TEAM WHOOSH GENERATOR

Flight Readiness Report

2016 NASA's SPACE GRANT MIDWEST HIGH POWER ROCKET COMPETITION

MILWAUKEE SCHOOL OF ENGINEERING

TEAM MEMBERS:

Team Mentor: Frank Nobile - maxq3@aol.com
Faculty Advisor: Dr. Anand Vyas – vyas@msoe.edu
Team Lead: Jordan Petrie – petriej@msoe.edu
Michael Hinaus
Ryan Koniecko
Henry Moroder
Matthew Pfeiffer
Michael Wiznitzer

6 May, 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 is 63 inches long and weighs 16.875 pounds. The rocket has a projected apogee of 5191 feet and a projected max velocity of 695 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 consists of a pulley-timing belt system that turns the flaps out of the side of the rocket at motor burnout, then brings them back in before apogee. A high torque 180 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 is then used to calculate coefficient of drag data. A camera is also located above the drag system internally to observe the flaps being deployed. A GPS was placed into the altimeter bay to allow for fast recovery of the rocket.

A test flight of the rocket was performed. Due to a malfunction in the Arduino micro-controller, the flaps did not deploy for the correct amount of time and no acceleration data was recorded. However, the flaps did deploy long enough to determine that the rocket remained stable when they deployed, and that they did indeed decrease the rocket's altitude. The rocket reached an apogee of 4,966 feet, which, while far from the desired 25% apogee reduction, still gives evidence to the fact that the drag system can be successful in reducing the rocket's apogee.

BUDGET

Section	Product	Source	Cost
Recovery System	5.38 13" Nose Cone	Apogee	$ 54.95
	1500# Kevlar Shock Cord (Main)	Apogee	$ 18.40
Altimeter Bay	5.38" 11" L Coupler	Apogee	$ 9.08
	5.38" 11" L Stiffy	Apogee	$ 10.95
	GPS Tracker	Whistle	$ 79.95
	GPS Subscription	Whistle	$ 20.00
Motor Mount	54 mm 34" L motor tube	Apogee	$ 8.09
	Aero Pack 54mm Retainer - L	Apogee	$ 31.03
Drag System	XL Series Timing Belt Pulley	McMaster-Carr	$ 30.44
	XL Series Timing Belt	McMaster-Carr	$ 5.37
	Shipping and Tax	McMaster-Carr	$ 5.25
	Kevlar 12-Strand Rope	US Rope and Cable	$ 29.70
	Shipping	US Rope and Cable	$ 11.95
	XL Series Timing Belt Pulley	McMaster-Carr	$ 7.61
	Shipping and Tax	McMaster-Carr	$ 5.25
Electronics	Accelerometer ADXL326	Adafruit	$ 17.95
	Shipping	Adafruit	$ 9.51
	Continuous Rotation Servo	Adafruit	$ 11.95
	Servo Wheel	Adafruit	$ 2.95
	Shipping	Adafruit	$ 9.51
	4-AA Battery Holder	Amazon	$ 4.19
	Metal Gear High Torque Servo Motor	Amazon	$ 11.99
	Key Switch	Amazon	$ 9.30
	1 Day Shipping	Amazon	$ 5.99
Building Supplies	Scale	Walmart	$ 20.03
	Public Missile Fins	Public Missiles	$ 127.59
	Birch Plywood - 1/4"*2'*4'	Home Depot	$ 12.42
	Birch Plywood - 1/2"*2'*4'	Home Depot	$ 19.95
	Loctite Epoxy	Home Depot	$ 15.67
	Home Depot Tax	Home Depot	$ 2.69
	Basswood Sheet - 1/4"*8"*24"	Architects Corner	$ 19.50
	Basswood Sheet - 1/2"*8"*24"	Architects Corner	$ 23.90
	Shipping	Architects Corner	$ 18.10
	Navy Blue Paint	Ace Hardware	$ 4.49
	Metallic Aluminum Paint	Ace Hardware	$ 3.99

Section	Product	Source	Cost
	Sandpaper	Ace Hardware	$ 8.97
	12 V Batteries	Ace Hardware	$ 3.99
	1" Rail Button	Apogee	$ 6.14
	AA Batteries	Ace Hardware	$ 12.99
	Misc Hardware (nuts, bolts, screws, washers)	Ace Hardware	$ 34.64
	Ace Hardware Tax	Ace Hardware	$ 3.87
	PNC-5.38" - Short	Apogee	$ 54.95
	Apogee Shipping	Apogee	$ 22.70
	5.38" LOC Body Tube	Apogee	$ 77.00
	Aero Pack 54 mm Retainer (Flanged)	Apogee	$ 40.66
	Centering Rings - 54mm to 5.38"	Apogee	$ 26.20
	Apogee Shipping	Apogee	$ 26.99
	Additional Hardware	Farm & Home	$ 6.77
	Additional Hardware/ Caulk	Ace Hardware	$ 18.10
Motors	K570 17A - Classic Competition Motor	Offwego Rocketry	$ 255.90
	Rocket Motor Refund	MnSGC	$ (100.00)
	K570 17A - Classic Test Launch Motor	Wildman Rocketry	$ 120.00
Competition	Registration Fee	MnSGC	$ 400.00
	Hotel		$ 240.00
	Travel		$ 374.00
	Meals		$ 180.00
		Total	**$2,493.56**

Budget Discussion

Following the final weeks of construction and testing, the budget was finalized. The budget was adjusted in order to include travel expenses, hotel accommodations for the launch, and meals for the competition time period. The costs associated with travel and meals may change in the coming weeks and as a result will be updated in the Post Flight Report. The largest change in the budget was the price of the fins, which ended over double the projected cost due to a low estimate and increased shipping costs to align the arrival time with our building schedule. Otherwise the final cost aligned well with our initial budget. The final cost of this project was $2,493.56.

SUMMARY OF DESIGN

Body Tube Selection

The body tube can 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 room for 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 superior 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.

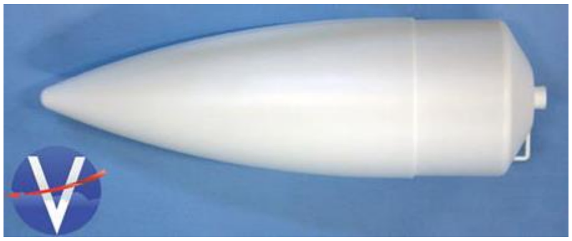


Figure 1: 13 inch ogive nose cone

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.

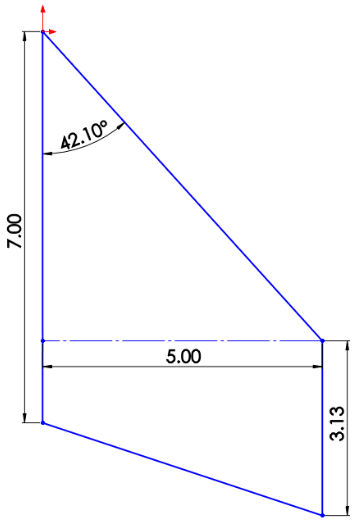


Figure 2: Fin dimensions

The fin material chosen for the rocket was 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 four fins. Four fins were chosen so the drag system design, which has four flaps, can be evenly spaced in between the fins.

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.

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 3: Altimeter Wiring

The altimeter bay will be positioned within the rocket on a flat plate connected to rods that will slide into the bay area.

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 was calculated from equation 4 to be 0.180 inches. For practicality, a 3/16 (0.1875) inch drill bit was used.

During the rocket's ascent the atmospheric pressure surrounding the rocket decreases. In order to relieve the pressure in upper section of the rocket, a 1/8 inch hole was drilled in the body tube five inches from the top of the rocket. Without this hole the higher pressure inside the upper section of the rocket could cause early separation of the nose cone, which could also result in early deployment of the main parachute, 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 should result in a descent rate of 33.32 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 17.46 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.

Stability Analysis

The stability of a rocket is determined by the distance between the rocket's center of pressure (CP) and center of gravity (CG). 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 relative to the rocket diameter can be used to predict the stability of the rocket during flight. Generally, the center of gravity 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 by using 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 does 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 stability caliber at ignition and at burnout according to the OpenRocket simulation. Figure 4 also displays the locations of the CP and CG at ignition.

	CP [Inches from Nose Cone Tip]	**CG** [Inches from Nose Cone Tip]	**Stability** [Caliber]
At Ignition	47.45	40.71	1.22
After Burnout	47.5	38.72	1.65

Table 1: Locations of CP and CG

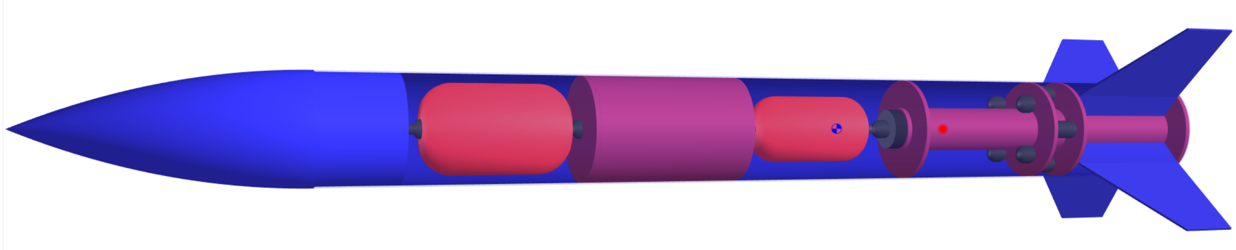


Figure 4: 3D figure of rocket components at ignition displaying CP (red circle) and CG (blue circle)

From this analysis, it can be concluded that the rocket will be stable during the entire ascent portion of the flight, and low winds will not have a large effect on the flight because the stability is within one to two calibers for the entire duration of the flight.

ROCKET CONSTRUCTION

After reviewing the competition parameters, the rocket design was modeled using OpenRocket, and the model proved the performance of the rocket to meet the specifications of the competition. Taking the results from OpenRocket, parts and supplies were then purchased in order to begin on the construction of the rocket.

It had been determined to utilize cardboard as the team members had worked with cardboard body tubes the previous year. Cardboard body tubes allow for an ability to easily cut tube lengths, fin slots, holes for key switches, rail button holes, and be able to apply epoxy and paint easily. The team also knew the performance that the cardboard body tubes would provide. Two 5.38” diameter body tubes were purchased and then cut to specified lengths determined in OpenRocket. Using an exacto knife, smooth, straight, and accurate cuts were able to be made cutting the body tubes to their specified sizes. Once the three sections of the body tube were cut to their 7.65”, 17”, and 23.85” sizes, the pieces were put together in order to get an idea for the size of the rocket.

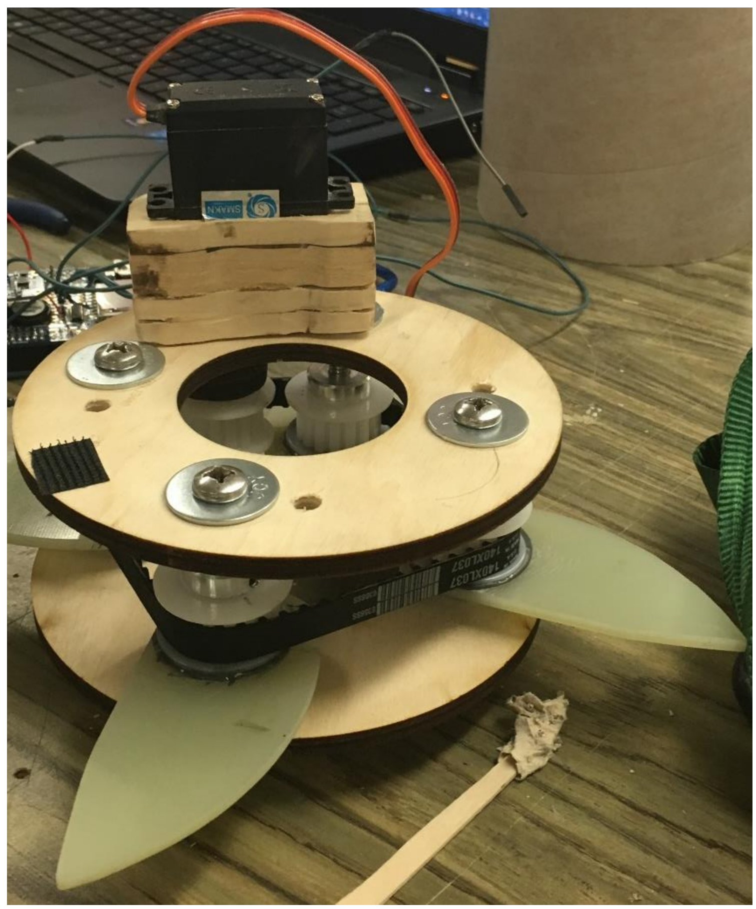


Figure 5: Drag system structure

The drag system was designed to be a system where a servo motor would turn a drive pulley that was attached with a belt to four other pulleys to make them turn straight out of the rocket. The drag system was made by mounting a 180° servo motor to a centering ring using a series of basswood pieces which were cut using a laser cutter. A shaft was then attached to the motor and drive pulley using JB weld. The drive pulley is not connected to any of the flaps itself, and is just used to turn the other pulleys. The flaps were then JB welded to the pulley. To attach the pulleys to the centering rings, a bolt was secured to each centering ring with the pulleys sitting freely on a nut and washer between them, allowing them to spin freely. The completed drag system outside of the rocket is shown in Figure 5. The drag system was then able to be secured around the motor mount tube and placed inside of the rocket.

To connect the top potion of body tubes together, there is a coupler that doubles as an altimeter bay connecting the top section of the rocket and the middle section of the rocket. The altimeter bay houses a GPS, the competition altimeter, and the recovery system altimeter. There are also electronics in another housing where the servo motor, battery pack, Arduino, and camera are located. All the electronics are controlled through three key switches. One switch controls the altimeter bay, another controls the drag system electronics power, and the other controls whether the drag system will activate or not on the flight. The altimeter bay is secured into the upper body tube with removable rivets and is held to the lower side by shear pins to allow the drogue parachute to deploy at apogee.

To connect the bottom portion of the rocket, two sections are held together by the drag system and motor mount tube. To connect the portions, the drag system was first completely put together with centering rings on either side of it. The motor mount tube was then inserted into the middle of the drag system in the centering ring holes and epoxied. Once the epoxy dried, the top centering ring and portion of the drag system was inserted into the middle section of the body tube and epoxied in. Once the epoxy was completely dry, the bottom half of the body tube was inserted into the other side of the drag system and epoxied in so that there was only a gap large enough for the flaps to deploy.

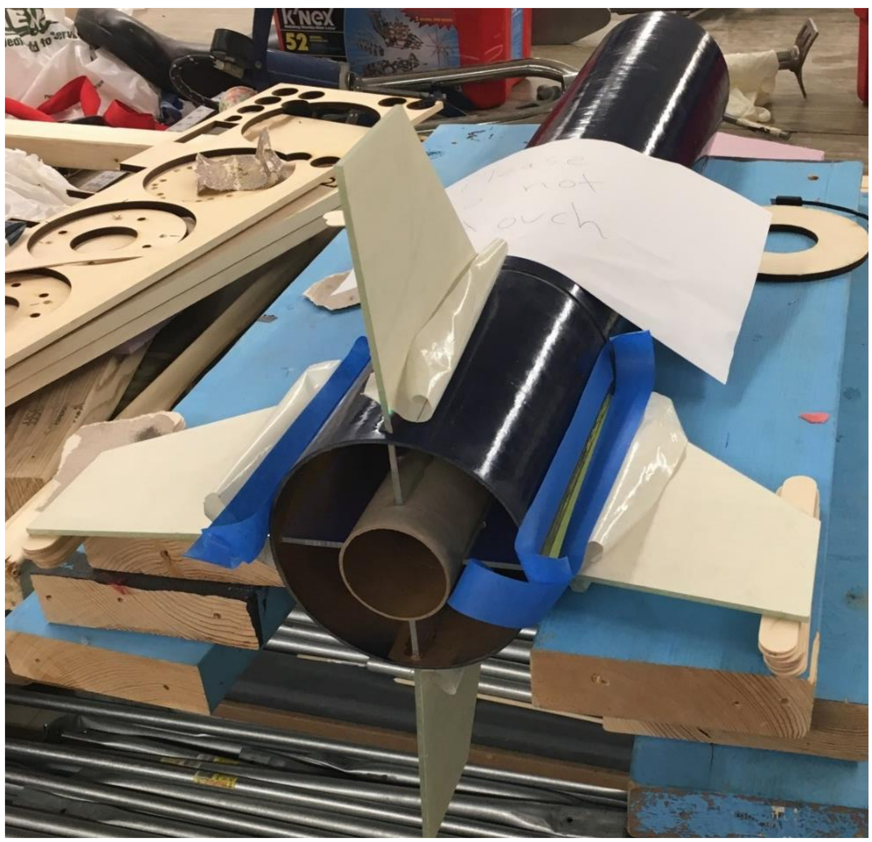


Figure 6: Fin epoxying setup

In the design of the rocket it had been determined that 4 fins spaced at 90 degree intervals would provide an acceptable stability for the rocket. The locations of the fins were marked on the body tube with pencil and then the slots were cut using a razor blade to allow for a snug fit. At first, all the fins did not fit perfectly so the slots were expanded slightly using a Dremel tool. The fins were then able to be inserted into the slots and epoxied to the outside and inside of the body tube and the outside of the motor mount tube. Two fins were able to be epoxied at a time. This was possible by using a level and making sure that the fins were both level when being epoxied as it is important that the fins are as close to 90 degrees apart as possible. The team waited until each fin was completely dry before epoxying the remaining fins as seen in Figure 6. The last centering ring was then epoxied into place and the motor retainer was JB welded to the motor tube. This allows for a strong and secure bond under the strong forces and heat that the motor produces during launch.

Having all the parts cut and essential pieces epoxied, the rocket was then assembled bringing all pieces together to form the completed rocket. With all parts placed together, it was decided to paint the rocket two solid colors, blue and silver. Painting was done in the MSOE paint booth in the student campus center. With the rocket painted, the switches were put into place and the shock cord, drogue chute, and main chute were attached inside the rocket. With all the chutes, cords, altimeters, data recorders, drag system, and locating devices placed in the rocket assembly, the construction of the Whoosh Generator rocket was complete as shown in Figure 7.

Figure 7: Team photo of members at the practice launch

DRAG SYSTEM DESIGN

Electronics Design

The electronic drag system consists of the following components that are wired up as shown in Figure 8.

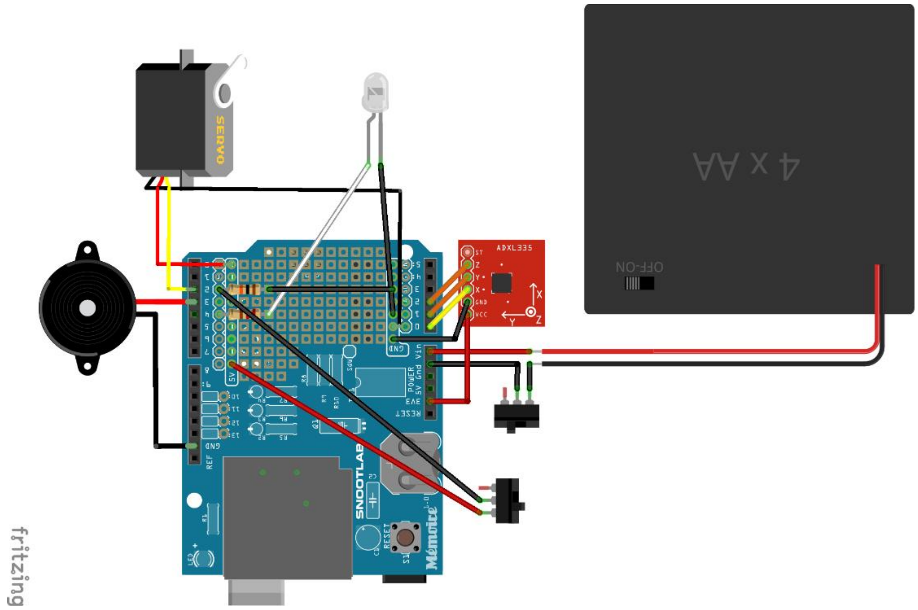


Figure 8: Drag System Electronic System

The system is placed in the rocket such that the SD port is facing up so that the card and/or Arduino programmer port can be accessed if need be as shown in Figure 9. The key switch (represented by a toggle switch in the diagram) that is connected to the battery pack was mounted on the outside of the rocket so that a simple turning of it could turn the whole system on without having to take apart the rocket beforehand.

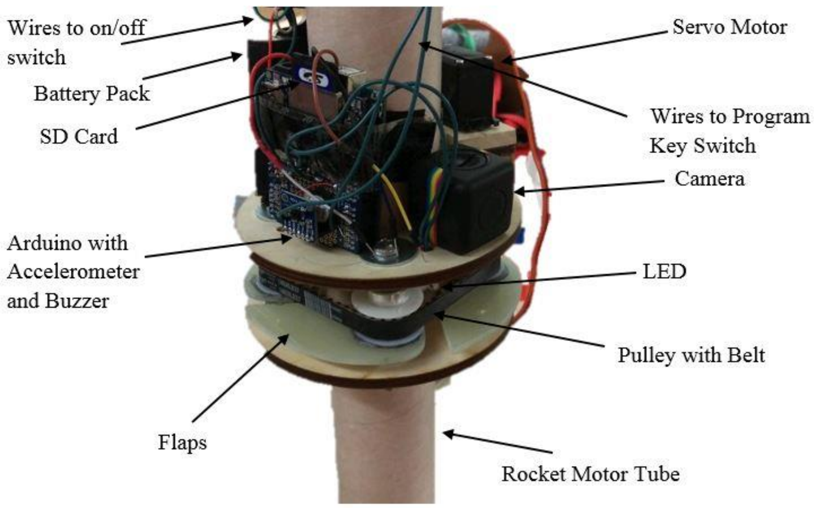


Figure 9: Drag System Mounting Setup

Additionally, another key switch (called the "program switch" in Figure 9) was incorporated into the system (which was mounted on the bulkhead above the system) that allows for toggling between the "Full Height" flight and the "Drag System Deployed" flight programs without having to reprogram the Arduino in between flights (which would otherwise have meant a lot of dismantling of the system just to reach the Arduino in its cramped space). To confirm that the right program is being run, the buzzer beeps at different tones during the delay period (factored into the program) before the launch.

The delay period was set to be 2 minutes to provide time for people to clear the area and so that space on the SD card wouldn't be wasted during that time period. Additionally, the program was set such that the SD card would only log data for 18 minutes after the delay period was done so that unnecessary data wouldn't be logged during the time it took to find the rocket after launch.

After the delay period is done, the LED illuminates the drag system area for the camera (for better video quality) and the rocket is armed and ready for the drag system to deploy (assuming that the drag system program is being run). At this point, the program consistently checks the acceleration data and waits for a consistent increase in acceleration (around 10 consecutive values above a specified acceleration limit [which in the program was set to roughly 12 ft/s^2 above the acceleration of gravity]). This triggers a predetermined delay time equal to the burn time of the rocket motor (3.6 seconds in this case) so that the program could deploy the drag system immediately afterwards to get the maximum drag from the flaps. The flaps are deployed for a predetermined time calculated from a Matlab simulation of the flight (in this case, 7 seconds). After this time, the flaps are retracted and the drag system is unarmed for the duration of the flight. Finally, it should be noted that throughout this entire process (besides during the initial delay) acceleration data is being logged to the SD card regardless of the fact if the system deploys or not.

Another aspect that should be noted is that when the electronic system in is initially turned on (before the rocket is launched), the flaps deploy and retract for 5 cycles to show that the system works and to show that the flap program is running (since this cycle wouldn't run if the "Full Height" flight program was running).

Some pictures of the drag system in action are shown below in Figures 10 and 11.

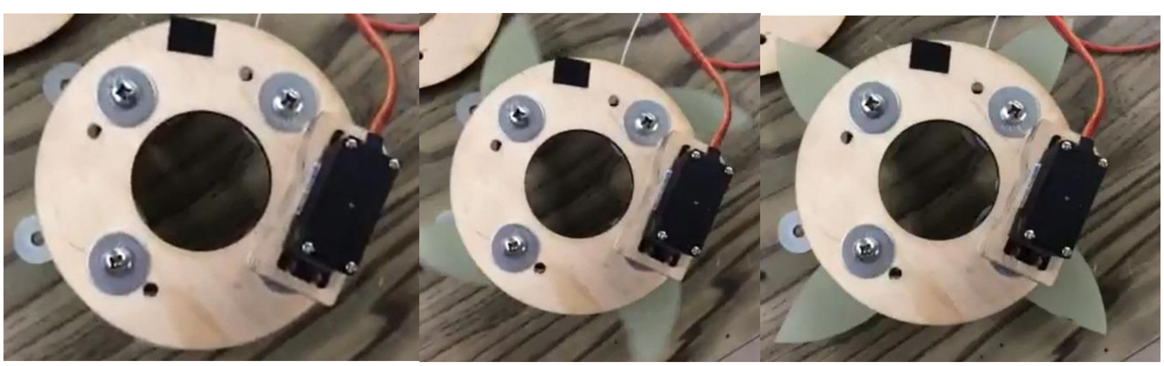


Figure 10: Progression of flaps deploying from left to right

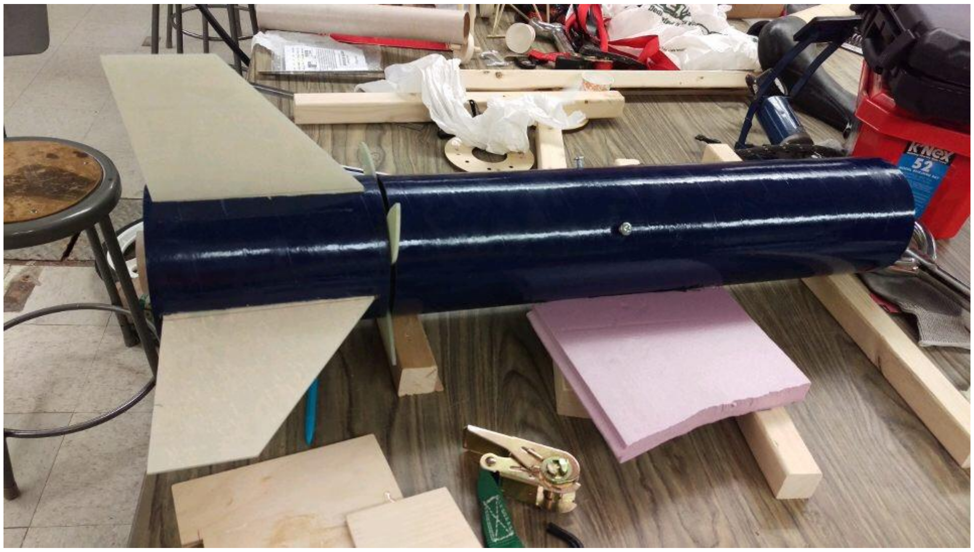


Figure 11: Flap System Deployed in Rocket

Mechanical Design

The mechanical flap system shown in Figure 12 shows the layout of the drag system.

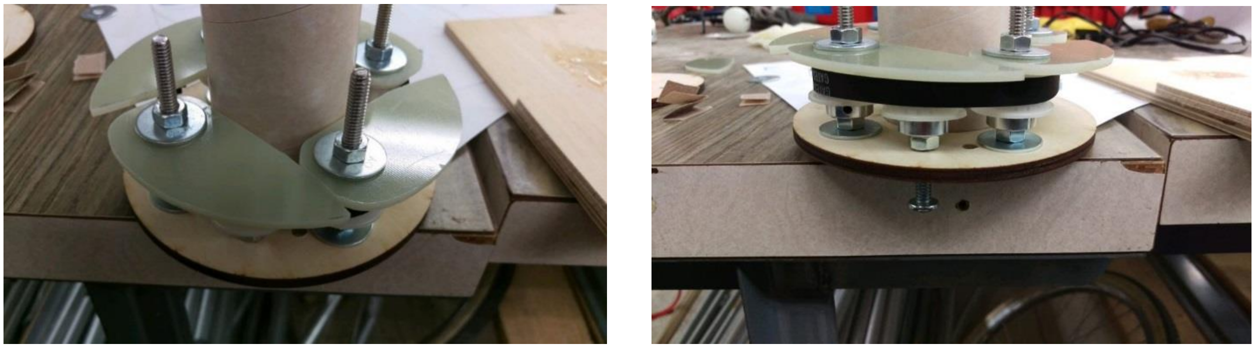


Figure 12: Mechanical Drag System

The flaps were positioned around the rocket motor tube on four equally spaced pulleys such that all of the flaps were completely enclosed, yet flush with the outer surface as well. This is shown clearly in the SolidWorks drawing below in Figure 13.

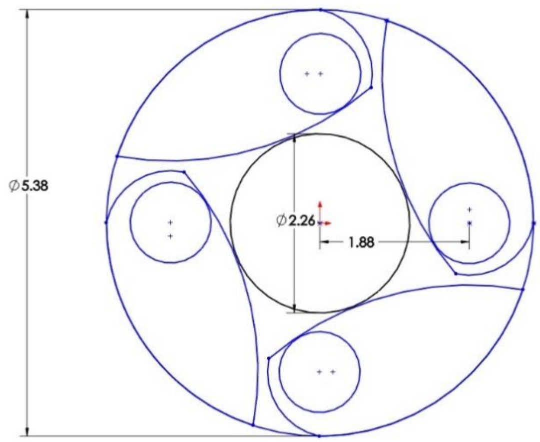


Figure 13: Drag System SolidWorks Drawing

The system consists of a belt and pulley mechanism so that the flaps can be easily rotated without hitting the rocket motor tube. Each pulley was secured in place by using a threaded rod that also functions as an overall structuring tool for the rocket. The flaps were glued to the bottom of each pulley and secured at the same level by using nuts, which were threaded to the structuring rod. A pulley was also attached to the shaft that is turned by the motor which is secured as shown in Figure 14.

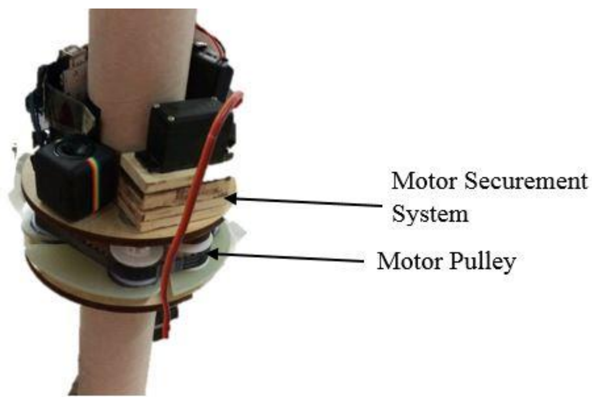


Figure 14: Motor Integration System

The motor was secured such that no bending would occur which would otherwise cause the pulley to “cave in” resulting in inadequate pulley grip. This system proved to be consistent in deploying the flaps in a secure and repeatable fashion.

TEST FLIGHT REPORT

The following sections detail the results of the test flight that took place on April 23rd, 2016. The purpose of the test flight was not only to demonstrate the safety of the rocket design but also to test and collect data on the drag system design. Only one test flight was held, and thus the rocket was only tested using the drag system. However, it is expected that a safe and stable flight with the drag system engaged is evidence that the rocket will be safe and stable without the system as well.

Flight Performance

The finalized rocket was completed and flown in the test flight. A Cesaroni K570 motor was used, as will be used in competition, and all aspects of the test flight were meant to mirror the conditions of the competition flight [6]. Table 2 shows the expected rocket altitude, velocity, and acceleration for the test flight.

Predicted Values	
Maximum Altitude	3976 feet
Maximum Velocity	695 ft/sec
Maximum Acceleration	331 ft/sec^2

Table 2: Test Flight Predictions

These predictions were estimated based on collective Matlab and OpenRocket data. Dimensions and mass measurements were recorded and updated up to the point of launch to ensure the rocket model was as accurate as possible. A numerical summary of the test flight performance can be seen below in the Table of Flight Characteristics section.

Drag System Performance

The performance of the drag system was of particular importance for the test flight. This was for a variety of reasons. First, the difficulty of modeling the drag system flaps in OpenRocket and Matlab made it difficult to be confident in the flight predictions. The data off the test flight would be used to compare against the Matlab predictions and to adjust the system and predictions accordingly. Secondly, the conditions the drag system would be facing were difficult to simulate in a laboratory setting. Force estimations and static load testing was conducted to ensure the system would not fail, but the MSOE wind tunnel was not sufficient to mirror the conditions that the rocket would face mid-flight. For these reasons, the test flight would serve as an important tool to observe and gather data about how the drag system behaved in flight.

While the results of the drag system are discussed in more detail below, the drag system proved able to work as it deployed following motor burnout. It had a positive effect on adding drag to the rocket and reducing the rockets altitude. However, the drag system faced significant problems following deployment, and those issues are discussed below.

Recovery System Performance

To deploy the parachutes, a black powder charge was needed on each end of the altimeter bay in order to separate the rocket mid-flight. The black powder charges, which will be detonated by the ALTS25 altimeter, needed to have their masses calculated in relation to the parachute bay's size.

Otherwise, if the charges were too large, the detonation of the black powder could damage the body tube or the parachute, or the rocket may not separate if the charges are not large enough. Equation 5 below was recommended in order to calculate the correct mass of the black powder [7].

$$Mass\ of\ \ Black\ Powder\,(g) = 0.006\ x\ Length\,(inches)\ x\ Diameter\,(inches)^2 \tag{5}$$

It worked out that the parachute bays were the same size, with the inner diameter of the body tube being 5.38 inches and a length of 10 inches. These measurements give us a mass of 1.74 grams for the black powder charges. However, it was recommended by our technical advisor to use 2 grams for the drogue parachute and 3 grams for the larger main parachute.

Table of Flight Characteristics

This section highlights the characteristics of the rocket prior to launching, as well as a summary of the numerical data of the flight.

Characteristic	**Value**
Rocket Mass	270 ounces
Rocket Length	63 inches
Motor Used	Cesaroni K570
Maximum Altitude	4966 feet
Maximum Velocity	720 ft/sec
Max Acceleration	335 ft/sec^2
Flight Time	179.9 seconds

Table 3: Flight Data Summary

DISCUSSION OF RESULTS

The test flight produced both positive and negative results for the rocket. First, the test flight proved the sound construction of the rocket and its ability to be launched and recovered safely. But the test flight also exposed flaws in the drag system design, as seen below.

Flight Data Results

The altitude, velocity, and acceleration data all recorded values higher than that of our flight predictions. The altitude data resulted in a 25% error, but this result is discussed below in the Drag System Results. The velocity data had a 3.6% error based on the predicted data, and the acceleration was off by roughly 0.3%. The maximum velocity and acceleration data for predicted vs. actual for this flight was extremely close. This puts confidence in the OpenRocket and Matlab simulations. The small difference in velocity could be a result of slight miscalculations in component masses or mass locations, while the acceleration difference can be considered negligible.

Drag System Results

During the test flight, the drag system experienced technical difficulties which resulting in less than satisfactory data acquisition. While it is not for certain, the recorded video and logged data from the Arduino micro-controller support the theory than inadequate securing of the micro-controller led to the Arduino restarting and disrupting the drag system. The logged data shows gaps and holes in the recorded values, evidence that it did not record the entire accent to apogee of the rocket. Furthermore, the recorded video shows the drag flaps going out correctly, only to be draw back in, and then put in and out in sequence. This sequential putting out and drawing back in effect that was seen indicated that the Arduino reset the program, as this was the same as the startup sequence when the micro-controller is first powered on. Upon observation of the rocket following recovery, it is believed that the Arduino micro-controller was not secured well enough through the flight, and the allowed movement triggered the reset button on the controller. This failure resulted in no flight acceleration data being recorded, since there was a two minute delay in data recording after the power-on sequence was initiated.

However, the following conclusions were still able to be drawn from the test flight. First, the video recording and testing after recovery prove that the drag system is able to deploy under the intense conditions following motor burnout, as well as not fail under loading. Secondly, while the drag flaps were not deployed for their intended amount of time, the brief time they were deployed did have an effect on the rocket’s apogee. For example, without the drag system engaged, the rocket’s predicted apogee is 5191 feet, and the results of the test flight, seen above in the Table of Flight Characteristics section, put the rocket’s apogee at 4966 feet. This is far from the desired 25% apogee reduction, but gives evidence to the fact that the drag system can be successful in reducing the rocket’s apogee.

PLANNED CHANGES AND IMPROVMENTS

As noted in the Drag System Results section, the largest change that will be made on the rocket between the test flight and the competition flights will be the housing of the drag system electronics. This is mainly in the Arduino micro-controller securement system. The initial design is being thrown out, and a new design will be implemented in order to prevent the problems outlined above from happening in the future. Two additional centering rings, connected by four threaded rods will form a payload bay above the drag system. This bay will not only be removable, but will ultimately prove to be a much better way to secure the drag system electronics and prevent failure as a result of the Arduino resetting. Additionally, the Arduino code was altered in order to better adapt in the case of failure. The code now logs data for 20 minutes after startup no matter what, and deploys the flaps 3.6 seconds after startup, just in case the Arduino resets right after launch. This provides a second layer of protection in the case that a failure similar to that of the test flight occurs. Otherwise, the program is still the same as described in the drag system section. Lastly, the decision was made to update and stick with the black powder charge amounts given to us at the test flight. For future launches, two and three grams of black powder will be used.

CONCLUSION

After reviewing the competition parameters, a stable rocket design was developed. Preliminary analysis of different components was performed to determine the optimal body tube diameter and length, nose cone, and fins. The final rocket design has a length of 63 inches, an outer diameter of 5.38 inches, and a weight of 16.875 pounds.

A drag system was designed within the competition parameters. It consists of a pulley-timing belt system that turns the flaps out of the rocket at motor burnout, and rotates them back in before apogee. A 180° high torque servo motor controlled by an Arduino Uno microcontroller was chosen to deploy the flaps. The Arduino is also fitted with an accelerometer to record acceleration data, which can then be used to calculate coefficient of drag data.

After establishing the specifications of the design, the rocket was constructed using acceptable high powered rocketry construction techniques. A test flight of the rocket was then performed, and revealed flaws in our design. The Arduino was not secured properly which caused its program to reset and proceed to run the pre-flight test of the flaps. This problem has been addressed by redesigning the electronics mounting system. The program was also changed to make the pre-flight test program identical to the in-flight program, so in the case of another reset, the flaps will still deploy correctly. We believe that these changes will result in a launch that will score highly in the flight portion of this competition.

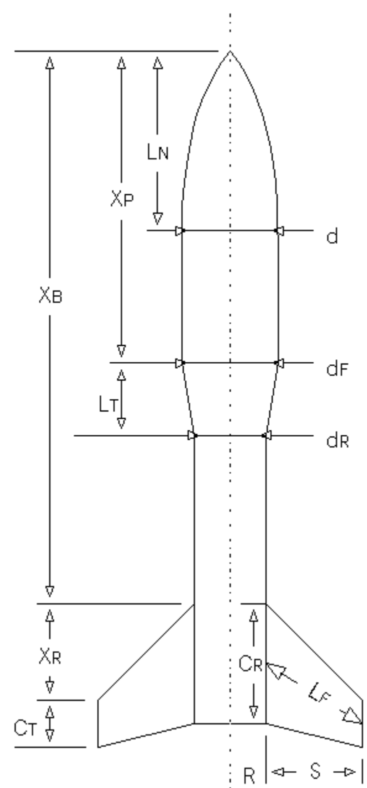
APPENDIX A: BARROWMAN'S THEORY

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) [8]

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: $X_N = 0.666L_N$
For Ogive: $X_N = 0.466L_N$

Conical Transition Terms

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

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

Fin Terms

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

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

Finding the Center of Pressure:

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

Find CP Distance from Nose Tip:

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

APPENDIX B: 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] Canepa, Mark B. *Modern High-Power Rocketry 2*. Victoria, B.C.: Trafford, 2005. Print.

[8] 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