charge testing will be to determine the proper mass of black powder needed to produce separation between each section without damaging the internals. The variable will be the black powder mass of each charge, and tests will be conducted with the physical full scale rocket outside in an empty area using black powder charges connected to an igniter hooked up to the altimeter in a vacuum pump.

The objective of the thrust plate loading test is to determine if it is thick and strong enough to withstand the forces of the motor pushing on it in flight, with success being defined as an undamaged thrust plate under equivalent impulse of the full scale motor, Facilities in Georgia Tech's Mechanical Engineering labs will be used to create equivalent loads on the thrust plate.

6.2. Requirements Compliance

6.2.1. Verification plan

Table 6.2.1. Verification Plan

Requirement	Design Feature	Verification
Vehicle altimeter will report an apogee altitude of most nearly 5,280 feet AGL.	The size and strength of the motor will be selected to ensure an apogee of 5280 ft	Gathering data post-launch from on-board altimeters
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
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
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 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
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
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
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

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
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

6.2.2. Team Derived Requirements

Table 6.2.2. Team Derived Requirements

Requirement	Verification
Vehicle should reach the apogee with an accuracy of 2% of the apogee	Gathering data post-launch from on-board altimeters
Vehicle should complete no more than 5 induced rolls	Use gyroscope data and post-flight calculation to determine roll rate and completed rolls
The only setup before and in between launches should be refilling black powder charges and putting in a new motor	Determined on launch days
There should be no damage or burns between section due to deployment of parachutes	Pieces will be looked at for signs of visual damage
Drogue chute should deploy at apogee, and main chute at 750 ft AGL	Altimeter data will be analyzed
Velocity before impact < 20 ft/s	Altimeter data will be analyzed
Each section of vehicle should sync its position to computer	Avionics systems will be tested beforehand to ensure that this is the case
Ensure all redundant systems are powered and capable	All systems will be tested beforehand so that the validity of their redundancy is legitimate

Ability to access components without compromising rocket in any way	Ease of access will be determined on launch day and through various stages of testing

6.3. Budget and Timeline

6.3.1. Line Item Budget

The projected budget of Team ARES for the 2016-2017 competition year is $5450, with Table 6.3.1 showing the breakdown between 5 categories: Launch Vehicle, Avionics, Outreach, Travel, and Test Flights. Figure 6.3.1 shows the percentage distribution of the categories. Table 6.3.2 shows the full line item budget for each category.

Table 6.3.1 Budget

Section	Cost
Launch Vehicle	$2100
Avionics	$550
Outreach	$800
Travel	$900
Test Flights	$1200
Total	**$5450**

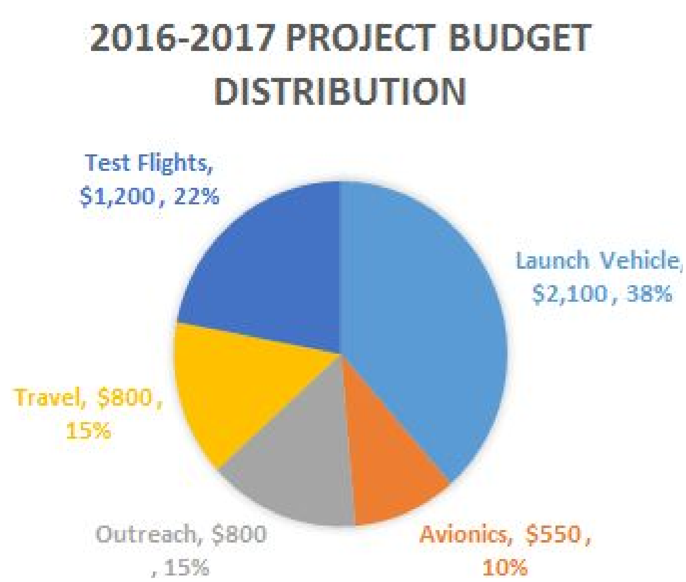


Figure 6.3.1. Budget Breakdown

Table 6.3.2. Cost 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 Bulkhead	$8.56	5	$42.80
	G10 5.5" Coupler Bulkhead	$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 transfer 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	PerfectFlite stratologgerCF	$54.95	2	$109.90
	teensy 3.2	$19.95	2	$39.90
	Data transfer cable	$24.95	1	$24.95
	IMU	$49.95	1	$49.95

	Main Chute	$99.00	1	$99.00
	Drogue Chute	$27.50	1	$27.50
	Nosecone	$21.95	1	$21.95
	Misc Bolts/wood/hinges	85	N/A	85
	J380 Motor	100	2	200
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)	111	1	$111
	Posters** (Promotional Material)	$1 per ft^2	30	$30
	Pens (Promotional Material)	$0.62	250	$155
Travel				$900
Total				$5,482.88

6.3.2. 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. The remaining costs have been agreed to be covered through the Georgia Tech Aerospace Department by alumni and corporate donations, which can allocate roughly $4000, more than covering all remaining expenses. CCTV Camera World has agreed to give us a camera that will be put on the rocket for flight data and publicity material. Table 6.3.2 shows our projected possible funding, which exceeds our cost estimates by 27%, giving appropriate room for unanticipated costs. The Georgia Tech Ramblin' Rocket Club has generously offered the use of some of their tools, storage space, and facilitating the purchase of rocket motors. Georgia Tech has also provided us a room in the Engineering Science and Materials Building to use for construction, storage, and meeting space.

Table 6.3.3 Planned Sponsors

Sponsor	***Contribution***	***Date***
2015-2016 Unused Funds	$388	--
Georgia Space Grant Consortium	$2,000-$3000	Oct 2016
Georgia Tech Aerospace Department	$3500	Jan 2017
Georgia Tech Student Foundation	$1000	Feb 2017
Total	$7000	

Table 6.3.4 Current Sponsorship

Sponsor	***Contribution***
Georgia Space Grant Consortium	$2000-$3000
Georgia Tech Aerospace Department	$2500
CCTV Camera World	Camera to be used to film rocket launches

6.3.3. Timeline and GANTT Chart

In order to meet the deadlines given by NASA and the internal deadlines created by Team ARES, we have created a Gantt Chart (Figure 6.3.2) to more easily visualize the timeline of our project, and broke down each task into smaller tasks with completion dates (Table 6.3.4). 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. The figure gives a streamlined visual layout while the table itself has much more detailed items and dates.

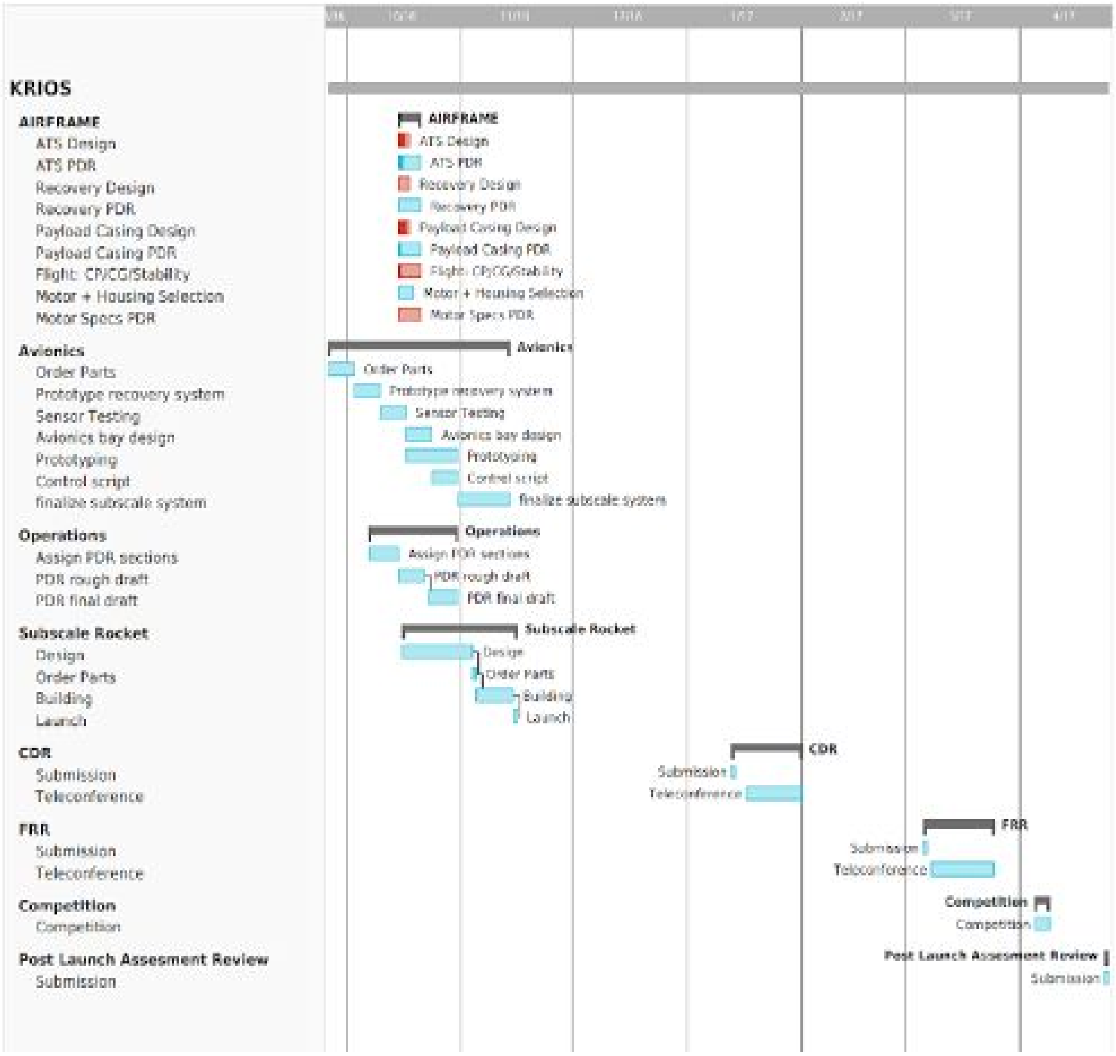


Figure 6.3.2 GANTT Timeline

Table 6.3.5 - GANTT Timeline Line Items

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	1/14/2017
Design	10/16/2016	11/3/2016
Order Parts	11/4/2016	11/4/2016
Building	11/5/2016	11/14/2016
Launch Window 1	11/15/2016	11/15/2016
Launch Window 2	12/3/2016	12/3/2016
Launch Window 3	12/10/2016	12/10/2016
Launch Window 4	12/11/2016	12/12/2016
Repair and Refitting	1/7/2017	1/13/2017
Final Launch Window	1/14/2017	1/14/2017
CDR	1/13/2017	1/31/2017
Assignment Distribution	12/11/2016	12/11/2016

Outline Creation	12/12/2016	12/12/2016
Design Updates	12/13/2016	1/7/2017
Report Writing	1/2/2017	1/13/2017
Formatting	1/13/2017	1/13/2017
Subscale Launch Results Addition	1/14/2017	1/14/2017
Submission	1/15/2017	1/15/2017
Teleconference	1/17/2017	1/31/2017
FRR	1/14/2017	3/24/2017
Final Design Decisions	1/14/2017	1/28/2017
Distribute Writing Assignments	1/20/2017	1/20/2017
Write Report	2/15/2017	3/4/2017
Order Full Scale Parts	1/21/2017	1/21/2017
Full Scale Construction	2/1/2017	2/20/2017
Document Formatting	3/1/2017	3/4/2017
Full Scale Launch Window	2/20/2017	3/6/2017
Submission	3/6/2017	3/6/2017
Teleconference	3/8/2017	3/24/2017
Launch Readiness Review	4/5/2017	4/7/2017
Competition	4/5/2017	4/8/2017
Post Launch Assessment Review	4/8/2017	4/24/2017
Document Write-up	4/8/2017	4/23/2017
Submission	4/24/2017	4/24/2017

7. Educational Engagement Plans 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. The team also is working closely with Boy Scout groups across the area to generate STEM interest in younger Scouts.

In regards to an update with the Boy Scout troops - the team has been in contact with Boy Scout Troop #433 and will be teaching them the Engineering Merit Badge at Georgia Tech on a Saturday afternoon. The team will also give the troop a tour of Georgia Tech facilities and labs, and if this event is successful, more events involving other troops will be planned.

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. Currently, Team ARES is planning on volunteering at the K.I.D.S. Club event on March 11th, 2017, which will involve kids from grades 2 to 12.

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 in the spring semester.