TEAM WHOOSH GENERATOR

# Preliminary Design Report

2016 NASA's SPACE GRANT MIDWEST HIGH-POWER ROCKET COMPETITION


MILWAUKEE SCHOOL OF ENGINEERING

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18 March, 2016

# TABLE OF CONTENTS

# PROBLEM STATEMENT

The objectives of the 2016 Midwest Rocket High-Power Rocket Competition are to design a high-power rocket with an active drag system that will reach an apogee of at least 3,000 feet above ground level and be recovered safely and in flyable condition, predict its flight performance (both with and without the drag system engaged), and construct a non-commercial on-board data collection package that will characterize its coefficient of drag over time and use an on-board video camera to document the state of the drag system. Additional points are awarded for additional altitude above 3,000 feet, up to 5,000 feet [1].

# EXECUTIVE SUMMARY

In order to meet all of the objectives of the competition, a unique, stable rocket design was formulated. Using preliminary analysis of drag of different rocket diameters fitted with different sized motors, along with reviewing the size of components we already possessed, a 5.38 inch diameter rocket was chosen. The final rocket design is 64 inches long and weighs 17.75 pounds. The rocket has a projected apogee of 5035 feet and a projected max velocity of 665 feet per second. A drogue parachute will deploy at apogee and the rocket will descend at a rate of 42.34 feet per second until the main chute is deployed at an altitude of 600 feet. The drogue and main chutes will allow the rocket to safely land at a velocity of 17.91 feet per second. An ALTS25 altimeter was selected to complete parachute deployment requirements. There will also be a competition required motor backup delay charge to deploy the drogue chute for an added safety feature.

The drag system design will consist of a pulley-timing belt system that will turn the flaps out of the side of the rocket at motor burnout, then bring them back in before apogee. A high torque 360 degree servo motor was chosen to deploy the flaps. An Arduino Uno microcontroller was chosen to control the motor. An accelerometer is also attached to the Arduino to record acceleration data, which will then be used to calculate coefficient of drag data. A camera is also located above the drag system internally to observe the flaps being deployed. In order to locate the rocket quickly, a GPS will be placed in the altimeter bay.

# ROCKET AIRFRAME AND ELECTRONICS DESIGN

The following sections detail the assumptions and limitations taken into consideration in this year's rocket design, the rocket airframe, parachute, payload bay design, and the construction of the rocket. All rocket parts were purchased from reputable high-powered rocketry vendors, and the rocket was designed thoroughly and carefully with a knowledge of engineering principles. It was also simulated using two methods. Therefore, the team is confident that the designed rocket will be safe to launch.

## Assumptions

There were several assumptions and limitations taken into consideration in the design of this rocket. Seven assumptions were made based on Barrowman's Theory, which is described in depth in Appendix B. These assumptions include that the fins are thin flat plates, and that the rocket is thin compared to its length. Also, the rocket needed to follow the competition restrictions, outlined in the problem statement.

## Rocket Airframe Design

### *Body Tube Selection*

The body tube could be selected from several different kinds of materials, including cardboard, fiberglass, and PVC. Cardboard was selected as the body tube material for the rocket because of its simplicity, strength, price, and ease of cutting and drilling. Cardboard LOC body tubes have proven to work well from previous years' rockets.

The rocket's diameter was chosen based on many factors including the size of the electronics and parachutes that we have obtained from previous years. Another factor was the size of flaps required to slow the rocket down enough to reach 75% of the rockets original apogee. After weighing the pros and cons of each size, a 5.38 inch body tube was chosen. It was chosen because it allowed for the electronics to fit around a 54 mm motor mount tube, and also allowed for us to get adequate flap area.

The body tube length was dependent on the lengths of the components that needed to fit inside of it. OpenRocket, a free rocket design software program, was the primary software used to calculate the optimum body tube length. It was determined that the body tubes lower and upper sections would be a total of 51 inches long, with a total rocket length of 64 inches with the nose cone.

### *Nose Cone*

The nose cone selected for this rocket is a 13 inch long ogive shaped nose cone. The nose cone is made of poly-propylene plastic. The ogive shape was chosen due to its aerodynamic properties compared to other nose cones available. It has the lowest coefficient of drag which allows for a higher apogee. The 13 inch ogive nose cone was determined to be more aerodynamic than the 21 inch nose cone offered by apogee by modeling both using OpenRocket.

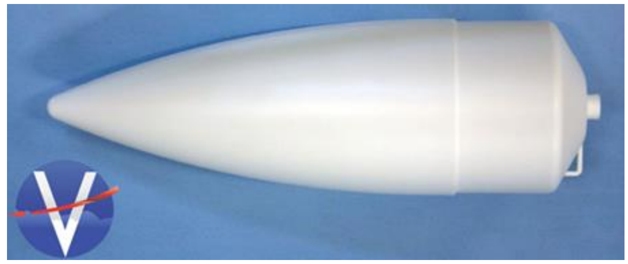


Figure 1: 13 inch ogive nose cone.

### *Fins*

According to Barrowman's theory, the fins are the main component on a rocket that determines the center of pressure. The nose cone also contributes to the location of the center of pressure, but not as much as the fins. The stability of the rocket is, therefore, highly dependent on the fin choice and placement. After the selection of major parameters such as the nose cone, tail cone, and body tube sizes, the fins were designed using an iterative method in OpenRocket.

The fin material chosen for the rocket were 0.093 inch thick G10 prism fins from Public Missiles. The dimensions of the fins are shown in the figure to the right. The optimum design includes a root chord of 7 inches, a span of 5 inches, a tip chord of 3.125 inches, and a sweep angle of 42.1°. The fins will be custom ordered to be cut to these dimensions. The rocket was designed with 4 fins. 4 fins were chosen so the drag system design, which has 4 flaps, can be evenly spaced in between the fins.

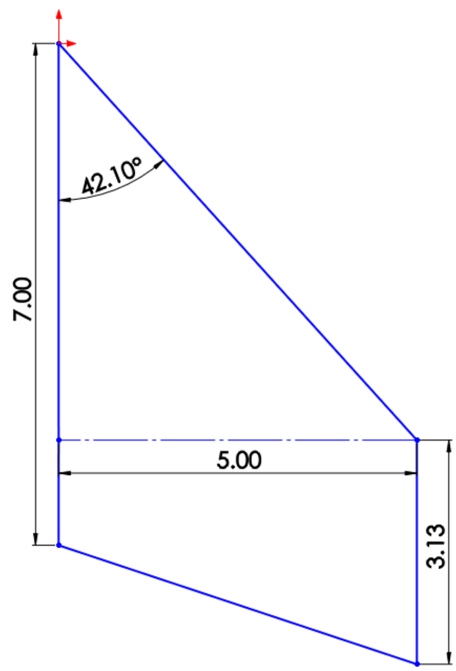



Figure 2: Fin dimensions.

### *Altimeter Bay Structure Design*

The altimeter bay design chosen for this rocket will comprise of a coupler strengthened by a stiffy, capped by two bulkheads with U-bolts secured to them to be used as attachment points for the parachutes. There will also be two threaded rods running through the inside of the bay, allowing for a fiberglass sled to be placed securely inside. The length of the bay is 8 inches. This length was chosen based on the size of the components that needed to be placed in the altimeter bay.

***Pressure Relief***

In order to deploy the parachutes effectively with barometric pressure altimeters, static port holes are needed to allow for pressure equalization between the interior and exterior of the rocket. Without this equalization, the parachutes would not deploy at the correct times, and could deploy too early or too late causing a potential catastrophic failure. A general rule for the sizing of ports is to use a ¼ inch diameter hole (or hole area equivalent if several smaller holes need to be used) for each 100 cubic inches of volume in the electronics bay. Another general rule is the use of at least three holes that are spaced evenly around the circumference of the body of the rocket. This will nullify the effect of crosswinds compared to having just two holes drilled on opposite sides of the rocket which would nullify the pressure relief. The RRC2 Mini, a barometric altimeter used in previous years, user manual was used and recommends the Equations 1, 2, and 3 for port sizing [2,3].

The volume of the bay:

$$Volume(in^3) = Bay\ Radius(in)\ x\ Bay\ Radius(in)\ x\ Bay\ Length(in)\ x\ \pi \tag{1}$$

The diameter of a single port hole:

$$Single\ Port\ Hole\ Diameter = 2\sqrt{\frac{Volume}{6397.71}} \tag{2}$$

The area of a single port hole:

$$Single\ Vent\ Area = \left(\frac{Single\ Vent\ Diameter}{2}\right)^2 x\,\pi \tag{3}$$

The diameter of multiple port holes:

$$Multiple\ Port\ Hole\ Diameter = 2\sqrt{\frac{Single\ Vent\ Area}{(\#\ of\ \ Holes)(\pi)}} \tag{4}$$

The diameter of the altimeter bay is 4.98 inches in diameter, and 8 inches long, yielding a volume of 156 cubic inches. A single port hole diameter was calculated to be 0.312 inches. When divided into 3 holes, each port hole should be 0.104 inches. For practicality, a 3/32 (0.09375) inch drill bit will be used.

During the rocket's ascent the atmospheric pressure surrounding the rocket decreases. In order to relieve the pressure in other areas of the rocket, a quarter inch hole will be drilled into both the top and bottom body sections of the rocket. Without these holes the higher pressure inside the body sections of the rocket could cause early separation of the body tubes of the rocket as well as early deployment of the parachutes, causing a potential safety hazard.

### *Recovery System Design*

The recovery system for the rocket will consist of a dual deployment system including a drogue and main parachute. The drogue chute will be a 44 inch SkyAngle parachute deployed by the altimeter using black powder charges. There is also a motor backup delay charge that will deploy the drogue parachute if the altimeter fails. This motor backup charge helps to mitigate the risk of a potential altimeter failure resulting in a catastrophic safety issue if the rocket were to come down with no parachutes deployed. The drogue parachute will result in a descent rate of 42.34 feet per second [4]. The drogue parachute will be connected to U bolts at the bottom of the altimeter bay and on the top of the highest centering ring. When the rocket descends to an altitude of 600 feet, the main chute will be deployed by the altimeter with black powder charges. The main chute has a diameter of 60 inches, and in combination with the drogue chute, will provide a safe landing velocity of 17.91 feet per second, which is below the competition required speed of 24 feet per second [4]. The main chute will be connected to a U bolt on the top of the altimeter bay and the hook on the bottom of the nose cone.

### *Drag System Structure Design*

There are several types of drag which can change a rocket's flight: skin-friction drag, pressure drag, form drag, and profile or boundary layer drag. Skin-friction drag is friction between the rocket's body and the flow of air. Pressure drag is the resultant force of normal pressures on the body. These two components of drag share some relation and both have to be accounted for in a rocket's flight. Form drag is due to the shape of the body and will create a streamline. Boundary layer drag or profile drag is caused by the both the form drag and the resultant boundary layer. A streamline occurs when a fluid is traveling with a tangential velocity to a path of the fluid flow, in other terms: it is the event that occurs when air is traveling over an object at a certain velocity. A boundary layer is an event that occurs when a body travels through a viscous medium; and, its thickness can be varied by the speed of the fluid. The fluid closer to the body moves slower than the fluid on the edge of the boundary layer. [5]

A rocket's flight is based on a balance of directed thrust, the resistive forces of drag, and gravity, among other things. For this drag system, the amount of pressure drag will be increased by adding additional surface area, from the top perspective of the rocket, to limit its overall velocity and apogee. By deploying the flaps and creating more pressure drag, an additional form drag will be created which will have a resultant streamline and profile drag. The angle of attack, $\alpha$, will be equal to zero because the rocket is launched perpendicular the ground. Therefore, the pressure drag will be orthogonal to flaps, when deployed.

There were many methods for flap deployment that were proposed, all of which would reach the similar end result of increased surface area on the exterior of the rocket. Each of the proposed method was first met with a series of questions on feasibility and reliability. However, further thought was given to each and the result of which can be seen in the decision matrix, Table 1, below. This figure is followed by a short explanation of each method and every method had several different ways to accomplishing a similar result.

| **Drag System Decision Matrix** | **Criteria [Weighting]** | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **Design Type** | **Reliability [4]** | **Ease of Manufacturing [3]** | **Maintain Stability [4]** | **Deployment/Retraction Time [2]** | **Electronic Requirements [2]** | **Price [1]** | **Weight [1]** | **% of Total Points** |
| Rotating Cylinder | **5** | 2 | 1 | **5** | **4** | 3 | 2 | 62 |
| Vertical Power Screw | 4 | 2 | 1 | 2 | 3 | 3 | 2 | 48 |
| Central Gear | 3 | 4 | 1 | 2 | **4** | 3 | 3 | 54 |
| Gear System | 4 | 2 | **5** | 4 | **4** | 2 | 1 | 72 |
| Belt and Pulley System | 4 | **5** | **5** | 4 | **4** | **5** | **4** | **89** |

Table 1: Drag System Decision Matrix

Rotating Cylinder: A central motor was to be placed between the bases of four flaps. Each flap would be adjacent to the exterior rocket and tilt out and upward. This system had a few different methods to create the surface area. One was by using push rods to extend the flaps out as stated above. Another version of this was having flat plates on the interior of the rocket that would be rotated out, rather than having the flaps adjacent to the exterior of the rocket. This means that the flaps wouldn't be extended at an increasing angle but be perpendicular to the side of the rocket.

Vertical Power Screw: The main point of this was to extend adjacent flaps out by using a push rod connected to a coupler, which was guided by a vertical structuring rod. The push rod would be connected to the base of a flap and then a power screw, which would be above the structure, would extend upward, pulling the coupler up and pushing the flaps out at an increasing angle. Other versions of this would have had a trapezoidal prism that would be pushed upward by a power screw and as it extended, rods with or without springs would have pushed out flaps at an increasing angle.

Central Gear: This method is fairly simple to visualize because it involves a smaller central gear that would push out flat plates from the exterior of the rocket. Each plate would have a rod with teeth on it, which would cross in the middle making contact with the main gear. The gear would rotate and two flaps would be pushed out perpendicular to the exterior of the rocket.

Gear System: This is a complicated method but the basic concept was attaching a flap to the bottom of a rotating gear. A number of gears would have been alighted and run from one motor. The gears would have been spun around and the flat plates would have been rotated out perpendicular to the exterior of the rocket.

Belt and Pulley System: This is the chosen drag system. The belt and pulley system is very similar to the gear system described above. The key feature for this method is the use of a synchronous timing belt to translate the force, rather than the gear teeth. The four pulleys will be positioned equally apart in the base of the rocket, which can be seen directly above the flaps in the OpenRocket Model section. The position of the drag system will be explained more in the Center of Pressure and Center of Gravity section below. The flaps will be aligned above rocket fins but spaced out so as to not impede the flow of air going over the fins, when the flaps are deployed.

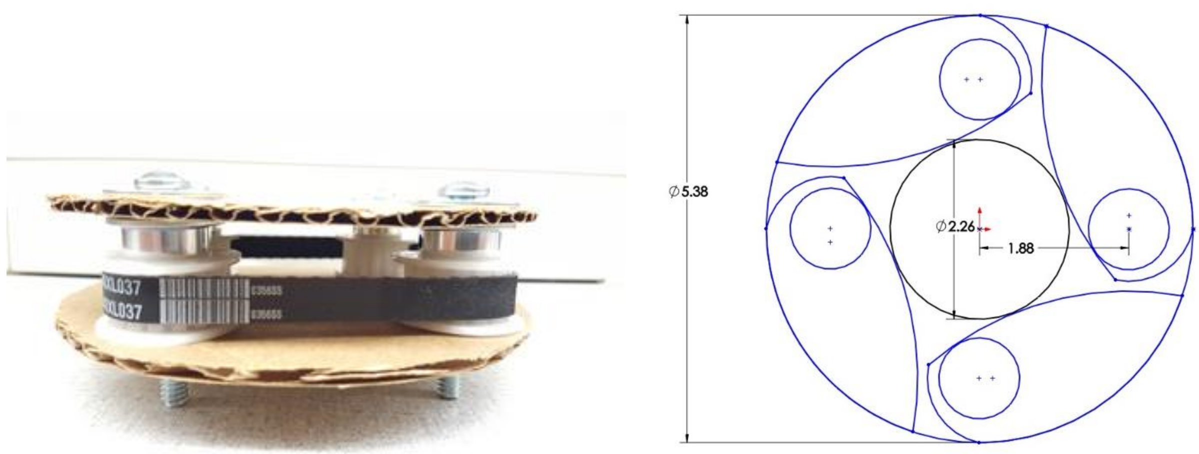



Figure 3: A prototype and design for the Belt and Pulley System is shown.

Each pulley is going to be secured in place by using a threaded rod that will also function as an overall structuring tool for the rocket. The flaps are going to be glued to the bottom of the each pulley and secured further by using nuts, which are threaded to the structuring rod. There will also be a series of bulkheads which will separate each section of the drag system that will both strengthen each piece and allow for increased structure for the bottom of the rocket. Slits in the side of the rocket body will be cut out to make room for the flaps to rotate out, and will be blocked off by the flaps when disengaged. The design of the flaps can be seen in Figure 3, a SolidWorks model, below. The 2.26 inches used for the center circle is to represent the solid rocket motor, a motor retainer, and a heat shield. The smaller circles are to represent the spinning pulleys and the curved shapes are the fiberglass flaps.

This design maximizes the flaps surface area being visible from the top of the rocket. A static load test will be done on the fiberglass flaps to confirm that they will be able to support the force. The force on the flaps can be calculated using the equation and sample calculation below. If there is a need, the flaps could be doubled up and attached together using epoxy. Each fiberglass flap will have to withstand an approximated maximum force of 264 lbf.

$$F_D = \frac{1}{2}\rho A C_D V^2$$

$$F_D = \frac{1}{2}(0.074887\frac{\text{lbm}}{\text{ft}^3})((2.25/144)\text{ft}^2)(1.2)(613\frac{\text{ft}}{\text{s}})^2 = 263.8\text{lbf}$$

The electronics, which will be discussed in the following section, will be above the belt, pulleys, and flaps. But the physical design of the electronics bay will attached using metal brackets and bulkheads.

## Rocket Electronics Design

### *Altimeter Bay Electronics Design*

The altimeter bay will consist of the ALTS25 dual-deployment altimeter (wiring diagram shown below in Figure 4), a GPS tracker, and a space for the MSGC altimeter. The ALTS25 will deploy the drogue parachute at Apogee, and the main parachute at 600 ft.

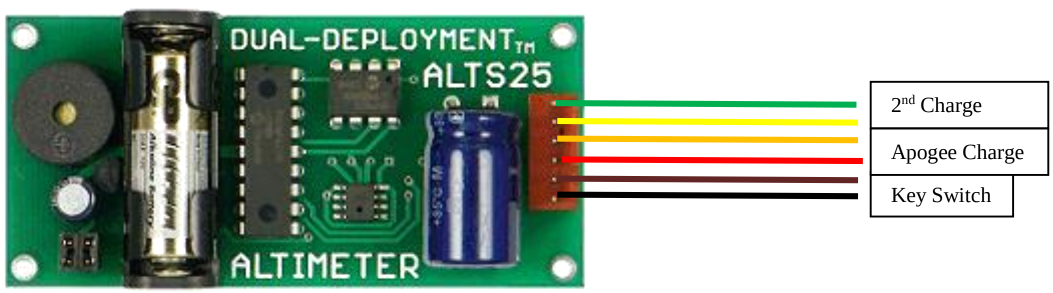



Figure 4: Altimeter Wiring

The altimeter bay will be positioned within the rocket similarly as was done last year in that it will be on a flat plate connected to rods that will slide into the bay area. A rough picture of the bay is shown below in Figure 5.

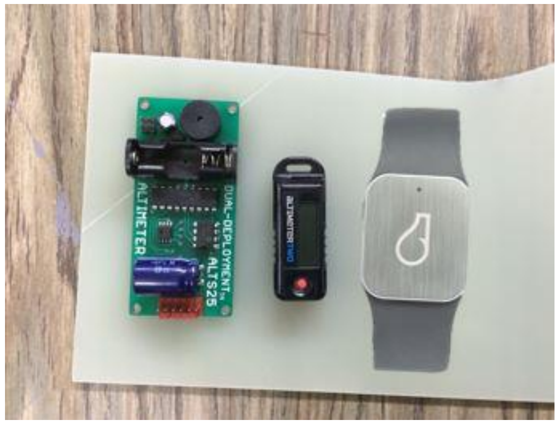



Figure 5: Altimeter Bay Components

***Drag System Electronics Design***

The electrical payload for this rocket will consist of a system that will trigger the air brake system to open the flaps right after burnout and to pull them back in before apogee. This will be accomplished by using an Arduino microcontroller that will be connected to an accelerometer (the ADXL326 which can measure +/- 16g) and a high torque 360 degree servo motor to be used in the system. Additionally, there will be an SD Arduino shield so that acceleration data can be logged so that the experimental coefficient of drag can be determined. Finally, there will be a camera positioned so that deployment of the air-brake system can be recorded. A wiring schematic is shown below in Figure 6:

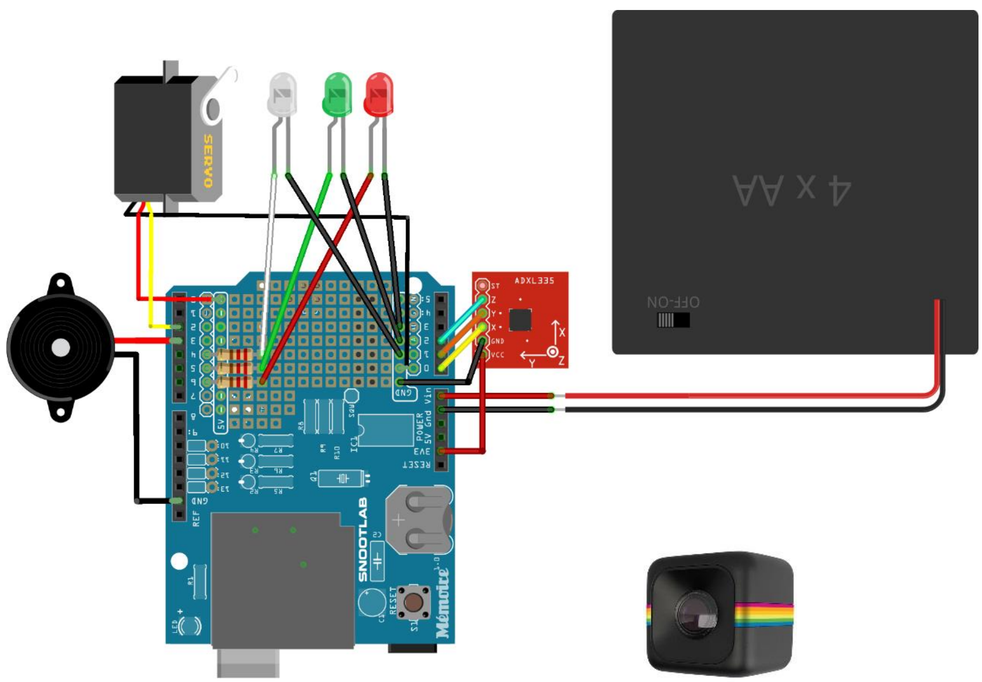



Figure 6: Electronic Layout

Essentially, the way this system will work is that the Arduino will wait until it detects a large increase of acceleration from the accelerometer (i.e. when the motor is burning). Afterwards, it will wait a predetermined amount of time until burnout occurs based on the thrust curve of the rocket motor, at which point the Arduino will trigger the air-brake motor to rotate the gears that will spin the flaps from within the rocket to an outward position through their corresponding slots located in the rocket tube surface. Afterwards, the Arduino will again wait a predetermined amount of time (the time from burnout to right before Apogee) calculated from the model flight program, at which point the Arduino will trigger the motor to retract the flaps for the duration of the flight. A rough flowchart that lays out this logic is shown below in Figure 7. It should also be noted that throughout this process, acceleration data will be logged onto an SD card via the SD shield.

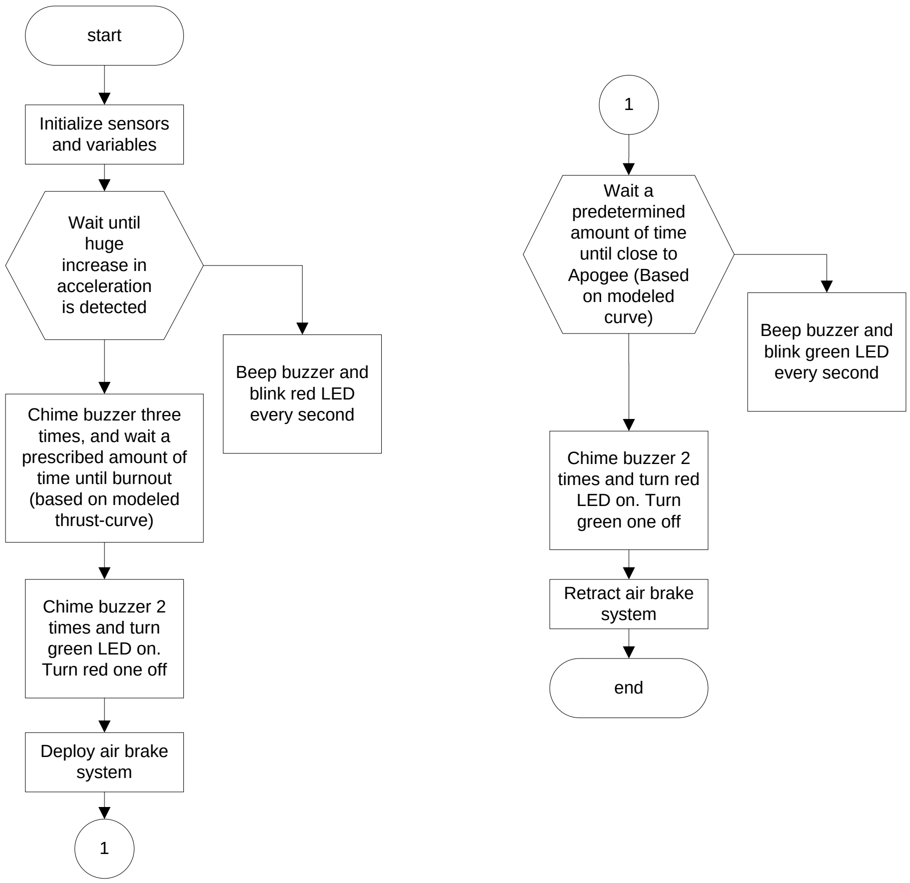



Figure 7: Electronic Flow Chart

It should be noted that buzzers and LEDs will be incorporated into the system for positive (or negative) feedback in regards to letting the user know that the system is armed and ready. The white LED will light up the space around the Polaroid Cube HD Action Camera (shown above) so that footage of the airbrake system being deployed will be recorded. Finally, the payload system will be positioned in the area surrounding the rocket motor due to the fact that there is a parachute located right above the rocket motor.

# PREDICTED PERFORMANCE

The anticipated performance of the rocket was simulated using two programs: OpenRocket and Matlab. The two simulations' results were compared against one another to estimate the performance of the rocket on the day of the launch. Matlab was also used to simulate the effects of the drag system on the rocket's altitude, velocity, and acceleration. The following sections detail the two simulations.

## Assumptions and Limitations

The motor's thrust curve for the Cesaroni K570 motor used for this competition was obtained from ThrustCurve.org, is shown below in Figure 8 [6].

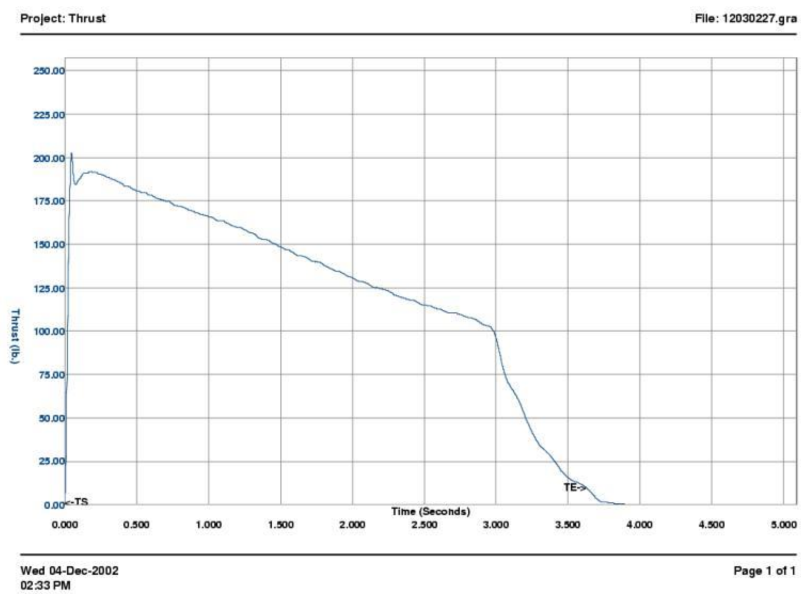



Figure 8: Motor Thrust Curve

The basic specifications for this motor, also obtained from ThrustCurve.org, are tabulated below in Table 2 [6].

| | |
|---|---|
| **Diameter** | 54.0 mm |
| **Length** | 48.8 cm |
| **Total Weight** | 1685 g |
| **Prop. Weight** | 990 g |
| **Burn Time** | 3.6 sec |
| **Average Thrust** | 574.0 N |
| **Max Thrust** | 892.7 N |
| **Total Impulse** | 2062.9 Ns |

Table 2: Motor Specifications

From the thrust curve, the weight of the propellant at any given time can be approximated as being equal to the area under unburned portion of the thrust time curve relative to the total area, which is then multiplied by the initial propellant mass. The assumption that this Cesaroni K570 thrust curve is accurate was used for the simulations.

A number of assumptions were taken for theses simulations. Mainly, the assumption that was rocket would be launched vertically and follow a vertical flight path. Standard temperature and pressure were also assumed to find air density, which was also assumed to be constant throughout the flight. When approximating the performance of the rocket, the only forces acting on the rocket are aerodynamic drag, mass change of the rocket, and gravitational forces. In the Matlab model other forces, such as from wind, are not taken into account (for the OpenRocket simulation, wind was taken into account). For both simulations, the outer body tube diameter was assumed to be 5.54 inches, and the motor was a K570 motor.

Additionally, there are of course factors that could not be taken into account in these simulations, such as stability, rotation, and deviation from vertical flight. Because of this, the estimates obtained are very likely overestimates of the likely flight performance. This fact was noted in the design of the rocket, and it is estimated that the rocket's apogee will be around 50-100 ft. lower than simulated.

## Matlab Model

A MATLAB simulation for the rocket flight performance was then developed using numerical methods. The main function used is from previous years of rocket competitions, but the simulation program itself was developed by the Team Lead this year. The function developed was designed to perform the following:

1) Load thrust data obtained from ThrustCurve.org.
2) Interpolate thrust curve for more discrete steps.
3) Calculate change in mass resulting from burnt propellant.
4) Calculate velocity from the combined impulse from drag, gravity, and thrust.
5) Calculate altitude and acceleration from velocity.

The rocket simulation function operates in the following way.
The velocity of the rocket was determined from the previous momentum plus the impulse. This relationship is shown in Eq. 5:

$$m_i v_i + F_i \Delta t = m_{i+1} v_{i+1} \tag{5}$$

Where $F_i$ is the net force acting on the rocket and $\Delta t$ is the time step between calculations. The net force acting on the rocket during accent is expressed in Eq. 6:

$$\begin{aligned} F_{net} &= F_{grav} + F_{drag} + F_{thrust} \\ &= m_i g + \frac{1}{2}\rho v_i^2 C_d A + T_i \end{aligned} \tag{6}$$

Where:

$\rho$ is the density of air

$C_d$ is the coefficient of drag

$A$ is the frontal cross sectional area of the rocket

$T_i$ is force from the motor

Substituting Eq. 6 into Eq. 5 and solving for $v_{i+1}$ yields:

$$v_{i+1} = \frac{1}{m_{i+1}}\left[v_i m_i + \frac{1}{\Delta t}\left(T_i - m_i g - k v_i^2\right)\right] \tag{7}$$

Where:

$$k = \frac{1}{2} C_d A$$

Acceleration was calculated using Newton's second law which is expressed in Eq. 8:

$$a_i = \frac{F_i}{m_i} \tag{8}$$

The trapezoidal method for approximating the area under a curve was used to calculate the altitude of the rocket during the flight.

The simulation calculated the altitude, velocity, and acceleration versus time for the flight until apogee, based on the assumptions as stated in the Assumptions and Limitations section. The drag coefficient for the MATLAB simulation was found in OpenRocket. The drag coefficient used was 0.415. These versus time were then plotted against the OpenRocket simulation results. These plots are shown in the Flight Predictions section.

The simulation for the rocket's altitude, velocity, and acceleration while the drag system is activated was calculated in a similar way. The same Matlab program was used, but the rocket's frontal area was adjusted to add the area of the flaps when deployed, and their coefficient of drag was also adjusted appropriately. The assumption that the flaps deploy fully in a negligible amount of time was also take for this simulation. The comparison between altitude, velocity, and acceleration for with and without the drag system is also seen in the Flight Predictions section.

## OpenRocket Model

OpenRocket is a free, open source, software similar to RockSim. It is capable of calculating acceleration, velocity, and position data while accounting for variables including elevation, wind speed, and the effects of individual components on performance such as surface roughness and leading edge fin radii on drag and stability.

Also included in the program is the ability to construct full scale schematics of the rocket design. From this schematic the CP, CG, stability, and apogee can also be approximated.

OpenRocket was the main source used in designing the rocket. The rocket was modeled entirely in the program, providing a way to design and calculate proper lengths of body tubes, optimal fin and nosecone designs, rocket weights, acceptable locations of the CP and CG, and drag coefficients. This was an extremely powerful tool, and it has already been mentioned in several previous sections.

***Center of Gravity and Center of Pressure***

The relationship between the center of pressure (CP) and center of gravity (CG) is one of the most important relationships in high-powered rocketry. The center of pressure is defined as the point at which aerodynamic forces on the rocket are centered. The center of gravity is the location at which the whole weight of the rocket can be considered to act as a single force. The ratio between the locations of relative to the rocket diameter can be used to predict the stability of the rocket during flight. Generally, the center of pressure must be at least one (but not more than two) body tube diameters in front of the center of pressure, and both should be in the bottom half of the rocket.

The center of pressure and center of gravity was determined for this design using the OpenRocket software. The results were then compared against the results using Barrowman's Theory, and the two agreed acceptably.

The following assumptions were made during the derivation of Barrowman's theory for predicting the center of pressure:

1) The flow over the rocket is potential flow.
2) The point of the nose is sharp.
3) Fins are thin flat plates.
4) The angle of attack is near zero.
5) The flow is steady and subsonic.
6) The rocket is a rigid body.
7) The rocket is axially symmetric.

The rocket design presented in this paper did violate some of these assumptions, particularly assumptions 2, 6, and 7. However, the theory was still applied with the understanding that minor uncertainties will be present as a result. Details into the equations used can be found in Appendix B.

Table 4 shows the locations of the CP and CG and the caliber stability at ignition and at burnout according to the OpenRocket simulation.

| | CP | CG | Stability (Caliber) |
|---|---|---|---|
| **Inches from Nose Cone Tip** | 47.3 | 39.1 | 1.48 |

Table 4: Locations of CP and CG

From this analysis, it can be concluded that the rocket will be stable during the entire ascent portion of the flight, and winds probably would not affect the flight very much because the stability is within one to two calibers for the entire flight.

From the finished rocket model, the flight predictions were simulated (altitude, velocity, and acceleration). For the OpenRocket simulations, different wind speeds were taken into account. Wind speeds varying from 0 mph to 20 mph produced an apogee altitude difference of only 80 feet. From this, it can be concluded that an assumption of 0 mph winds is a suitable assumption to be made in these simulations, including in the MATLAB simulation. At 0 mph winds, the predicted apogee is 5035 ft., although with factors such as stability, rotation, and deviation from vertical flight, the apogee should closer to 5000 ft.

Figure 9 shows the full assembly of the rocket, as modeled in OpenRocket, with a side cross-section view and a 3D component view.

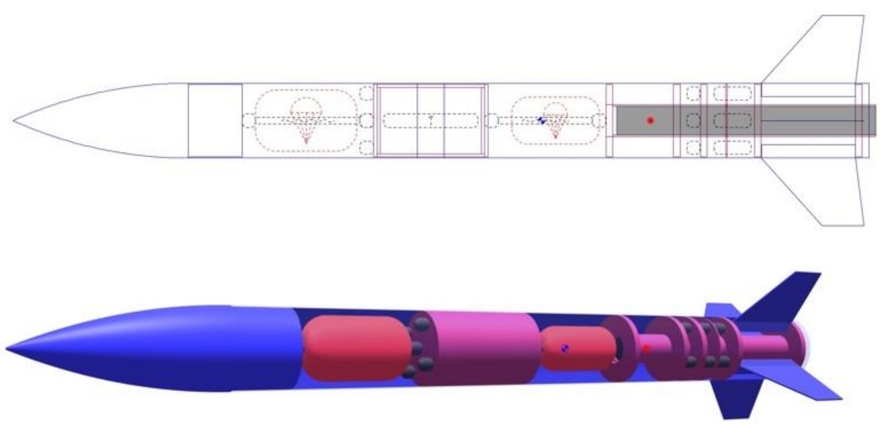


Figure 9: Fully rocket assembly with a side cross-sectional view and three dimensional model

## Flight Predictions

Altitude, velocity, and acceleration predictions to apogee from MATLAB and OpenRocket are compared in Figures 10a, 10b, and 10c. Time to apogee is approximately 17 seconds. The peak altitude, acceleration, and velocity for both simulations are shown in Table 5, and F10.

| Maximum Value of | OpenRocket | MATLAB |
|---|---|---|
| **Altitude (ft)** | 5035 | 5021 |
| **Velocity (ft/s)** | 665 | 663 |
| **Acceleration($ft/s^2$)** | 329 | 331 |

Table 5: Maximum Flight Predictions

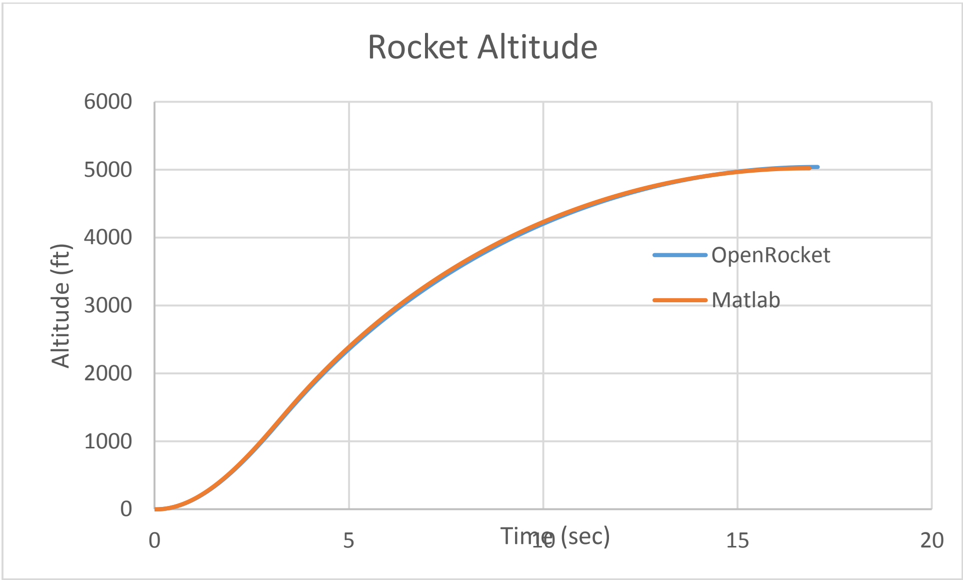



Figure 10a: Rocket Altitude vs time after launch plot

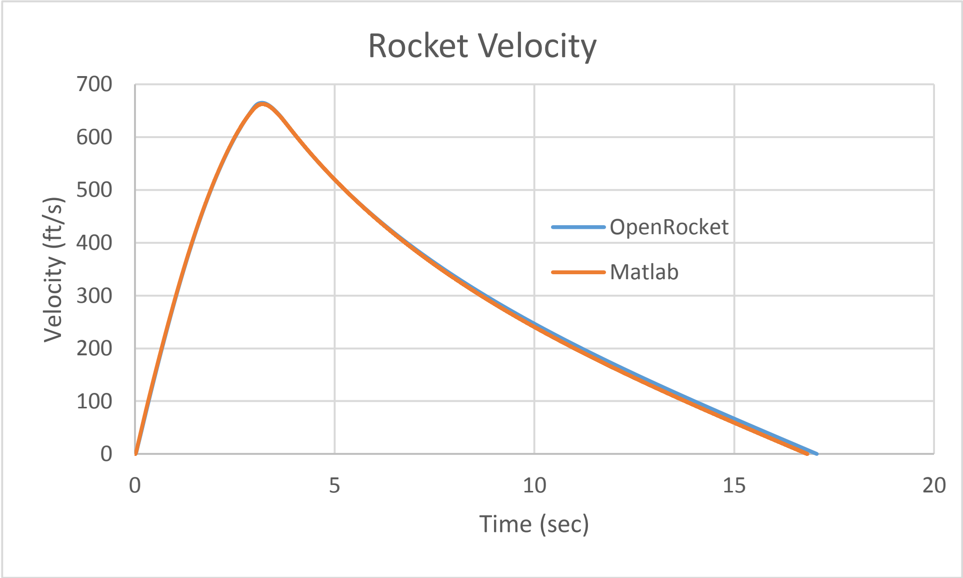



Figure 10b: Rocket Velocity vs time after launch plot

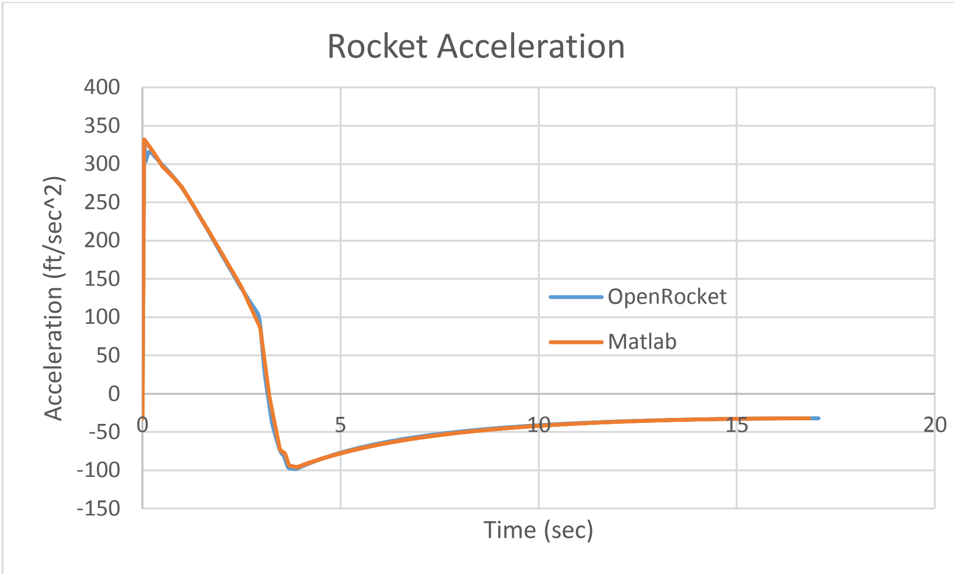



Figure 10c: Rocket Acceleration vs time

The simulations of the drag system were performed using only Matlab. Table 6 shows the compared altitude. Maximum velocity and acceleration are anticipated to remain the same. Figures 11a, 11b, and 11c also show the data in graphical form.

| | **Without Drag System** | **Activated Drag System** |
|---|---|---|
| **Altitude (ft)** | 5021 | 3976 |
| **% Altitude** | 100% | 79% |

Table 6: Drag System Predictions

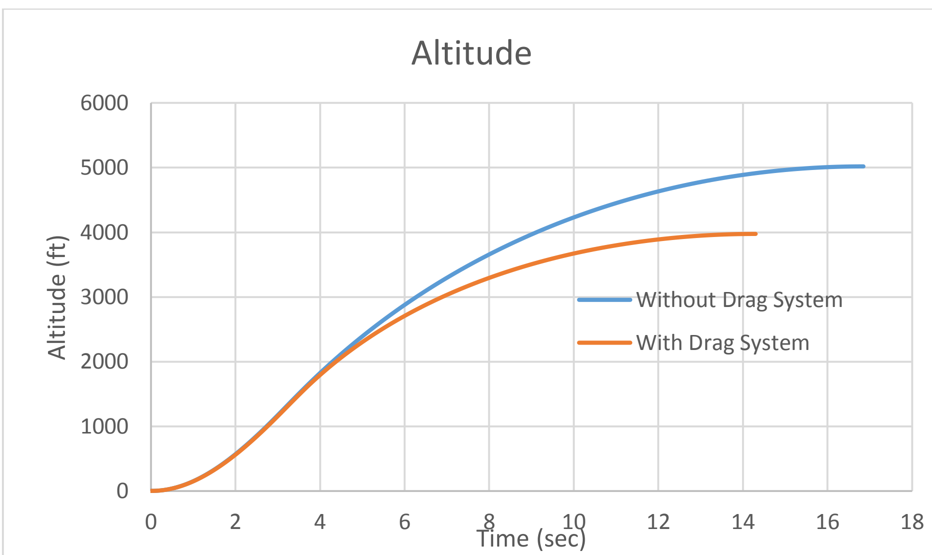



Figure 11a: Rocket Altitude vs time with and without the drag system activated.

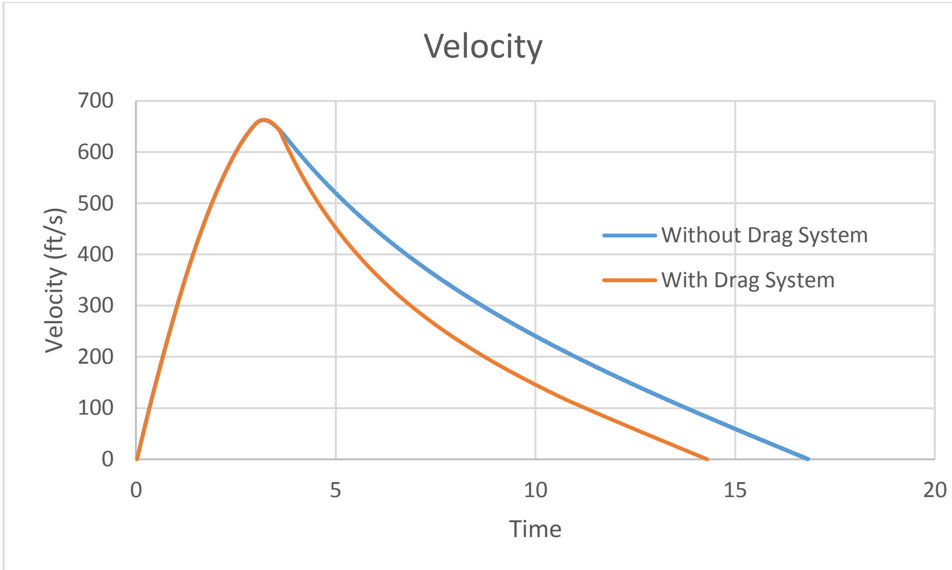



Figure 11b: Rocket Velocity vs time plot for the rocket with and without the drag system activated.

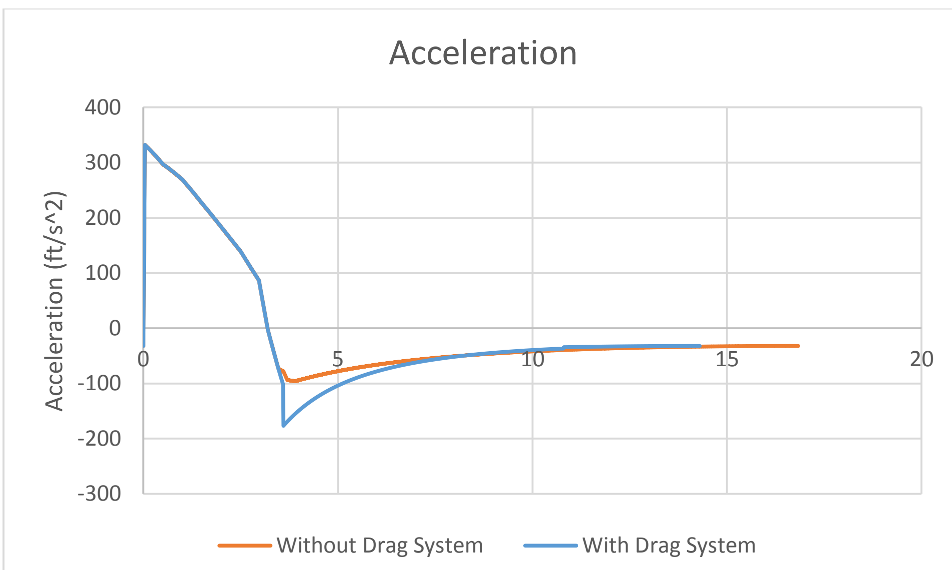



Figure 11c: Rocket Acceleration vs time plot for the rocket with and without the drag system activated.

OpenRocket was used to determine the coefficient of drag throughout the flight without the drag system activated. Using the acceleration data off of the Matlab simulation, the coefficient of drag was back calculated, but only for the portion of flight between motor burnout and apogee. The results of this data is seen below in Figures 12a and 12b.

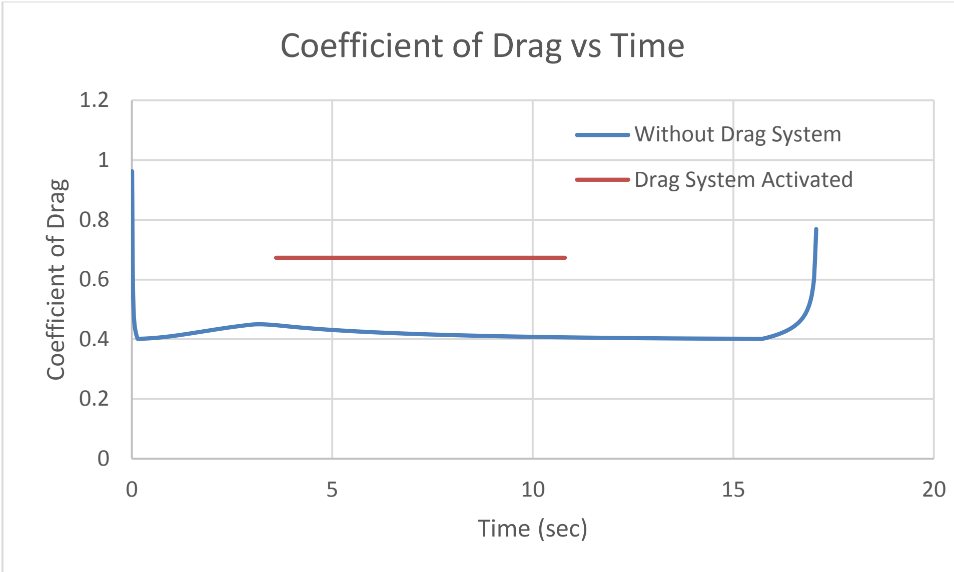



Figure 12a: Rocket Coefficient of drag vs time for the rocket during flight with and without the drag system activated.

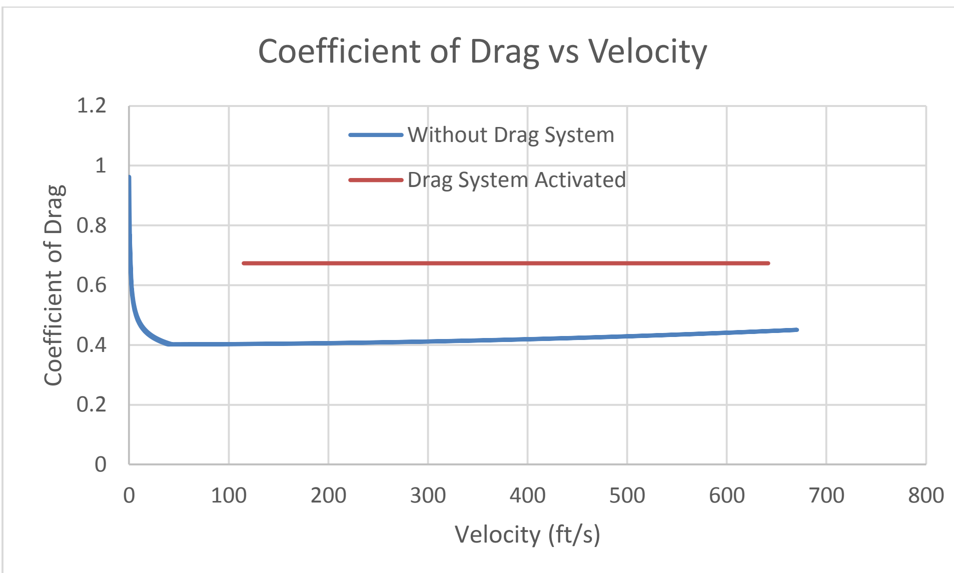



Figure 12b: Coefficient of Drag vs velocity for the rocket during flight with and without the drag system activated.

# CONCLUSION

This rocket design will provide a safe and effective flight in which the objectives set by the competition are achieved. The rocket was optimized to reach an apogee of 5036 feet without flaps activated and 3976 feet with the flaps activated. The apogee without flaps was predicted using both OpenRocket and Matlab. The apogee with flaps activated was only predicted using Matlab, due to OpenRocket's limited capabilities. The drag system structure consists of a belt and pulley system powered by a servo motor arranged around the rocket motor mount tube below the drogue parachute. It was positioned in this location to ensure the stability of the rocket and avoid damage from the motor ejection charge. An accelerometer will also be added to the electronics bay to obtain acceleration data which will be used to calculate the coefficient of drag, which is a competition requirement. A camera is going to be placed above the drag system to monitor its state.

Conditions such as temperature, wind speed, and launch rail angle will be inputted into the OpenRocket simulator on launch day to determine the exact weight of the rocket that is needed to acquire the desired altitude. The weight of the rocket will be adjusted using easily removable/addable weights. The engineering, construction techniques, and innovative ideas incorporated into the design of this rocket will result in a launch that will score highly in the flight portion of this competition.

# APPENDIX A: DETAILED EXPENSE REPORT

| **Section** | **Product** | **Source** | **Units Needed** | **Price per unit** | **Cost** |
|---|---|---|---|---|---|
| Recovery System | 5.38 13" Nose Cone | Apogee | 1 | $ 54.95 | $ 54.95 |
| | 1500# Kevlar Shock Cord (Main) | Apogee | 20 | $ 0.92 | $ 18.40 |
| | 1500# Kevlar Shock Cord (Drogue) | Apogee | 20 | $ 0.92 | $ 18.40 |
| Altimeter Bay | 5.38" 11" L Coupler | Apogee | 1 | $ 9.08 | $ 9.08 |
| | 5.38" 11" L Stiffy | Apogee | 1 | $ 10.95 | $ 10.95 |
| | GPS Tracker | Whistle | 1 | $ 79.95 | $ 79.95 |
| | GPS Subscription | Whistle | 1 | $ 20.00 | $ 20.00 |
| Motor Mount | 54 mm 34" L motor tube | Apogee | 1 | $ 8.09 | $ 8.09 |
| | G10 Prism Fin | Public Missiles | 3 | $ 16.67 | $ 50.00 |
| | Aero Pack 54mm Retainer - L | Apogee | 1 | $ 31.03 | $ 31.03 |
| Drag System | XL Series Timing Belt Pulley | McMaster-Carr | 4 | $ 7.61 | $ 30.44 |
| | XL Series Timing Belt | McMaster-Carr | 1 | $ 5.37 | $ 5.37 |
| | Shipping and Tax | McMaster-Carr | 1 | $ 5.25 | $ 5.25 |
| | Kevlar 12-Strand Rope | US Rope and Cable | 30 | $ 0.99 | $ 29.70 |
| | Shipping | US Rope and Cable | 1 | $ 11.95 | $ 11.95 |
| Electronics | Accelerometer ADXL326 | Adafruit | 1 | $ 17.95 | $ 17.95 |
| | Shipping | Adafruit | 1 | $ 9.51 | $ 9.51 |
| | Continuous Rotation Servo | Adafruit | 1 | $ 11.95 | $ 11.95 |
| | Servo Wheel | Adafruit | 1 | $ 2.95 | $ 2.95 |
| | Shipping | Adafruit | 1 | $ 9.51 | $ 9.51 |

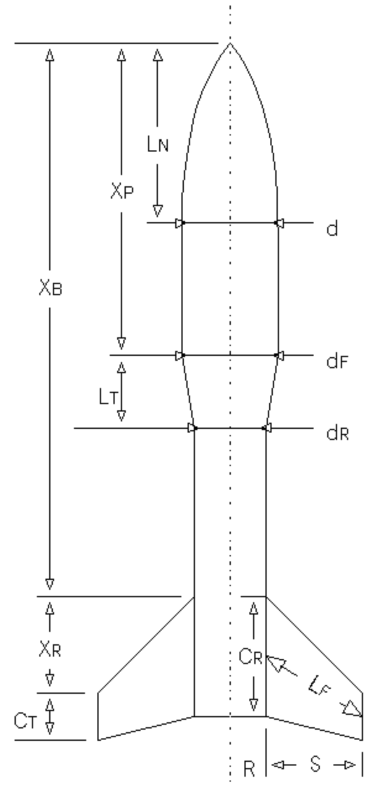
| Section | Product | Source | Units Needed | Price per unit | Cost |
|---|---|---|---|---|---|
| | 4-AA Battery Holder | Amazon | 1 | $ 4.19 | $ 4.19 |
| Building Supplies | Scale | Walmart | 1 | $ 20.03 | $ 20.03 |
| | Birch Plywood - 1/4"*2'*4' | Home Depot | 1 | $ 12.42 | $ 12.42 |
| | Birch Plywood - 1/2"*2'*4' | Home Depot | 1 | $ 19.95 | $ 19.95 |
| | Loctite Epoxy | Home Depot | 1 | $ 15.67 | $ 15.67 |
| | Home Depot Tax | Home Depot | 1 | $ 2.69 | $ 2.69 |
| | Basswood Sheet - 1/4"*8"*24" | Architects Corner | 2 | $ 9.75 | $ 19.50 |
| | Basswood Sheet - 1/2"*8"*24" | Architects Corner | 2 | $ 11.95 | $ 23.90 |
| | Shipping | Architects Corner | 1 | $ 18.10 | $ 18.10 |
| | Navy Blue Paint | Ace Hardware | 1 | $ 4.49 | $ 4.49 |
| | Metallic Aluminum Paint | Ace Hardware | 1 | $ 3.99 | $ 3.99 |
| | Sandpaper | Ace Hardware | 3 | $ 2.99 | $ 8.97 |
| | 12 V Batteries | Ace Hardware | 1 | $ 3.99 | $ 3.99 |
| | AA Batteries | Ace Hardware | 1 | $ 12.99 | $ 12.99 |
| | Misc. Hardware (nuts, bolts, screws, washers) | Ace Hardware | 1 | $ 34.64 | $ 34.64 |
| | Ace Hardware Tax | Ace Hardware | 1 | $ 3.87 | $ 3.87 |
| Motors | K570 17A - Classic | Offwego Rocketry | 3 | $ 127.95 | $ 383.85 |
| | Rocket Motor Refund | MnSGC | 2 | $ (100.00) | $ (200.00) |
| Competition | Registration Fee | MnSGC | 1 | $ 400.00 | $ 400.00 |
| | Hotel | | 3 | $ 80 | $ 240.00 |
| | Travel | | 748 | $ 0.60 | $ 448.80 |
| | Meals | | 30 | $ 10.00 | $ 300.00 |
| | | | | **Total** | $ 2,217.47 |

# APPENDIX B: BARROWMAN'S THEORY

The Barrowman equations permit you to determine the stability of your rocket by finding the location of the center of pressure (CP). The value computed is the distance from the tip of the rocket's nose to the CP. In order for your rocket to be stable, you would like the CP to be aft of the center of gravity (CG).

You can find the CG of your rocket by simply finding the balance point after loading recovery system and motor. (Literally - balance the rocket on your hand - or finger - and that's the CG). You can then measure from the tip of the rocket's nose to the CG. The calculated CP distance should be greater than the measured CG distance by one rocket diameter. This is called "one caliber stability".

Terms in the equations are defined below (and in the diagram) [7]




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

Nose Cone Terms: $(C_N)_N = 2$
For Cone: $X_N = 0.666 L_N$
For Ogive: $X_N = 0.466 L_N$

Conical Transition Terms

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

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

Fin Terms

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

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

Finding the Center of Pressure:

Sum up coefficients: $(C_N)_R = (C_N)_N + (C_N)_T + (C_N)_F$ $(C_N)_R = (C_N)_N + (C_N)_T + (C_N)_F$

Find CP Distance from Nose Tip:

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

# APPENDIX C: RESOURCES AND ACKNOWLEDGEMENTS

[1] “NASA’s Space Grant Midwest High-Power Rocket Competition Handbook” Minnesota Space Grant Consortium, 20 Aug. 2015. Web. 17 Mar. 2016

[2] Knowles, Vern. "Altimeter Port Sizing." Altimeter Port Sizing. Altimeter Port Sizing, 2002-2007. Web. 17 Apr. 2015.

[3] "RRC2X User Manual." Missile Works Corporation, n.d. Web. 17 Apr. 2015.

[4] Hiller, Jordan “Model Rocket Parachute Descent Rate Calculator.” Web

[5] Duncan, W.J., Thom, A. S., and Young, A.D. “Mechanics of Fluids,” American Elsevier Publishing Company, Print.

[6] “Cesaroni K570,” ThrustCurve, Web

[7] Barrowman, James. "Barrowman Equations." Barrowman Equations. NASA, 25 Feb. 2000. Web. 17 Mar. 2016.

**Acknowledgments**

Wisconsin Space Grant Consortium

Minnesota Space Grant Consortium

MSOE AIAA Chapter