Delta VT

Virginia Polytechnic Institute and State University

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TABLE OF CONTENTS

EXECUTIVE SUMMARY

The 2015-2016 Midwest High-Power Rocketry Competition is a collegiate rocketry design challenge being hosted in North Branch, MN. As per competition guidelines the rocket will fly to an altitude of 5000 feet and accrue points in the process. A subsequent launch of the same rocket with an electronically activated drag system will bring the rocket to 75% of the initial flight's altitude. To be considered successful, the rocket must also implement ejection charges in a dual-deploy recovery system for the safe retrieval of the rocket after each launch. This is a challenging endeavor and will require the team to design, construct and conduct a multitude of test flights with no external assistance.

The Delta VT team is part of the inVenTs community, a living-learning community at Virginia Tech devoted to improving STEM education by fostering 1st year students and providing them with a community dedicated to success. It is comprised of four integral communities. Galileo and Hypatia cater to students in Engineering, and Curie and DaVinci support students in the Life, Physical and Quantitative Sciences. The communities provide tutoring, assist in professional development, conduct outreach events, host technical skills workshops, encourage social activities, and assist with service learning opportunities for members. For this competition, the team will be working out of Studio 1, an in-dorm workshop, in which members have access to a variety of handheld power tools, as well as 3D printers, laser cutters, CNC routers, soldering stations, and training on how to use all of the equipment.

The 15-member multidisciplinary team is composed of primarily first-year students who will be representative of the communities present within inVenTs. Dr. Kevin Shinpaugh, an Aerospace Engineering professor and avid rocketry enthusiast himself, has agreed to be the faculty sponsor. Although the team is relatively new in the field of high-power rocketry, sub-team leads are working closely with the Virginia Tech Rocketry Club and the New River Valley Rocketry Association, the local Tripoli branch, for assistance in ensuring the safety of the design and construction of the rocket.

ROCKET DESIGN

Overall Design and Stability Analysis

The rocket design has been broken up into three sections based on function. First is an upper section containing the nose cone and recovery system, a midsection that houses the electronics and the drag system, and a lower booster section that contains the motor and the fins. To obtain the requisite height during the second launch, a specialized midsection will create an airflow obstruction to increase the drag of the rocket overall, allowing for a lower apogee. **Figure 1** shows the separation of these sections with the drag system retracted while **Figure 2** shows this distinction with the drag system activated.

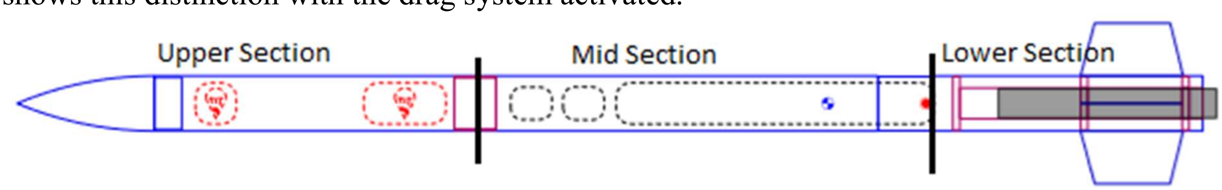


Figure 1: Diagram of rocket with drag system retracted showing where sections are located

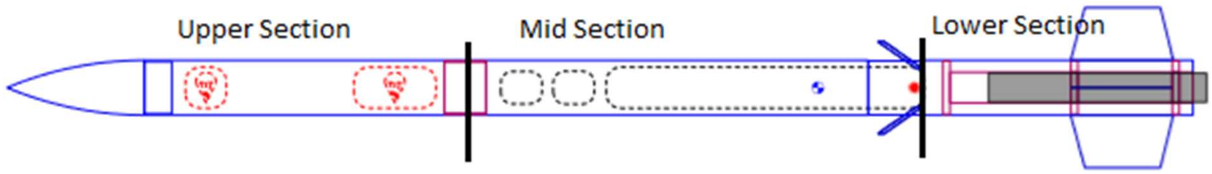


Figure 2: Diagram of rocket with drag system deployed showing where sections are located

The rocket has been designed to have a 98 mm outer diameter body tube and a total length of 2.200 meters. When fully assembled and ready to launch, the rocket has a mass of 6.755 kg and a center of gravity 0.150 m from tip of the nose cone. When the motor is not in place the mass decreases to 5.357 kg and the center of gravity to 13.700 cm. When the drag system is activated or retracted, the mass remains uniform.

When activated, the rocket's drag system has a center of pressure at 16.80 cm from the end of the nose cone. This results in the rocket having a stability of 1.790 calibers when the motor is in place and a stability of 3.120 calibers when the motor is removed. When the drag system is activated, the center of pressure moves to 16.80 cm from the nose cone. This small change in center of pressure results in a stability change to 1.760 calibers with the motor in place and 3.090 calibers with the motor removed. **Figure 1** and **Figure 2** also display the center of gravity and center of pressure with the motor in place.

UPPER SECTION

Figure 3: The upper section of the rocket

Body Design

The upper section of the rocket encompasses the recovery systems along with the nose cone. This upper body is made of Blue Tube due to its material properties, including high strength and durability. [1] The overall length of the body tube is 60.00 cm, with an outer diameter of 0.980 cm and a thickness of 0.125 cm. With the nose cone, the complete length of the upper section is 70.00 cm.

Parachutes

Due to the high altitude the rocket will achieve, the team chose to use two parachutes- a main and a drogue. Deploying the main chute at apogee greatly increases the risk of the rocket drifting far away due to winds. The drogue chute helps mitigate this risk by controlling the descent rate of the rocket and allowing the main chute to deploy at a lower altitude. Once the main chute has been deployed, it will reduce the speed of the rocket until it is below the requisite 7.315 m/s. Both the drogue chute and the main chute will be made out of rip stop nylon, with a diameter of 0.417 m and 1.914 m respectively.

Nose Cone

The nose cone has been designed with an ogive shape, as this shape resulted in the highest apogee compared with other common designs. ULTEM 9085, which has a very high strength to weight ratio [2], will be used in the 3D printer to produce the nose cone. The nose cone also has an extra 5.00 cm of shoulder that inserts into the body tube to allow for a tight and secure fit. The nose cone has a thickness of 0.200 cm throughout, giving it a total mass of 0.144 kg. Refer to the **Figure 1A** in the appendix to see a view of the nose cone.

MID SECTION

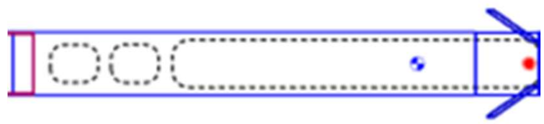


Figure 4 (Left): Mid-section of rocket with drag system retracted
Figure 5 (Right): Mid-section of rocket with drag system deployed

Body Design

The midsection, also made out of Blue Tube, measures 84.0 cm long and contains the electronics necessary to control the rocket and drag system. The midsection was designed to be relatively easy to construct and, if necessary, repair. The electronics and drag system are located on either ends of the section, which are easily accessible locations. During flight, the mid-section is connected to the rest of the rocket using nylon shear screws, which contribute negligibly to air resistance. When the rocket is stationary, the screws can easily be removed to allow access to the components.

The two small dotted rectangles in **Figure 4** and **Figure 5** are representative of the electronic equipment. The electronics add a total of 0.350 kg to the rocket. While all of the components of the drag system add approximately 3.150 kg to the rocket strongly changing the center of gravity. The location of the drag system was specifically chosen to be as close to the center of pressure as possible to ensure that the stability remains almost constant when it is deployed.

LOWER SECTION

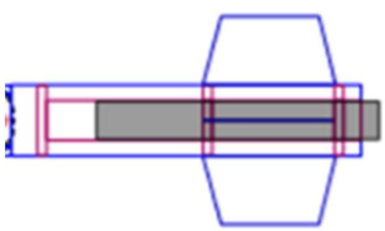


Figure 6: Close view of lower section

Motor

The motor chosen is the reloadable Cesaroni P54-4G Classic, or K445. This K-class motor is 40.40 cm long and has a total mass of 1.389 kg with 0.792 kg of that mass coming from propellant which results in a total impulse of 1636.300 N-s.[3] This motor was chosen because it has a longer burn time than other motors of similar size, while still getting the rocket to the target height. Refer to the **Figure 1B** in the appendix to see the thrust curve of the motor. A long burn time is important to the rocket's design because it is able to reach motor burnout with a lower velocity compared to other rockets. This decreases the amount of wind turbulence that the drag system must produce.

Body Design

The body tube is built with Blue Tube, with a length of 50 cm, wall thickness of 0.980 cm, and a mass of 0.256 kg. The motor is held in a motor casing 45 cm long, with 2 centering rings holding the casing in place. The centering rings are made of 1.5 cm plywood. A bulkhead is placed at the top of the motor casing to prevent damage to the upper components. The motor protrudes out of the back end of the rocket 2.0 cm to make for ease of removal and reloading.

Fins

The four trapezoidal rocket fins are offset 45 degrees from the drag system flaps so that, when the drag system is activated, the air flowing to the fins is turbulent. The fins have a height of 9.750 cm, with a root chord of 0.190 cm and a tip chord of 0.140 cm. The angle of the sweep of the fins is 15 degrees, resulting in a sweep length of 2.6 cm. The fins begin 3.63 cm from the bottom of the body tube. This distance along with the trapezoidal shape eliminates the risk of the fins being damaged as a result of being in contact with the ground. The fins are 3D printed using the same strong material as the nose cone, ULTEM 9085. Since the fins are 3D printed, the design is very specific: the fins are in the shape of a symmetrical airfoil with the fore section rounded and the aft section swept to a point. This results in better airflow over the fins, adding stability to the rocket. **Figure 1B** shows a model of the fins.

DRAG SYSTEM

Method of Operation

The drag system is required to wait until motor burnout to actuate. An accelerometer will determine when this event occurs, and an algorithm will signal the deployment of the panels. These panels will increase the cross-sectional area of the rocket body, creating a large obstruction to the windflow around the midsection. This results in a rapid decrease in speed to reach 75% of the initial height. During motor burn, the linear actuator holds the drag flaps under tension until deployment. At deployment, the linear actuator will extend to 8 cm, allowing the flap to deploy. In order to assist with deployment, a small leaf spring is placed between the edge of the drag flap portion of the hinge. When the algorithm estimates that the speed is sufficient to achieve the 75% mark, the linear actuator will return to the zero position while pulling the drag flaps in.

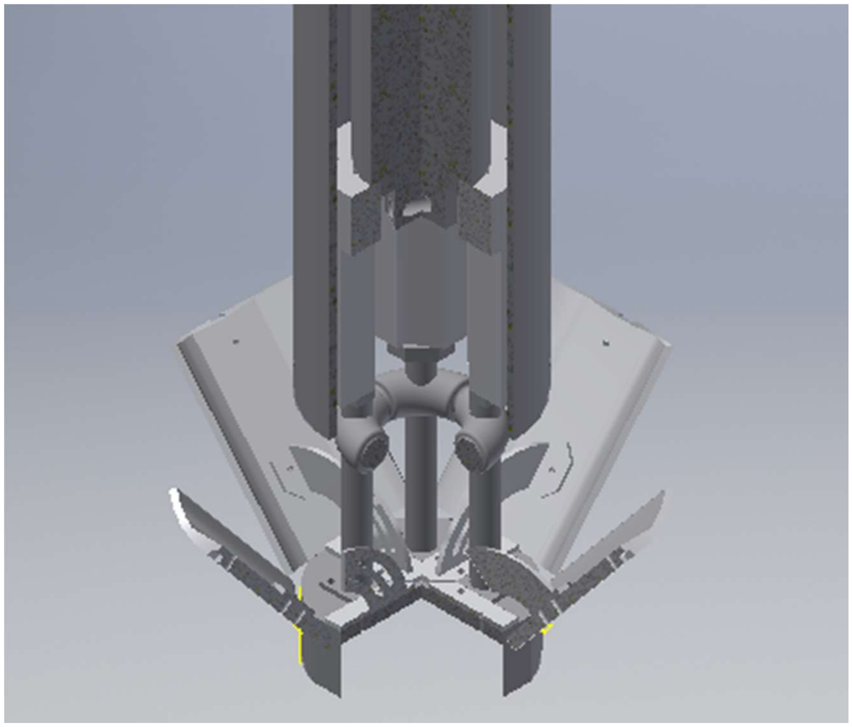


Figure 7: Drag System Assembly in its deployed state

Drag System Assembly

The active drag system is comprised of eight unique parts in two major subassemblies. These subassemblies are the upper actuator assembly and the lower drag flap assembly. All bolts, screws, and pins (except for the pin connecting the actuator to the outer body) are 3.175 mm.

The lower flap assembly consists of four aluminum flaps which have a combined diameter that matches the rocket body, thus completely closing around the lower assembly without need for further external structure. Each flap connects to an aluminum sliding hinge system. The curved sliding hinge system was designed to mount directly onto the base of the entire active drag system. Aluminum was selected for the hinge system due to its high strength to weight ratio.

The upper drag actuator assembly comprises of a 10.16 cm stroke Firgelli high speed linear actuator. The actuator is attached vertically in the rocket body and holds four cords on the movement arm. These chords move through the center of a torus shaped bracket and attach to each of the four side panels as seen in **figure 2C**. The panels are held onto the rocket via planar hinges, and the angle of deployment will be determined by the position of the actuator.

SIMULATION AND ANALYSIS

All simulations were performed using Autodesk Inventor stress analysis. All safety factors are based on tensile strength of the material.

Drag Flaps

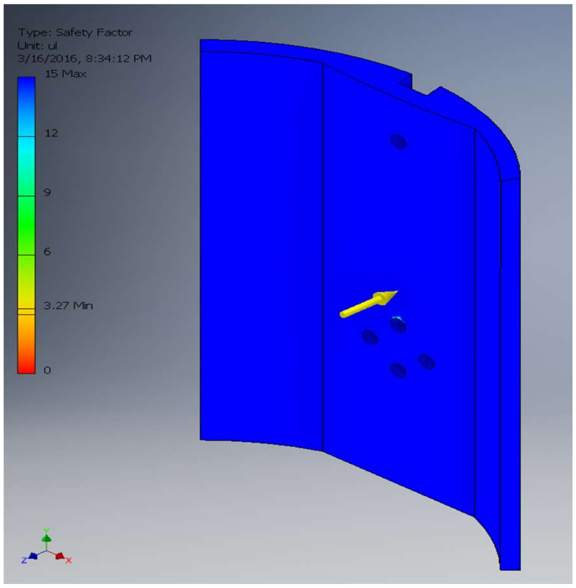


Figure 8: Side panel of drag system

The primary concern regarding the drag flaps is the point at which the drag flap attaches to the hinge as seen in **Figure 8**. A worst case scenario of drag was used while performing the analysis. A force of 133 Newtons (approximately one quarter of the max drag found using Open Rocket simulation) was applied to the face where the drag flap mounts to the hinge. The mounting holes were made a fixed constraint to simulate the mounting screws. At 133 Newtons there was a safety factor of 3.27 based on aircraft grade aluminum.

Hinge Assembly

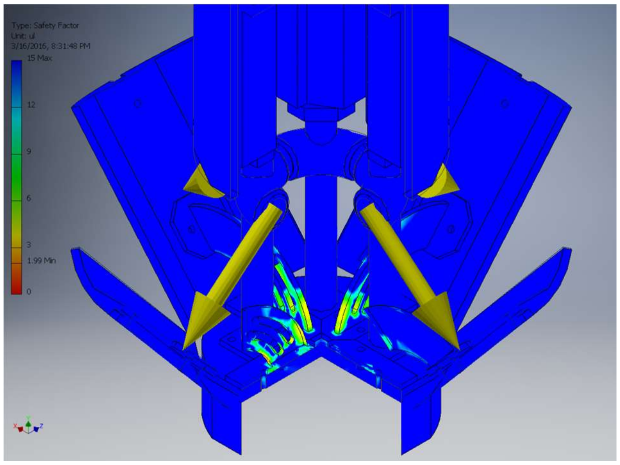


Figure 9: Drag System Top Pressure Simulation

The primary concern regarding the hinge assembly is that the posts where the drag flap portion of the hinge connects to the base plate hinge as seen in **Figure 9**. In order to simulate the conditions that would be experienced, a force of 133 Newtons was applied to the drag flap perpendicularly to how it connects to the hinge. The minimum safety factor under these conditions is 1.99 also based on aircraft grade aluminum.

Main Assembly

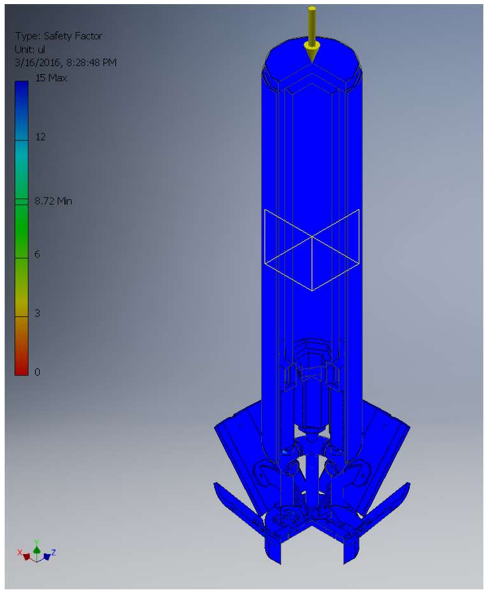


Figure 10: Compression Simulation on Drag Module

The primary concern with regards to the structural integrity of the drag flap assembly is the compressive forces that would be experienced during the launch. The thrust rating of our motor (664 N) was applied to the top face of the assembly, with the base plate being held static. Under these conditions a minimum safety factor of 8.72 is attained.

VEHICLE AVIONICS AND GUIDANCE

Procedural Airbrake Trajectory Algorithm

The vehicle uses an onboard algorithm to determine drag flap open and close times. This process will allow the rocket to guide itself to the target apogee, which is defined as 75% of the first flight height.

Several assumptions were made for the sake of simplicity. For example, wind speed and pressure are assumed to be zero and constant, respectively. We may amend this algorithm in the future in order to better approximate a pressure over altitude curve and varying wind speeds, but for the time being these are the limitations being used.

The algorithm plots two components of the rocket's flight: the vehicle's velocity over time and the moment of motor burnout. These plots are determined by a piecewise function of two continuous (but not differentiable) curves. These curves are defined by **Equation 1** and **Equation 2** below.

$$V_c(t) = v_{tc}\left(\frac{v_b - v_{tc}\tan\left(\frac{tg}{v_{tc}}\right)}{v_{tc} + v_b\tan\left(\frac{tg}{v_{tc}}\right)}\right)$$

Equation 1: Velocity over time with drag flaps closed

$$V_o(t) = v_{to}\left(\frac{v_b - v_{to}\tan\left(\frac{tg}{v_{to}}\right)}{v_{to} + v_b\tan\left(\frac{tg}{v_{to}}\right)}\right)$$

Equation 2: Velocity over time with drag flaps open

In **Equations 1** and **2**, v_b is defined as the velocity at burnout – this will be calculated by taking measurements with the accelerometer while the motor is firing and integrating these values over time. The variables v_{to} and v_{tc} are defined as the terminal velocity of the vehicle when the drag flaps are open and closed – these values will be calculated beforehand.

The cross sectional area for the vehicle while the drag system is open, A_o, is 1.8×10^{-2} m^2, and the drag coefficient is 1.9. The reference area for the vehicle while the drag system is closed, A_c, is 8.11×10^{-3} m^2, and the drag coefficient is 0.75. As per Equations 3 and 4 below, with a vehicle mass of 7 kilograms, -v_{to} = 57.3 m/s, and v-$_{tc}$ = 135.8 m/s.

$$v_{tc} = \sqrt{\frac{2mg}{\rho c_c A_c}} \qquad\qquad v_{to} = \sqrt{\frac{2mg}{\rho c_o A_o}}$$

Equation 3 (Left): Terminal velocity with flaps open
Equation 4 (Right): Terminal velocity with flaps closed

Burnout time is defined at t = 0. Immediately at t = 0, the drag flaps will open. At some time t_c (where $0 <$ t-$_c < t_a$) the drag flaps will close, and the vehicle will coast to apogee, which it will reach at time t_{a}-. The algorithm chooses a specific t-$_c$ value that will satisfy this Equation 5.

$$y_a = y_b + \int_0^{t_c} V_o(t)\,dt + \int_{t_c}^{t_a} V_c(t + D(t_c))\,dt = \frac{3}{4}y_f$$

Equation 5: Piecewise altitude integral function

In **Equation 5**, y_a is defined as the target apogee of the second flight; y_b, as the measured vehicle height at motor burnout, which will be measured by the altimeter and accelerometer during each flight; y_f, as the apogee height of the first flight.

$D(t_c)$ is determined as a “displacement factor” which moves the flaps-closed curve, $V_c(t)$, along the x-axis in order to produce a continuous piecewise function of t. It is defined in **Equation 6**.

$$D(t_c) = \left(\frac{v_{tc}}{g}\right)\tan^{-1}\left(\frac{v_b - v_{to}\left(\frac{v_b - v_{to}\tan\left(\frac{t_c g}{v_{to}}\right)}{v_{to} + v_b\tan\left(\frac{t_c g}{v_{to}}\right)}\right)}{v_{tc} + \frac{v_b v_{to}}{v_{tc}}\left(\frac{v_b - v_{to}\tan\left(\frac{t_c g}{v_{to}}\right)}{v_{to} + v_b\tan\left(\frac{t_c g}{v_{to}}\right)}\right)}\right) - t_c$$

Equation 6: The displacement factor

The displacement factor also solves the upper limit of the piecewise altitude integral, t_a.

$$t_f - t_a = D(t_c)$$

Equation 7: Extension of displacement factor

Avionics System Design Specifications

Due to the unique design challenge presented by the active drag system, the avionics package in this rocket will possess multiple modules. Altitude, velocity, and acceleration will be collected throughout the duration of the flight in order to determine when the drag system should be opened and closed by the computational airbrake deployment algorithms discussed below. In addition, video of the drag system deployment and GPS telemetry data will be recorded and recovered post-flight.

An Arduino Uno microcontroller will be used to integrate all of the package's components. This was chosen primarily for its ease of implementation and its ability to interface cleanly with MATLAB. All of the altitude, velocity, acceleration, and GPS data will be received, processed, and recorded by the Uno. The Uno requires 7-12V DC power in order to operate, so it will be powered by a 12V 2000mAh lithium battery pack. All three of the Parallax sensor units were chosen for their diminutive size and weight, their low power draw, and their ease of integration with Arduino systems. The Parallax MMA7455 3-axis accelerometer module requires a minimum of 2.5 V DC in order to operate, so it will be powered by a 3.6V 1200mAh Lithium battery pack. The module digitally outputs acceleration measured along its X, Y, and Z axes, which will be used in the airbrake trajectory algorithms. The Parallax MS5607 Altimeter module measures altitude with resolution up to 20 cm, in addition to pressure and temperature. These readings are vital in determining the altitude at which to deploy the drag system. The altimeter module requires a minimum of 3.3 V DC, and will also be powered by the 3.6V Lithium battery. The Parallax PAM-7Q GPS module will provide rocket location data, and requires only 3.3V DC to operate. Thus, it will also be connected to the 3.6V Lithium battery.

The drag-system camera and a tracking radio will be separate from the Arduino microcontroller. The camera will be a self-contained mini-lifestyle action recorder that will mount on the inside of the rocket, facing the drag-system. This will record drag system deployment and be recovered post-flight. The tracking radio will be a Communications Specialist Inc. AT-2B transmitter, which is self-contained and will transmit location data to the ground station in conjunction with the GPS module.

Code

The vehicle's avionics system runs on two different MATLAB programs. The first, which is run during the first launch collects data and triggers the deployment of the parachutes. The second program, run during the second launch, determines when the active drag system needs to deploy using the Procedural Airbrake Trajectory (PAT) algorithm. Many of the dependent variables in the second program are determined by the first program during the initial flight. Many of these variables have been predetermined, such as coefficients of drag and surface area; others are initialized at zero because they will be used as vector variables.

```
%% waiting to launch
while acceleration(count) == 0 %This loop when run when the acceleration is zero.
    acceleration(count) = 1;%This is a place holder number. The loop will run and check acceleration every iteration
    %and overwrite the first entry in the vector.
end
```

Figure 11: Rocket MATLAB pre-launch code

The simple loop in **Figure 11** begins as the rocket is on the launch pad, with its run condition starting the acceleration equal to zero. Once the rocket launches and the acceleration is greater than zero, the code will exit the starting loop and continue.

```
%% Launch to Burnout
while acceleration > 0 %This loop will stop at burnout. This is when the acceleration becomes negative.
    acceleration(count) = 0;%This is a place holder number. The loop checks acceleration, velocity, and altitude.
    velocity(count) = acceleration(count) * time_interval;
    altitude(count) = velocity(count) * time_interval;
    time(count+1) = time(count) + time_interval; %This time interval helps keep track of when the data was recorded.
    burnout_altitude = altitude(count); %When the loop ends, the burnout altitude and velocity are recorded.
    burnout_velocity = velocity(count);
    count = count + 1; %The count variable increases by one.
end
%The fins deploy
```

Figure 12: Rocket MATLAB data collection and motor status

The condition for the code in **Figure 12** is the acceleration on the rocket is greater than zero. This loop will keep track of the acceleration, velocity, and height over time as vectors until the rocket goes to burnout. Once burnout occurs, the code will exit the loop due to the change in acceleration. At this moment, the velocity and height at burnout is recorded.

A while loop will run after burnout measuring and recording acceleration, velocity and altitude. The loop will run as long as the velocity is not zero. When apogee is reached, the velocity will be zero, and the loop will end. Apogee height is recorded and the drogue chute is deployed. When the rocket reaches a safe altitude, the large parachute is deployed. Once the rocket has touched down, the data collection is concluded.

```
%% Chute Deployment

while altitude > deployment_height %This loop will run if the altitude is above the deployment height
    acceleration(count) = 1; %This is a place holder number. The loop checks acceleration, velocity, and altitude.
    velocity(count) = acceleration(count) * time_interval;
    altitude(count) = velocity(count) * time_interval;
    time(count) = time(count) + time_interval;
    if time(count) == apogee_time + 4; %If the time is equal to the 4 seconds after apogee, the drogue chute deploys.
        %The drogue chute deploys
    end
    count = count + 1;
end
%The parachute deploys
while altitude ~= 0 %This loop will run if the acceleration is a non-zero number
    acceleration(count) = 1; %This is a place holder number. The loop checks acceleration, velocity, and altitude.
    velocity(count) = acceleration(count) * time_interval;
    altitude(count) = velocity(count) * time_interval;
    time(count) = time(count) + time_interval;
    count = count + 1;
end
```

Figure 13: Rocket MATLAB Code Loop 4 and 5

The second launch is very similar to the first. The initialization area, launch detection, and data collection are all the same. As shown in **Figure 13**, once the motor has depleted its fuel, the drag system is immediately deployed to reduce the rocket's velocity. The program will determine how long the drag system is deployed. The calculated apogee is then compared to the original apogee, creating a theoretical apogee percentage of 75%. The retraction time will be accurate to a one-hundredth of a second, and the rocket will retract its active drag system.

ANTICIPATED RESULTS

Simulations and Assumptions

These simulations have been performed using the program OpenRocket and a program the team designed using GeoGebra and equations listed above to calculate altitude with drag system deployment. The equations used are considered in ideal situations so some variables were overridden with variables determined from OpenRocket simulations since these simulations take more variables into account. Refer to **Appendix B** to view the graphs of simulations of all necessary variables in various conditions. Unfortunately OpenRocket was unable to simulate deployment of the drag system was so these few simulations are with the drag system deployed for the entire flight. However, the ratio of the change in variables with this constraint can be assumed to be similar to if the drag system was deployed at motor burnout and then retracted before apogee.

Anticipated Flight Results

	No Wind (0 m/s)	**High Wind (6.3 m/s)**
Motor Burnout Time	4.08 s	4.08 s
Motor Burnout Velocity	175 m/s	174 m/s
Motor Burnout Altitude	518 m	518
Apogee (Without Drag)	1447 m	1441 m
Apogee (With Drag)	1080 m	1070 m
Time at Apogee	16.89 s	16.88 s
Percent of Initial Apogee	74.6%	74.2%
Max Velocity	190.9 m/s	190.2 m/s

Table 1: Anticipated flight results

SAFETY

Material Handling Procedures

During the construction of the rocket, materials must be handled properly to ensure safety. The rocket will be constructed in a workspace staffed by multiple graduate students available to provide assistance and to ensure that appropriate safety measures are taken. Eye protection will also be available for team members to use during construction. The workspace is well-ventilated, providing a suitable environment for painting and using epoxy. The black powder ejection charges and motor must also be handled with care. During storage and transportation, it is important that these materials be kept cool, and separated from any possible sources of ignition. During construction, the ejection charge will be kept disconnected from any live wires at all times, until the rocket is ready to launch.

Pre-flight Checklist

1. Ensure the electronics are activated and are secure in the rocket
    a. Turn on and test tracking beacon
    b. Set delay
    c. Turn on and secure both competition altimeters
    d. Turn on and secure dart camera
    e. Download the flight program to the microcontroller, ensuring everything is connected and working properly
    f. Secure the microcontroller system
2. Test security of the motor in the rocket
3. Verify the timing of the ejection charge in the booster
4. Verify that the correct amount of black powder is in the ejection canister
5. Place flame resistant wadding separating the ejection charge devices from the payload components in the booster and the dart sections
6. Pack and secure parachute and drogue chute
7. Inspect fin connections
8. Verify that nose cone is secured to the dart
9. Verify that top and bottom sections of the boosters are securely connected
10. Verify that the dart is properly aligned and secured inside the transition piece
11. Have the Range Safety Officer (RSO), inspect and approve the rocket for flight
12. Mount rocket on launchpad
13. Activate microcontroller
14. Ensure transmitter is activated

Post-flight Checklist

1. Wait for RSO to declare the area clear
2. Recover booster and dart using tracking beacon
3. Ensure all components were recovered and examine for possible damage
4. Examine the rocket for possible damage
5. Download video from camera
6. Download flight data from microcontroller
7. Deactivate camera, microcontroller, and beacon

If rocket is in good condition, prepare for next flight

APPENDIX A

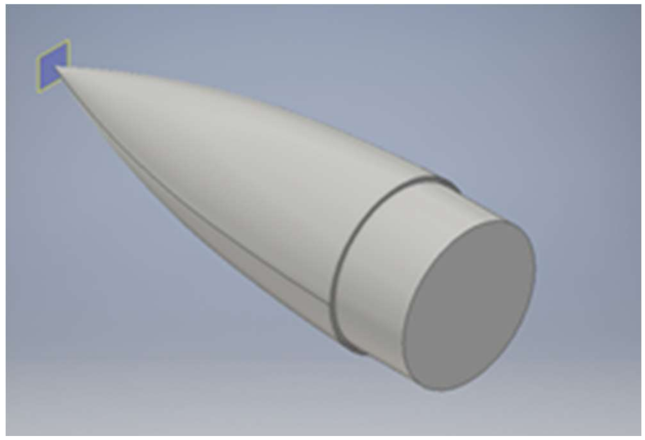


Figure 1A: Isometric view of CAD model of Nose Cone

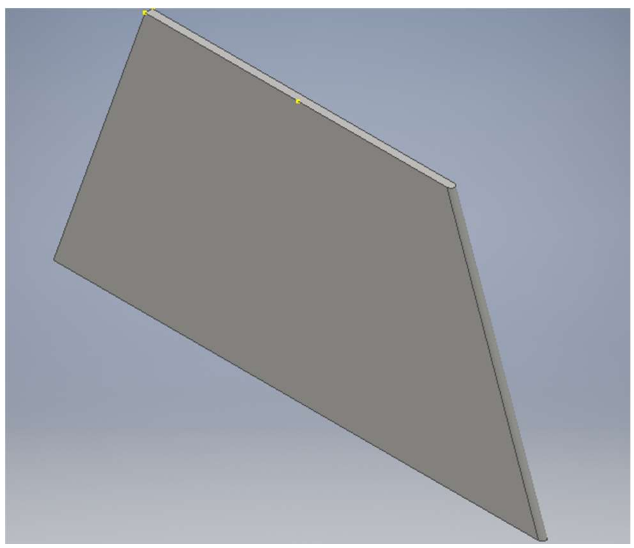
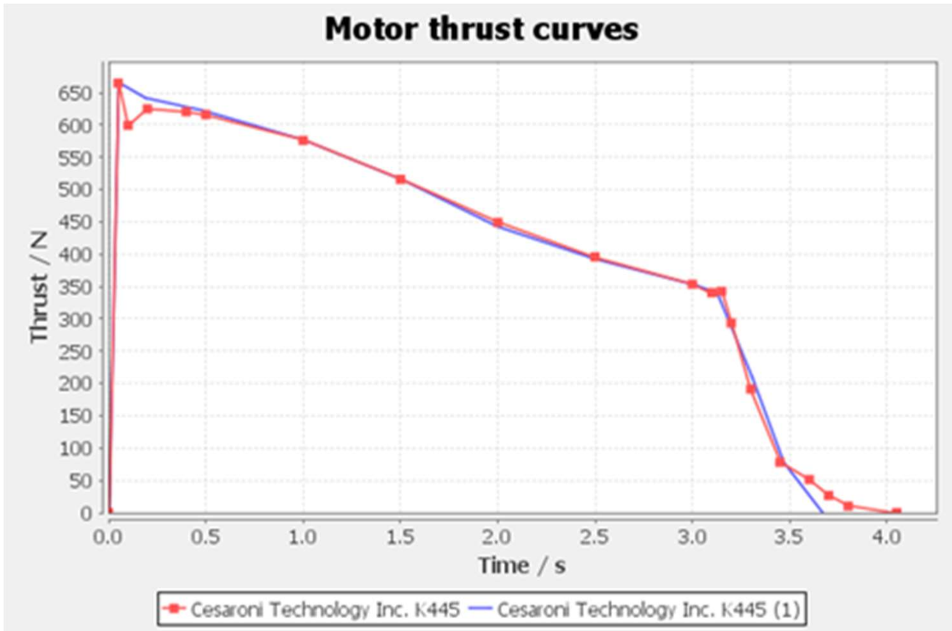
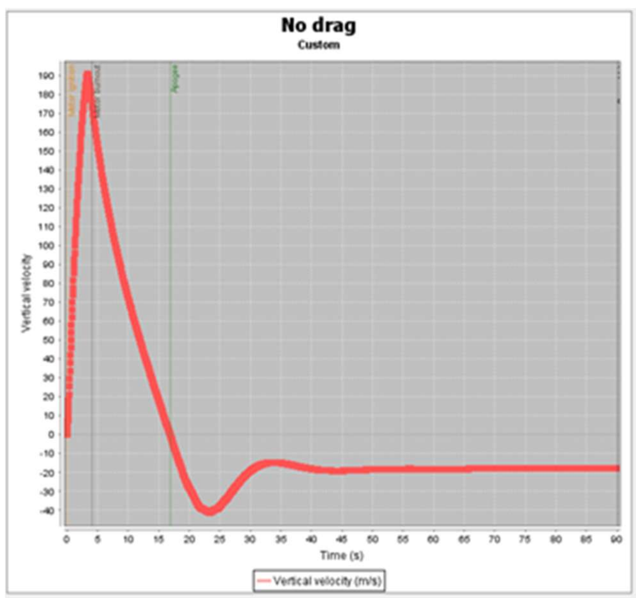


Figure 1B: Isometric view of CAD model of fins

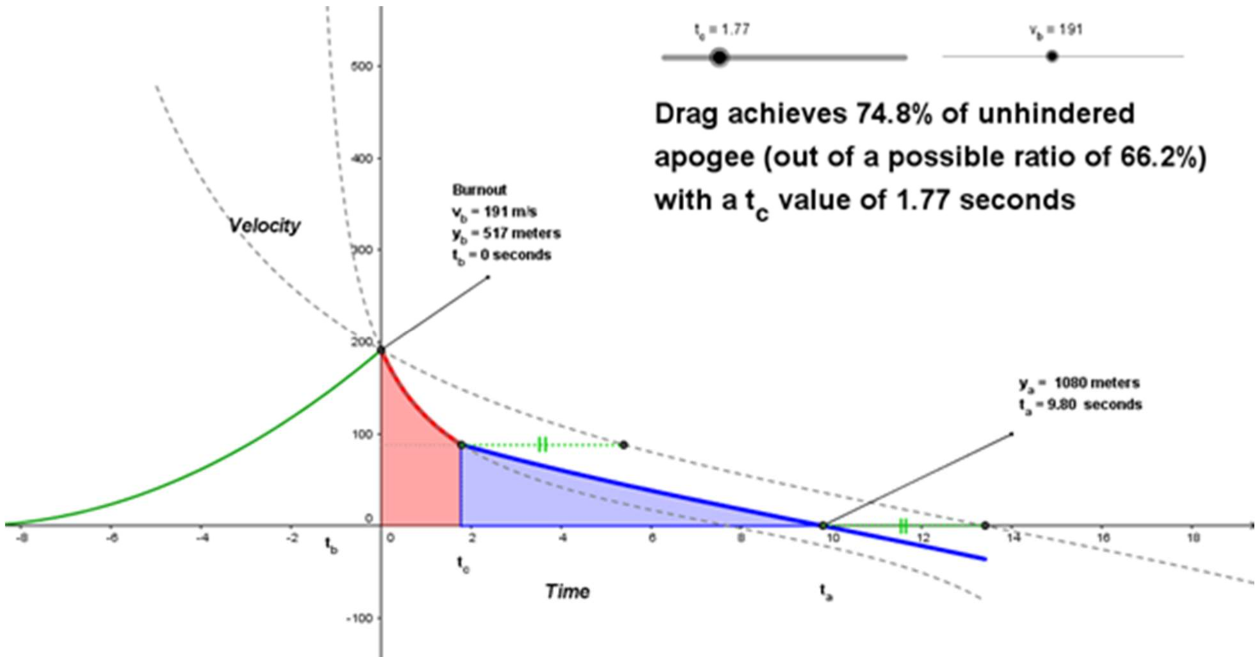
APPENDIX B



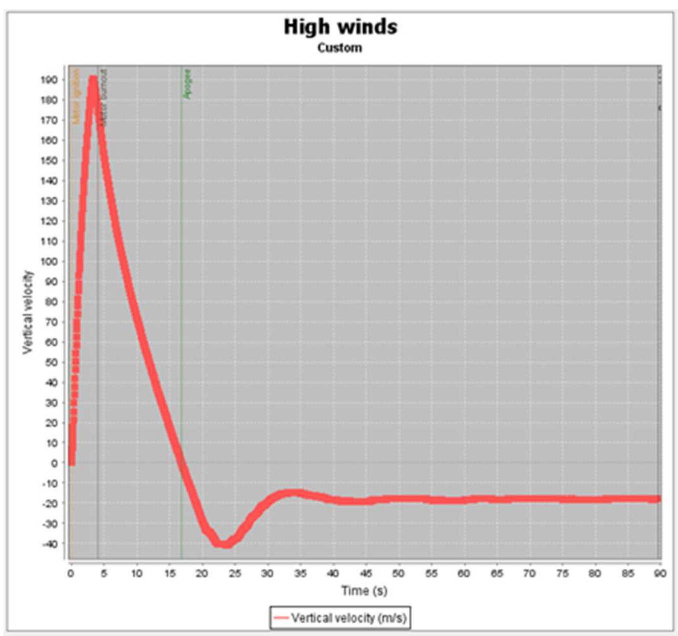
Graph 1B: Motor thrust curve of Cesaroni K445



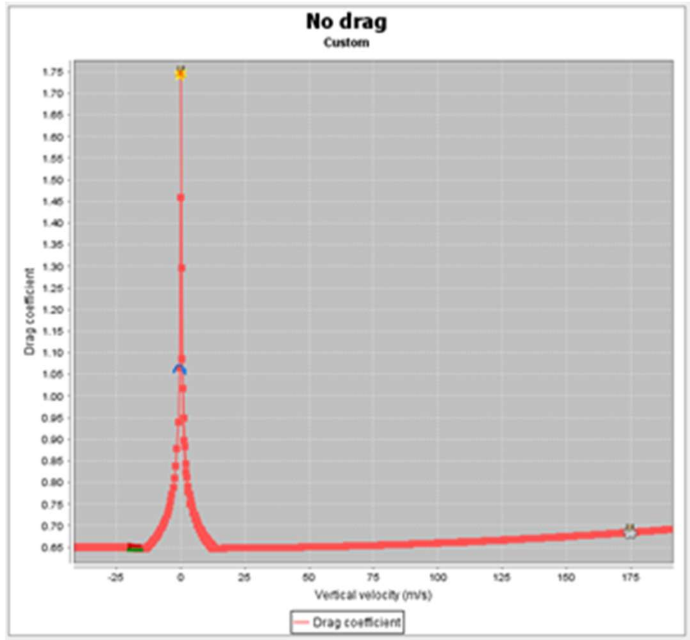
Graph 2B: Velocity vs. time of rocket with retracted drag system in no wind



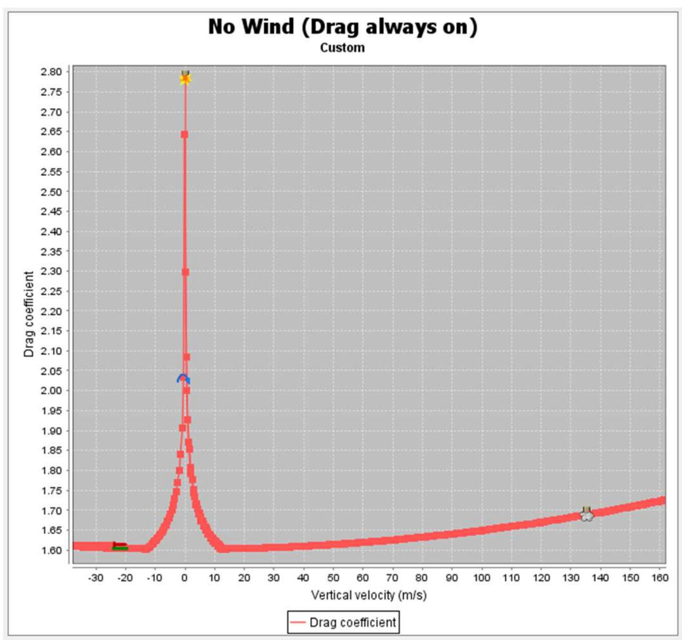
Graph 3B: Velocity vs time of rocket with drag system deployed in no wind



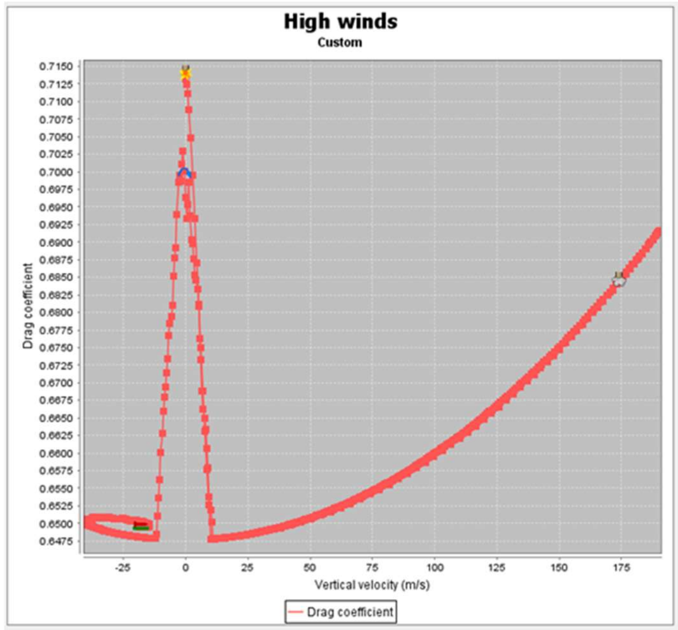
Graph 4B: Velocity versus time of rocket retracted drag system in winds of 6.3 m/s



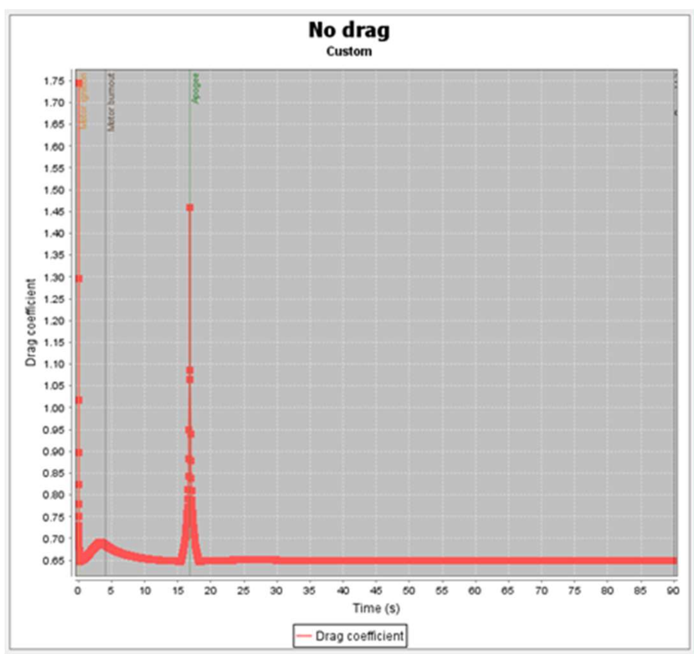
Graph 5B: Coefficient of drag vs velocity of rocket with retracted drag system in no wind



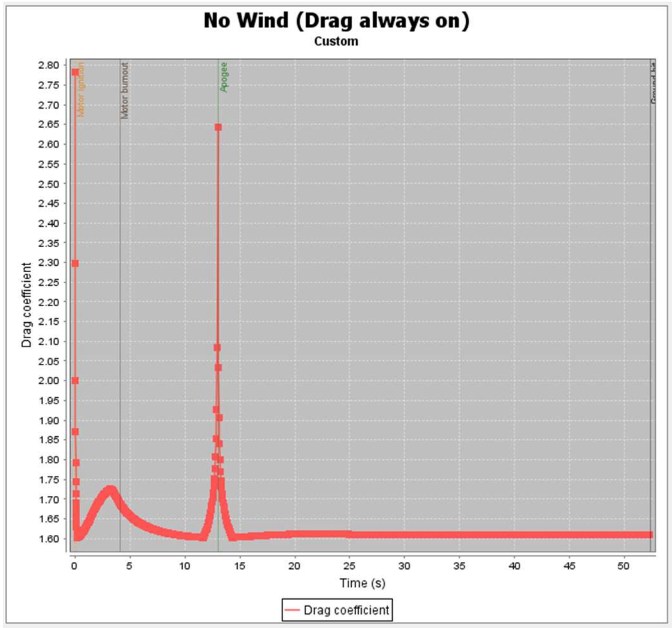
Graph 6B: Coefficient of drag vs velocity of rocket with deployed drag system in no wind



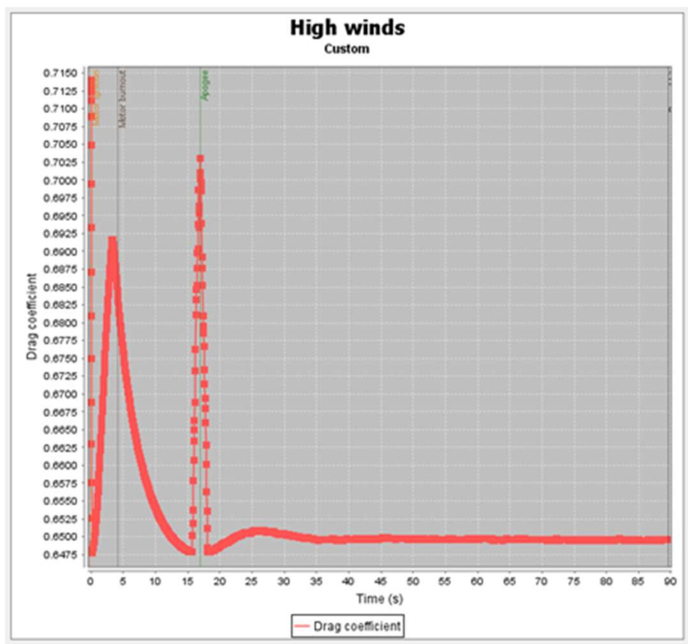
Graph 7B: Coefficient of drag vs velocity of rocket with retraced drag system in winds of 6.3 m/s



Graph 8B: Coefficient of drag vs time of rocket with retracted drag system in no wind



Graph 9B: Coefficient of drag vs time of rocket with deployed drag system in no wind



Graph 10B: Coefficient of drag vs time of rocket with retracted drag system in winds of 6.3 m/s

APPENDIX C

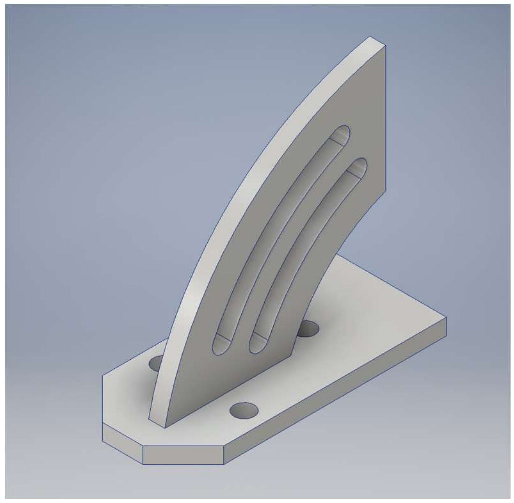


Figure 1C: The lower half of the hinges attached to the flaps.

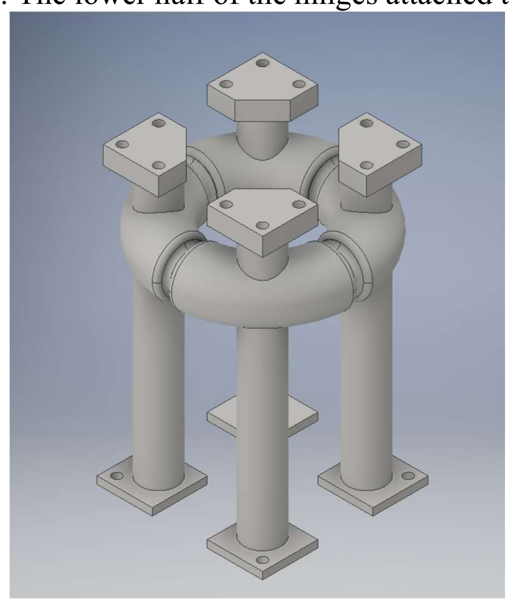


Figure 2C: The “donut” structure which pulleys the wires and ensures structural integrity.

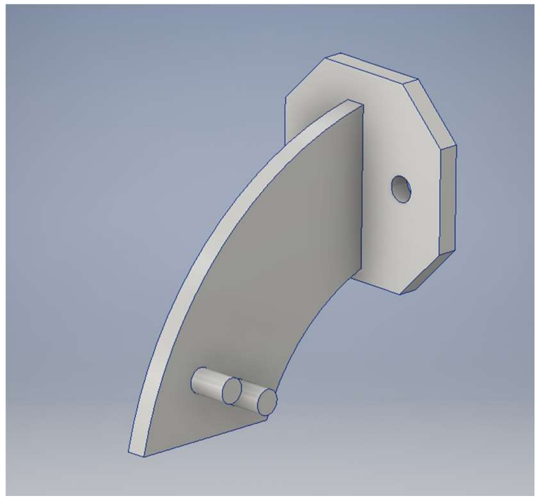


Figure 3C: The upper half of the hinge attached to the flaps.

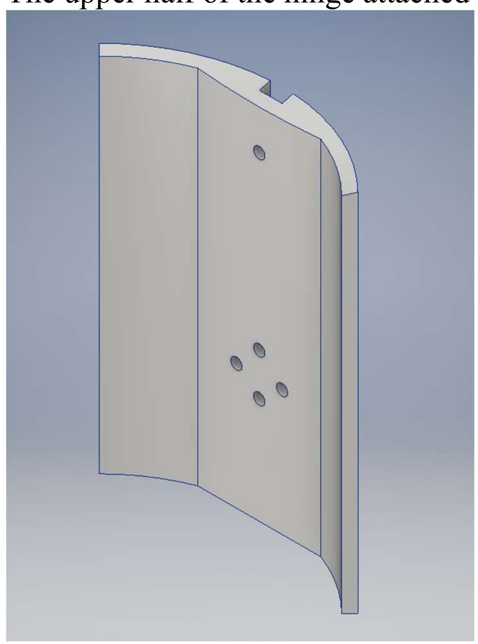


Figure 4C: One of four drag flaps.

APPENDIX D

Figure 1D: Team photo at model rocket launch site

Figure 2D: Model rocket launch site

APPENDIX E

Spendings

Date	Description of Transaction	Comments	Category	Debit (-)	Credit (+)	Balance
1/1/16	beginning balance					$0.00
2/2/16	Model Rocket Components	Already Procured	Test Launch Costs	$0.00		$0.00
2/2/16	4x K-Class Motors		Test Launch Costs	$400.00		-$400.00
2/2/16	Arduino	3 arduino	Construction	$60.00		-$460.00
2/2/16	Sensors	Altimeter, tracker	Construction	$265.00		-$725.00
2/2/16	Camera	Standard CCTV camera	Construction	$55.00		-$780.00
2/2/16	Structure and Payload		Construction	$1,500.00		-$2,280.00
12/5/16	Tolls	3 cars, estimated at $40	Travel	$120.00		-$2,400.00
12/5/16	Car Rental		Travel	$214.29		-$2,614.29
12/5/16	Gas	Assuming 3 cars	Travel	$822.86		-$3,437.15
12/5/16	Hotels	4 rooms, 4 people each, 4 nights, about $150 per night	Travel	$2,400.00		-$5,837.15
12/5/16	Food	15 people, 2 days, 2 meals per day, about $8.33 per meal	Travel	$500.00		-$6,337.15
12/5/16	Registration		Travel	$400.00		-$6,737.15

Figure 1E: Budget Expenditure

Components	Price
Motors (2 for testing)	213.9
Blue Tube (2 Sections)	77.9
ULTEM Filament Canister	685
Rip Stop Nylon Fabric	17.97
Ejection Charge (5 pk)	10
54mm 5-Grain Case	97.64
Kevlar Cord	27.6
Shipping	71.98
Total	1201.99

Figure 2E: Rocket Construction Expenditure

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