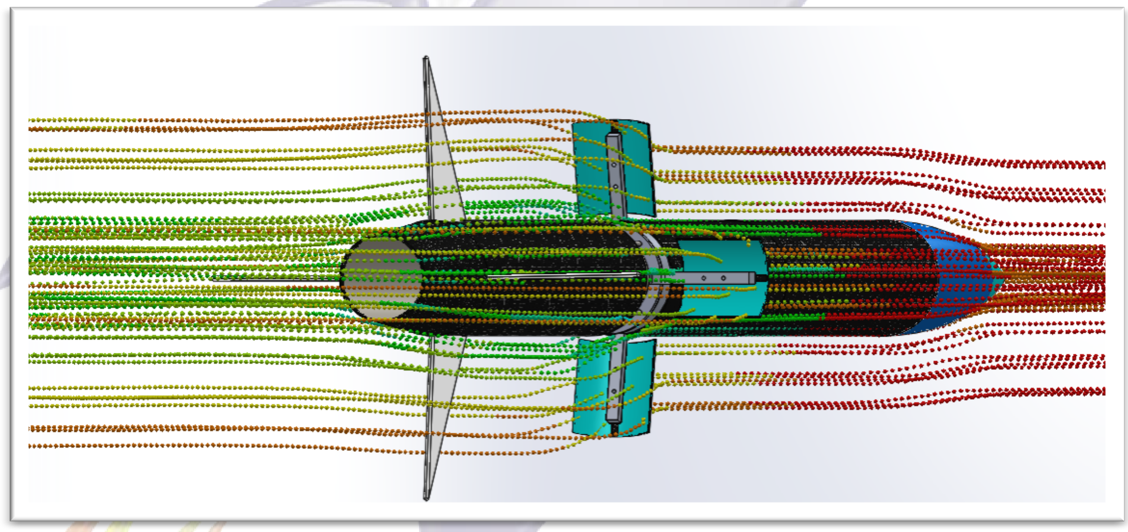
2016-2017 NASA Space Grant Midwest High-Power Rocket Competition

Team Wiscosmonauts

PRELIMINARY DESIGN REPORT



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I. Executive Summary

Team Wiscosmonauts, in coordination with the American Institute of Aeronautics and Astronautics UW-Madison chapter, is profoundly grateful to have been given the opportunity to compete in this year's NASA Midwest High Power Rocket Competition. We were presented a unique challenge this year– one which we are all very excited to tackle head on. The competition required us to launch using two different motors as different as possible from each other, for which we chose one J-class and one K-class, along with implementation of an active drag system. These constraints challenged us to come up with a high-powered rocket with low aerodynamic drag to ensure the J-class powered flight reaches a minimum altitude of 3000 feet, while also being able to induce incredible amounts of drag to slow the K-class powered flight enough such that the maximum altitude in this configuration matched the altitude of the J-class powered flight. Additionally, we were required to predict the performance of the rocket, construct a non-commercial on-board data collection package to directly measure velocity/time, and document the separation of the drogue and main chutes using both the data collection package and up and down video from outside the airframe. This report outlines the extensive engineering effort undergone to complete the design and construction of our rocket.

Section II, underlying our extensive carbon-fiber based design features, begins with the rocket airframe in part a, followed by the active drag mechanism in part b, power plant in c, electronics in d, and recovery in e. We continue in section III by underlying the specific processes undergone to predict mission performance for both motors. The report is concluded in section IV with our budget estimates for the rocket and competition expenses.

II. Design Features of Launch Vehicle

a. Rocket Airframe

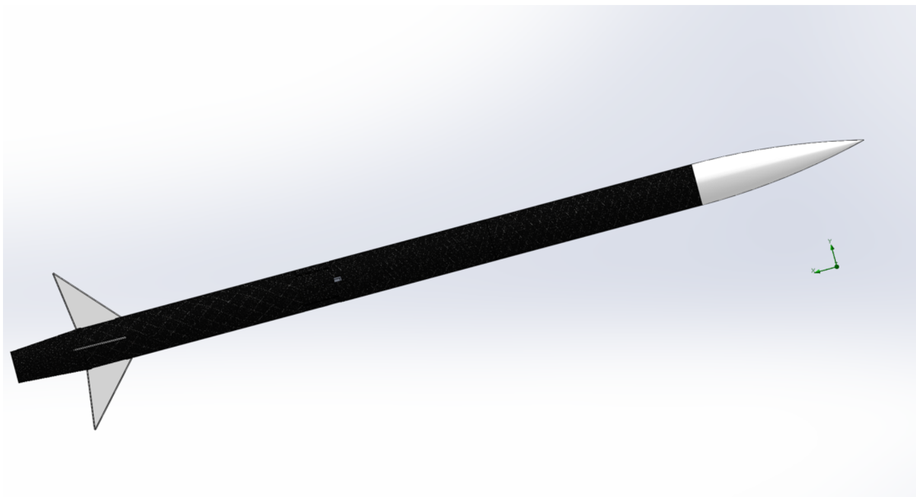


Fig 1. Airframe assembly

The airframe is comprised of the following components:

- Body Tube
- Nose cone
- Fins
- Tail cone
- Motor Retention System

Carbon fiber was chosen as the primary material of the airframe tube due to the high strength to weight ratio. The airframe will experience not only external aerodynamic forces, but also internal loads from the drag mechanism, which will distribute drag force loads throughout the mid-section of the fuselage. Thus, having a high strength, yet lightweight fuselage was a key design consideration in the project.

The nose cone is a 13.5" long 4:1 ogive fiberglass nose cone. It will be attached using 2 nylon 2-56 nylon shear pins.

The four main fins are constructed out of 0.125” plywood, then wrapped in fiber glass for additional strength to prevent breakage upon landing. The dimensions shown of the main fins are show in Figure 2.

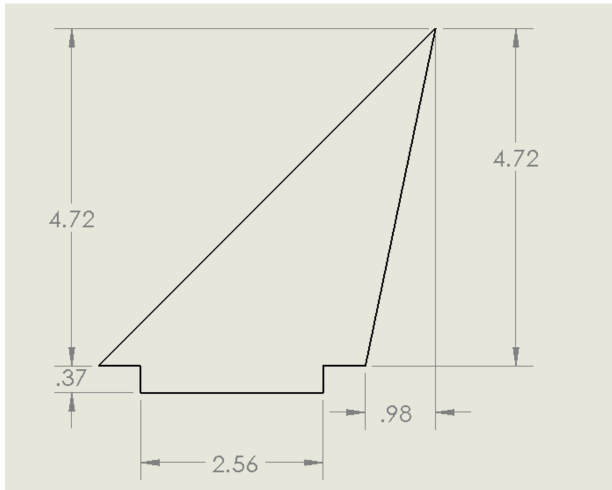


Fig 2. Main Fin shape [in]

The tail cone is a tapered conical section that allows for addition room for the longer K-1440 motor, while reducing the mass in the aft section of the airframe, which provides additional stability. This section will be made of plywood centering rings wrapped in balsa wood, then wrapped in carbon fiber.

The motor retention system uses a 54 mm ID thick-walled tube. It is centered in the airframe using three plywood centering rings in the main fuselage, as well as two centering rings in the tail cone. An aluminum centering ring (Fig 4) and aluminum thrust plate (Figure 3) fix the motor mount assembly to the airframe. The aluminum centering ring and thrust plate are also used in conjunction with the drag system to distribute the load throughout the fuselage. This is accomplished by attaching the thrust plate and drag mechanism to the centering ring by running bolts through the entire assembly and fastening to each sub assembly to the fuselage.

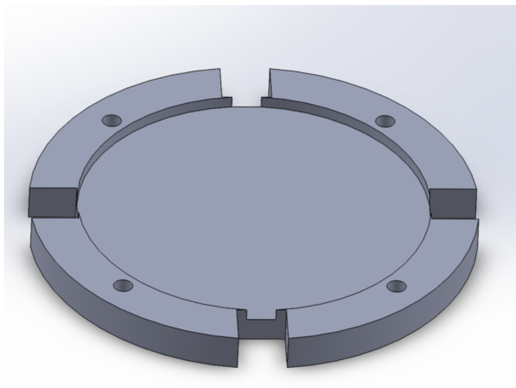


Fig 3. Thrust Plate

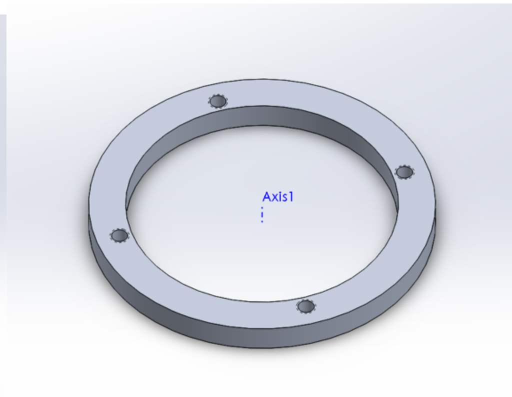


Fig 4. Aluminum Centering ring

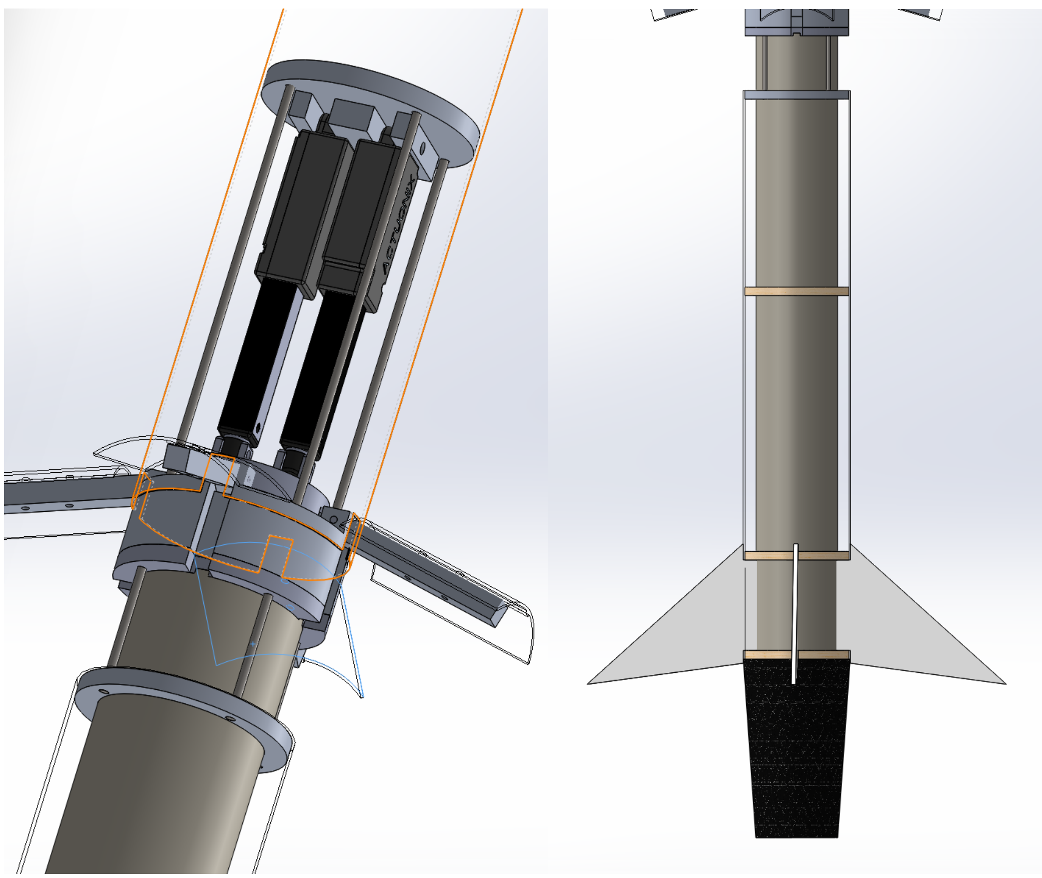


Fig 5. Thrust plate, Centering Ring, and Drag mechanism assembly

b. Active Drag Mechanism

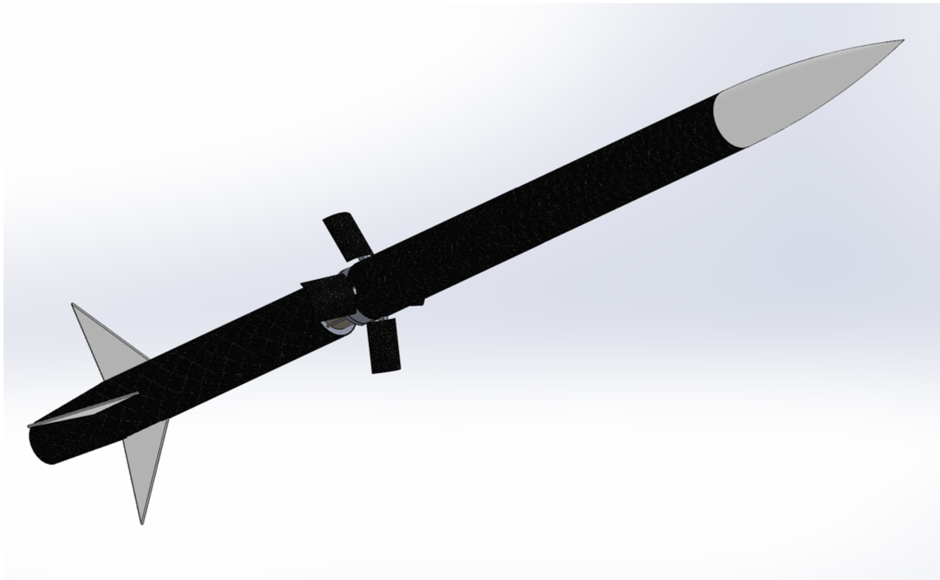


Fig 6. Airframe assembly with drag mechanism actuated

The active drag system uses four moment arms that are extended outward by applying a load to the upper assembly via two linear actuators (Figure 7). This downward force pivots the arms about the lower assembly using a slotted design in the upper assembly (Figure 8). The 64mm long fins are made of the same carbon fiber material as the body tube and are reinforced with aluminum guides. This ensures minimal bending occurs at max Q and allows for minimal discontinuity in the airframe when the drag mechanism is retracted.

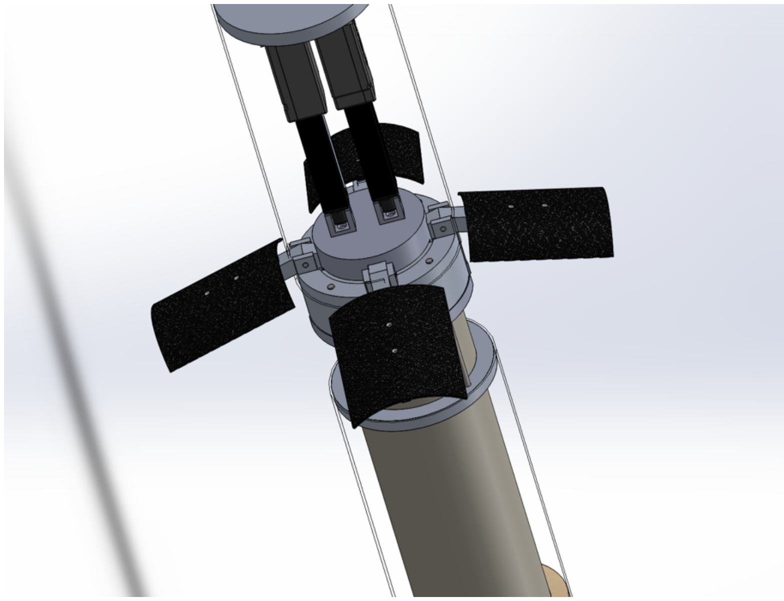


Fig 7. Two linear actuators extending drag mechanism

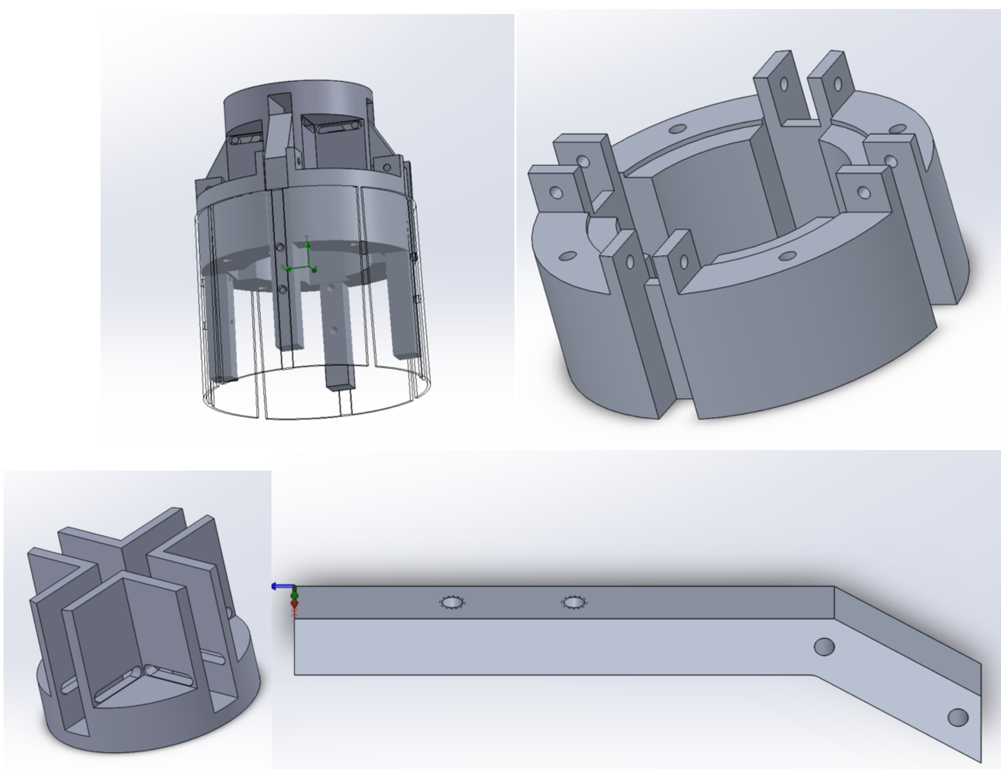
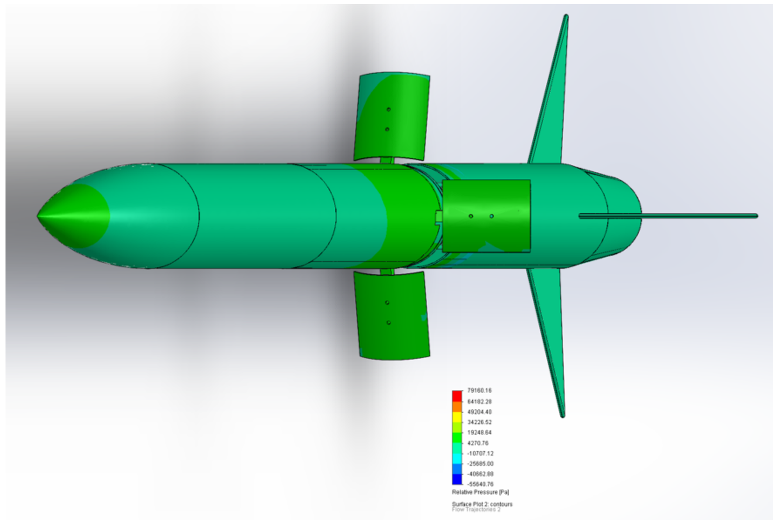


Fig 8. Drag mechanism components

CFD analysis (Figure 9) resulted in the drag system applying 140 pounds (4.3 g's) of additional force to the airframe.



To ensure the drag mechanism could withstand these loads we used finite element analysis to predict the stresses applied to the arms of the mechanism (figure 10). As shown in the figure, it is estimated that the maximum stress occurs at the pivot point of the arm, however the arm experiences a maximum stress of 78 MPa, well within the limits of aluminum. Other possible locations of possible failure include the sliding pin in the upper arm, as well as the bolt that attaches the arm to the lower assembly. Our estimations in these regions yielded a maximum shear stress of 68 MPa for the sliding pin and 130 MPa for the bolt. These are also well within the limits of steel.

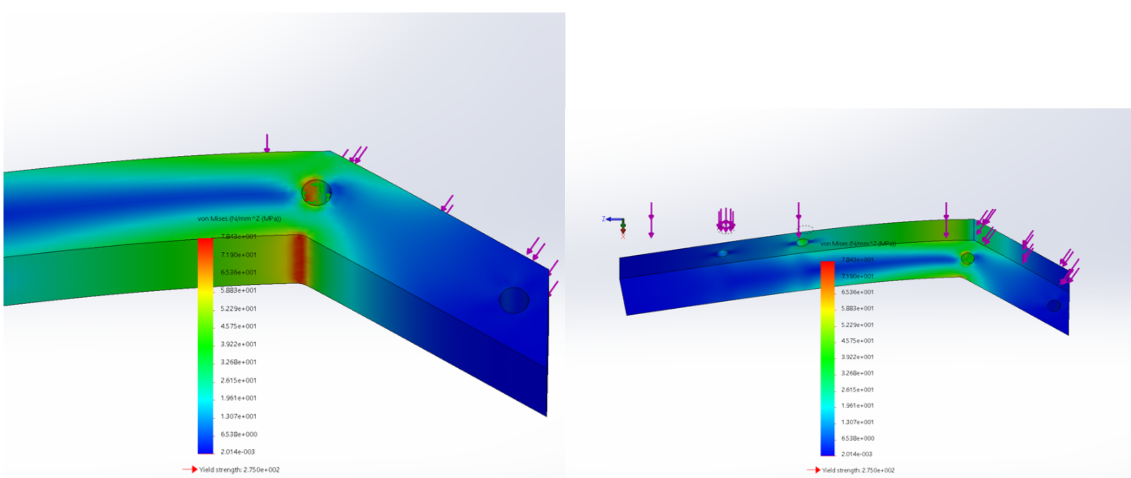


Fig 10. Stress in arm

c. Power Plant

Our competition rocket will be propelled by a CTI 2-grain J-240 Red Line motor for the lower impulse flight and a CTI 6-grain K-1440 White Thunder motor for the larger impulse flight. The J-250 provides a peak thrust of 67 lbs, with a total impulse of 806 Ns. The K-1440 is a much more powerful motor, with a peak thrust of 411 lbs and a total impulse of 2372 Ns. Choosing these two motors provided us with several interesting constraints. The J-class motor must still provide the rocket with enough power to reach the minimum altitude of 3000 ft. While the K-class motor provides plenty of power to reach an altitude of over 10000 ft, our drag system must induce enough drag to reach the same maximum altitude of the J-class motor without overstressing the airframe or the drag mechanism.

In order to assure proper safety is followed the team will not be unboxing the motors prior to launch dates and will be sure to take proper care of each motor, handing them in safe ways and storing them in a cool, dry place.

d. Electronics

One of the competitions main goals is for the team to implement a custom-built computer system to actively control and video document the drag system of the rocket during the second launch, along with characterizing velocity over time of the entire rocket. To do this the team is incorporating the use of two separate computer systems, one in the nosecone and one in the main body. The system in the nosecone will be used for tracking and recording data whereas the main body system will be used to control the drag fins deployment. The main body system is all affixed inside a cardboard pre-purchased electronics bay and the electronics in the nosecone are affixed with a bulkhead.

The nosecone computer assembly will consist of a 12V lithium-ion battery, an Arduino Uno, a 6-axis gyroscope, a barometric pressure sensor, a GPS module, and an SD-card module. Our GPS module will be affixed to the inside of the nosecone with glue and the Uno attached to the topside of the bulkhead securing the section. The Uno is being used in this situation to store the data from recorded from the gyroscope and the accelerometer. The Arduino will be programmed to indicate when the launch has occurred by detecting the large change in acceleration and marking that time, and doing the same for apogee by marking when the upward acceleration becomes zero. Once we have these locations marked, we can correlate these times to the barometer readings for altitude, allowing us to find velocities at different times of the flight by simply taking the change in altitude at a certain divided by the change in time.

From the first flight of the J-class motor we will use the altitude at apogee to create a new estimate for velocity over time for the flight of the K-class motor with the tabs deployed fully (the estimate is with the tabs fully deployed due to the large size of this motor, it must slow considerably to match the J-class apogee). The method for doing so is outlined in Section III. We will then take the characterized data points for velocity at specific times and store them on the Arduino in the main body, which is powered by an additional 12 V battery and contains an additional barometric pressure sensor. During the second flight, the same Arduino will take measurements of altitude over time, allowing us to once again create an estimate for velocity at specific times. This found velocity will be compared to the estimated velocity for the flight at the time since launch, and will adjust the drag tabs accordingly. If the velocity is higher than what it should be, the drag tabs remain deployed, if it is lower, they will begin the stowing sequence, which takes about a second to complete. As a failsafe for if the velocity is never lower than what it should be, the tabs will begin to stow at 85% of the altitude of the predicted apogee.

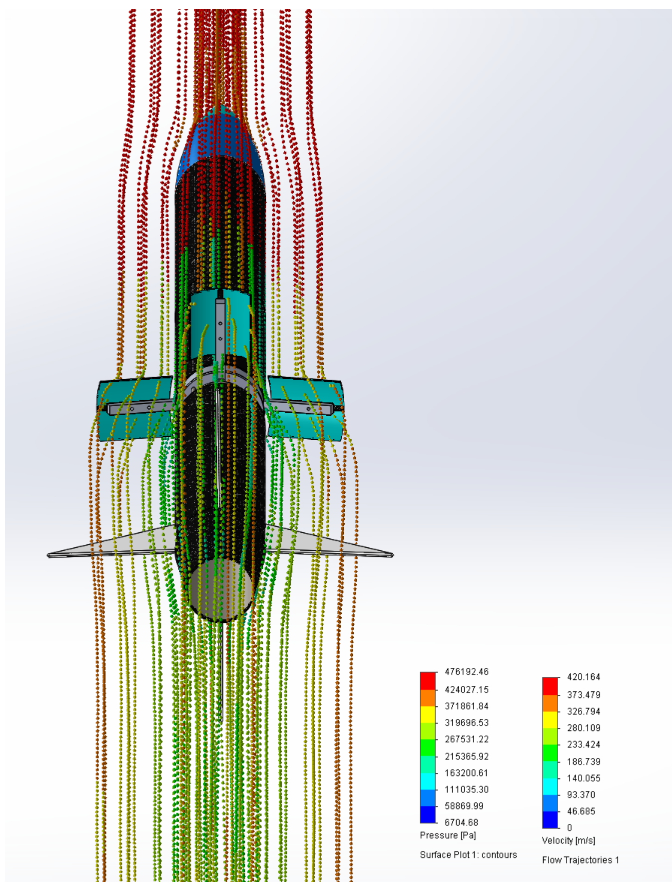
To document all of this occurring, we will be attaching two 1080p polaroid cube cameras, which have wide angle lenses, to the outside of the body tube of the rocket. The cameras will be enclosed inside an aerodynamic 3D printed housing which will in turn be screwed to the midsection of the carbon fiber body tube, one on each side of the tube opposite one another, facing in opposite directions, the downward facing to document the drag system and upward the chute deployment.

e. Recovery

The rocket will use dual deployment system with a 24-inch drogue chute deployed from the main body tube at apogee and a 44-inch main parachute deployed at 800 ft above ground level from the upper body tube. An ALTS-25 commercial altimeter will provide power to the ejection caps for both the main and drogue chutes. An un-capped ejection charge on the motor will deploy a parachute in the event our ejection charges fail to detonate. Since the drag mechanism is directly above the motor and the body tube will not be sealed, the pressure from the ejection cap will be routed to the sealed main tube assembly.

Open Rocket simulations predict the rocket will touch the ground at approximately 5 m/s (~16 ft/s) for the K-class flight and slightly slower for the J-class flight. Locating the rocket after landing will be accomplished by a GPS tracking receiver. After recovery, our team will conduct an extensive and thorough post flight inspection of the rocket to assure it is in flyable condition.

III. Predicted Mission Performance



Predicted flight performance was based off a variety of simulations using computational fluid dynamics (CFD), finite element analysis (FEA), and open rocket simulation data. The J-class configuration is estimated to reach a maximum altitude of 1230 meters (~4000 feet) with a maximum velocity of 160 m/s. The K-class configuration estimations with the drag system retracted yielded a maximum altitude of 3540 meters (~11500 ft) with a maximum velocity of 440 m/s. However, estimations with the drag system extended yielded a maximum altitude of 720 meters with a maximum velocity of 250 m/s. These results are plotted in figure 11 and 12.

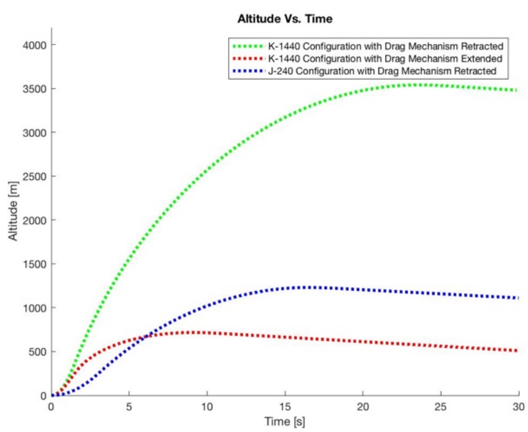


Fig 11. Comparison of Altitude Vs Time

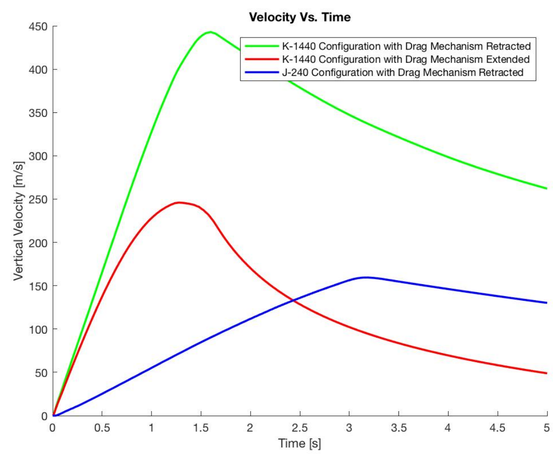
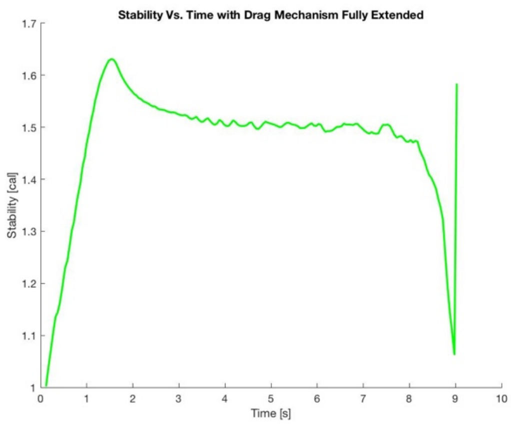


Fig 12. Comparison of Velocity Vs time

Additionally, the altitude and velocity estimates for the drag system assumed the system was deployed from takeoff to apogee. Since the drag system will be retracted at both launch and apogee, further calculations still need to be worked out based on data from our test flight. This is because the linear actuators extend at a rate of 18 mm/s under zero load, however, the drag mechanism is expected to apply approximately 140 pounds (~4.3 g's) of additional drag force. Under these conditions, the extension rate of the actuators will be slowed, leaving us with only rough approximations until further data is recorded. With these unknown factors, we are setting our baseline estimate at a maximum altitude of between 1100 and 1300 meters. These approximations were obtained using Open Rocket to mimic the coefficient of drag, which was calculated using CFD. Then averaging the drag force during the first second of extension, as well as factoring in ~1 second of retraction time. Further refinement to these approximations during testing will allow us to further control the extension/retraction of the actuators to reach the desired altitude.

Stability of the rocket was also a key concern. The stability calibers were estimated using Open Rocket simulations. Due to the nature of the location of the drag mechanism, the center of pressure will shift forward while the drag fins are extended. To account for this, our initial stability caliber will be slightly higher (~3-3.5 cal) for the lower impulse flight. This ensures the stability caliber for the K-class configuration never drops below one caliber during full extension of the drag mechanism (figure 13).



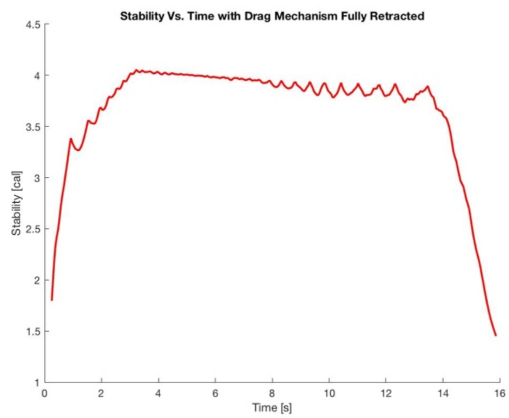


Fig 13. Stability Vs Time with drag mechanism at full extension (left), J-class configuration with drag mechanism at full retraction (right)

IV. Budget

Purchase	Cost
3” Carbon Fiber Body Tube-48” Section	179.95
44” Angel Parachute	69.00
54mm Retainer	31.03
54 mm LOC Thick-Wall Motor Mount Tube	8.09
101 Airfoil Rail Buttons	7.00
3” Carbon Fiber Coupler Tube	44.95
3" Plywood Bulkhead Disk w/ Hardware x3	11.49
Fiberglass Nose Cone (4:1 Ogive)	30.95
CR-3.0-2.1 Plywood Centering Rings x4	12.36
Quick Links x2	15.76
24" Nylon Drogue Parachute	9.79
9/16" Tubular Nylon - 36 ft x12	15.00
12" Nomex Chute Protector x2	16.30
58" Shock Cord Protector	15.99
Ejection Charge Canisters w/ Igniters (10/pk)	17.95
FPV Camera x2	40.00
Adept T400-M-LB AM Radio Transmitter	49.00
3-Axis Accelerometer/Gyro/Multi-Sensor	25.00
Arduino Uno x2	50.00
Adafruit SD shield	8.00
8GB Micro SD Card	5.00
1600 mah 3S 25~50C Lipo Pack	24.00
Terminal Blocks x2	6.82
Push Button Switch x2	12.60
Jolly Logic Altimeter Two Holster	10.65
CTI 2 Grain 54mm Motor Casing	51.65
CTI J240 Red Line x3 (after discounts)	118.85
CTI K1440 White Thunder x2 (after discounts)	215.9

2-56 Nylon shear pins (20/pk)	3.10
Clear Coat Paint and Various Sandpaper	20.00
JB Weld	5.67
Epoxy	35.00
Misc. Hardware	20.00
Hotel Fee (2 rooms, single night)	250.00
Actuonix Linear Actuator x2	220.00
Registration Fee	400.00
Total Cost:	2016.85