By:

Georgia Tech A.R.E.S.

NASA Student Launch 2017

Project Name: KRIOS

March 6th, 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 |
| **Team Email** | gtares@gmail.com |
| **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<br>gmora3@gatech.edu<br>NAR Number: 98543<br>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.

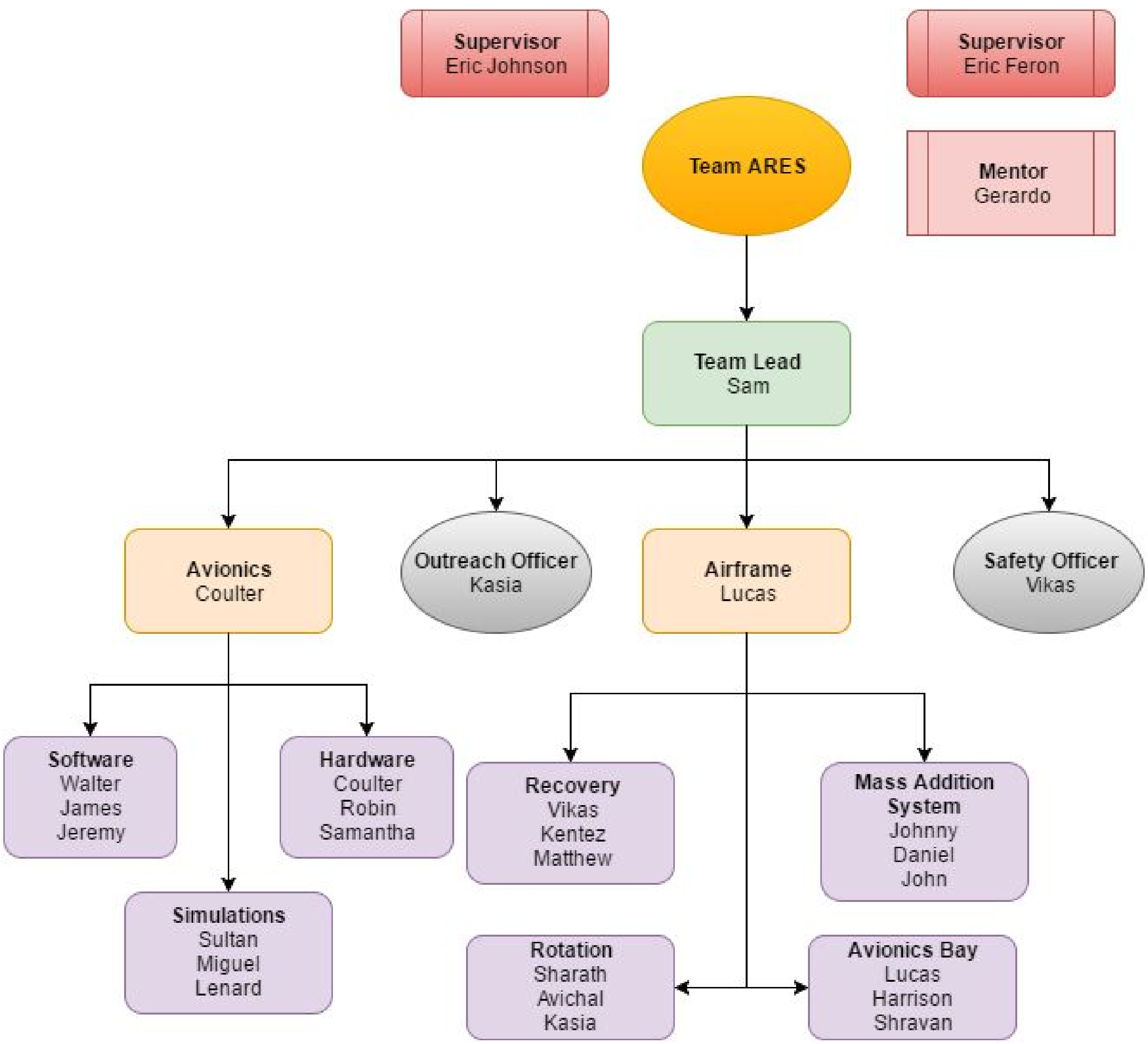


Figure 1.1.1: Team Structure

## 1.3. Launch Vehicle Summary

KRIOS is 102 inches long and 5.5 inches outer diameter When loaded, weighing 33.4 pounds when loaded. The rocket is wide enough to house all avionics while maintaining a sufficient stability. At the bottom of each fin is an aileron mounted on a hinge. These ailerons are actuated by servos mounted at the bottom of the booster section. This actuation will induce the moment needed to accomplish the "roll" mission objective. The Mass Addition System is located in the GPS bay in the Nose Cone. Its purpose is to house any ballast needed to adjust the rocket's center of mass to match the simulations that have been conducted. Above the Motor is the Weight Addition Transmission Equipment System (WATES). It consists of a sealed compartment with a removeable PVC cap. If, after construction, the rocket was found to have less mass than anticipated, sand could have been added to WATES to increase the overall mass. WATES is located near the rocket's center of mass, so adding mass in this location would not greatly affect the center of mass.

## 1.4. Avionics Summary

The main components of the avionics of system of the Krios are listed as follows: two stratologgerCF altimters to ensure a dual redundant recovery, the Pixhawk px4 autopilot system, used as an external IMU and data collection device, and the MBED

## 1.5. Control System Summary

Team ARES's payload will consist of an experimental control system. The mission is to induce a roll and counter roll post motor burnout. Roll will be controlled by ailerons located on the trailing edge of each fin. Each aileron is individually controlled by a servo, and each servo assembly is mechanically linked by a common gears. The servos will receive commands from a Pixhawk collecting gyroscopic and air-speed data.

## 1.6. Structural Changes Since CDR

There have been some very minor changes to the structure of the rocket. The length of both parachute compartments have been decreased due to the realization that the packing volume was significantly less than what was estimated. To keep a similar stability, the MAS compartment was increased such that the overall length of the rocket did not change.

## 1.7 Avionics Changes since CDR

The recovery system of the rocket has not changed since the submission of the CDR. The roll system of the rocket has undergone adaptations due to difficulties surrounding the Pixhawk autopilot system.

As discussed in the CDR, the Pixhawk px4 is an autopilot system designed for RC copters and fixed wing aircrafts. The board is designed with users of these vehicles in mind and, therefore, only offers firmware to support the motor control of these types of aircrafts. The original plan was to code a custom firmware for the purpose of our flight in C++, bypass the system's GUI, and flash our custom build onto the board. However, the development guide for the Pixhawk is still in its beta stages and lacks the resources to complete such a project in a timely manner. Because the motors on the launch vehicle serve a far different function than those found on the RC crafts, the px4 will no longer be responsible for actuating the servo motors of the vehicle. Instead, an MBED ARM microcontroller will fulfill this role within the roll system of the rocket. The MBED is coded using C++ and has an expansive and well established developer's library for creating custom builds. The Pixhawk, equipped with 9DOF IMU, dedicated telemetry, and data acquisition capabilities, is still responsible for streaming sensor data to the MBED and reporting the official roll path of the rocket. The fixed wing firmware will be flashed to the board with many features disabled. This decision was made to ensure that our system is both reliable and achievable.

## 1.8. Roll Control Changes Since CDR

Changes to the Roll Control System since the CDR have been minimal. The servos which actuate the ailerons are now mounted to a bottom plate now sit on an ABS plastic mount. This mount was added to ensure that the servo would remain secured in place during flight and to more easily allow wires to be routed through the compartment. Additionally, the shaft in the ailerons' shaft has been changed from a square shaft to a D-shaft. A D-shaft was chosen to make assembly less complex

## 1.9. Project Plan Changes

- Available funding expanded to $7000
- Peachtree Charter Outreach timeline slowed due slow response times
- Permanent access to rocket construction area acquired
- Student Foundation funding unsuccessful, however funding still exceeds budget
- March 4th Launch unsuccessful- plan to launch in future and participate in USLI

# 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

### 2.2.1 Mission Objectives

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 | Modular/flexible assembly | Conduct evaluation of time |

| | | |
|---|---|---|
| assembly/disassembly time and effort | construction | 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 | Main parachute selected by deriving Kinetic | Evaluate post-recovery altimeter data to check |

| | | |
|---|---|---|
| kinetic energy of 75 ft-lbf. | Energy for heaviest independent section | 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 |

### 2.2.2. Mission Success 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 | All systems will be tested beforehand so that |

| | |
|---|---|
| are powered and capable | 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 |

# 3. Launch Vehicle

## 3.1. Overview

### 3.1.1. Rocket Requirements and Specifications

Our team has designed the Krios rocket to fulfill all of the mission objectives described in section 2.2 as safely and effectively as possible. The rocket is 102 inches long and 5.5 inches wide. When loaded, The weight is approximately 33.4 pounds.  The rocket is wide enough to house all avionics while maintaining a sufficient stability margin of 2.56.

The Nose Cone, like the rest of the airframe, is fiberglass. The GPS unit and its power supply are located in the nose cone to ensure that they are far enough from the avionics equipment to not be affected by electromagnetic interference. The Avionics Bay is located near the middle of the rocket, between the main chute and drogue chute. It houses the Pixhawk microcontroller, its power supply, and the primary and backup altimeters. The fins provide stability. At the bottom of each fin is an elevon mounted on a hinge. These elevons are actuated by servos mounted at the bottom of the booster section. This actuation will induce the moment needed to accomplish the "roll" mission objective. The Mass Addition System is located in the GPS bay in the Nose Cone. Its purpose is to house any ballast needed to adjust the rocket's center of mass to match the simulations that have been conducted. Above the Motor is the Weight Addition  Transmission  Equipment System (WATES). It consists of a sealed compartment with a removeable PVC cap. If, after construction, the rocket was found to have less mass than anticipated, sand could have been added to WATES to increase the overall mass. WATES is located near the rocket's center of mass, so adding mass in this location would not greatly affect the center of mass. After the rocket was constructed, we decided that additional mass was not needed, so WATES is empty.

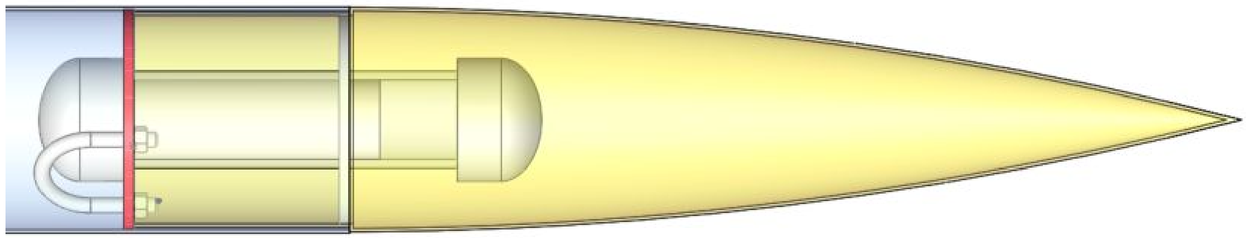
### 3.1.2. Assembly of Sections

The different sections of the rocket are held together by friction with the couplers and shear pins. The shoulder of the Nose Cone fits into the Upper Transition Tube. The Avionics bay acts as a coupler between the Upper Transition Tube and the Main Body Tube. The fins fit into slots in the Main Body Tube. They epoxied to the outside of the Main Body Tube as well as Centering Rings inside the tube to ensure secure attachment. The Centering rings are epoxied to the Engine Mount which contains the Motor Casing. A Thrust plate is epoxied to the Main Body Tube above the engine mount, and the Bottom Plate is screwed to the Main Body Tube below the Engine Mount. The Bottom Plate also supports the servos for the Roll System, which are mounted on 3D printed Servo Brackets.

## 3.2 Launch Vehicle Features

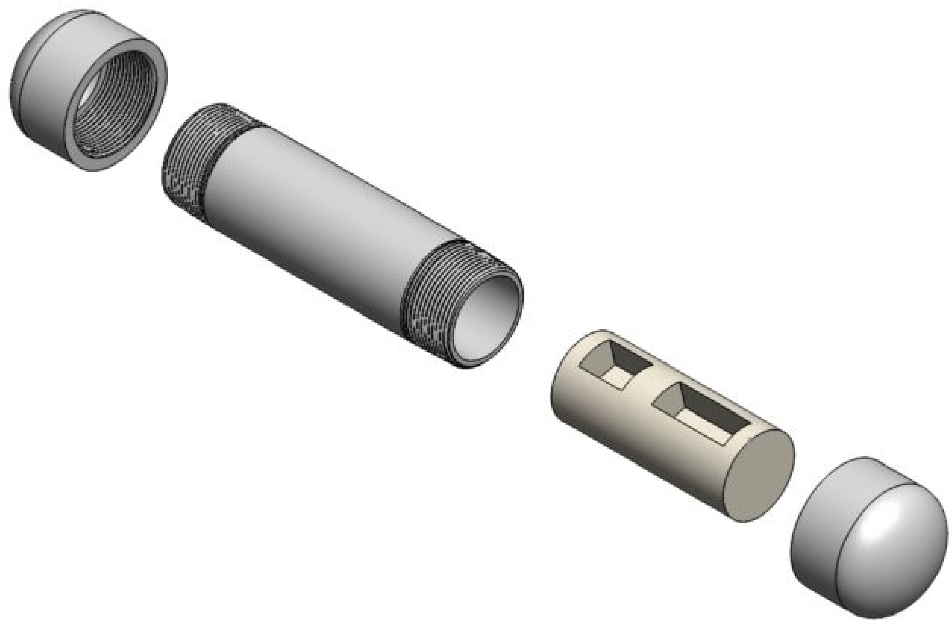
### 3.2.1 Nosecone GPS

The purpose of installing a separate, isolated GPS system in the nose cone was to ensure that no detrimental electromagnetic interference would be likely to occur. Interference was seen as a possible issue if the GPS was located in the avionics bay due to the high concentration of crucial flight control electronics. An additional benefit of the nose cone placement is that the GPS system is farther from the recovery system charges and therefore in a lower pressure and thereby safer area for the durability of the GPS system as a whole.



GPS Bay on Rocket

The GPS is housed in the GPS Bay, which shares space with the Mass Addition System. Both are located within the PVC pipe near the nose cone. The GPS Bay is well separated from the Mass Addition System because the GPS and its equipment, including a 9 V battery are to be placed inside a foam insert. The foam insert has holes cut out to make the exact amount of space for the GPS. The reason the GPS is to be placed in the foam is to help cushion the impact of the launch and the fall. The ends of the PVC pipe are capped on both ends. The GPS assembly is held in place by the centering rings which are epoxied to the pvc pipe and to the inside of the nose cone up to the cone shoulder. They were epoxied to ensure that the entire system is kept safe and doesn't move during the launch or when the rocket is airborne.



Exploded GPS Capsule

### 3.2.3 Avionics Bay

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 removable 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. Figure 3.2.1 shows the location of the A-Bay in the rocket.

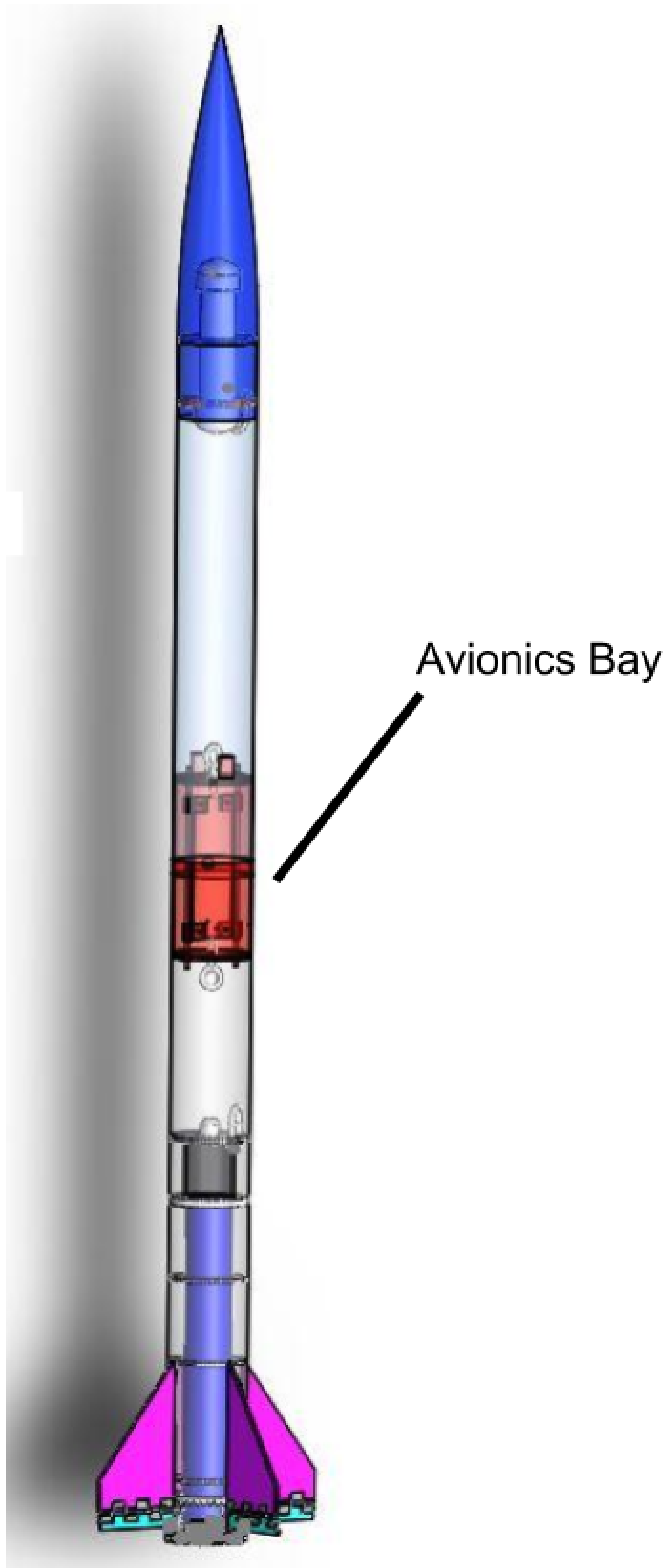

Avionics Bay

Figure 3.2.1 Avionics Bay Location

When designing the A-Bay, we decided to place it on a sled rather than attach it to the airframe body due to the safety and accessibility improvements. By being on a sled attached to multiple bulkheads at multiple locations, the components of the A-Bay would be stable from ejection charge discharges and other events that would cause instability within the rocket. In addition, a removable tray would allow for easy modification of A-Bay components as well as data collection after flights. As the components of the A-Bay are necessary for a proper flight, the removable nature of the tray allows for emergency maintenance, such as battery replacement.

The Avionics Bay (A-Bay) is housed inside of a 12in section of fiberglass coupler tube. Avionics components are mounted onto a 9.75in by 3.25in 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.

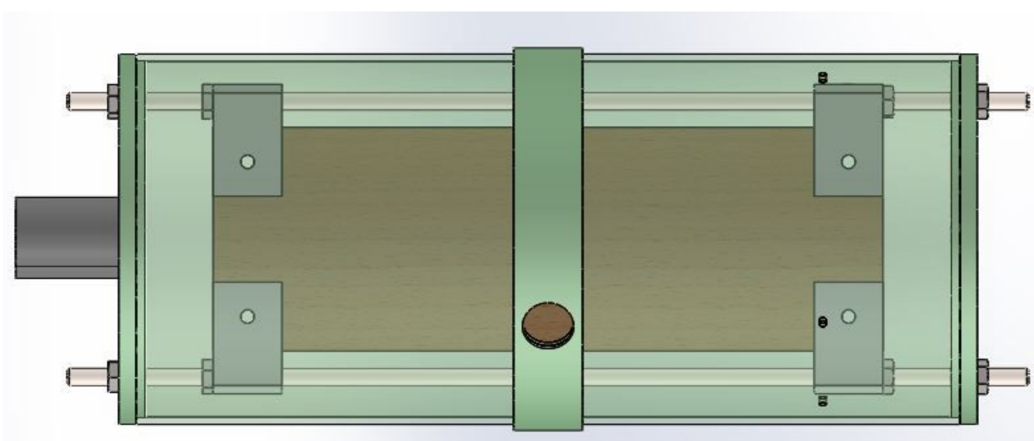


Figure 3.2.2 Empty Avionics Bay

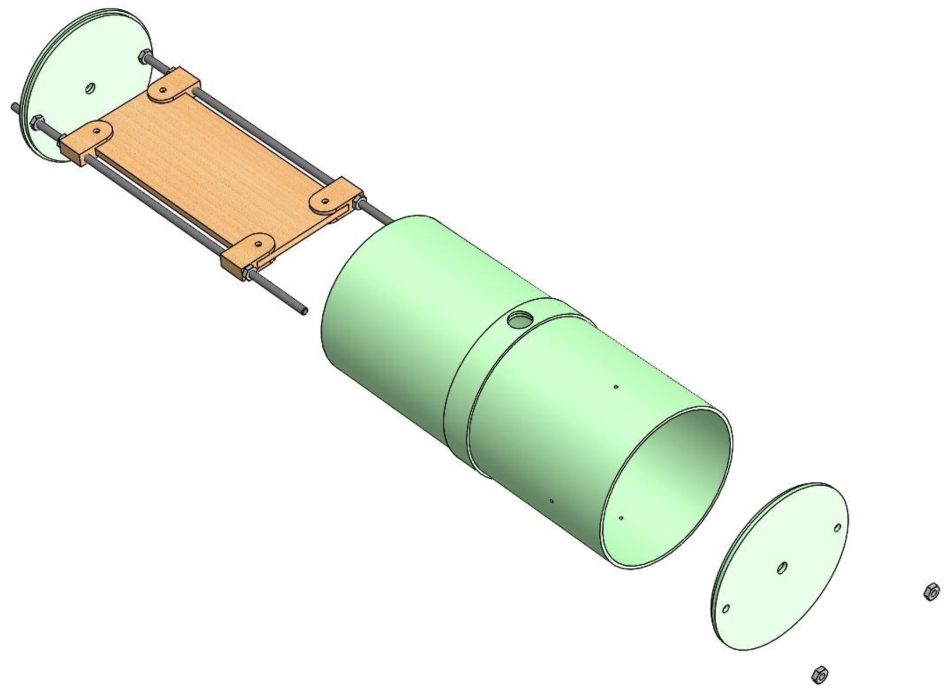


Figure 3.2.3 Exploded View

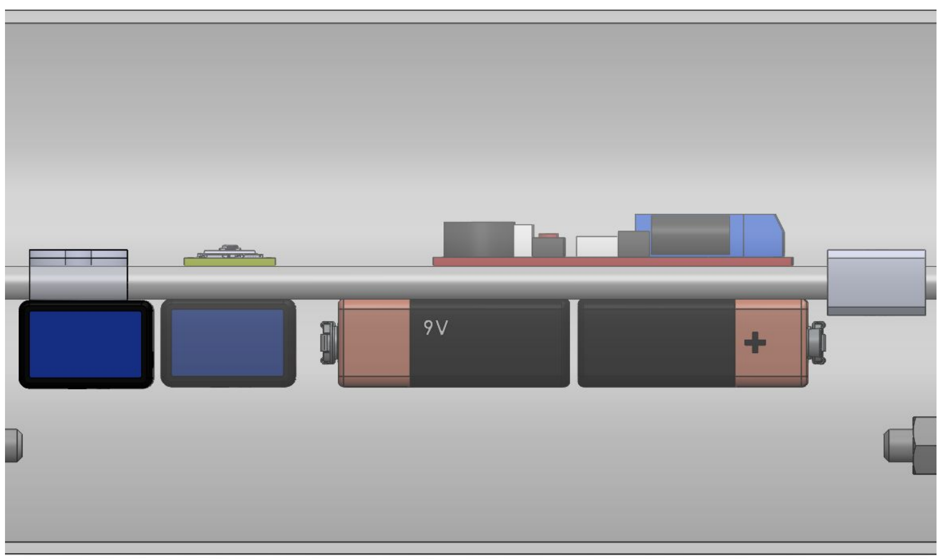



Figure 3.2.4  Tray With Mounted Hardware

### 3.2.4 Booster Section

The booster section assembly has not changed since the submission of the CDR. A .5 in thrust plate resides on the end of a 75mm LOC tube, which houses the motor. There are 3 centering rings, two within the fin and one at the end of the LOC tube. Every plate/ring going down from the avionics bay was designed with the intention of eventually being drilled and assembled with avionics equipment to pass wiring through all parts of the rocket down to the servos.

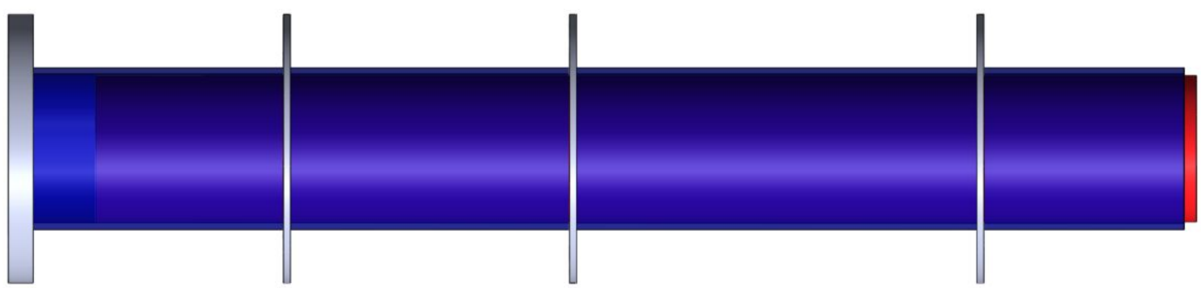


Figure 3.2.5 CAD Booster Tube

The entirety of the booster section, which comprises of the mounting of the 4 fins to their respective ailerons, as well as the mounting of the fins to the LOC and fiberglass tubes remained unchanged. The only problem identified with this design was that with constant removeall of the servo+pinion gear plate on the bottom of the rocket, it becomes very difficult to lign up the gear perfectly enough to ensure a good mash.

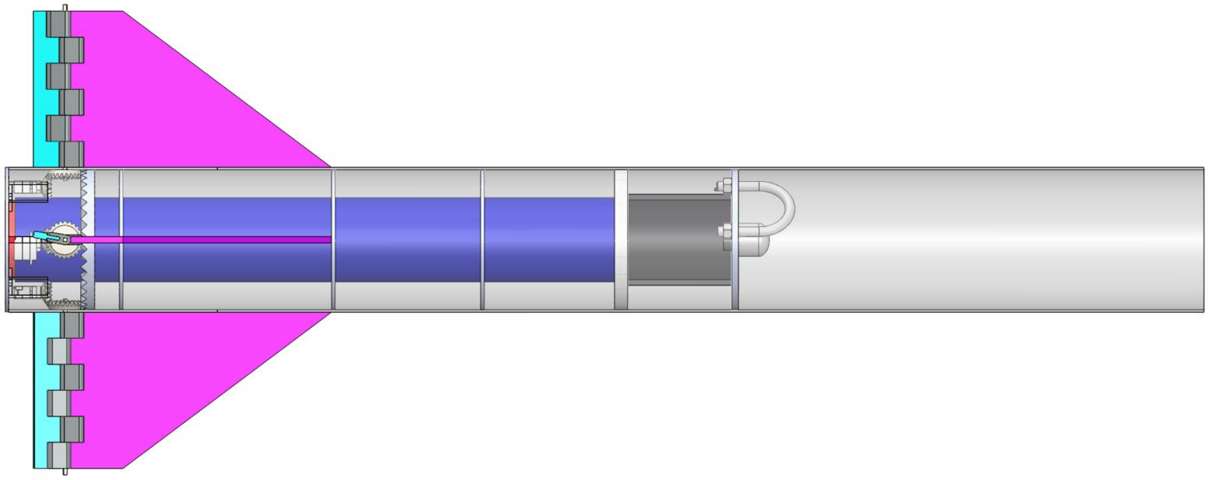


Figure 3.2.6 CAD Booster Section

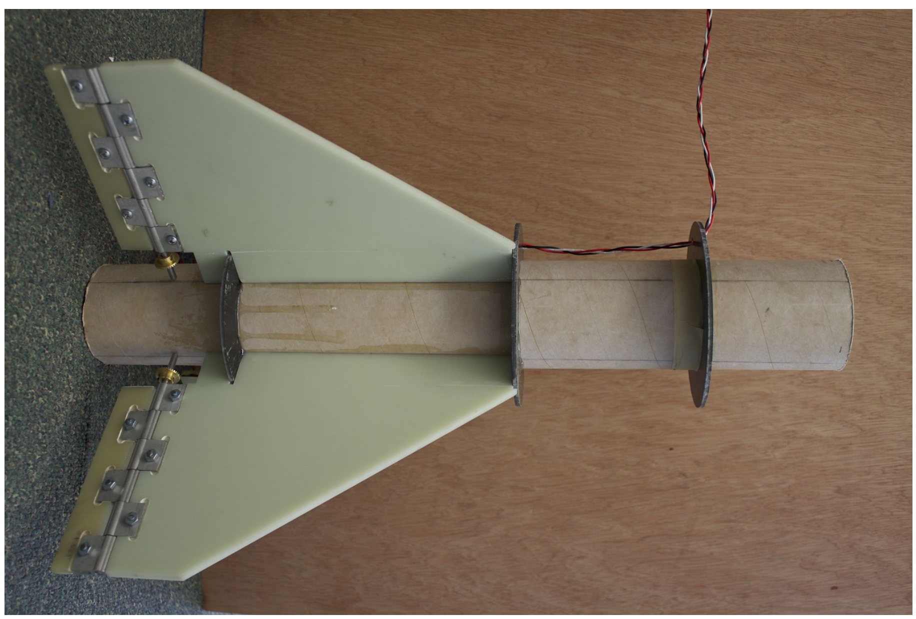


Figure 3.2.7  Fabricated Booster Section

### 3.2.5 Fins and Ailerons

The fins and elevons of KRIOS are made of G10 fiberglass. The aft end of the fins and forwards end of the ailerons have rectangular depressions machined into them which allow them to interface with the roll control system via aluminum brackets.

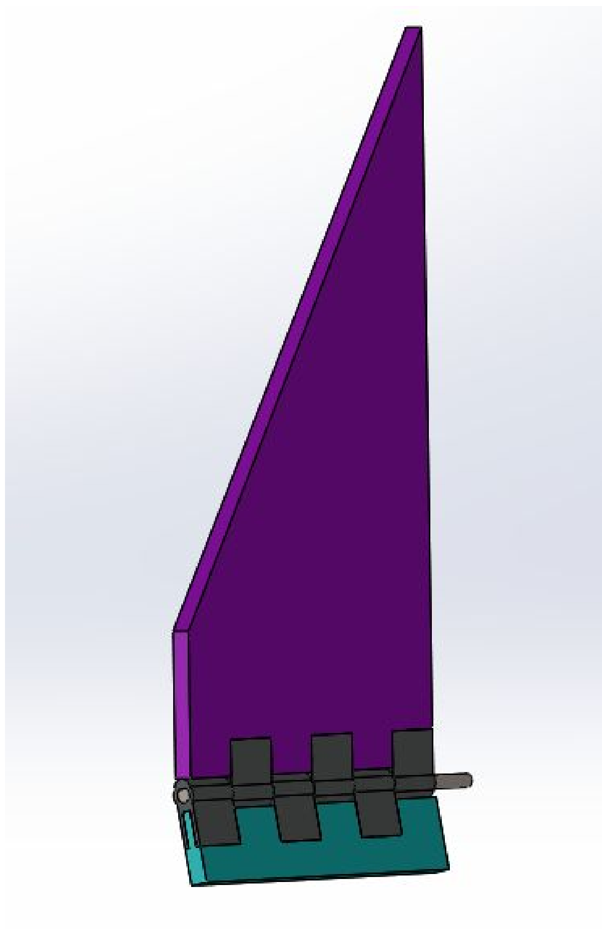


Figure 3.2.5 Fin + Aileron Assembly

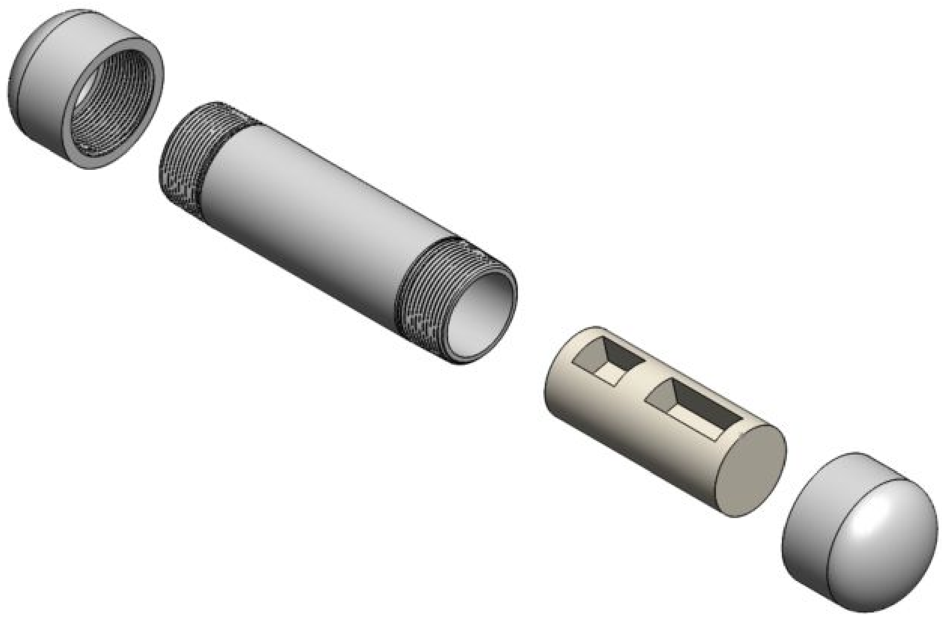
### 3.2.6 GPS Bay

The Mass Addition System is coupled with the GPS Bay. They are both housed in the same component. The Mass Addition System is held towards the top of the rocket near the nose-cone. The system along with the GPS bay are housed in a PVC pipe. The PVC pipe is capped on both ends. The mass is added to the system in the form of sand. The PVC pipe is epoxied to the the centering rings, and the centerings rings are epoxied up to the inside of the nose cone shoulder.

Figure 3.2.6 GPS Bay

Figure 3.2.7 EndCap

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



Mass Addition System

### 3.2.7 Final Motor Selection

The final motor selected remains the Aerotech L1150. The expected apogee given its thrust profile is within 5 feet of 5280ft. The data of the L1150 is below in table 3.2.5 and the thrust profile in figure 3.2.5.

| Aerotech L1150 | |
|---|---|
| Diameter | 75.00 mm |
| Length | 53.1 cm |
| Propellant Weight | 2065.3g |
| Overall Weight | 3,673.6g |
| Average Thrust | 1,102.2 N |
| Maximum Thrust | 1,309.7 N |
| Total Impulse | 3,488.6 Ns |
| Specific Impulse | 96.9s? |
| Burn Time | 3.2s |

Table 3.2.5- Aerotech L1150 Specifications

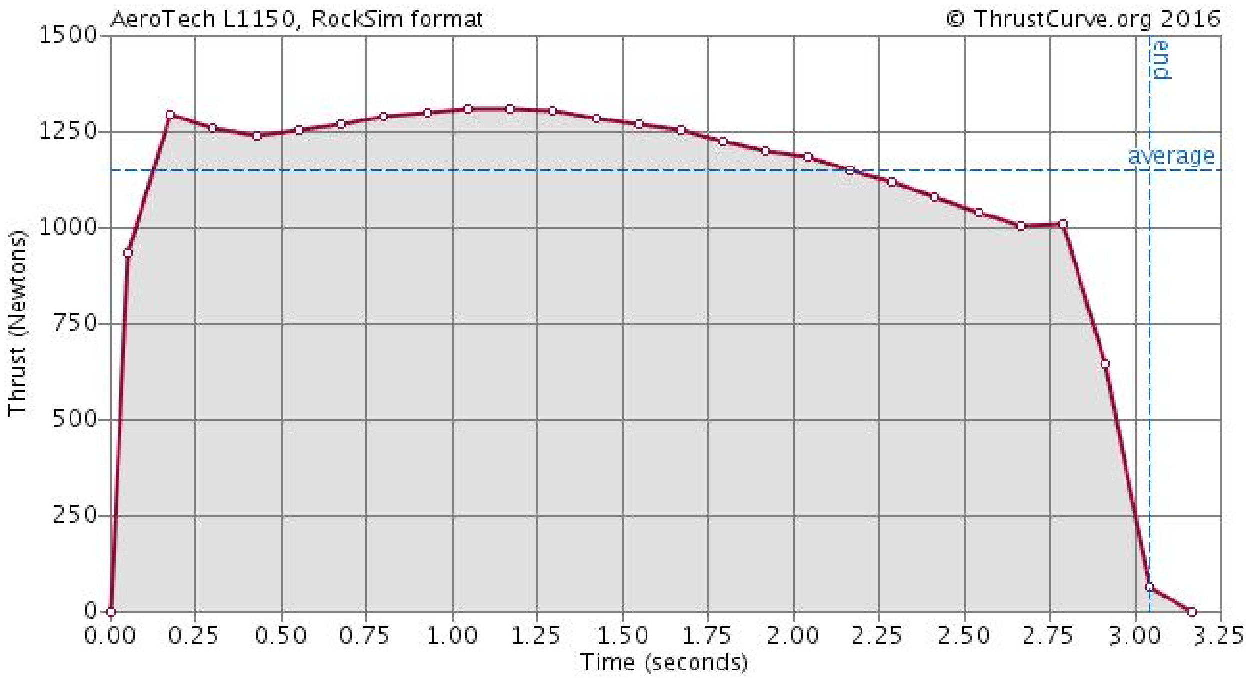



Figure 3.2.5 Thrust Curve Profile for L1150

## 3.3. Structural Elements

It was necessary to test different components of the rocket prior to full assembly, due to the risk involved with the failure of these components. If a bulkhead failed in flight, parachute deployment would not be successful, as a proper connection between the bulkheads and the airframe is necessary for the parachutes to work properly. In addition, if the avionics bay bulkheads failed, the altimeters and other electronics equipment would be put at risk of damage, which may interfere with parachute deployment and data collection. Therefore, the bulkheads of the rocket required the most structural analysis, to confirm that these components could withstand the forces of a rocket launch.

During the rocket's flight, the bulkheads would experience two major forces: the pressure from the ejection charge explosion during parachute deployment, and the impulse from the shock cord as the parachute deployed. In both of these situations, the components with a likelihood of failing were the fiberglass bulkheads themselves and the epoxy that held the bulkheads to the body tubes. To test these components, it was necessary to first calculate the forces exerted on each, perform simulations on Solidworks, then design and perform physical load tests to determine if the simulations were accurate. Figure 3.3.1 below shows each bulkhead to be tested, as well as its location in the rocket.

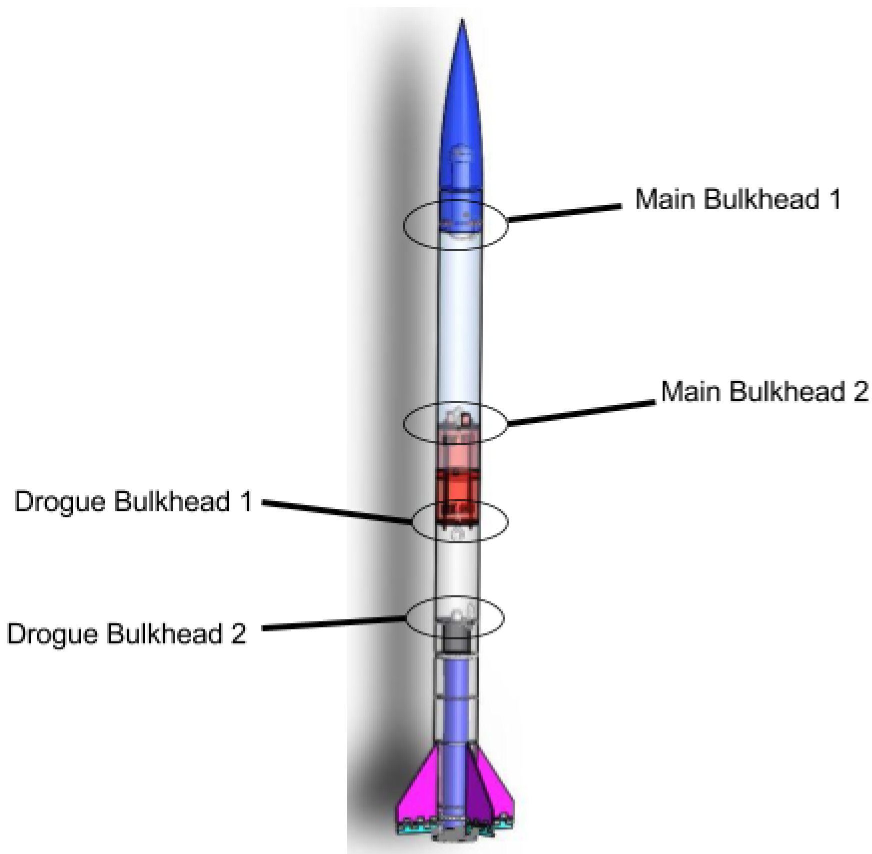



Figure 3.3.1 Bulkhead Locations

### 3.3.1. Ejection Charge Simulation

The first internal force exerted on the bulkheads adjacent to both the main parachute and drogue parachute would be from the detonation of black powder ejection charges to snap the shock cords. Table 3.3.1. details the pressure of each charge on the bulkheads.

Table 3.3.1 Pressure from Ejection Charges

| Bulkhead | Amount of black powder(grams) | Volume of compartment($in^3$) | Pressure on bulkhead (psi) |
|---|---|---|---|
| Main 1 | 3 | 594.8 | 9.9 |
| Main 2 | 3 | 594.8 | 9.9 |
| Drogue 1 | 3 | 297.4 | 19.8 |
| Drogue 2 | 3 | 297.4 | 19.8 |

When first conducting the simulation tests on Solidworks, it was necessary to create the fiberglass material, as it was not one of the presets on the software. Using data sheets for G10 fiberglass, the material was created and applied to the parts in the CAD model. When testing each bulkhead, a fixed geometry was assumed, chosen based on the area of the component that was fixed in place. For the avionics bay bulkheads, the fixed geometry was the intersection of the bulkhead and the threaded rod that connected the two. This was represented by the inside of the two holes on either side of the bulkhead, as this was where the threaded rod was placed. In order for this fixed geometry to fail, the nuts would have to fail or the threads of the rods themselves would have to be destroyed, something that was unlikely to occur. For the other bulkheads, the fixed geometry was on the outside circumference of the bulkheads, where epoxy connected them to the body tube. The assumption in this case was that the fiberglass bulkheads would fail before the cured, crosslinked epoxy bond. The pressure was then applied to the plate. The figures below show the results of the tests from the ejection charges. Every bulkhead successfully withstood the simulated pressure from the respective charge detonations.

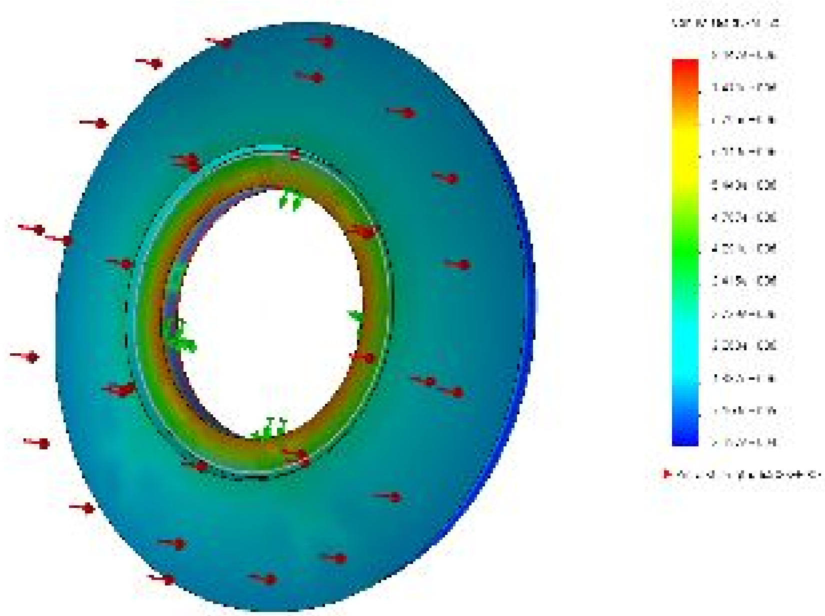


Figure 3.3.2. Main 1 Ejection Charge Test

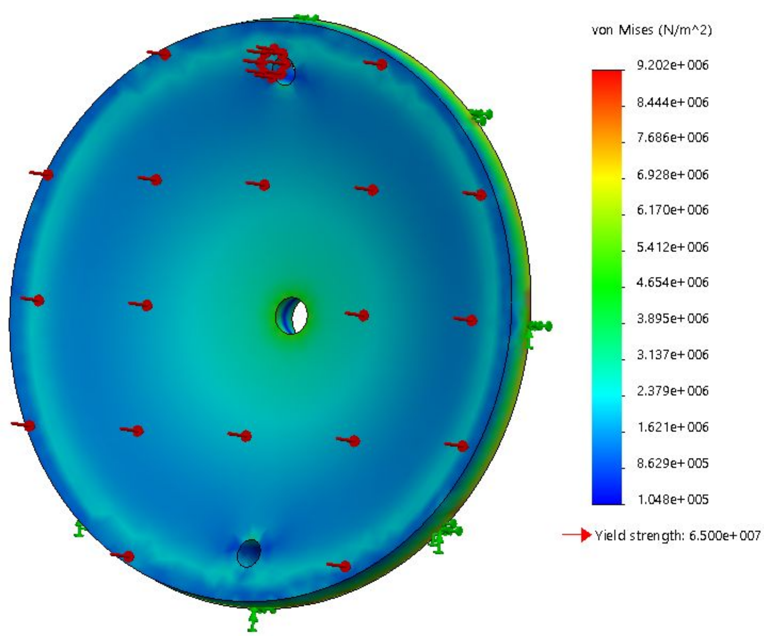



Figure 3.3.3. Main 2 Ejection Charge Test

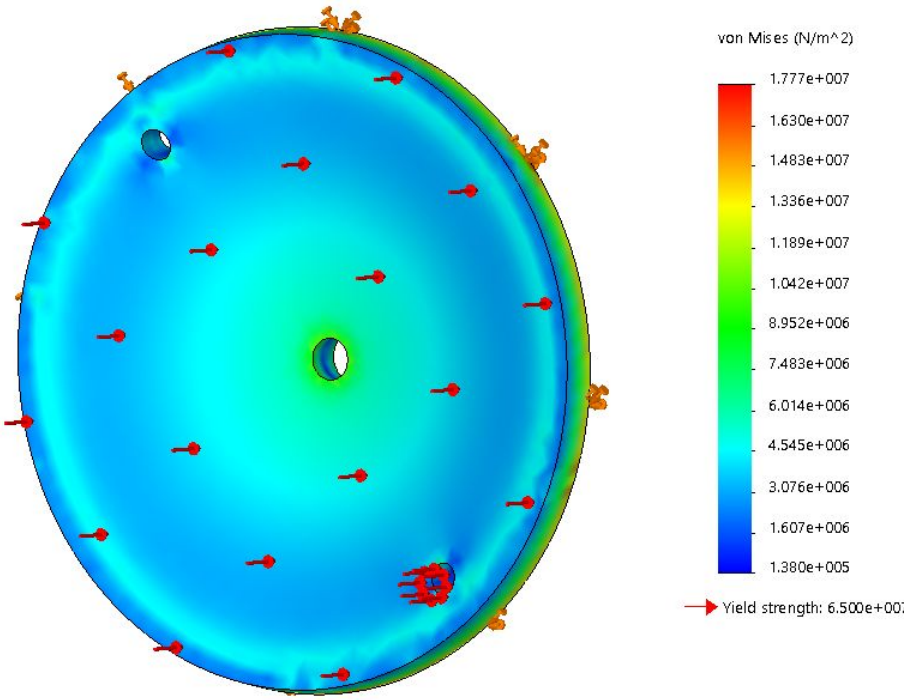



Figure 3.3.4. Drogue 1 Ejection Charge Test

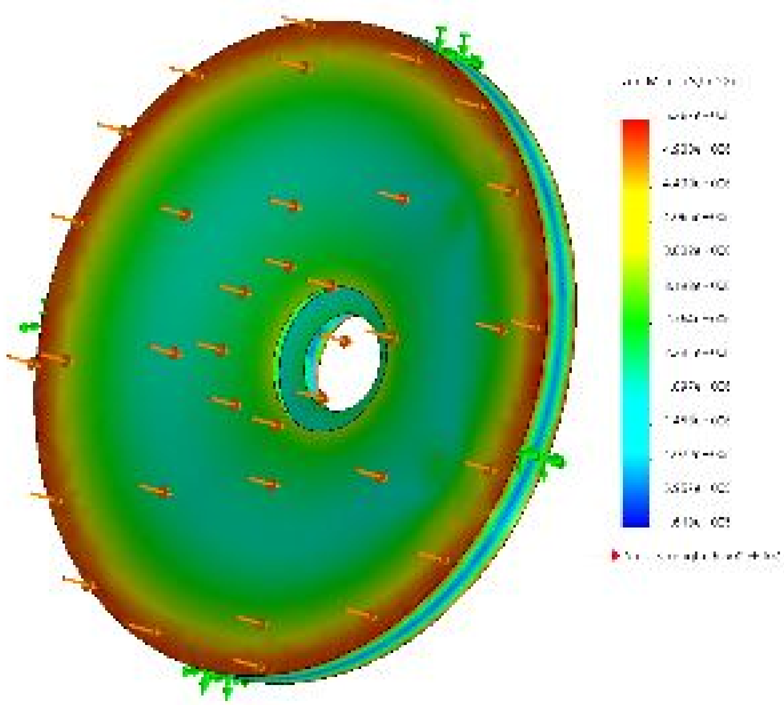


Figure 3.3.5. Drogue 2 Ejection Charge Test

### 3.3.2 Parachute Deployment Simulation

The next force that each bulkhead experiences would be an impulse from parachute deployment. Each parachute deployment would drastically reduce the downwards acceleration of the rocket, and would create an upwards force on the bulkhead due to Newton's First Law. Using OpenRocket simulations, we measured the acceleration of the rocket at different wind speeds, and with the mass of the rocket, we were able to measure the maximum force on a bulkhead at each given time. For these tests, Main Bulkhead 2 and Drogue Bulkhead 2, as those sections would support the most mass of the rocket after parachute deployment and therefore experience the most force. Table 3.3.2 details the acceleration and force on the bulkheads. In terms of the OpenRocket software, as seen in Figure 3.3.6, the exact location characteristics of the Huntsville, AL launch site were inputted into the program to ensure that the proper scenario is put into play when running the simulations, such as the coordinates, altitude, etc.

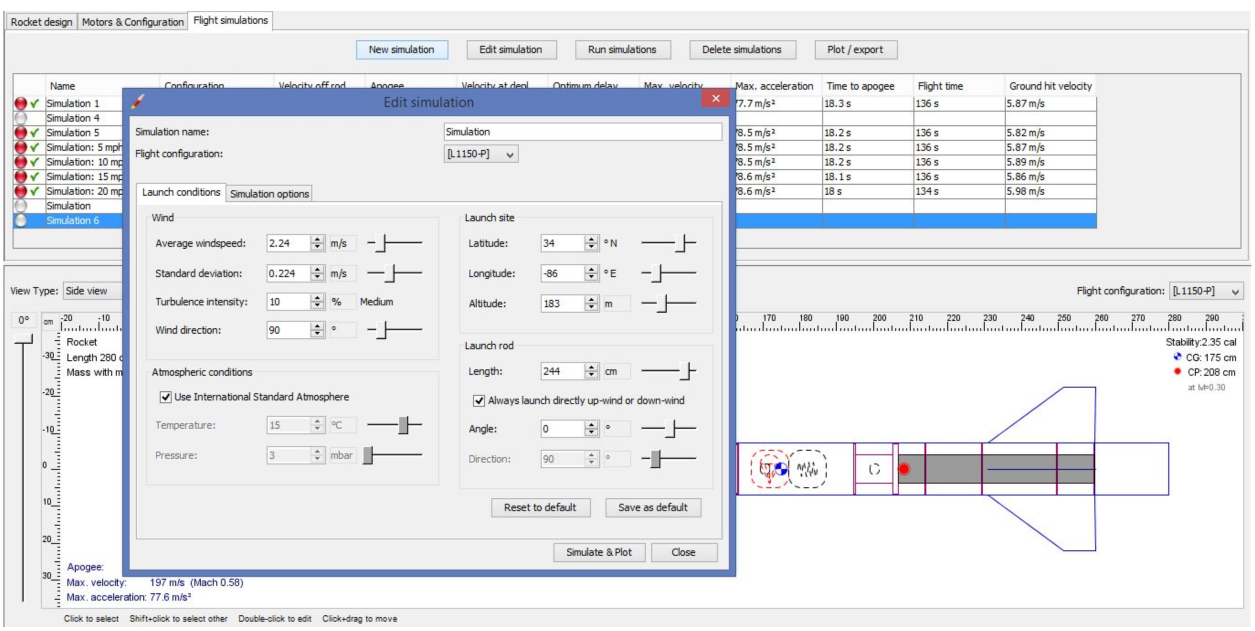



Figure 3.3.6 from OpenRocket Simulations

Table 3.3.2 Force from Parachute Deployment

| Wind Speed (mph) | Mass of Rocket (kg) | Mass of Booster/Avionics Bay(kg) | Acceleration ($m/s^2$) | Force (N) on Main 2 |
|---|---|---|---|---|
| 5 | 13.232 | 12.706 | 78.5 | 997.421 |
| 10 | 13.232 | 12.706 | 78.5 | 997.421 |
| 15 | 13.232 | 12.706 | 78.6 | 998.711 |
| 20 | 13.232 | 12.706 | 78.6 | 998.711 |

| Wind Speed (mph) | Mass of Booster (kg) | Acceleration ($m/s^2$) | Force (N) on Drogue 2 |
|---|---|---|---|
| 5 | 9.469 | 78.5 | 743.296 |
| 10 | 9.469 | 78.5 | 743.296 |
| 15 | 9.469 | 78.6 | 744.243 |
| 20 | 9.469 | 78.6 | 744.243 |

Using the same fixed geometries assumed during ejection charge testing, these forces were tested in the SolidWorks Simulations add-on. The worst-case scenario force was 998.711 N, so this was used during the testing. The figures below show the results of the simulation tests. Each bulkhead successfully withstood the maximum possible force.

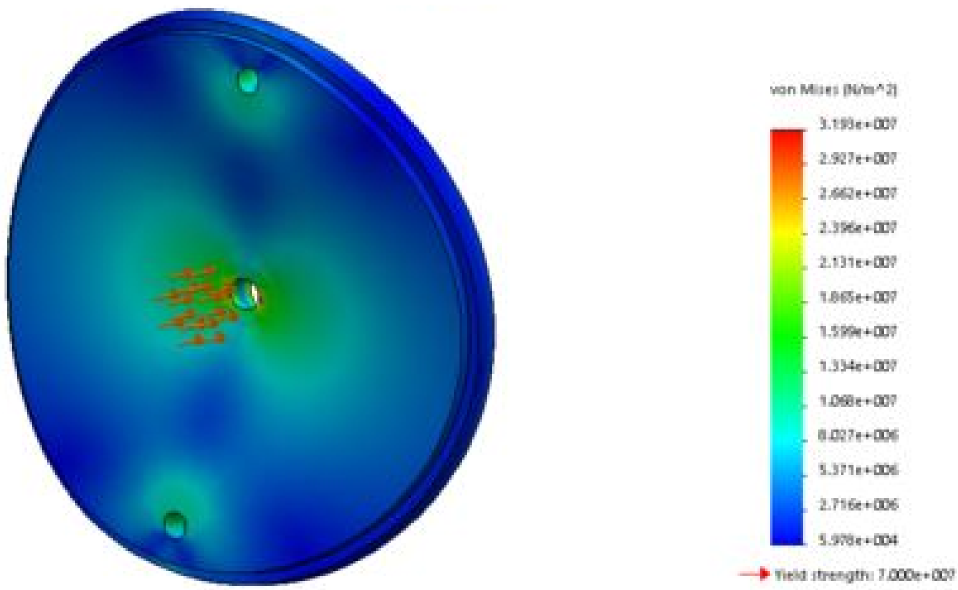



Figure 3.3.7 Main 2 Parachute Deployment

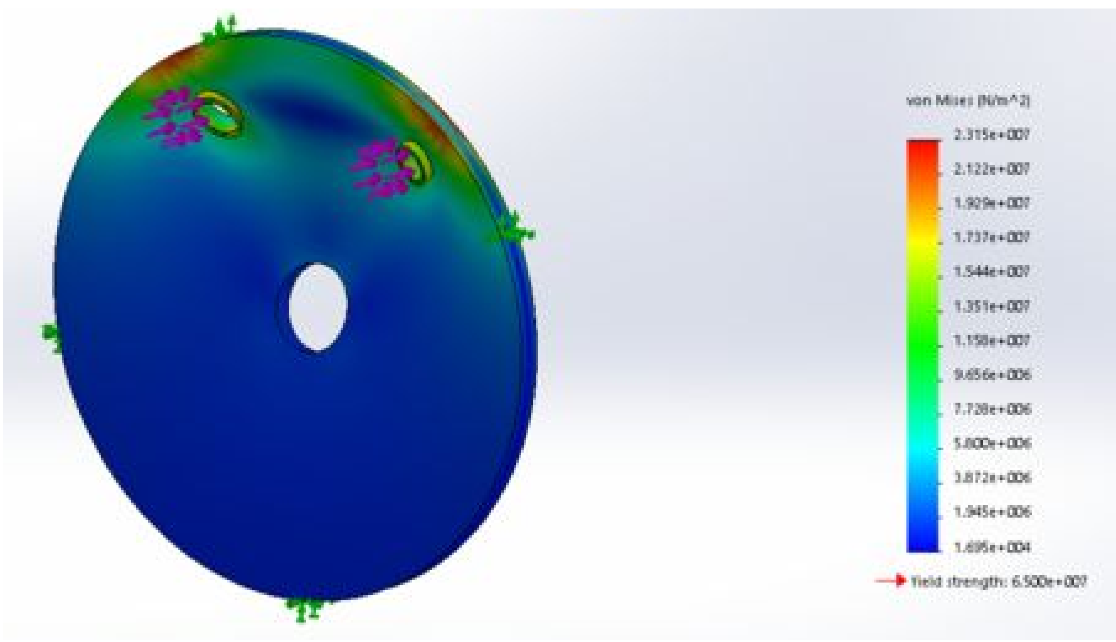



Figure 3.3.8 Drogue 2 Parachute Deployment

All structural components withstood the simulated stress. The next step was to construct physical mockups of the different components for load testing, which is discussed later in the Testing section.

## 3.4 Mass Breakdown

The components of KRIOS and their masses are sorted by subsystem below in table 3.4.1.. It can be seen from these tables and figures that the subsystems with the greatest mass are the Structure of the rocket and Propulsion. The components with the most mass are the motor and the fiberglass airframe tubes. The rocket's center of mass is located in the middle of the Drogue Chute Compartment above the MAS.

Table 3.4.1 Mass Breakdown

| System | Component | Material | Mass per Unit (lbm) | QTY. | Total Mass (lb) |
|---|---|---|---|---|---|
| Nose Cone | Nose Cone | Fiberglass | 1.07 | 1 | 1.07 |
| | GPS Bay Tube | PVC | 0.66 | 1 | 0.66 |
| | Bottom Nose Cone Bulkplate | Fiberglass | 0.27 | 1 | 0.27 |
| | Top Nose Cone Bulkplate | Fiberglass | 0.26 | 1 | 0.26 |
| | U-Bolt | Steel | 0.127 | 1 | 0.127 |
| | GPS Bay Foam | Foam | 0.09 | 1 | 0.09 |
| | Nose Cone Weight | Lead Shot | 2.1 | 1 | 2.1 |
| Structure | Upper Transition Tube | Fiberglass | 3.06 | 1 | 3.06 |
| | Main Body Tube | Fiberglass | 5.28 | 1 | 5.28 |
| | Drogue Chute | Rip-Stop Nylon | 0.16 | 1 | 0.16 |

| | | | | | |
|---|---|---|---|---|---|
| Recovery | Main Chute | Rip-Stop Nylon | 1.07 | 1 | 1.07 |
| A-Bay | Airframe Bulkhead | Fiberglass | 0.37 | 2 | 0.74 |
| | A-Bay Airframe | Fiberglass | 0.1 | 1 | 0.1 |
| | A-Bay Coupler | Fiberglass | 1.41 | 1 | 1.41 |
| | Coupler Bulkhead | Fiberglass | 0.18 | 2 | 0.36 |
| | Mounting Plate | Balsa Wood | 0.05 | 1 | 0.05 |
| | Plate Bracket | Aluminum | 0.05 | 4 | 0.2 |
| | Threaded Rod | Steel | 0.2 | 2 | 0.4 |
| | Nut | Steel | 0.01 | 8 | 0.08 |
| | Batteries | N/A | 0.96 | 1 | 0.96 |
| | Blast Cap | N/A | 0.04 | 2 | 0.08 |
| | Eye-Bolt | Steel | 0.11 | 2 | 0.22 |
| | Hardware | N/A | | | |
| MAS | PVC Cap | PVC | 0.04 | 1 | 0.04 |
| | PVC Nozzle | PVC | 0.02 | 1 | 0.02 |
| | Compartment | PVC | 0.42 | 1 | 0.42 |
| | U-Bolt | Steel | 0.127 | 1 | 0.127 |
| Roll | Flap Bracket | Aluminum | 0.01 | 12 | 0.12 |
| | Fin Bracket | Aluminum | 0.01 | 12 | 0.12 |
| | D-shaft | Steel | 0.06 | 4 | 0.24 |
| | Flap | Fiberglass | 0.09 | 4 | 0.36 |
| | Fin | Fiberglass | 0.75 | 4 | 3 |
| | Face Gear | ABS Plastic | 0.41 | 1 | 0.41 |

| | | | | | |
|---|---|---|---|---|---|
| | Small Bevel Gear | Brass | 0.01 | 4 | 0.04 |
| | Large Bevel Gear | Brass | 0.01 | 4 | 0.04 |
| | Servo Hub | Aluminum | 0.01 | 4 | 0.04 |
| | Servo Mount | ABS Plastic | 0.03 | 4 | 0.12 |
| Propulsion | Motor Casing (loaded) | N/A | 8.15 | 1 | 8.15 |
| | Centering Rings | Fiberglass | 0.13 | 3 | 0.39 |
| | Thrust Plate | Plywood | 0.23 | 1 | 0.23 |
| | Bottom Plate | Aluminum | 0.21 | 1 | 0.21 |
| | Bottom Plate Bracket | Steel | 0.02 | 4 | 0.08 |
| | Engine Mount | Cardboard | 0.49 | 1 | 0.49 |

Table 3.4.2 Mass by Subsystem

| **Subsystem** | **Mass (lb)** |
|---|---:|
| Nose Cone | 4.577 |
| Structure | 8.34 |
| Recovery | 1.23 |
| A-Bay | 4.3 |
| MAS | 0.607 |
| Roll | 4.49 |
| Propulsion | 9.55 |
| **Total** | 33.394 |

Figure 3.4.1: Mass Distribution Pie Chart

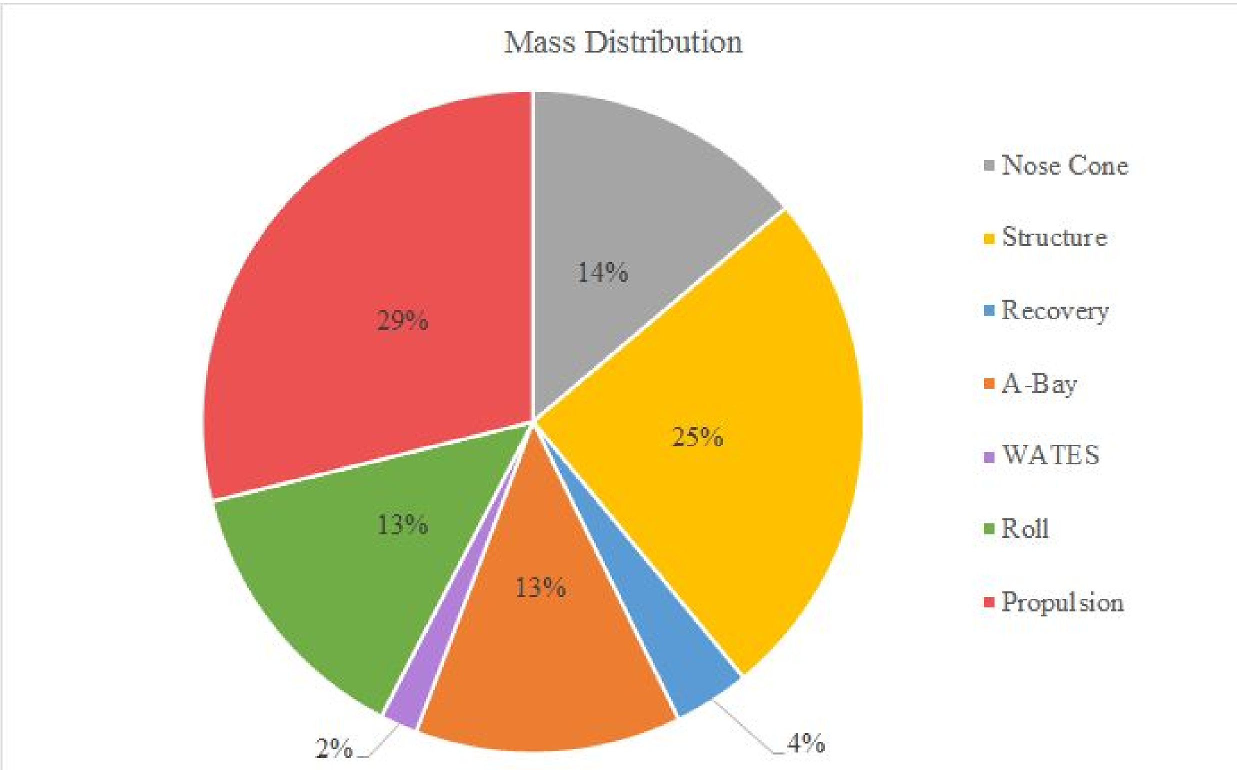



Figure 3.4.2: Mass Visualization

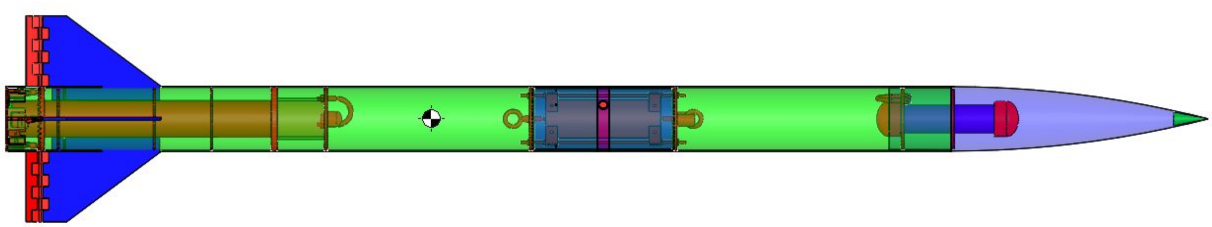


Table 3.4.3: Mass Visualization Key

| **Color** | **Mass** |
|---|---|
| Green | Greater than 2 lb |

| | |
|---|---|
| Blue | Between 0.5 lb and 2 lb |
| Red | Less than 0.5 lb |

*Note that the motor appears red because it is inside the Engine Mount, which is made from cardboard and weighs less than 0.5 lbs. The rocket's center of mass is shown as the black and white circle.

## 3.5 Mission Performance

### 3.5.1 Mission Performance Overview

The success of the mission can be measured by various criteria and the ability of the rocket flight to meet these objectives. Through OpenRocket and ANSYS simulations, the flight of the rocket can be tracked to determine if these objectives are expected to be accomplished.

### 3.5.2 Mission Performance Criteria

In order for the mission to be considered a success, the following criteria must be met:

1) The launch vehicle will report an apogee within 2% of 5,280 ft, the target altitude, due to the Mass Addition System (MAS).
2) The launch vehicle will return reusable, with fully functioning systems and no structural damage.
3) The roll system completes at least two rolls and produces a counter-roll between time of motor burnout and time at apogee.
4) The launch vehicle successfully separates into three stages connected via shock cord.
5) The drogue parachute deploys at apogee, and the main parachute deploys at 750 ft above ground level.
6) The velocity of the launch vehicle before impact is less than 20 ft/s.
7) The GPS successfully remains synced to the computer and reports its position.

3.5.6 Kinetic Energy Breakdown

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 20 ft/s. The calculations are shown below:

According to OpenRocket, the vehicle will touchdown with a velocity of 18.5ft/s. The most massive section of the vehicle upon touchdown will be the booster section, with a weight of 220oz. First convert this weight into a mass.

$$220oz * \frac{1lbf}{16oz} * \frac{1slug}{32.17lbf} = .427\ slugs$$

Now kinetic energy may be calculated using the equation:

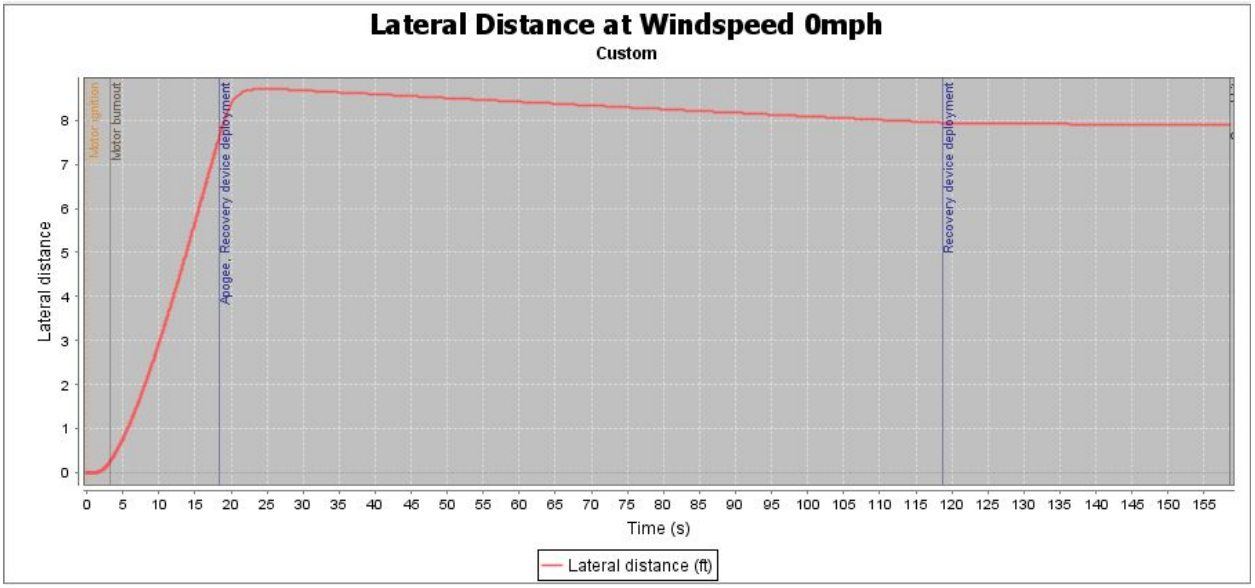
$$E_k = \frac{1}{2}mv^2$$

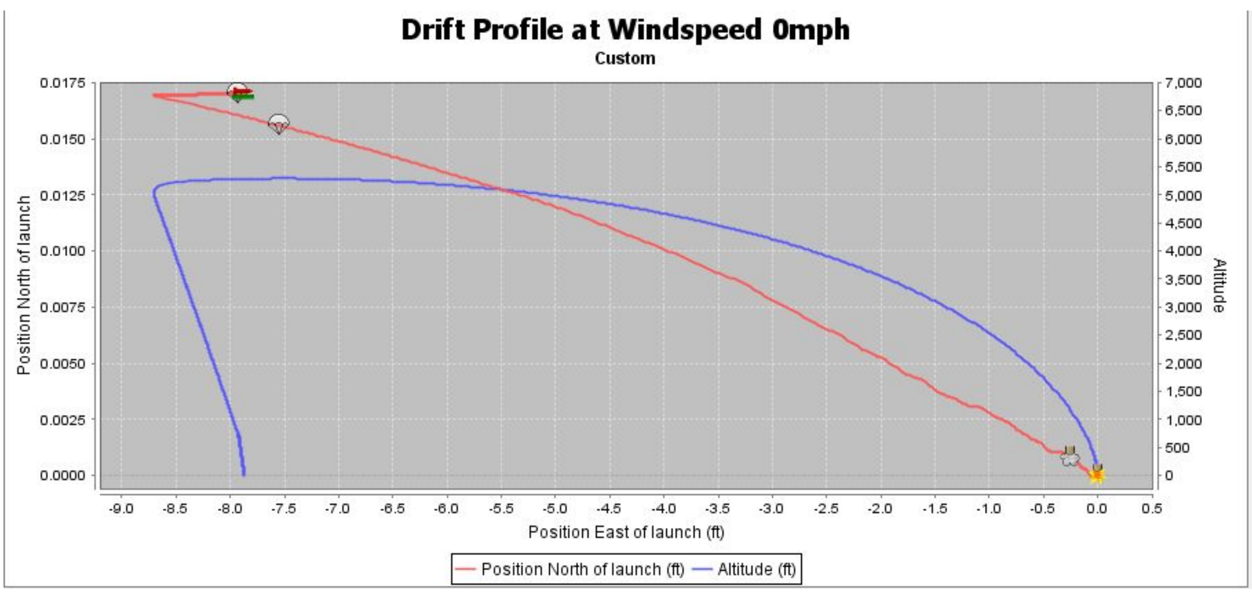
$$E_k = \frac{1}{2} * .404\ slugs * (18.5\,ft/s)^2$$

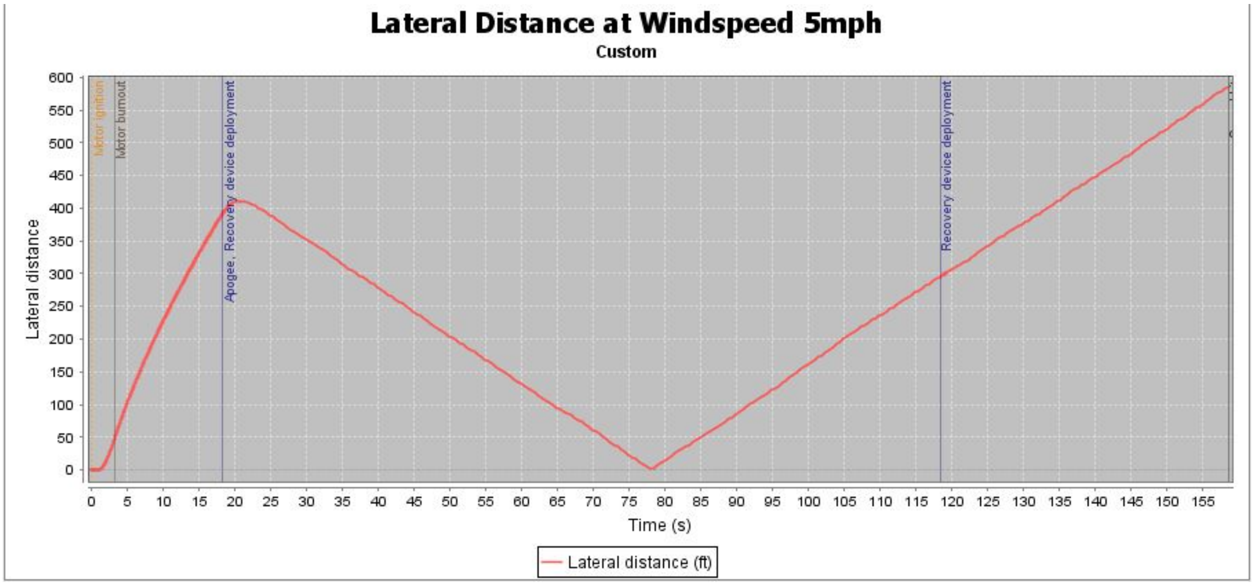
$$E_k = 87.32\ lb \cdot ft$$

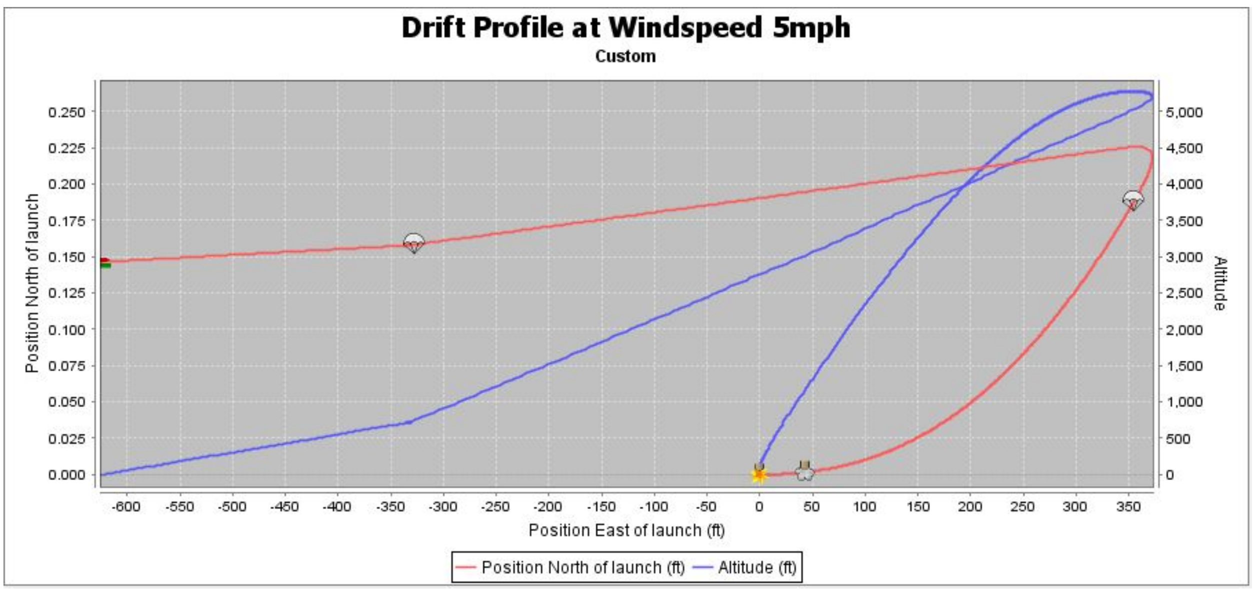
| **Section** | **Mass(lb)** | **Kinetic Energy (ft-lbf)** |
|---|---|---|
| Nose Cone | 9.177 | 49.05 |
| Avionics | 7.53 | 40.27 |
| Booster | 16.03 | 87.32 |

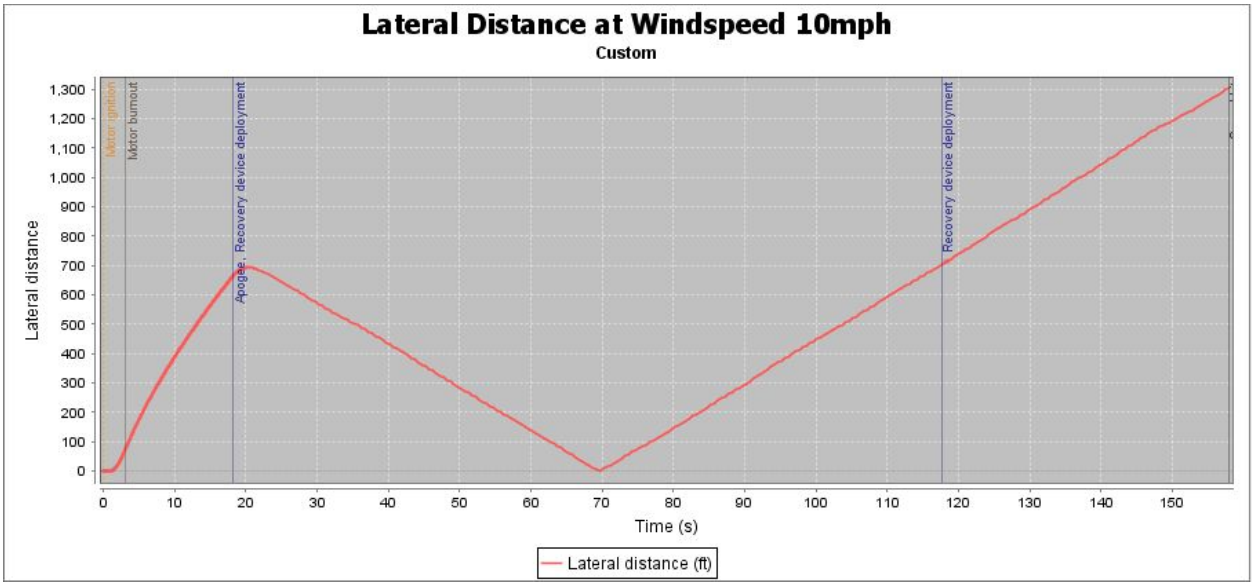
3.5.7 Drift Profile

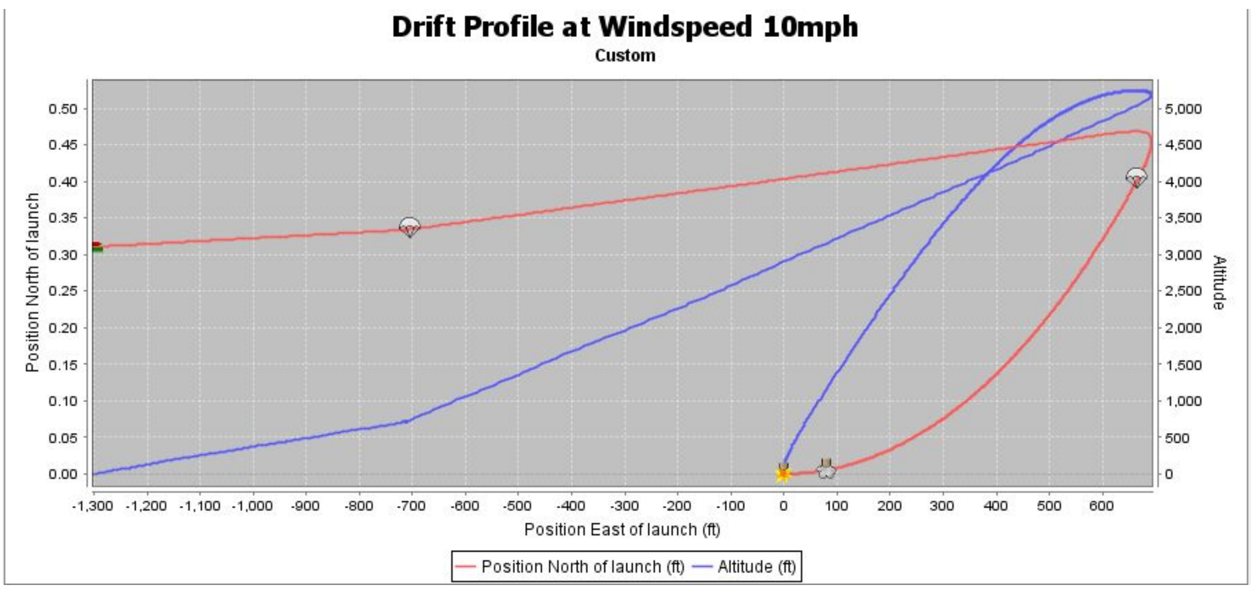


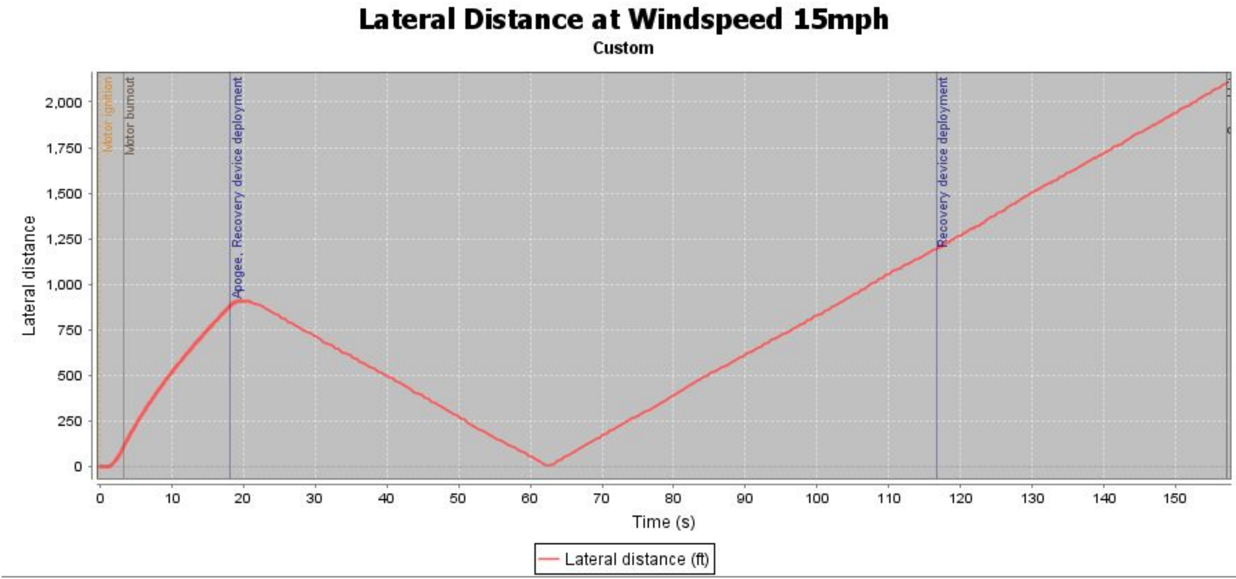




Lateral Distance at Windspeed 5mph
Custom
Motor ignition
Motor burnout
Apogee, Recovery device deployment
Recovery device deployment
Lateral distance
Time (s)
Lateral distance (ft)

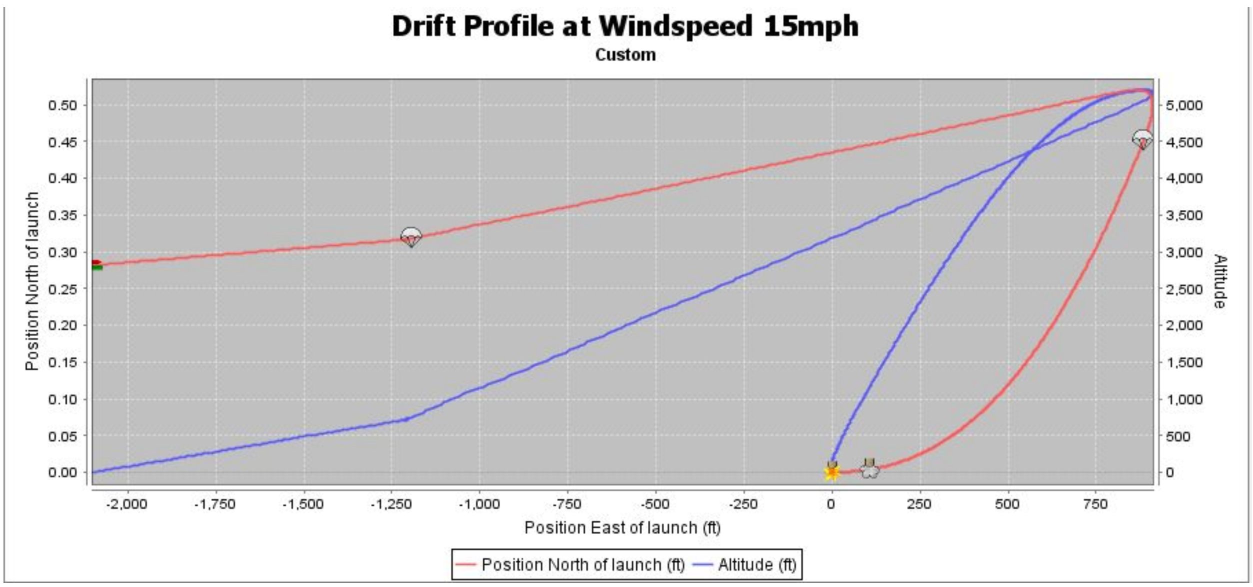

Drift Profile at Windspeed 5mph
Custom
Position North of launch
Altitude
Position East of launch (ft)
Position North of launch (ft)
Altitude (ft)


Lateral Distance at Windspeed 10mph
Custom
Motor ignition
Motor burnout
Apogee, Recovery device deployment
Recovery device deployment
Lateral distance
1,300
1,200
1,100
1,000
900
800
700
600
500
400
300
200
100
0
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
Time (s)
Lateral distance (ft)

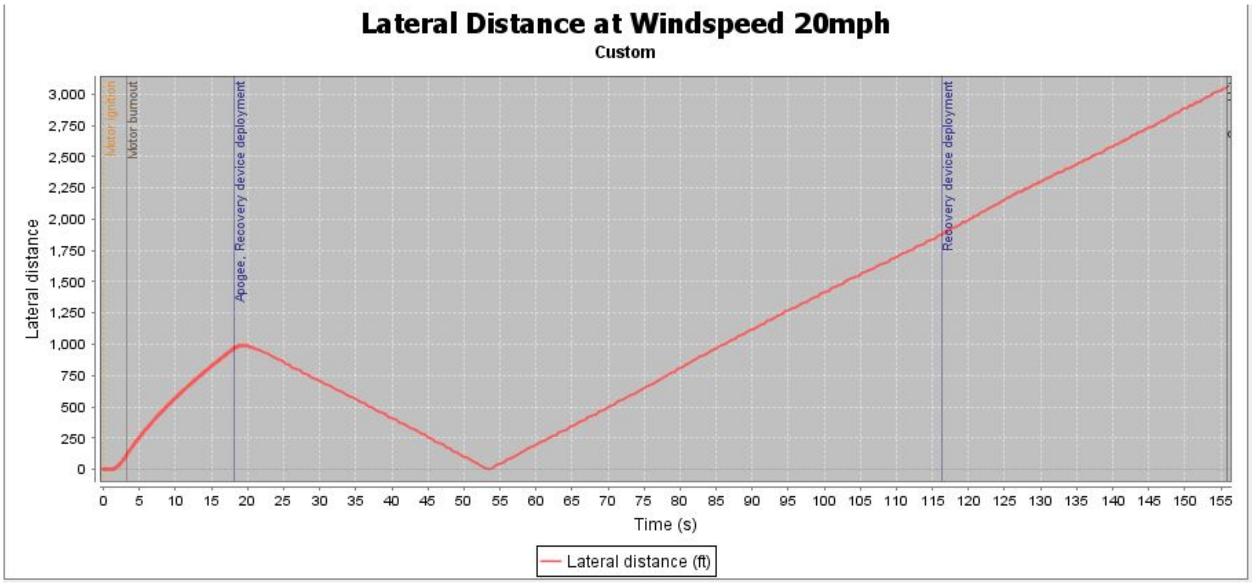

Drift Profile at Windspeed 10mph
Custom
Position North of launch
0.50
0.45
0.40
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00
Altitude
5,000
4,500
4,000
3,500
3,000
2,500
2,000
1,500
1,000
500
0
-1,300
-1,200
-1,100
-1,000
-900
-800
-700
-600
-500
-400
-300
-200
-100
0
100
200
300
400
500
600
Position East of launch (ft)
Position North of launch (ft)
Altitude (ft)

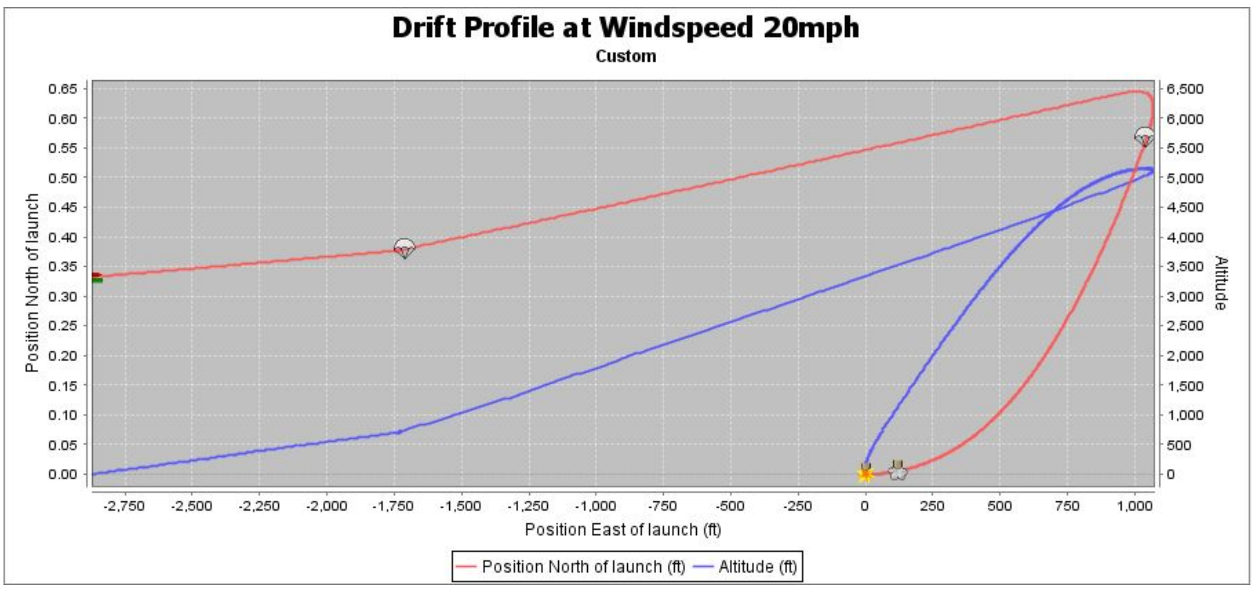


Lateral Distance at Windspeed 15mph
Custom
Motor ignition
Motor burnout
Apogee, Recovery device deployment
Recovery device deployment
Lateral distance
2,000
1,750
1,500
1,250
1,000
750
500
250
0
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
Time (s)
Lateral distance (ft)

Drift Profile at Windspeed 15mph
Custom
Position North of launch
0.50
0.45
0.40
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00
Altitude
5,000
4,500
4,000
3,500
3,000
2,500
2,000
1,500
1,000
500
0
-2,000
-1,750
-1,500
-1,250
-1,000
-750
-500
-250
0
250
500
750
Position East of launch (ft)
Position North of launch (ft)
Altitude (ft)




3.5.8 Mass Addition in GPS Bay

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

One End of the system

Opposite end of the system

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

Assembled GPS Bay

## 3.6 Recovery Subsystem

### 3.6.1 Recovery System Overview

The recovery system has not changed since the preliminary design or the CDR. At the top desired high a drogue parachute is deployed in order to start the rocket's descent and to lower its speed. A second main parachute is deployed closer to the ground to bring the rocket down to the desired landing speed. Each parachute is deployed using small charges that are set to explode at the desired heights. Each parachute has a series of redundancies, such as a secondary charge, to be sure that the parachute will be deployed.


Figure 3.6.1 Parachute Positions in Rocket

### 3.6.2 Structural and Electrical Elements

The primary component of the recovery system is the Perfectflite StratloggerCF altimeter which is capable of measuring altitude through 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 3.6.2, 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.

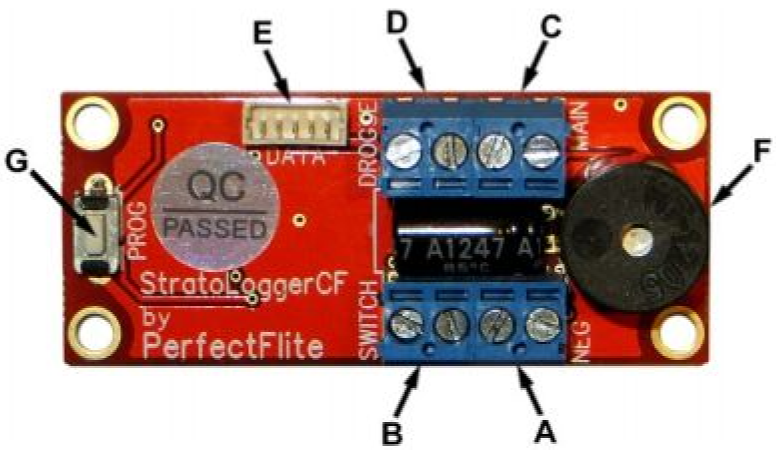



Figure 3.6.2 The StratologgerCF altimeters with connection labels

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 3.6.3 below depicts the StratologgerCF wiring path and illustrates the dual redundant system.

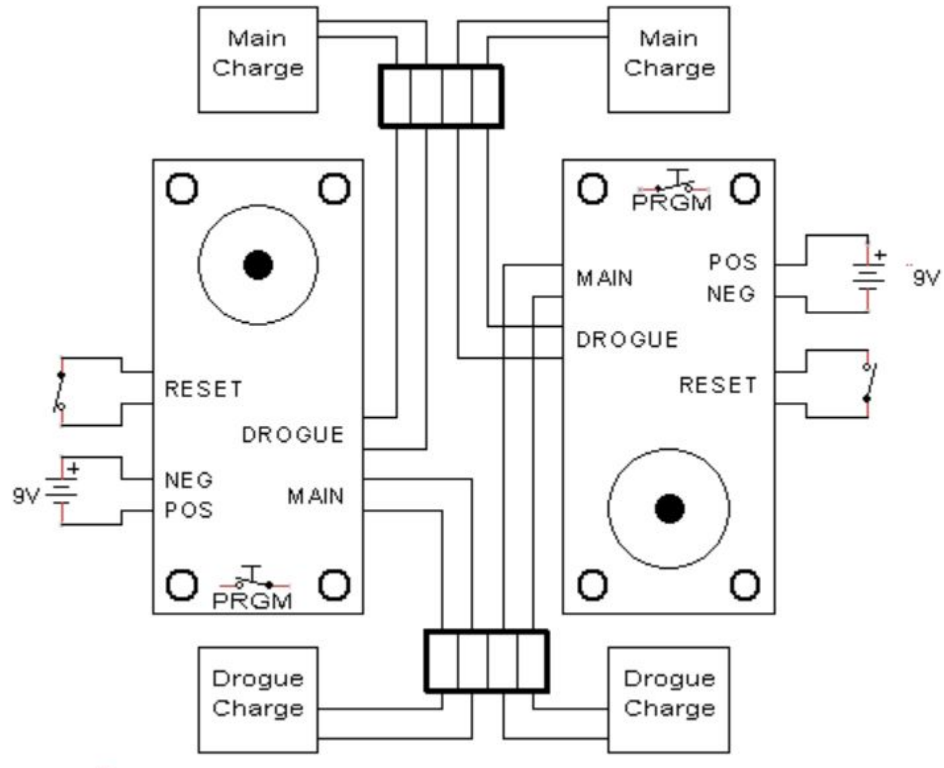



Figure 3.6.3: Dual Redundant System

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.

### 3.6.3 Parachute Analysis

The recovery system will consist of one drogue and one main parachute of 120” and 45” respectively. A GPS system is placed in the nosecone of the rocket and 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.

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.

Figure 3.6.4 Rip-Stop Nylon Parachute

## 3.8. Testing

### 3.8.1 Bulkhead Load Tests

After the bulkheads simulations had been completed, it was necessary to construct and test a mockup of the different bulkheads to confirm that the simulations were accurate. For this testing, two different mockups had to be constructed: an avionics bay setup using the threaded rods, coupler bulkheads, main bulkheads, and eye-bolts used in the actual rocket, and a bulkhead epoxied to the fiberglass body tube. This would allow us to test the durability of both the fiberglass bulkhead material and the epoxy bond used in the rocket.

For the main bulkhead mockup we used the waterjet to cut a piece of fiberglass tubing to the dimensions of the CAD model that was used for simulations of that part. We also waterjetted the plate to be used for the top.  Then we drilled holes in the top for where the u-bolt goes and drilled four holes around the tube. We mixed epoxy and used it to connect the top plate to the tubing. It can be seen in Figure 3.8.1 that we created fillets with the epoxy in the figure below. To simulate the force we tied string to the u-bolt, as it would be in the actual rocket.

Figure 3.8.1 Bulkhead after epoxy

And to hold it down in testing and simulate the force from the other side we strung cord through the four holes that were drilled into the side of the tubing, as seen in Figure 3.8.9. This way when put into the stress testing machinery we would be sure that the single point of contact, the system we were testing, the u-bolt would fail before the other side since it had many points of contact and therefore spread out the pressure evenly along the whole body of the tubing.

Figure 3.8.2 Mockup with cord

When constructing the avionics bay mockup, it was necessary to construct both sides of the avionics bay, as the two bulkheads are connected to each other by threaded rods in the full scale rocket. To create the bulkheads, a waterjet was used, which accurately cut both the coupler bulkheads and the main bulkheads. However, when using the waterjet on the fiberglass, air bubbles formed within the fiberglass, due to the high pressure of the water causing a separation in the fiberglass layers. Therefore, the holes for the threaded rod and the eyebolt had to be drilled by hand.

To measure the center of the bulkheads, multiple methods were used. First, we drew multiple chords across each bulkhead, and drew line segments from their midpoints. The intersection of these lines was the location of the center of the bulkhead. This was not accurate, however, so we used a caliper and ruler to measure the widest section of the bulkhead, the diameter, and used its midpoint to determine the center. In order to drill these holes, all four bulkheads (2 coupler, 2 main) were clamped together, and a hole was drilled at the center multiple times, with incrementally increasing drill bit sizes. To determine the location of the threaded rod holes, measurements were taken in the CAD model, and were replicated using a caliper on the actual bulkheads. Once again, the four bulkheads were clamped together while drilling to ensure that the holes were at the same location on each. Figure 3.8.3 shows a bulkhead with the hole locations.

Figure 3.8.3 Bulkhead with Hole Locations

Then, the bulkheads were placed 3 inches apart, a value that allowed them to not be interfering with each other while minimizing the length of threaded rod used. The rods were inserted through the holes, and nuts and washers were used to fix the bulkheads in place. The eyebolts were fastened in a similar fashion. Finally, shock cord was tied to each eyebolt, to simulate the parachute shock cord connection to the bulkheads. The final assembly is shown in Figure 3.8.4.

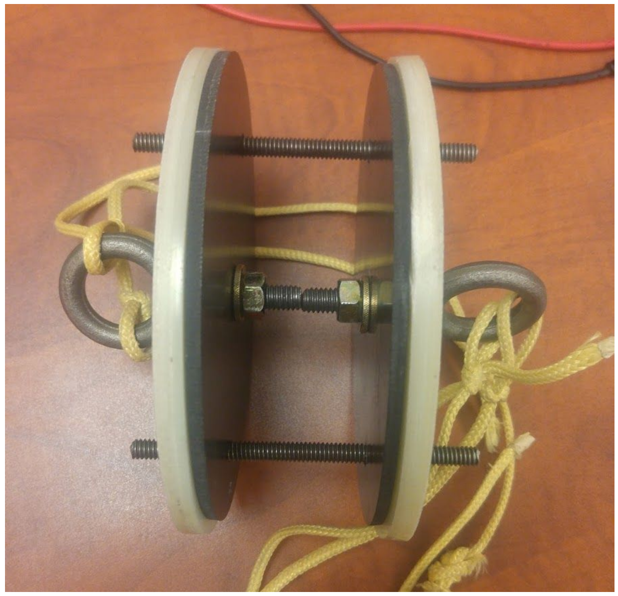


Figure 3.8.4 Avionics Bay Mockup

The impulse from parachute deployment generated a larger force than the ejection charge detonation, so the parachute deployment force was chosen as the test force.

Testing the mockups required placing them in a tensile tester, which pulled the mockups from both sides until they failed. To test each mock up, we tied a segment of the shock cord to either side with a bowline knot, and tested by attaching the shock cord to the tensile tester. Then, we repeated the experiments with doubled-up shock cord to provide additional strength. The figures below show the test setup.

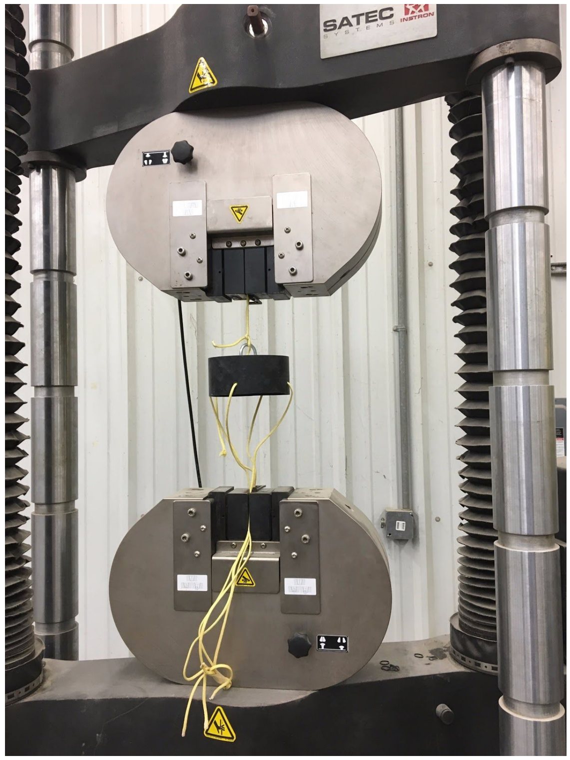



Figure 3.8.5 Bulkhead Epoxy Test

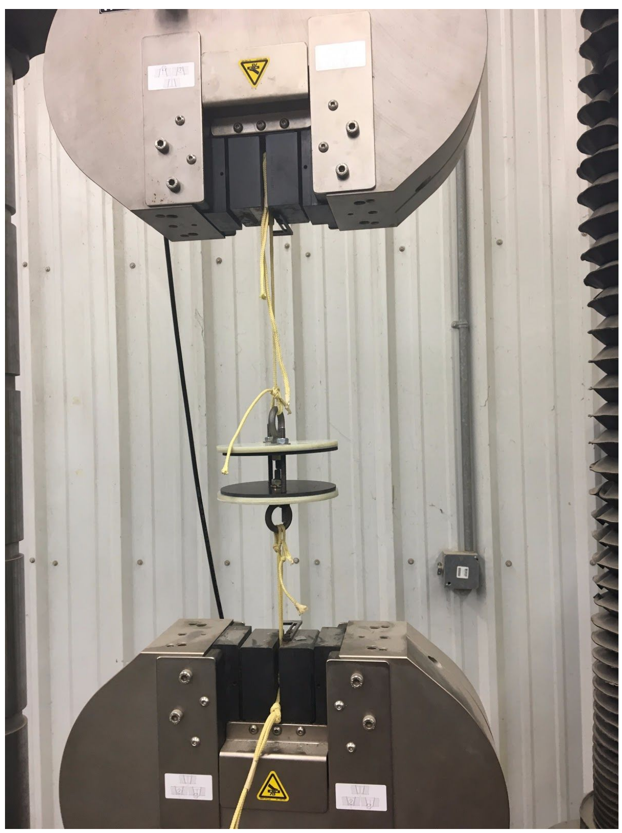


Figure 3.8.6. Avionics Bay Bulkhead Test

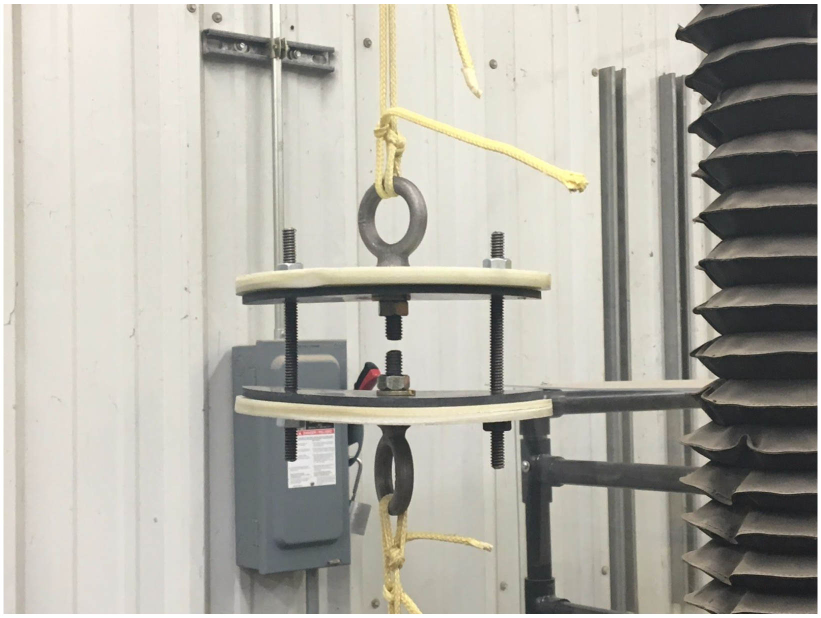


Figure 3.8.7. Deformation of fiberglass bulkheads

As seen in Figure 3.8.6 and 3.8.7, failure in all instances occurred due to a breakage of the shock cord rather than a failure in the fiberglass or the epoxy bond. The maximum force experienced in the simulations was 998.711 N, or 224.5 lbs. During the load testing, the loads approached near 500 lbs, over double the maximum force that the rocket would theoretically experience. However, the shock cords were rated to withstand up to 1500 lbs, so they failed much before they were expected to. One explanation for this is that tying the knots on the cord and clamping these knots in the tensile tester caused fraying, which detracted from the structural integrity of the shock cord. Another observation was that at the maximum load force, the fiberglass bulkheads were beginning to bend, an example of an elastic deformation. This is shown in Figure 3.8.7, as the centers of the bulkheads moved away from their equilibrium positions. However, this will not pose a problem, as the force was double the magnitude of the force the rocket would experience, and the bulkheads still returned to their original configuration after the test was completed. Overall, all of the components tested passed the physical load tests as well as the simulations from the calculated forces, and will perform as expected during the rocket's flight.

### 3.8.2 Bulkhead Failure Modes

As mentioned previously, the process of testing these simulations is tremendously pivotal to the creation of a proper structure. Without these tests, there would be absolutely no data to support the durability of the rocket, allowing many possible points of breakage. The CAD models definitively show the distribution of stress along the bulkheads, expressing their weakest points. However, the force simulation emphasized the fact that the durability of each bulkhead was well above the max force experienced from both the impulse of the parachute deployments, and the black powder explosions. Had the bulkheads experienced a force greater than their limits, they would immediately break away from the body of the rocket. This would cause the launch vehicle to separate, and then quickly accelerate pass the maximum, allowed velocity. Depending on which bulkhead would initially break, either the nosecone section or the thruster section would become separated, accelerating without any resistance and possibly injuring those below. To support this claim, in accordance with the CAD models, if the bulkheads exceeded a force greater than the G10 fiberglass' maximum yield strength of $6.5 * 10^7$ N/m^2, the bolts attached would break away, destroying the only connection between the main sections of the rocket.

Even though the destruction of the bulkhead is a major concern, according to the data presented in the load testing section, the thread connection between the bulkhead and the parachute has a greater tendency to break. If there was 500 lbs of force created during the impulse of the parachute deployment, the thread would rip, thus causing the rocket to, again, separate. The thread failure testing setup consisted of a tensile testing machine with a aluminum force transducer setup attached. The failure point of the transducer setup was first tested to determine the max load that could be accurately measured before necking occurred in the aluminum used to construct the instrument. However, the thread would be the first to break, emphasizing that it's the rocket's weakest point. Even though it's the weakest connection, the testing is imperative in that it allows the team to know that it will *not* reach its maximum force load, keeping the rocket intact. Therefore, these tests are crucial to ensuring the team that the rocket structure will not fail.

As for the ejection testing, the black powder explosion has the most points of possible errors. This is not only due to its inherently volatile nature, but the direction in which the explosion can be concentrated in. This could lead to numerous breaches in the tubing of the rocket, which will alter the aerodynamics of the overall air flow. However, as seen in the ejection simulations, the max force of the black powder explosion is nowhere near the maximum load, thus ensuring the team, once again, that the launch vehicle will persevere through the flight as safely return.

The force simulations for the aluminum plates and brackets in the launch vehicle all indicated an ability to withstand much greater loads than they will be subjected to from flight. To ensure the accuracy of the data obtained from the simulations, tensile tests were done on aluminum stock to understand at exactly what loading profile the aluminum will fail.

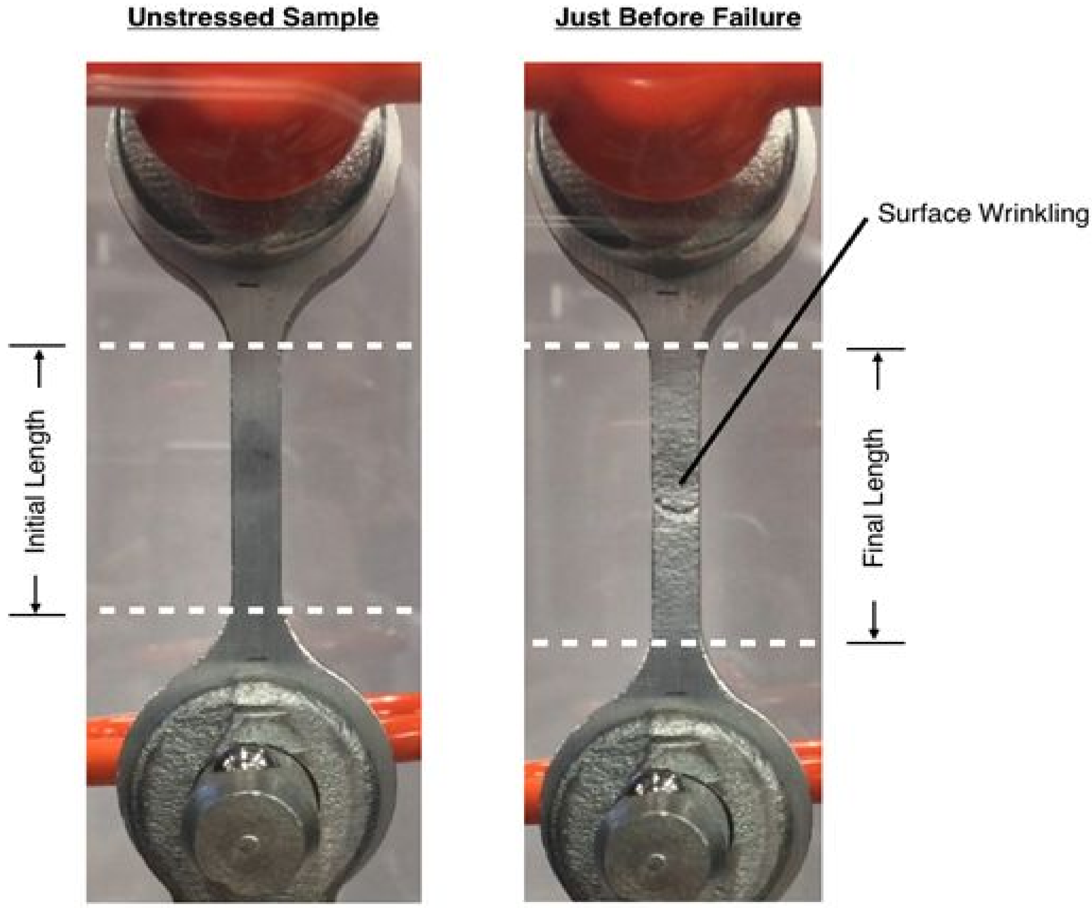



Figure 3.8.8 Aluminum Stress Tests

The displays above show images of the aluminum test piece before it had been stressed, and just before it has reached its ultimate tensile stress and failed. It is clear that the workpiece has been strained, as the uniform section is significantly longer after being stressed. There is also a clear difference in the surface appearance at the two moments. While the part was initially smooth, the Aluminum surface becomes severely wrinkled after stressed, and is most affected toward the center of the piece where necking occurred at the moment of failure. This wrinkling is a results of the stress overcoming the surface tension of the part and causing it to crack as it elongates.

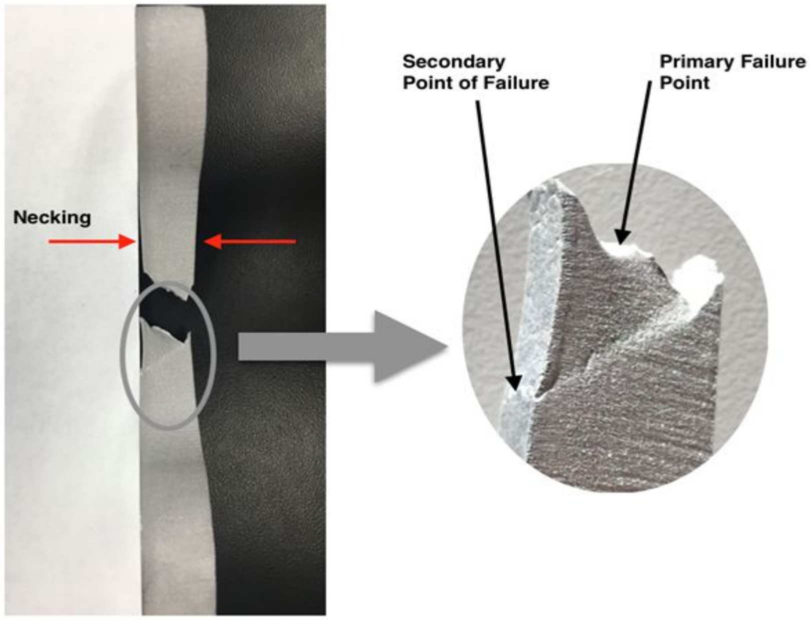



Figure 3.8.4: Aluminum Test Piece After Failure

Figure 3.8.4 shows the aluminum workpiece after failure. When lining the pieces up against a straight piece of paper, it is clear to see the curvature of the piece that was created during necking. This phenomenon occurred because, as the part was strained, it needed to reduce the cross sectional area to satisfy its conservation of volume. An interesting observation that was made after analyzing the pieces was that there were two points of severe cracking that resulted in failure. The figure on the right shows the primary and secondary points of failure. It seems that, although the primary point of failure was the final place of separation, there was a secondary point along the workpiece that was very close to failing as well. There is a deep wrinkle that would most likely have completed failed if stressed for a little bit longer.

If the aluminum were to fail it is expected that any external parts attached would have a significant detrimental impact to the flight profile of the rocket. External aluminum parts include: the wing brackets ( both the parts that rotate the flap and the parts that hold on to the fins) and the bottom most plate of the rocket. The only internal aluminum fixtures are the brackets that hold the avionics tray in place and the gear that ensures the synchronization of the flap motion . If the internal aluminum brackets failed it is expected that the avionics bay mounting tray with the electronics installed will be subjected to the previously modeled flight forces and subsequently be free to move around the entire bay. This movement could theoretically damage the crucial control and recovery systems and allow the vehicle to go ballistic and impact the Earth at a detrimental rate. If the gear failed it is likely that at least one of the flaps would rotate out of sync and impart a significant torque that may lead to a ballistic trajectory back to Earth where the rocket would impact the Earth at a seriously destructive velocity. If the bottom plate failed the motor would fall out of the rocket and back to Earth. If the fin brackets failed then they would be subjected to a strong drag force and would subsequently depart from the vehicle and fall back to Earth.

## 3.9 Manufacturing Process


Figure 3.9.1: Invention Studio

Figure 3.9.2: Student Competition Center

3.9.1 Access

On of the most significant resources that Team ARES had access to on campus is the Invention Studio (Figure 3.9.1). This is a student-run makerspace that provides Georgia Tech students access to a fully equipped Metal Shop, Wood Shop, 3D Print Room, Waterjetting and Laser-Cutting Room, as well as other miscellaneous tools. Much of our prototyping and fiberglass cutting was done here.

Also notable in providing the team with access to machining space and tools is the Georgia Tech Student Competition Center (Figure 3.9.2). This is a large garage-style space where all of the competition team of the school do their work. Equipped with its own waterjet, a set of mills, bandsaws, grinders/sanders, and drill presses, this space was extremely valuable for high precision machining.

3.9.2. Fabrication Tasks

The full list of what tools were used for what can be found below in Table 3.9.1. The tasks laid out are color coded according to what section of the rocket they pertain to. This color coding scheme can be found under the chart.

Table 3.9.1: Fabrication Tasks

| # | Task Description | Material Handled | Fabrication Techniques | ETA | Fabrication Locations | Safety Precautions |
|---|---|---|---|---|---|---|
| 1 | 3D Print Servo Brackets | PLA/ABS | 3D Printer | < 1hr | Inv Studio / AE MakerSpace | N/A |
| 2 | Cut Motor Tube to Length | Cardboard | Chop Saw | < 1hr | Inv Studio / SCC | N/A |
| 3 | Cut Tubing to Length | Fiberglass | Chop Saw | < 1hr | Inv Studio | 2 ppl, shop vac, N95/P95 mask |
| 4 | Drill Shear Pin Holes (8) | Fiberglass | Drill | < 1hr | RR room / Inv Studio | 2 ppl, shop vac |
| 5 | Drill Rivet Holes (4) | Fiberglass | Drill | < 1hr | RR room / Inv Studio | 2 ppl, shop vac |
| 6 | Drill wire routing holes | Fiberglass | Drill | < 1hr | RR room / Inv Studio | 2 ppl, shop vac |
| 7 | Drill Holes for Bottom Plate | 6061 Aluminum | Drill | < 1hr | RR room / Inv Studio | |
| 8 | Slots into Body Tubing | Fiberglass | Jigsaw/Bandsaw/ Chop Saw/Mill | 2 hrs | Inv Studio / SCC | 2 ppl, shop vac, N95/P95 mask |
| 9 | Cut out Thrust Plate | Plywood | Laser Cutter | < 1hr | Inv Studio / AE MakerSpace | N/A |
| 10 | Fin Features for Brackets | Fiberglass | Mill | 1-2 hrs | BME Shop | 2 ppl, shop vac, N95/P95 mask |
| 11 | Flap Features for Brackets | Fiberglass | Mill | 1-2 hrs | BME Shop | 2 ppl, shop vac, N95/P95 mask |

| | | | | | | |
|---|---|---|---|---|---|---|
| 12 | Flats into Shafts | 1024 Steel | Mill/Grinder | 1-2 hrs | Montgomery MM | N/A |
| 13 | Fin Brackets | 6013 Aluminum | Waterjet | 1-2 hrs | Inv Studio / SCC | N/A |
| 14 | Avionics Bay Tray Brackets | 6013 Aluminum | Waterjet | 1-2 hrs | Inv Studio / SCC | N/A |
| 15 | Fins Cut Out | Fiberglass | Waterjet | 2 hrs | Inv Studio | N/A |
| 16 | Avionics Bay bulkheads (2 coupler, 2 body) | Fiberglass | Waterjet | 1-2 hrs | Inv Studio | N/A |
| 17 | Cut Out Bottom Plate | 6061 Aluminum | Waterjet | 1-2 hrs | Inv Studio / SCC | N/A |
| 18 | Cut Out Bevel Ring Gear | 6061 Aluminum | Waterjet | 1-2 hrs | Inv Studio | N/A |
| 19 | Cut Out Flaps | 6061 Aluminum | Waterjet | 1-2 hrs | Inv Studio | N/A |
| 20 | Set Screws for gears / servo hub attachments | Brass / Aluminum | Drill, Saws, etc... | 2 hrs | Anywhere you can | N/A |
| 21 | Cut servo hub to length | Aluminum | Band Saw | <1hr | Inv Studio | N/A |
| 22 | Drill gears bore diameter | Brass | Drill | <1hr | Inv Studio | N/A |

| |
|---|
| Booster |
| Fins |
| Avionics Bay |
| Recovery |
| Fin-Roll Mechanism |

Looking at the chart, it is clear to see that the majority of work revolved around the cutting of fiberglass, aluminum alloys, and plywood. All of our precision cuts were made on computer controlled machines that just took our design files and interpreted them to create precise cuts. This chart was used as a checklist to monitor the progress of the machining effort that occurred in the last three weeks before the deadline of the FRR.

### 3.9.3. Machining Plywood

Plywood is a comparatively soft material and is very easy to work with. For the cutting of the avionics bay, and other miscellaneous bracket for avionics equipment, a Trotec speedy300 laser cutting machine was used. While laser cutting wood does profuce a fair amount of smoke, the rooms were vacuumed and the machines actively suck it out of the cutting bed.


Figure 3.9.3: Prototyped Avionics Bay using Laser Cutter

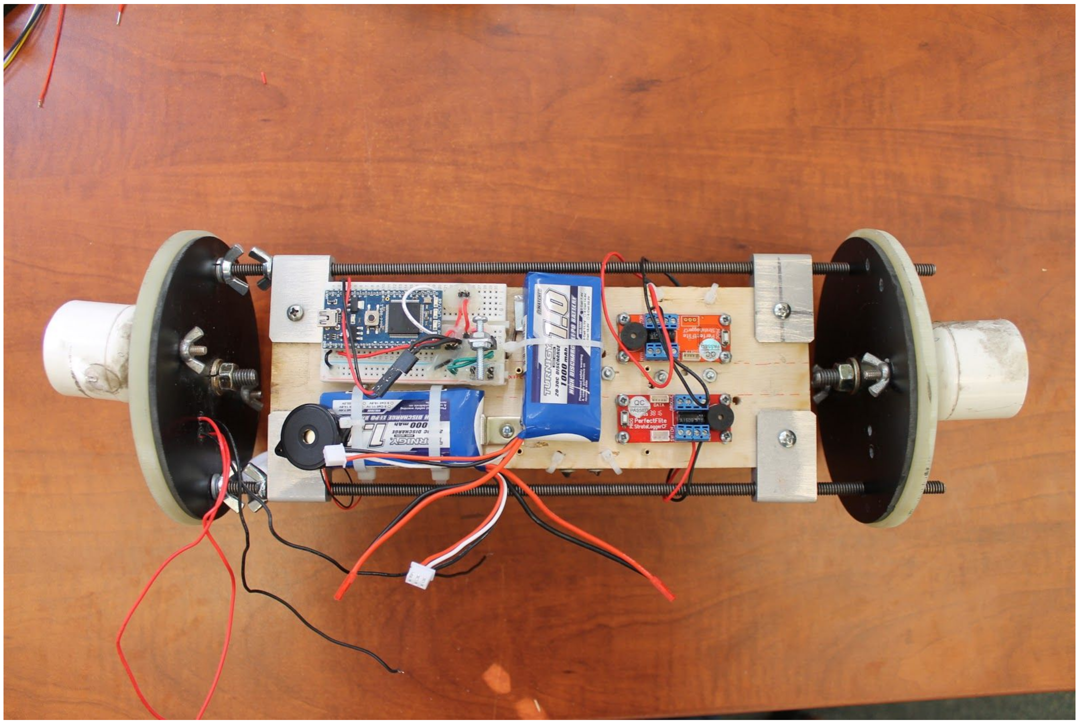


Figure 3.9.3: Assembled Avionics Bay

3.9.4. Fabrication Using 3D Printers

3D printing is a convenient way of creating complex geometry at the cost of strength, but at the gain of creating much lighter parts. Due to the large amount of vibration to be expected during launch, team ARES avoicded using 3D printed parts they were load bearing. For this reason, this tool was used primarily to make small brackets and prototype ideas. This method of manufacturing was used for:

- Brackets to mount Pixhawk and other avionics components to avionics tray
- Brackets to hold the servos upright and creat the correct standoff distance needed to achieve a perfect mesh beteween the standard bevel and pinion bevel gears used in the fin-roll mechanism
- Prototyping the large, custom, ring gear made to be place above all of the gears in the fin-roll mechanism to mechanically lock the rotation of the servos

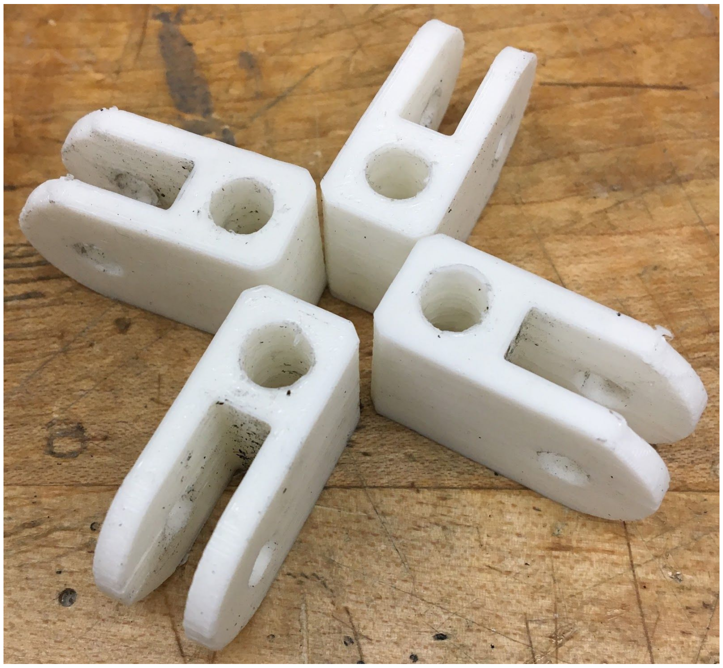


Figure 3.9.4: 3D Printed Avionics Tray Brackets

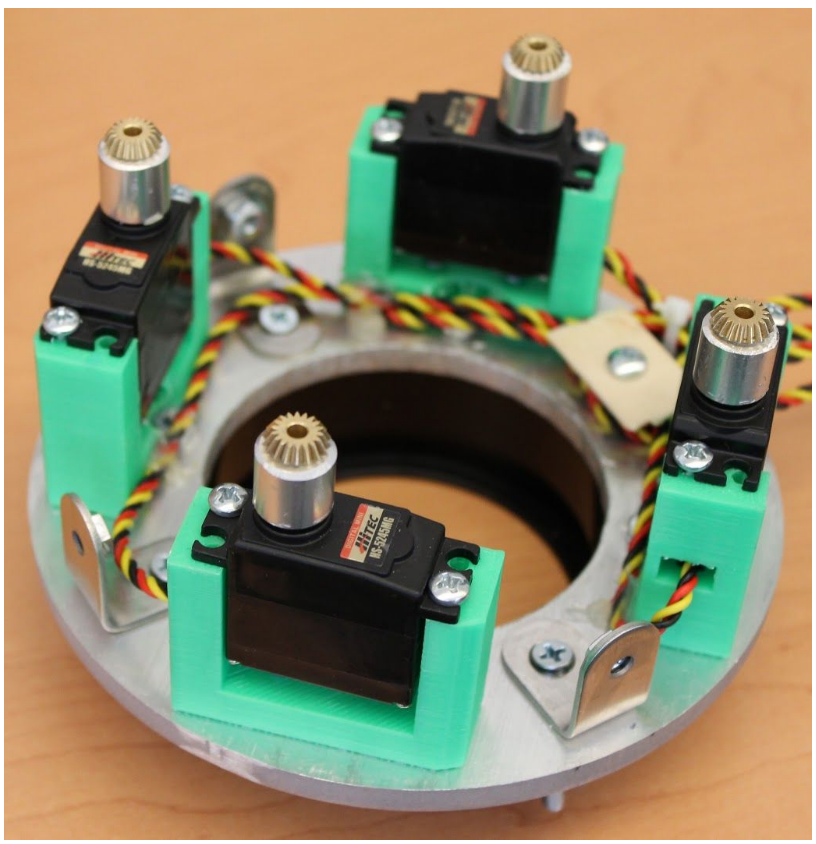



Figure 3.9.5: 3D Printed Servo Mounts

### 3.9.5. Machining Aluminum Alloys

Due to the results of our simulations, we decided to purchase Aluminum 6013 for all of our brackets. This is an alloy that has almost double the yield strength of 6061, and is cheaper to use than 7075. Unfortunately, it is also a very difficult material to machine using cutting blades. For this reason, all of the brackets for the find roll mechanism, as well as for the avionics tray, were done using a waterjet. By providing the 2 dimensional cross section of the workpiece to the computer it can generate a cut layout.

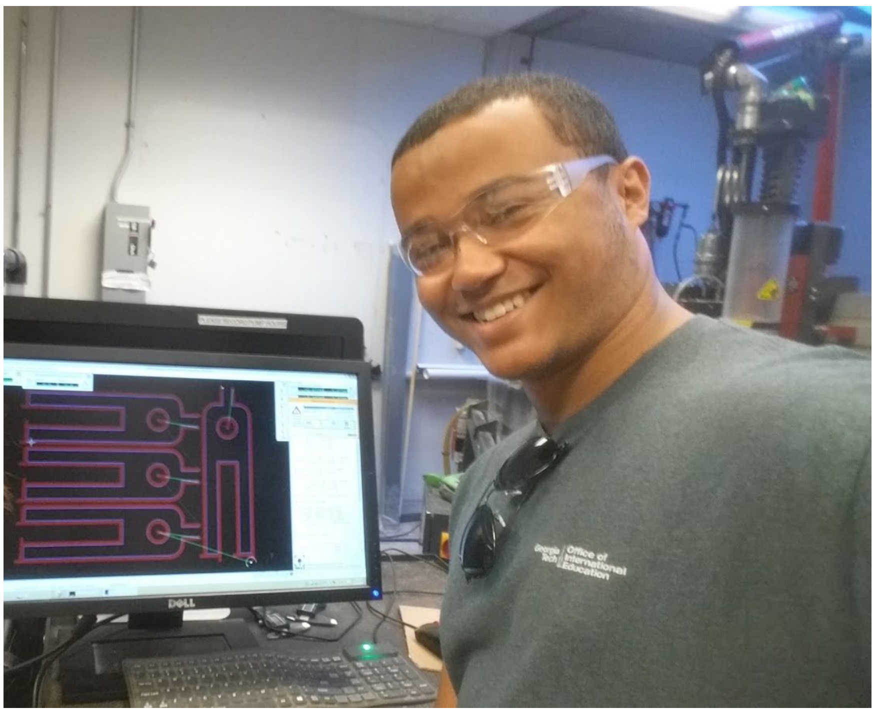


Figure 3.9.6: Setting Up WaterJet Cut of Avionics Tray Brackets

3.9.6. Machining Fiberglass

The most dangerous of all the maching jobs was the machining of fiberglass. Due to the danegr of inhaling the small glass fibers that are thrust into the air when it is machined, everyone in the area must wear masks and eye protection. It is also advised to cover all areas of exposed skin on hands and arms, as the fibers will pierce skin and remain lodged for quite some time.

Fortunately, waterjetting fiberglass does not produce any such hazards, as the dust particulates become instantly trapped in the large bed of water under which the the part is cut. However, a number of milling operations were carried out that required full protection. In order to allow the fin hinge brackets to fit over the fin and flaps, and still sit flush with the surface, a number of packets had to be created along the edges of the fins and flaps to accomodate the brackets. (Figure 3.9.8)

Figure 3.9.7: Waterjetted Fins

Figure 3.9.8: Resulting Fins

As necessary, all of the milling operations took place while using full protection, as well as the application of a shop vac on the workpiece throughout the cut to prevent buildup of dust.

Figure 3.9.9: Protection While Cutting Fiberglass

### 3.10 Payload Integration

Each servo used in the roll system is held in place by individual, 3D-printed, PLA servo mounts. The four servo mounts are bolted to the baseplate of the rocket securely. Careful consideration was taken in the design of the servo mounts. Holes for the bolts were included in the CAD file as to prevent having to drill into the interior, honeycombed structure of the prints. The baseplate and servos were designed as to be easily removable in case adjustments regarding the positioning and meshing of the geared components were deemed necessary. Each of the four servos is independently wired to a microcontroller in the avionics bay. The wires are run through the sides of the servo mounts and up the sides of the launch vehicle through concentric holes the motor centering rings.

Each of the four fins is attached to the sides of the motor tube and to the centering rings with epoxy. After the motor assembly and fins were inserted into the main body tubes, fillets between the body tube and the fins were created by skillful use of tongue depressors and more epoxy.

## 4. Roll Control Criteria

### 4.1 Roll Control  Overview

The launch vehicle includes a system capable of controlling the launch vehicle's roll after burnout. Between the instances when burnout occurs and when the rocket reaches its apogee, the launch vehicle will perform two complete rotations around its longitudinal axis. Shortly afterwards, the same system will induce a counter-moment returning the launch vehicle to its initial, post-burnout angular velocity. Hinged ailerons on the trailing edge of the fins are used to induce the roll and counter-roll. The roll system is comprised entirely of mechanical devices.

## 4.2 Roll Control  Features

The roll control system mainly consists of 3 sub-assemblies, including the fin roll assembly and the bevel gear assembly. Figure 4.2.1 illustrates the integration of the roll control system. The fin roll assembly consists of a fin, a flap, fin brackets, flap brackets, and an D-shaft. Figure 4.2.2 shows how the parts are assembled together in the fin roll assembly. Figure 4.2.3 illustrates how the flap brackets, fin brackets, and D-shaft are assembled. A 7” D-shaft with 5 mm diameter was chosen to provide torque that allows the flap brackets to move. The flat surface on the D-shaft provide a secure set screw mount. The fin brackets and the flap brackets have different hole profiles. The flap brackets have the same hole profile as the surface profile of the D-shaft to provide contact with the shaft. The fin brackets have a round hole with 5.1 mm diameter to prevent any friction with the shaft. The bevel gear assembly consists of a pair of bevel gears with 2:1 gear ratio. Figure 4.2.4 represents the bevel gear assembly. The Y48036 bevel gear is mounted to the D-shaft. The Y48018 pinion bevel gear is attached to a HS-5245MG servo, which provides the torque to turn the D-shaft. The D-shaft runs through each of brackets on the hinge assembly. A custom made, aluminum gear links all four ailerons by engaging the bevelled gear attached to the shaft.

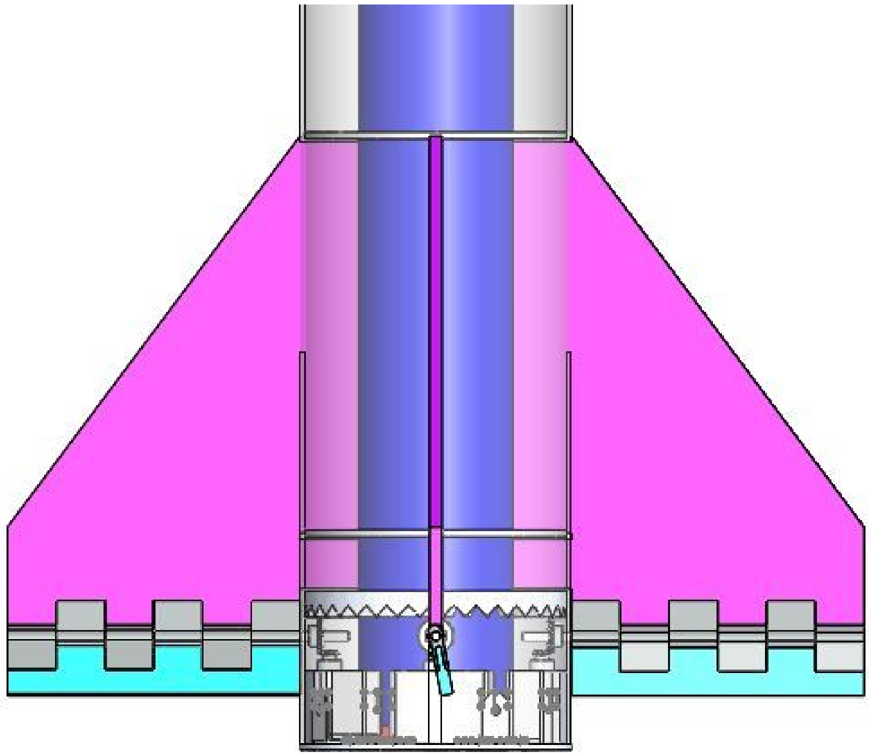


Fig 4.21. Roll Control System

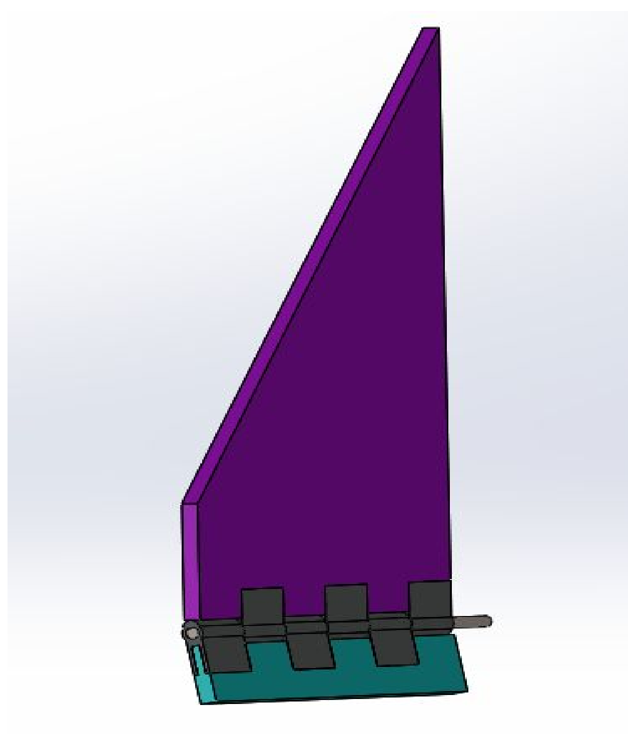


Fig 4.2.2. Fin Roll Assembly

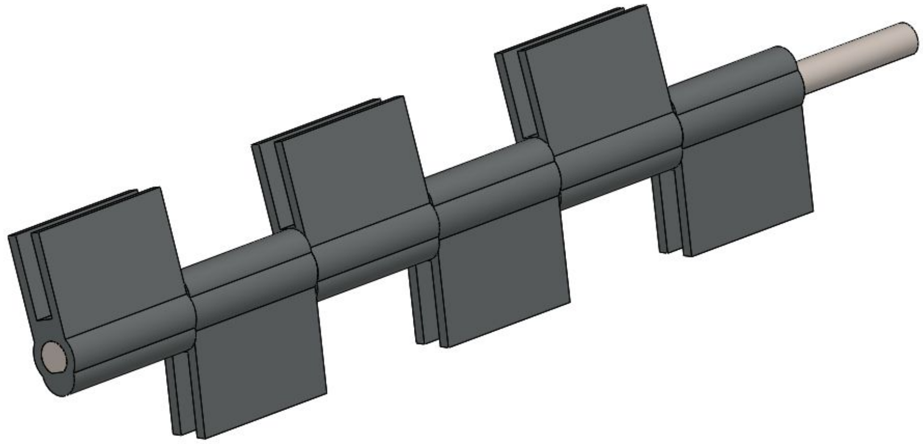


Fig 4.2.3. Hinge Assembly

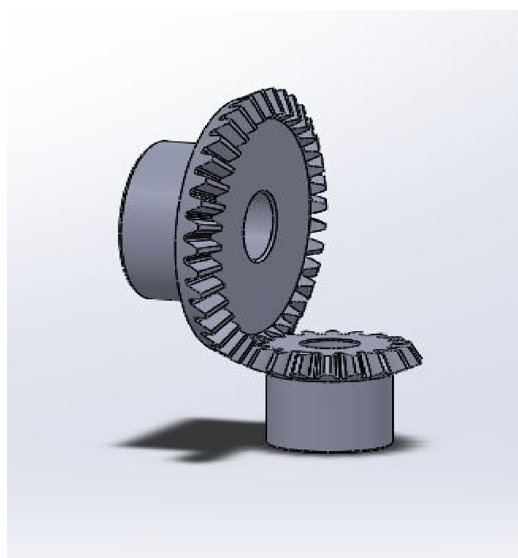


Fig 4.2.4. Bevel Gear Assembly

## 4.3 Structural Elements

The roll system is fitted with four HS-5245MG servos that are held in place by four, individual, 3D printed, PLA mounting structures shown in figure 4.3.1. These mounts are affixed to the base plate. This design allows all four servos to be easily removed when it is necessary to access the mechanics of the roll system.

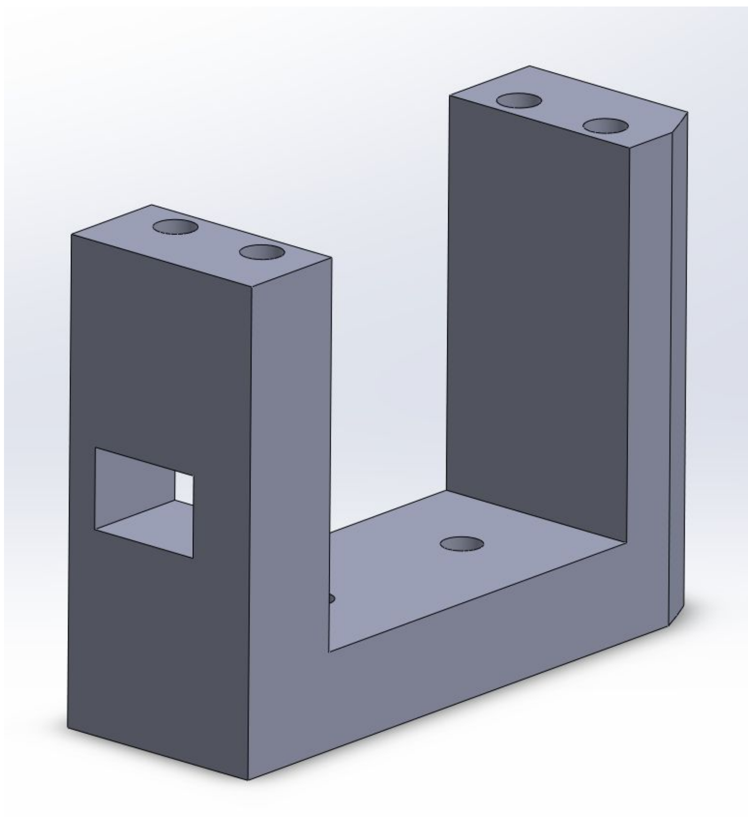


Fig 4.3.1. Servo Mount

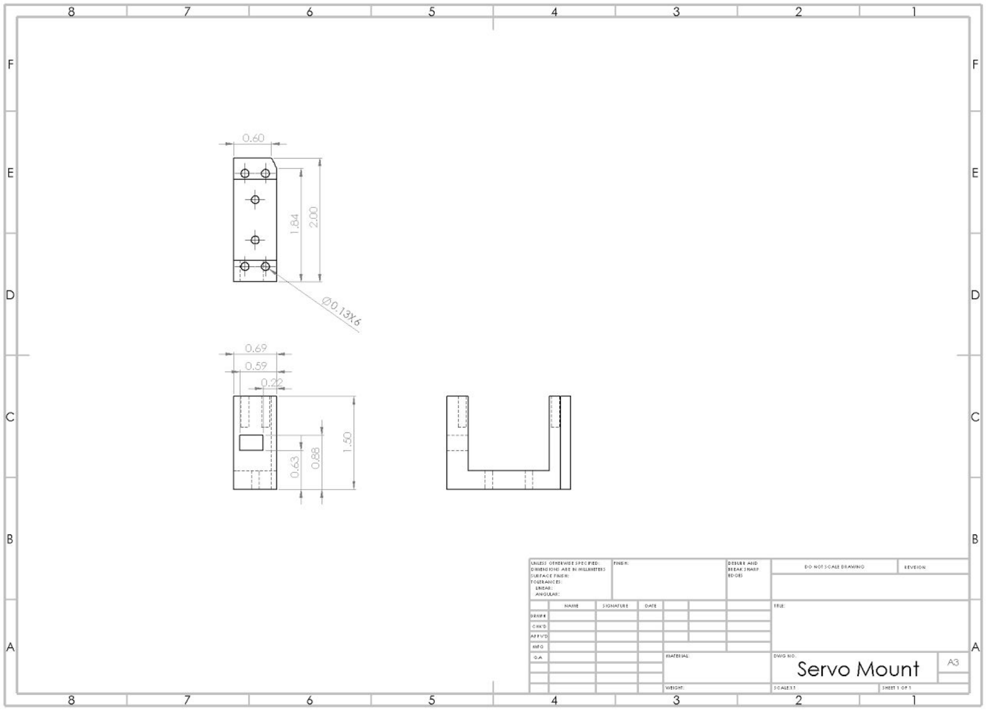



Fig 4.3.2 Servo Mount Dimensions

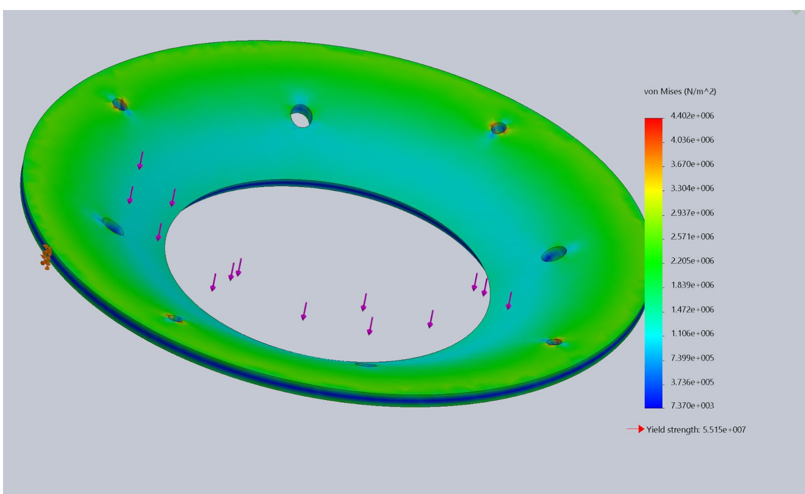



Fig 4.3.3 Base Plate

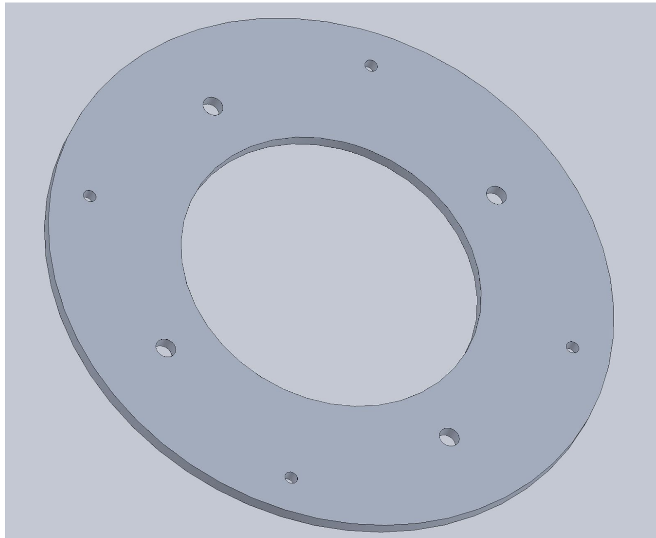


Fig. 4.3.4 Base Plate

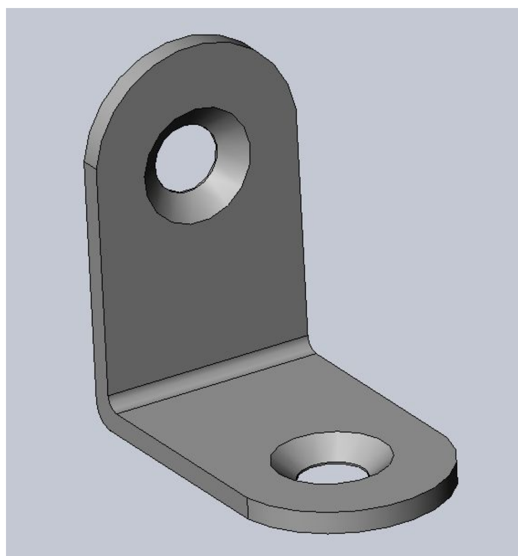


Fig 4.3.5. L-Bracket

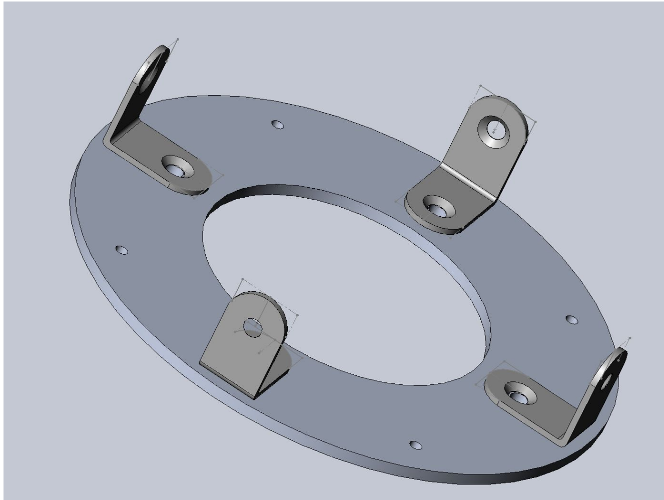


Fig. 4.3.6 Base Plate Bracket Assembly

The base plate is attached to the body tube by 4 25x25mm stainless steel L-Brackets. These L-brackets are affixed to the base plate by screws and the sides of the main body tube by screws. The 4 brackets assure that the forces will be evenly spread out along the body of the rocket and the base plate. In Fig. X it is shown that the rocket is able to easily withstand the forces that will be presented on it. L-brackets were used because they provide easy access to the inside of the rocket by simply removing 4 easily accessible screws at the bottom of the base plate. The L-Brackets are mounted to the sides of the body tube around 7mm up from the bottom of the tube. This is done with screws and hex nuts on the inside of the body tube as well as on the actual base plate. All the holes are fitted and placed exactly so the brackets and servo mounts lie flush with the body tube of the rocket.

The base plate is water jetted for perfect hole sizes and locations to ensure that the servos can be mounted properly in place as well as the brackets. The staggering of the holes allows for plenty of space between the servos and the brackets as well as keeping the weight distribution exactly even within the rocket. The water jetting of the base plate allows for perfect dimensions for the motor assembly to fit into.

## 4.4 Precision and Repeatability

The system can be confidently predicted as consistent because the microcontroller sends a consistent signal to each servo, and each servo is both electrically and mechanically linked to each other, so they always rotate to the same angle. Electrically, if one servo is shown to fail or not be moving, all servos will hold their position to prevent the rocket from spinning out of control. Mechanically, the attached to each servo shaft is a bevelled gear that interfaces to one large gear. This forces each servo to always actuate to the same angular position, and if a motor fails the gear will still be turned by the other 3 motors, and the system will perform the same.

## 4.5 Performance Predictions

The team has planned the roll system to induce slightly over 2 full rolls post burnout. After doing this, gyroscopes will detect the current angular velocity and induce a counter roll to bring the rocket back to its initial angular velocity. This will be done using a closed loop autonomous program to induce the correct angle given current position and angular velocity, and initially will be controlled with a hard coded roll system in order to choose between our possible final configurations for the final launch . We have primarily used OpenRocket and simple calculations to determine this initial hard coded roll. The calculations are listed below:

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

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

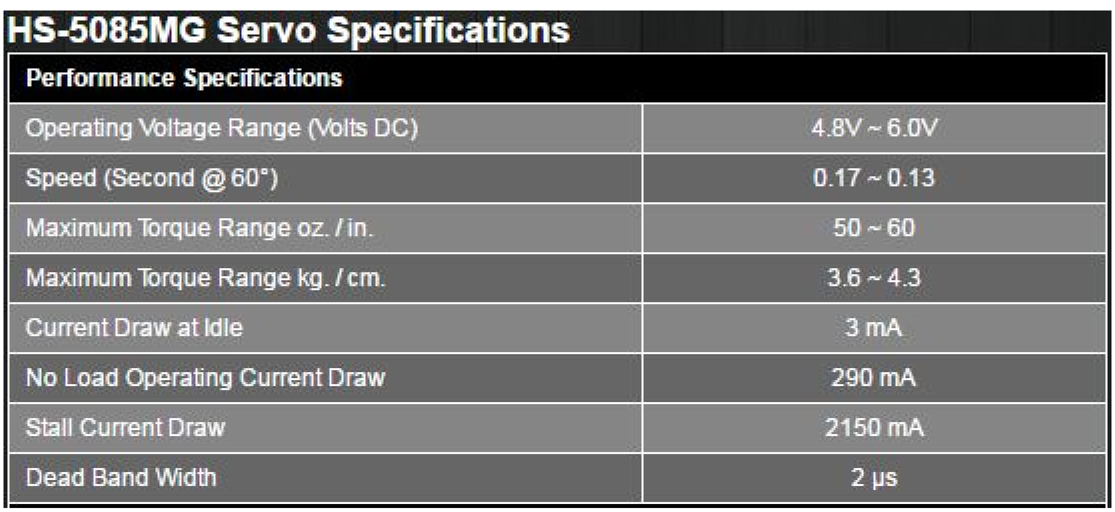
$$t = .708\ secs$$

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. According to our OpenRocket simulations,this will occur approximately 11 seconds into flight.

# 5. Electrical Subsystem

## 5.1 Flight Systems Overview

As stated previously, the development guide for the Pixhawk is still in its beta stages and lacks the resources to complete such a project in a timely manner. The Pixhawk will no longer be responsible for actuating the servo motors of the vehicle, but instead, an MBED ARM microcontroller will take its place. 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. Simply put, our flight systems consists of the Pixhawk, the recovery system, and the Servo Actuation System, which comprised of MBED and HS-5085 servo motors. Figure 5.1.1 below includes the performance specifications of the HS-5085 Premium Metal Gear Micro Servo in the Servo Actuation System, and Figure 5.1.2 includes the specifications of the Eggfinder GPS system.



**HS-5085MG Servo Specifications**

| Performance Specifications | |
|---|---|
| Operating Voltage Range (Volts DC) | 4.8V ~ 6.0V |
| Speed (Second @ 60°) | 0.17 ~ 0.13 |
| Maximum Torque Range oz. / in. | 50 ~ 60 |
| Maximum Torque Range kg. / cm. | 3.6 ~ 4.3 |
| Current Draw at Idle | 3 mA |
| No Load Operating Current Draw | 290 mA |
| Stall Current Draw | 2150 mA |
| Dead Band Width | 2 μs |

Figure 5.1.1 HS-5085 Servo Specifications

| Eggfinder TX Module | |
|---|---|
| Accuracy | 2.5 meters |
| Operating Voltage (Volts DC) | 3.3V |
| Current Draw at Idle | 10-20 mA |
| Current Draw Operating | 70-100 mA |
| Size (in^3) | .9"w x 3"l x .4" h |
| Mass | 20 grams |

Figure 5.1.2 Eggfinder TX GPS Module Specifications

## 5.2 Flight System Features

The electrical subsystem onboard the flight vehicle has several purposes including: deployment of parachutes, acquisition of data for post-flight analysis, and control of the flaps in order to reach the desired apogee of one mile. Data acquisition and parachute deployment are accomplished by the altimeter solely, but control of the rocket flaps calls for a more elaborate flight software, a microcontroller flight computer, and the use of an added sensor: the accelerometer. Both the altimeter and the accelerometer output sensed values into an Mbed microcontroller, which then filters noise from the sensors according to the kalman filter specifications. The filtered values are then compared to flight simulation data generated via Simulink, and the control algorithm makes the difference between sensed and simulation values go to zero as time gets larger. The control algorithm works based on an equation, shown in Figure XX, that relates the change in height to the change in velocity.

```
s = (lambda * delta_h) + delta_v;
*control = (sign(s) + 1)/2;
```

Figure XX. The equation that describes control of the rocket.

### 5.2.1 Launch Vehicle

The avionics system is comprised of three primary components: a Pixhawk flight controller, an mbed microcontroller, and an array of servos.

The integrated IMU (Inertial Measurement Unit) of the Pixhawk is used to gather angular velocity, acceleration data. An airspeed sensor and Eggfinder GPS provide the Pixhawk with airspeed and location data. This data is then transferred from the Pixhawk to the mbed via serial from the Pixhawk's UART port to the serial pins on the mbed. The mbed then uses this information to actuate the 4 servos linked to the fins and induce a roll and counter-roll. The Pixhawk is set up with a triple redundant power supply. Utilizing the Pixhawk allows for a more compact and simpler wiring scheme, easy calibration of sensors, and an all-around more robust system.

Power, ground, and PWM signal must be transferred from the avionics bay roughly 55 inches down the fuselage to the servos mounted near the base of the rocket. This is accomplished using a single braided cable. Two female servo plugs joined by a three pin header fasten the servo leads at the junction between the avionics bay and lower-most fuselage section. This configuration ensures smooth detachment of the servo connections during separation. At the base of the rocket, this cable interfaces with a breakout board that distributes power, ground, and signal to all four servos. The use of a single cable and breakout board simplifies the wiring scheme, allows for easy assembly and disassembly (each servo, as well as the central cable, can be unplugged from the power distribution board) and reduces the number of wires that must be severed at separation from 12 to 3.

The avionics system is powered by a two amp hour, three cell, 11.1 volt, lithium polymer battery. This capacity was chosen to ensure that the vehicle can remain on standby for a minimum of one hour. The voltage is reduced to the 5 volts needed to operate the servos, Pixhawk, and mbed using step down regulator mounted on a protoboard. An addition one amp hour battery and 5 volt regulator are also present to provide redundancy in the event that a battery or regulator fails. Also, on this protoboard are headers to supply the Pixhawk and mbed with power, headers to supply the servo cable with power, ground, and signal (from the mbed), and circuitry that supports two switches on the exterior of the fuselage.

The avionics system has only three components visible from the exterior of the rocket: a key switch to turn on power to the system, an arming switch for the Pixhawk, and a SPDT (Single Pole Double Throw) switch that turns on the mbed as the vehicle leaves the launch rail.

The arming switch interfaces directly with the Pixhawk. Both the key switch and the SPDT switch interface with the protoboard housed in the avionics bay. The SPDT switch is required because the code running on the mbed requires the microcontroller to boot up only once the rocket has taken to the air. While on the pad, the SPDT switch remains depressed against the guide rail, depriving the mbed of power. As soon as the rocket clears the rail, the switch closes the circuit with the mbed, the mbed boots up, and its code is executed.

### 5.2.2 Roll Control

#### 5.2.2.1 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.

#### 5.2.2.2 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.

#### 5.2.2.3 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 5.2.2.1, 5.2.2.2, and 5.2.2.3 below, with dimensions given in Table 5.2.4.1. 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.

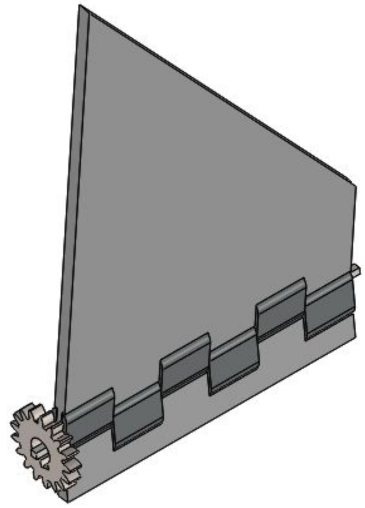


Figure 5.2.2.1 - Rocket Fin & Flap Mechanism

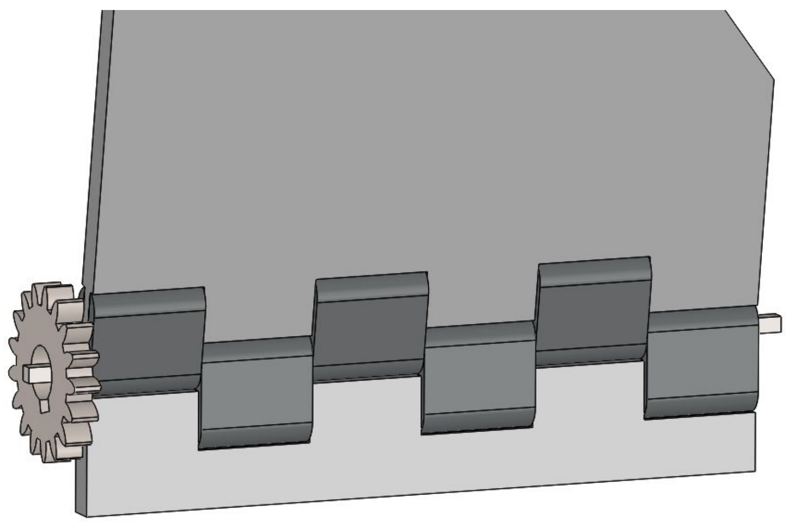


Figure 5.2.2.2 - Hinge Mechanism

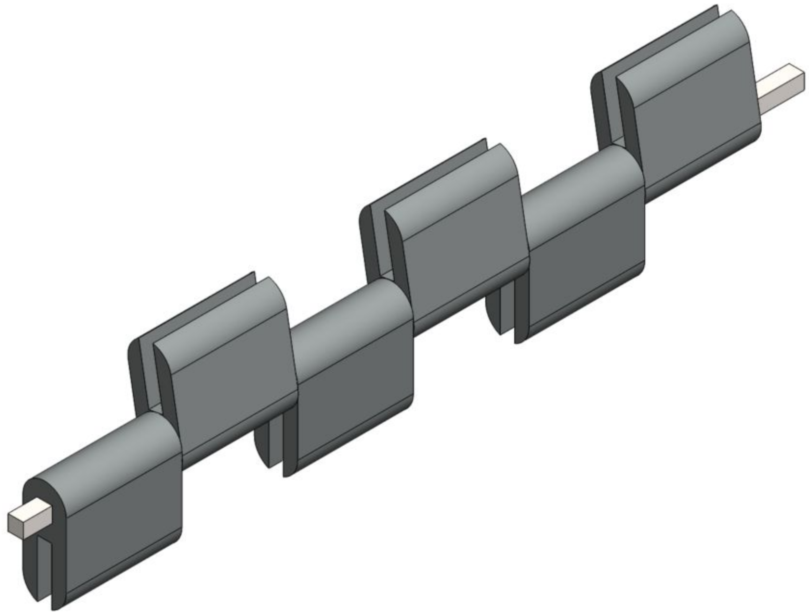


Figure 5.2.2.3 Hinge Assembly

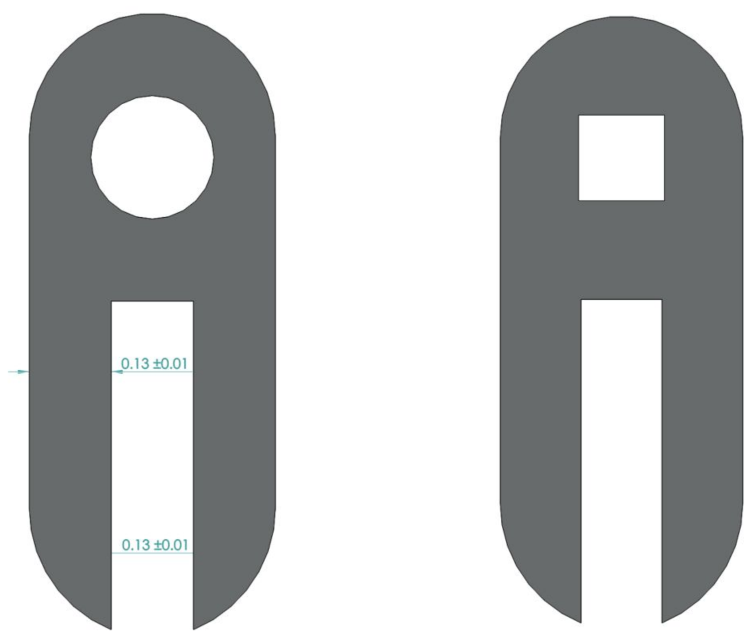



Figure 5.2.2.4 Fin Bracket (left), Rotating Flap Bracket (right)

5.2.2.4 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.

5.2.2.5 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 5.2.2.1. 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 5.2.2.3. 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. The fins themselves will be attached to the body tube through both epoxy and the use of fiberglass molds to create strong points of adhesion for the fins.

Table 5.2.2.1: 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 |

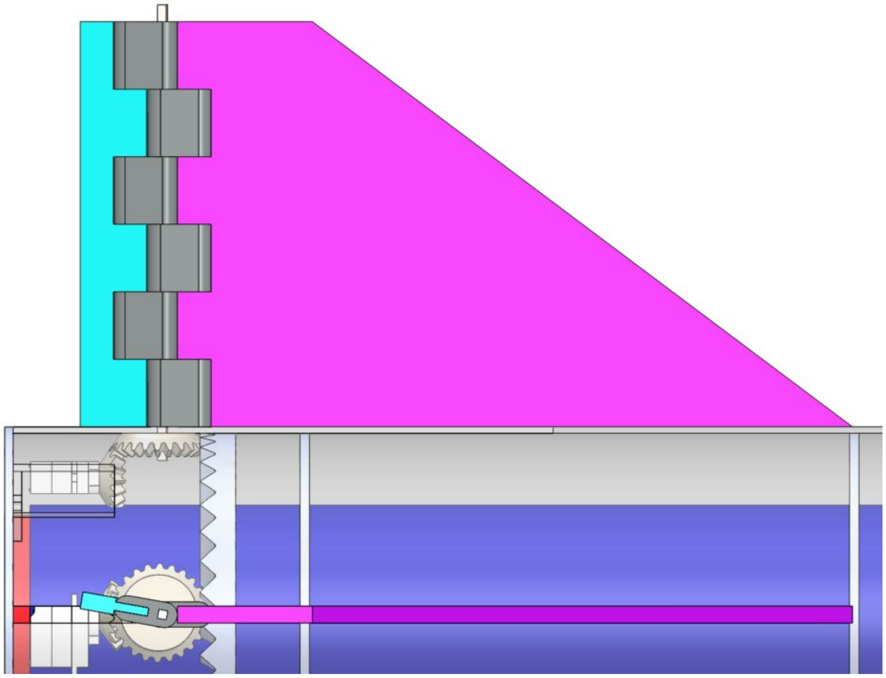


Figure 5.2.2.5 - System on Rocket

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 5.2.2.2. 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 |

## 5.3 Flight Systems Software

The software component of the rocket operates in three primary stages: data collection, data transfer, and response. Location of the rocket in latitude and longitude is collected by the GPS; this data is then sent to the Pixhawk. Airspeed is recorded by an airspeed sensor, which is also sent to the Pixhawk. The Pixhawk itself takes in the angular velocity of the rocket, as well as the acceleration and altitude. The Pixhawk stores all of this data collectively, which can be analyzed after flight. This completes the data collection stage of the software component. After the following data is collected, it is compiled and sent to the MBED Microcontroller. The MBED compares this data that of previous launches and based on certain criteria determines if the fins should be adjusted. If an adjustment is necessary, the MBED activates the 4 servos to respond. The following diagram Figure 5.3.1 shows a schematic of the flight software and the data flow.

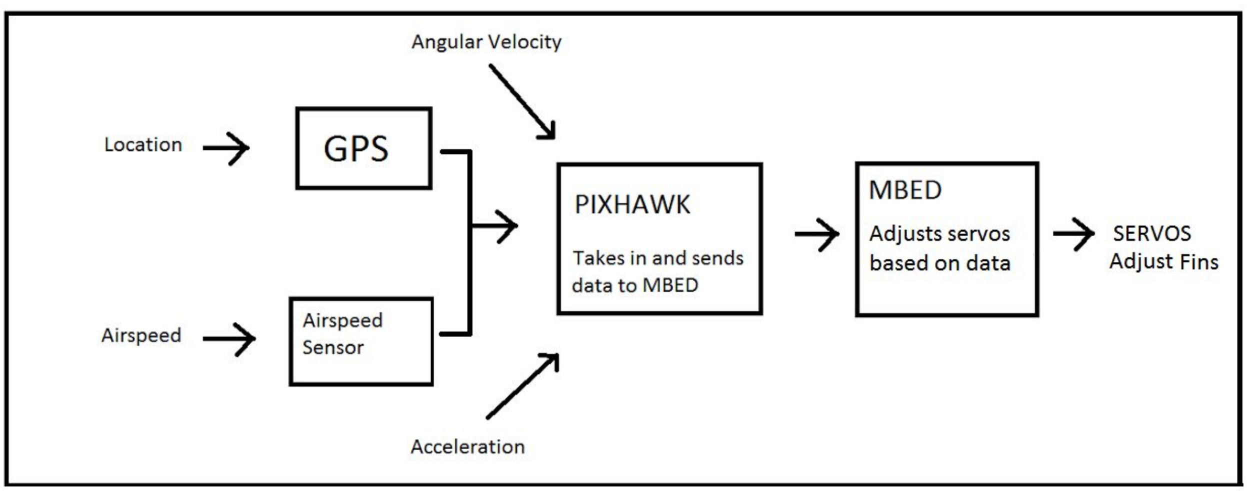



Figure 5.3.1 Flight System Software Flow of Data

## 5.4 Recovery System Electronics

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 5.4.1, 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.

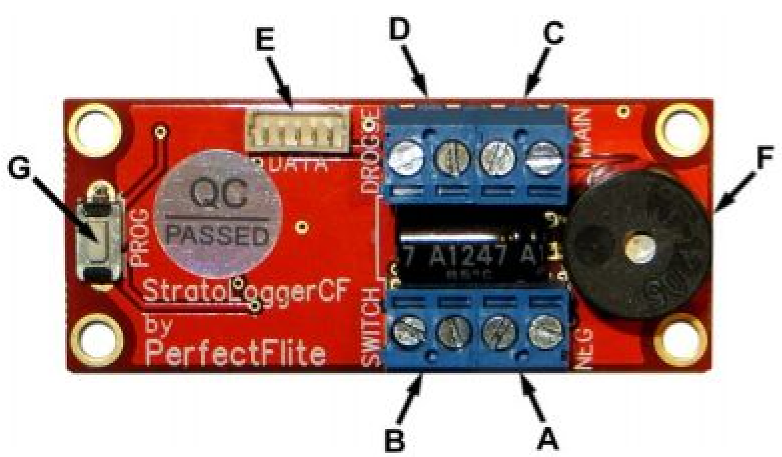



Figure 5.4.1: The StratologgerCF altimeters with connection labels (for reference)

# 6. Safety

## 6.1 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 6.1.1. 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. |
| Fiberglass | irritate the eyes, skin and upper respiratory tract | High | Gloves, particulate masks, safety glasses, and the proper clothing will be worn. Work in well ventilated areas and wash hands thoroughly after. Hold vacuum over any open machining process. |
| 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. |
| Sanding | Irritation of skin, dust particles | Low | Only use sander while wearing safety glasses and mask |
| Waterjet Cutter | Cuts, serious/fatal injury, flying debris | Low | Only operate under supervision of Undergraduate/Graduate Learning Instructors or PI in the Invention Studio, and with other teammates. Follow proper operating procedures, wear safety glasses. |
| Laser Cutter | Serious burns, eye damage | Low | Be sure to use proper materials when laser cutting and wear safety goggles |
| 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. |

## 6.2 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 6.2.2. Failure Mode

| ***Potential Failure*** | ***Effects of Failure*** | ***Mitigation and Control*** |
|---|---|---|
| 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, launch vehicle may become ballistic | Perform ground test and flight test to ensure drogue separation |
| Fins | Fins could fall off, causing unstable flight.<br><br>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.<br><br>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 |
| Altimeters are not Powered | Parachutes do not deploy, launch vehicle becomes ballistic, becoming a danger | Follow Launch Checklist, make sure batteries have enough charge, turn the power switch, listen for altimeter |

| | | |
|---|---|---|
| | to people and property | beeps when switches are activated. |
| Altimeter Switch wires break | Altimeters will not arm | Provide for space within the avionics bay so that the other electronics and structures will not pull or apply force to the wires. |
| Ejection charges do not detonate | Parachutes do not deploy, rocket becomes ballistic, payload does not deploy | Test connections of the terminal blocks with wires shorting the connections, listen for the right number of beeps from the altimeter |
| Flame retardant cloth is not attached to shock cords | Parachutes and Shock Cords may become burned and do not decelerate the rocket sufficiently, the rocket will have too much kinetic energy, causing the rocket to break on impact, and become a danger to people and property | Follow Launch Checklist, attach the cloth to shock cord before parachute is inserted into appropriate bay. |
| Parachute shock cords are not connected to the tethered sections | Sections of the rocket will become detached without parachutes, becoming a danger to people and property | Follow Launch Checklist, ensure shock cords are connected to each tethered section using appropriate knots |
| Failure to separate | Inevitable deployment failures with ballistic descent and guaranteed severe | Sand the coupler extensively to assure a smooth separation and pay close attention to separation during testing |

| | | |
|---|---|---|
| | structural damages due to high velocity impact with an additional risk of injury | |
| High descent speed | Likely structural damages due to high velocity impact | Drogue parachute sizing calculations |
| Low descent speed | Likely loss of launch vehicle due to cross range displacement and rocket may land in unauthorized areas | Use of a properly sized parachute and careful timing of drogue parachute deployment |
| Parachute ignition | Avionics bay or payload may also be set on fire | Will use “dog barf” to insulate |
| Parachute rupture or entanglement | Likely structural damages due to high velocity impact | Will ensure that parachute is properly folded and packed |
| Premature, unintended deployment | If mid-flight, rocket may de-stabilize the structural integrity of parachutes is in peril | Key switch and electronics regulations; off until rocket is on launchpad |

## 6.3 Mitigation List

The following table entails potential failures that were experienced by the Launch Vehicle team and the mitigation for each failure mode.

Table 6.3.3. Failure Mode

| Place of Failure | Failure | Cause | Solution |
|---|---|---|---|
| ATS | Tube could buckle during flight or landing | Cut-outs for flaps would structurally weaken tube | Removed ATS |
| Parachute deployment | Both main and drogue parachutes were prone to getting caught on shear pins during deployment | Shear pins were in the coupler that joined avionics bay to adjacent sections. The parachutes lie in these couplers | Placed avionics bay into a coupler rather than tube, and placed shear pins inside avionics bay, so they would never interact with parachutes |
| Fasteners | Risk of having nuts and screws shake loose | Intense vibrations during ascent | Minimize fasteners, and use locktite where possible |
| Battery Fastening | Batteries could be forced out of their method of securement and disconnect mid-flight | High acceleration during launch could break form of securement as it did in subscale (zipties) | Use actual battery holders designed for high stress applications. Screw down battery mounts to the avionics tray. |
| Servo failure in roll control Mechanism | A servo failure, or misalignment could cause one of the flaps to not rotate equally, thus inducing a moment on the rocket that | A servo could burn out or become misaligned with regards to the other servos. Its connection to the pixhawk in the avionics bay could | All servos are mechanically joined with a single large gear that is connected to the small gears riding on each shaft to ensure all the shafts are |

| | | | |
|---|---|---|---|
| | could fully destabilize it | also become severed due to the high acceleration during launch | always in the same position |
| Parachute deployment | Parachutes could become wedged in couplers during deployment and end up becoming stuck in the rocket. | By placing ejection charges on each side of the rocket as was done in subscale, the parachutes would be blown into the couplers, creating higher chance of becoming compressed and stuck | The ejection charges will be placed on the opposite side of the coupler to ensure that the explosion pushes the parachutes out of the couplers they are held in |

## 6.4 Environmental Concerns

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

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

## 6.5 Launch Procedures

Table 6.5.1 Launch Preparation

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

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

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

| | |
|---|---|
| | Insert cellulose wadding into main parachute bay between ejection charges and parachute |
| | Insert main parachute and shock cord into main parachute bay and |
| | Insert upper body section into the lower section of the payload parachute bay, and secure with shear pins |
| | Attach payload parachute shock cord to payload section |
| | Attach parachute to the end of the payload parachute shock cord |
| | Pack payload section parachute |
| | Fold excess shock cord so it does not tangle |
| | Attach Nomex cloth to shock cord so it will enclose and shield the parachute while exposing only the Kevlar shock cord to ejection charge |
| | Insert cellulose wadding into upper payload parachute bay between ejection charges and parachute |
| | Insert drogue parachute and shock cord into upper payload parachute bay |
| | Insert payload section into payload parachute bay and secure with shear pins |
| **Assemble motor** | |
| | Follow manufacturer's instructions |
| | Do not get grease on propellant grains or delay grain |
| | Do not install igniter |

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

## 6.6 Launch Checklist

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

| LAUNCH | | |
|---|---|---|
| **Checklist** | **Performer** | **Inspector** |
| **Prepare Payload Bay** | | |
| Ensure the batteries and switches are properly connected to the altimeters. | | |
| Ensure the batteries, power supply, switches, data recorders, and pressure sensors are properly wired. | | |
| Install and secure new batteries into the battery holders. | | |
| Insert the altimeter into the bay. | | |
| Arm the altimeters to verify the jumper settings. Check the battery voltage and continuity once the altimeters have been armed. | | |

| | | |
|---|---|---|
| Disarm the altimeters afterwards. | | |
| **Assemble Charges** | | |
| Test e-match resistance and make sure it is within specifications. | | |
| Remove protective cover from e-match. | | |
| Measure the required amount of black powder that was determined during testing. | | |
| Place e-match on tape with the sticky side facing up. | | |
| Pour the black powder over the e-match and seal the tape. | | |
| Retest the e-match resistance. | | |
| **Check Altimeters (Figure 1 for configurations)** | | |
| Ensure altimeters have been properly disarmed. | | |
| Connect charges to the ejection wells/altimeter bay. | | |
| Turn on altimeters and verify continuity. Disarm altimeters afterwards. | | |
| ALTIMETER 1 | | |
| ALTIMETER 2 | | |
| **Pack Parachutes** | | |
| Connect drogue shock cord to booster section and altimeter. | | |
| Make sure shock cord and parachute have no tears, burns or frays | | |

| | | |
|---|---|---|
| Fold excess shock cord so it does not tangle. | | |
| Add Nomex cloth to ensure only the Kevlar shock cord is exposed to ejection charge. | | |
| Insert altimeter bay into drogue section and secure with shear pins. | | |
| Pack main chute. | | |
| Attach main shock cord. | | |
| Tug on both ends of the shock cord or recovery harness. It should be firmly attached. | | |
| **Assemble Motor** | | |
| Follow manufacturer’s instruction. | | |
| Use the necessary safety equipment needed such as gloves and safety glasses. | | |
| Be careful not to get any grease on propellant or delay grain. | | |
| Do not install the igniter until at launch pad. | | |
| Install motor in launch vehicle. | | |
| Secure motor retention system. | | |
| **Final Preparation** | | |
| Make sure fin flaps are aligned properly | | |
| Inspect the launch vehicle. Verify the CG in order to make sure it is in safe range. Add nose weight in the MAS if necessary. | | |
| Connect shock cord to nose cone, install nose cone, and secure with shear pins. | | |

| | | |
|---|---|---|
| Bring launch vehicle to the range safety officer (RSO) table for inspection. | | |
| Bring launch vehicle to pad, install on pad, and verify that it can move freely. | | |
| Install igniter in launch vehicle. | | |
| Touch igniter clips together to make sure they will not fire igniter when connected. | | |
| Make sure clips are not shorted to each other or blast deflector. | | |
| Arm altimeters via switches and wait for continuity check for both. | | |
| **Launch** | | |
| Watch flight so launch vehicle sections do not get lost. | | |

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

# 7. Project Plan

## 7.1 Budget Plan

The Figure 7.1.1 below shows all the purchases made for the rocket. The items that still need to be purchased follow in figure 7.1.2.

Figure 7.1.1 Purchases Made

| **Part** | **Cost** | **Quantity** | **Total Cost** |
|---|---|---|---|
| Ordered before 10/25 (not Space Grant) | | | |
| PerfectFlite stratologgerCF | $54.95 | 1 | $54.95 |
| | | | |
| USLI Avionics Part ordering 10/25/16 | | | |
| **Part** | **Cost** | **Quantity** | **Total Cost** |
| teensy 3.2 | $19.95 | 2 | $39.90 |
| Data transfer cable | $24.95 | 1 | $24.95 |
| IMU | $49.95 | 1 | $49.95 |
| | | | |
| 11/2 Ordering | | | |
| **Subscale Parts** | | | |
| Main Chute | $99.00 | 1 | $99.00 |
| Drogue Chute | $27.50 | 1 | $27.50 |
| Nosecone | $21.95 | 1 | $21.95 |
| PerfectFlite stratologgerCF | $54.95 | 1 | $54.95 |
| Servos? | N/A | N/A | N/A |
| Other Electronics/Board/Connectors | | | |

| | | | |
|---|---|---|---|
| | | | |
| | | | |
| Home Depot Subscale Parts | 85 | - | 85 |
| | | | |
| | | | $458.15 |
| 1/24/2017 | | | |
| Part | Unit Cost | Quantity | Total Cost |
| G10 1/8" 12"x12" Sheet | $18.00 | 2 | $36.00 |
| G10 5.5" Coupler Bulkplate | $8.00 | 2 | $16.00 |
| G10 5.5" Bulkplate | $8.00 | 2 | $16.00 |
| G10 5.5" to 75mm Centering Ring | $9.00 | 1 | $9.00 |
| G12 5.5" Coupler 12" long | $54.10 | 1 | $54.10 |
| 5.5" 4:1 Ogive Nosecone | $84.95 | 1 | $84.95 |
| G10 1/4" 12"x12" Sheet | $54.00 | 3 | $162.00 |
| Eyebolt: 5/16"-18, 1-1/8" long thread | $3.20 | 2 | $6.40 |
| Ubolt: 1/4"-20 Thread Size, 1-1/4" ID | $4.16 | 2 | $8.32 |
| 1 ft 5.5" G12 Body Tube | $38.84 | 1 | $38.84 |
| 120" TFR Standard Chute | $94.95 | 1 | $94.95 |
| 45" TFR Standard Chute | $23.95 | 1 | $23.95 |
| Shock Cord | $0.97 | 40 | $38.80 |
| Servos | $39.99-$59.99 | 4 | 200 |
| Airspeed Sensor | $49 | 1 | 49 |
| | | | |
| | | | |

| | | | |
|---|---|---|---|
| | | Total = | $838.31 |
| 2/7 | | | |
| Part Name | Unit Cost | Quantity | Total Cost |
| APOGEE COMPONENTS | | | |
| 75mm LOC tube | $14.95 | 1 | $14.95 |
| Removeable plastic rivet | $3.71 | 2 | $7.42 |
| AeroPack 75mm Retainer (Flanged) | $53.50 | 1 | $53.50 |
| | | | |
| SERVOCITY | | | |
| 5mm Shaft (250mm) | $2.29 | 4 | $9.16 |
| | | | |
| WILDMAN | | | |
| 5.5" G10 Coupler Bulkplate | $8.00 | 3 | $24.00 |
| Parachute Protector | $10.95 | 1 | $10.95 |
| 5.5" G12 Body Tube (5ft length) | $194.18 | 2 | $388.36 |
| 2/56 Shear Pins | $2.95 | 3 | $8.85 |
| Ejection Charges (10 pack) | $15.79 | 2 | $31.58 |
| 3/8" Tubular Kevlar Shock Cord | $2.50 | 12 | $30.00 |
| 5.5" G12 Coupler (12" length) | $54.11 | 1 | $54.11 |
| 5.5" G10 Bulkplate | $8.00 | 5 | $40.00 |
| 5.5" to 75MM centering ring | $9.00 | 4 | $36.00 |
| | | | |
| SDPSI | | | |
| 5 mm (HTD) Pitch,22 Teeth, 8mm Bore pulley | $13.04 | 1 | $13.04 |
| 5 mm (HTD) Pitch, 59 Teeth, 9mm belt | $8.27 | 1 | $8.27 |

| | | | |
|---|---|---|---|
| Pinion Bevel Gear | $13.89 | 4 | $55.56 |
| Bevel Gear | $16.58 | 4 | $66.32 |
| | | | |
| MCMASTER-CARR | | | |
| 4 flute, 1/4" end mill (carbide) | $21.46 | 1 | $21.46 |
| G10 12"x12" sheet .25" | $30.28 | 1 | $30.28 |
| G10 12"x24" sheet .25" | $52.68 | 1 | $52.68 |
| 2" dia 36" Lg Foam Rod | $6.64 | 1 | $6.64 |
| 1" x 2" x 1' Al 6063 Bar | $34.68 | 1 | $34.68 |
| | | | |
| | | | |
| | | | $997.81 |
| | | | |
| 2/5 | | | |
| Gerardo Purchase from CS Rocketry | | | Payment w/ AE Dept hasn't gone through yet |
| L1150R Motor | 200 | 2 | 400 |
| Motor Casing+Aft/Front Closure | 360 | 1 | 360 |
| | | | 760 |
| Servo Hub (24 tooth splines) | $7.99 | 5 | $39.95 |
| 5mm Shaft (250mm) | $2.29 | 3 | $6.87 |
| Aluminum .25" sheet 6x20" | $25.03 | 1 | $25.03 |
| Mask | $22.99 | 1 | $22.99 |
| *P100 Filter* | $6.48 | 1 | $6.48 |
| | | | **$101.32** |
| Shipping Costs | 200 | | **200** |

| | | | |
|---|---|---|---|
| | | | |
| **Total Spending from Space Grant** | | | **2600** |
| **Total Spending from AE Department** | | | **760** |

Figure 7.1.2 Items to Be Purchased

| Part Name | Unit Cost | Quantity | Total Cost |
|---|---|---|---|
| J380 Motors from Rambling Rocket Club | 100 | 2 | 200 |
| | | | |
| | | | |
| Eggfinder GPS | $50 | 1 | $50 |
| 1 night in 4 hotel rooms- competition | $330 | 3 | $1,000.00 |
| Gas reimbursement Competition travel | $150 | | $150.00 |
| Rental Car competition | $200 | | $200.00 |
| **Total** | | | **$1600** |

Figure 7.1.3 and Table 7.1.1 show the projected total budget for this year's competition. Some categories became more costly than anticipated, while others became cheaper. The cost of the launch vehicle has now been estimated to $3000, larger than the original estimated $2100, and travel and lodging became more expensive due to the necessity of a rental vehicle. However, our avionics cost decreased because the Pixhawk controller we use is owned r by our department, not internally. The expenses we anticipated for outreach also disappeared, because all the events we are hosting have the materials covered by the participants. For example, the engineering merit badge we hosted had all materials and food supplied by the troop, and the outreach program

we’re doing with Peachtree Charter Middle school will have the low powered rocket purchases covered by the school. Our total estimated expenses grew to $5900, which would be concerning; however,  we expanded our funding sources by more than necessary to at least $6900, ensuring we will not run out of monetary resources.

Table 7.1.1 Projected Budget

| Section | Cost |
|---|---|
| Launch Vehicle | $3000 |
| Avionics | $300 |
| Outreach | $0 |
| Travel | $1400 |
| Test Flights | $1200 |
| **Total** | **$5900** |

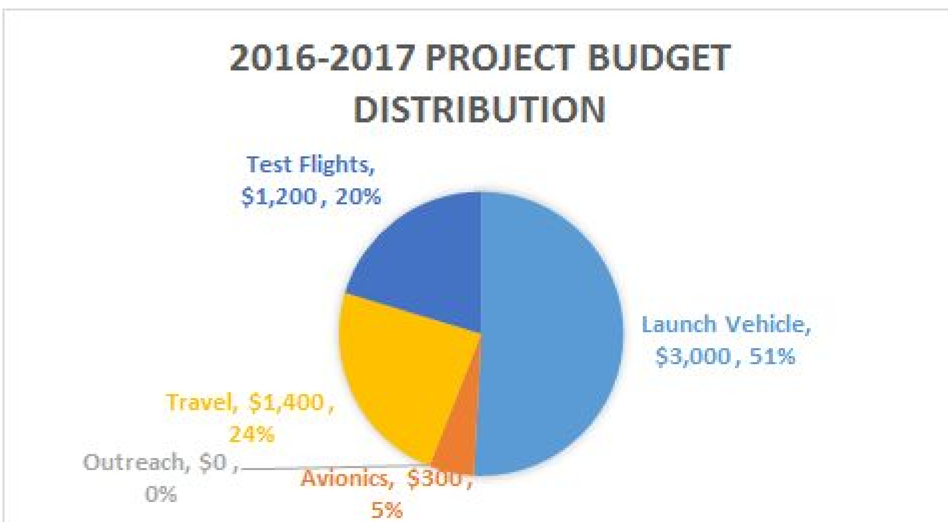



Figure 7.1.3 Projected Budget Distribution

## 7.2 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 allocated us $4000, a marked increase from the $2500 they estimated earlier.  The remaining costs will covered through the Georgia Tech Aerospace Department by alumni and corporate donations, which can allocate

$2500, more than covering all remaining expenses. CCTV Camera World has given us a camera that will be used to film launches, rocket construction, and outreach events for publicity purposes. Table 7.2.1 shows our funding sources, which exceeds our cost estimates by 15%, 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. Orbital ATK also generously provides a motor and travel stipend.

Table 7.2.1 Planned Sponsors

| ***Sponsor*** | ***Contribution*** | ***Date*** |
|---|---|---|
| 2015-2016 Unused Funds | $388 | -- |
| Georgia Space Grant Consortium | $4000 | Oct 2016 |
| Georgia Tech Aerospace Department | $2500 | Jan 2017 |
| Orbital ATK Motor and Travel Stipend | ? | Apr 2017 |
| **Total** | $6888+ | |

## 7.3 Timeline

### 7.3.1 Gantt Chart

In order to meet the deadlines given by NASA and the internal deadlines created by Team ARES, we have created a streamlined Gantt Chart (Figure 6.3.2) to more easily visualize the timeline of our project milestones, and broke down each task into smaller tasks with completion dates (Table 6.3.4). This task breakdown  contains every step required to achieve our project milestones and the timing of them to ensure everything is done by deadline. The 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.

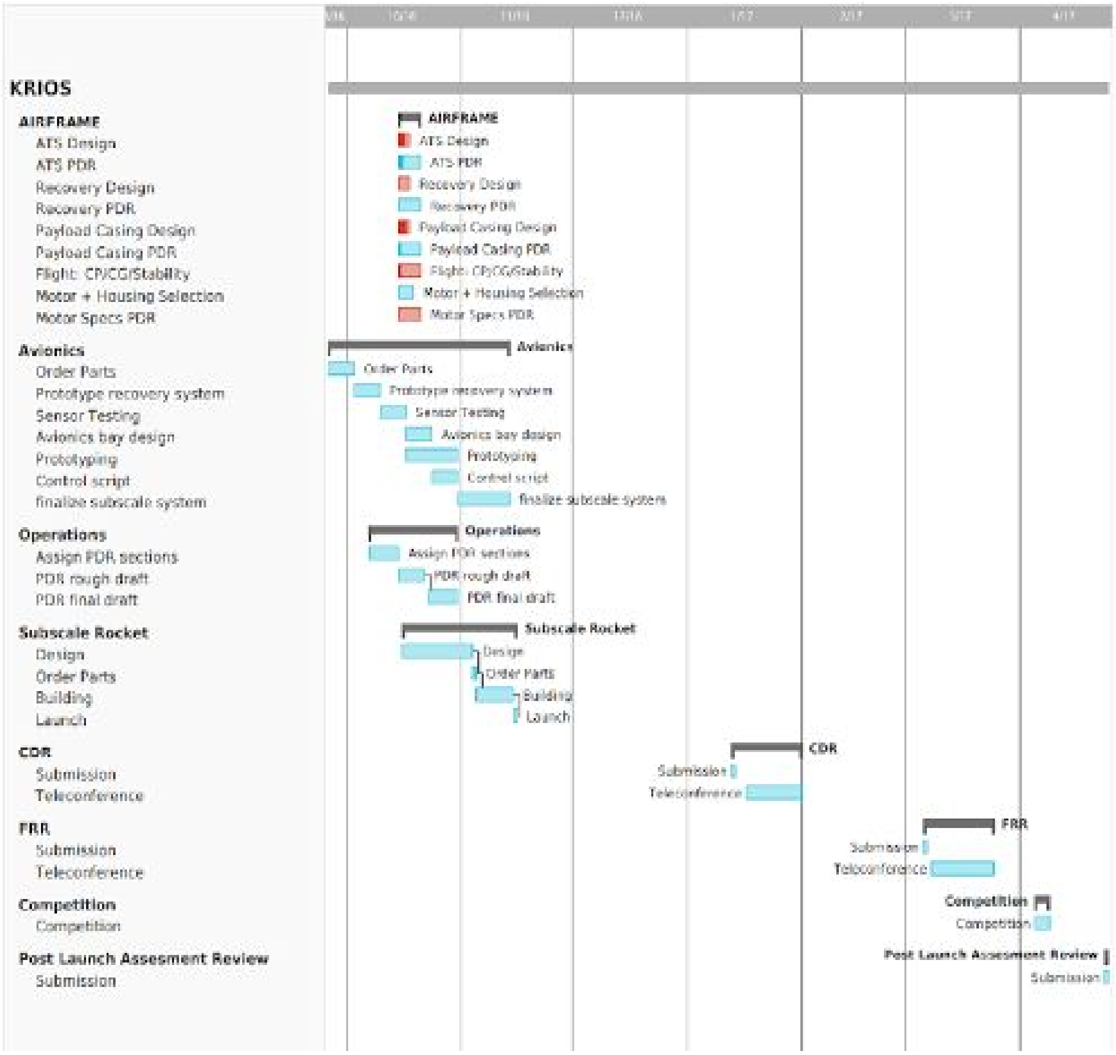



Figure 7.3.1 GANTT Chart

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 |
| Finalize CAD and OpenRocket | 1/28/2017 | 2/3/2017 |
| Engineering Merit Badge Clinic | 2/04/2017 | 2/04/2017 |
| Create Document Distribution Spreadsheet | 2/15/2017 | 2/15/2017 |
| Distribute Writing Assignments | 2/16/2017 | 2/16/2017 |
| Order Full Scale Parts | 1/21/2017 | 2/15//2017 |
| Create Load Testing Setups | 1/15/2017 | 2/3/2017 |
| Load Tests | 2/3/2017 | 2/10/2017 |
| Roll Control Motor Skeleton Working | 1/20/2017 | 2/3/2017 |
| Finalize Wind Tunnel Test Setup | 2/1/2017 | 2/20/2017 |
| Wind Tunnel Testing | 2/21/2017 | 2/24/2017 |
| Full Scale Part Manufacturing | 2/12/2017 | 2/23/2017 |
| **Full Scale Construction** | **2/20/2017** | **3/3//2017** |
| Avionics Bay Construction | 2/22/2017 | 2/26/2017 |
| Booster Section Construction | 2/22/2017 | 2/26/2017 |
| Nosecone/GPS Bay Construction | 2/19/2017 | 2/26/2017 |
| Completed Section Assembly | 2/26/2017 | 3/1/2017 |
| Ejection Charge Testing | 3/2/2017 | 3/2/2017 |
| Avionics Working on Rocket | 3/1/2017 | 3/3/2017 |

| | | |
|---|---|---|
| Miscellaneous Rocket Assembly | 3/1/2017 | 3/3/2017 |
| **Full Scale Test Launch** | **3/4/2017** | **3/4/2017** |
| FRR Section Writing | 2/18/2017 | 2/24/2017 |
| FRR Editing | 2/25/2017 | 3/1/2017 |
| Document Formatting | 3/1/2017 | 3/4/2017 |
| Student Foundation Funding Results | 2/20/2017 | 2/20/2017 |
| Submission | 3/6/2017 | 3/6/2017 |
| Teleconference | 3/8/2017 | 3/24/2017 |
| Secondary Test Launch | 3/18/2017 | 4/1/2017 |
| **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 |

## 7.4 Educational Engagement Plan and Status

### 7.4.1 Overview

One of the main goals of the GT A.R.E.S. Team is to reach out to the community in order to promote the Science, Technology, Engineering, and Math fields and to positively affect anyone with whom the team interacts. Throughout the school year, the A.R.E.S. Team has taken part in multiple outreach events, including teaching classes to children and talking to teachers about the team and about how to teach rocketry. The team plans to visit schools in the Atlanta area, with the goal of encouraging students there to seek careers in STEM fields.

### 7.4.2. Engineering Merit Badge

The A.R.E.S. team taught an Engineering Merit Badge to a Boy Scouts Of America Troop, specifically Troop 433, a local metro-Atlanta troop. The badge was taught at Georgia Tech at an aerospace facility, and the badge included a presentation that showcased different careers in engineering and introduced numerous examples of engineers' methods and mindsets. The team then took the troop on a tour of campus and the aerospace labs located in multiple buildings. This has created a large amount of interest in teaching more Engineering Merit Badge classes as well as other merit badges as well, such as Astronomy, Aviation, and Robotics badges.

### 7.4.3. Peachtree Charter Middle School

Team A.R.E.S. had a successful afterschool program at Frederick Douglass High School in the previous year, and when the team attempted to restart the program, they learned that the previous teacher contact at that school had moved to Peachtree Charter Middle School. The teacher, Aaron Campbell, was greatly interested in creating a similar program at his new school, so the team went to PCMS one day and formed a plan to come to PCMS during the school day to help teach rocketry, physics, and math principles to students.This program will be implemented in March and April, when the curriculum at the middle school begins to include rocket-related topics.

### 7.4.4 Atlanta Science Festival

The Atlanta Science Festival is a yearly event in Atlanta celebrating and promoting STEM in the community. Team ARES plans on volunteering at the festival, and hosting our own booth to teach the community about our team and rocketry. This event will be held March 14th-25th.

## 7.5 Team Derived Requirements

## 7.6 Verification Plan

Table 7.6.1 - Requirements and Design Features

| Requirement | Design Feature |
|---|---|
| Vehicle altimeter will report an apogee altitude of most nearly 5,280 feet AGL. | Mass Addition System(MAS) |
| 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 upon landing. Bullet connectors will be used on wires spanning multiple sections to prevent damage to wiring upon separation. |
| Vehicle will require minimal assembly/disassembly time and effort | Vehicle will be designed to be assembled from a series of sections/modules with basic hand tools. |
| 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. Roll rate and direction controlled by Pixhawk. |
| The launch vehicle shall have a maximum of four (4) independent sections. | Three (3) sections include: nosecone, avionics, and booster |
| 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 |
| The launch vehicle shall stage the deployment of its recovery devices, where a drogue parachute is | All recovery systems will be dual-redundant to ensure deployment at a safe altitude |

| | |
|---|---|
| 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 |
| 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 | A master key-switch installed at the rear of the avionics bay to close all circuits simultaneously |
| Each detachable section of the vehicle and payload must contain an electronic tracking device and continue transmission to the ground throughout flight and landing. | A properly shielded GPS system will transmit real-time position to the ground station via a radio modem. |

Table 7.6.2 - Requirements and Verification Method

| Requirement | Verification |
|---|---|
| Vehicle altimeter will report an apogee altitude of most nearly 5,280 feet AGL. | Data from the three onboard altimeters will verify this requirement is met. |
| Launch vehicle will be designed to be recoverable and reusable within the day of initial launch. | Every element of the launch vehicle will be inspected post recovery |
| Vehicle will require minimal assembly/disassembly time and effort | Conduct evaluation of time required to assemble/disassemble key components of vehicle |
| The vehicle will complete two rolls and then produce a counter-roll | Angular acceleration data recorded in the log file will verify that this requirement has been met. Camera footage may also be utilized. |

| | |
|---|---|
| The launch vehicle shall have a maximum of four (4) independent sections. | 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. | 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. | Inspect flight log file 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. | Inspect flight log to determine 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 | Altimeters will visually inspected after each launch and their batteries switched prior to each 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. | Range checks will be performed prior launch. |

Table 7.6.3 - Team Goals and Design Features

| Team Goals | Design Feature |
|---|---|
| Vehicle will attain an altitude within 150 feet of the 5,280 foot AGL goal. | Mass Addition System(MAS) |
| A log of velocity, acceleration, airspeed, fin position, and time will be recorded during each flight. | Pixhawk will write a log file of mission data to its onboard microSD card. |

| | |
|---|---|
| The roll/counter roll maneuver will be performed in under 5 seconds. | Modular/flexible assembly construction |
| The vehicle will be capable of waiting on standby for a minimum of 1.5 hours. | Battery capacities chosen to fulfill this goal. |
| Roll control system will incorporate backups for mission all critical components within reason. | The Pixhawk will be utilize a triple redundant power supply and four servos will actuate the gear train that tilts the fins. |

Table 7.6.4 - Team Goals and Verification method

| Team Goals | Verification |
|---|---|
| Vehicle will attain an altitude within 150 feet of the 5,280 foot AGL goal. | Data from the three onboard altimeters will determine whether we have met this goal. |
| A log of velocity, acceleration, airspeed, fin position, and parachute deployment with respect to time will be recorded during each flight. | Verified by removing the flight controller and ensuring the log file is present and that it contains the desired measurements. |
| The roll/counter roll maneuver will be performed in under 5 seconds. | Angular acceleration data recorded in the log file will determine if we have met this goal. Camera footage may also be utilized. |
| The vehicle will be capable of waiting on standby for a minimum of 1.5 hours. | Vehicle will be armed (without a motor or ignition system present) for 1.5 hours then battery voltages checked. |
| Roll control system will incorporate backups for mission all critical components within reason. | Failure of one or more redundant components will be simulated to ensure the vehicle will operate properly on the backup components. |