TEAM WHOOSH GENERATOR

REGIONAL DESIGN REPORT

2014 GREAT MIDWESTERN

REGIONAL ROCKET COMPETITION

MILWAUKEE SCHOOL OF ENGINEERING

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PROBLEM STATEMENT

The objective of the 2014 Wisconsin Space Grant Consortium (WSGC) Collegiate Rocket Competition is to design, build, and fly a single-stage, high-powered rocket to accurately reach an apogee of 3000 feet, along with design restrictions and two added design objectives. The rocket must use a motor as specified by WSGC, have a maximum length of 84 inches, have a body tube diameter between 4 and 6 inches, use a flight data recorder provided by WSGC, and be safely recovered in a flyable condition by an electronically deployed parachute system. Also, a system in addition to the altimeters already on board must be implemented that records data which can be used to find the rocket's velocity and acceleration during ascent. This report describes Team Whoosh Generator's rocket design and anticipated performance based on these restrictions and objectives.

EXECUTIVE SUMMARY

In order to meet all of the objectives of the competition, a unique, stable rocket design was formulated. Using preliminary analysis of thrust and drag for varying motors and rocket diameters for a target altitude of 3000 feet (must be between 2500-3500 feet), the K454 motor was selected, along with a 5.54 inch rocket diameter. Using a combination of MATLAB simulations and modeling in OpenRocket, a 13-inch ogive nosecone and trapezoidal fins were selected for stability, and a rocket length of 65.5 inches and a total rocket weight of 17 pounds (fully loaded) were chosen. An RRC2 mini altimeter and an ALTS25 altimeter given to the team at last year's altimeter conference were selected to complete the parachute requirements and for recording flight data. At an estimated apogee of 3012 feet, a drogue chute will deploy, and upon reaching 600 feet, a main chute will deploy. This will slow the rocket to a safe ground hit velocity of about 18 ft/s.

As an additional measure of velocity and acceleration during the rocket's ascent, a pressure sensor system was designed to measure drag forces on the nosecone. From this, velocity and acceleration can be calculated. With this system and the other internal electronics requirements, two payload bays were needed. In order to recover the rocket in a minimum amount of time, a GPS was placed in the upper bay, bright paint colors were used for easy spotting, a drift calculator was utilized to estimate drift distance for varying wind speeds, and several cars and people will be scattered around the grounds for quick recovery at the launch. Included in this report are a detailed design overview, anticipated performance, photos of the construction process, and a detailed budget.

TABLE OF CONTENTS

PROBLEM STATEMENT ... 2
EXECUTIVE SUMMARY ... 2
ROCKET DESIGN AND CONSTRUCTION ... 4
Assumptions and Limitations ... 4
Airframe Design ... 4
Motor Choice ... 4
Body Tubes and Length ... 5
Nose Cone ... 5
Fins ... 5
Center of Gravity and Center of Pressure ... 6
Pressure Relief ... 7
Parachute Design ... 8
Lower Payload Bay Design ... 8
Alternate Velocity Measurement System Design ... 9
Rocket Recovery Considerations ... 11
Rocket Construction ... 12
ANTICIPATED PERFORMANCE ... 14
Assumptions and Limitations ... 14
MATLAB Simulation ... 15
OpenRocket ... 17
Flight Predictions ... 18
CONCLUSION ... 20
APPENDIX A: DETAILED EXPENSE REPORT ... 21
APPENDIX B: BARROWMAN’S THEORY ... 22
APPENDIX C: RESOURCES AND ACKNOWLEDGEMENTS ... 24

ROCKET DESIGN AND CONSTRUCTION

Assumptions and Limitations

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.

Airframe Design

Motor Choice

The motor was chosen using MATLAB code developed in previous years and improved upon this year. The code uses the thrust curves of various motors, the propellant masses, the drag coefficient, and the outside diameter of the rocket (which is inputted). All possible motor choices for the competition were placed in the code and a plot of possible rocket masses versus altitude of the rocket's flight was created. This is shown in Figure 1 for a diameter of 5 inches. To achieve an altitude of 3000 feet and still have room for the extra mass added from the Alternate Velocity Measurement System (AVMS), which is described later, a large motor was necessary. The chosen motor was the Cesaroni K454 because it was lowest power motor that would achieve an apogee of at least 3000 feet and allow for extra weight, with a total rocket weight (without fuel) of around 16 pounds.

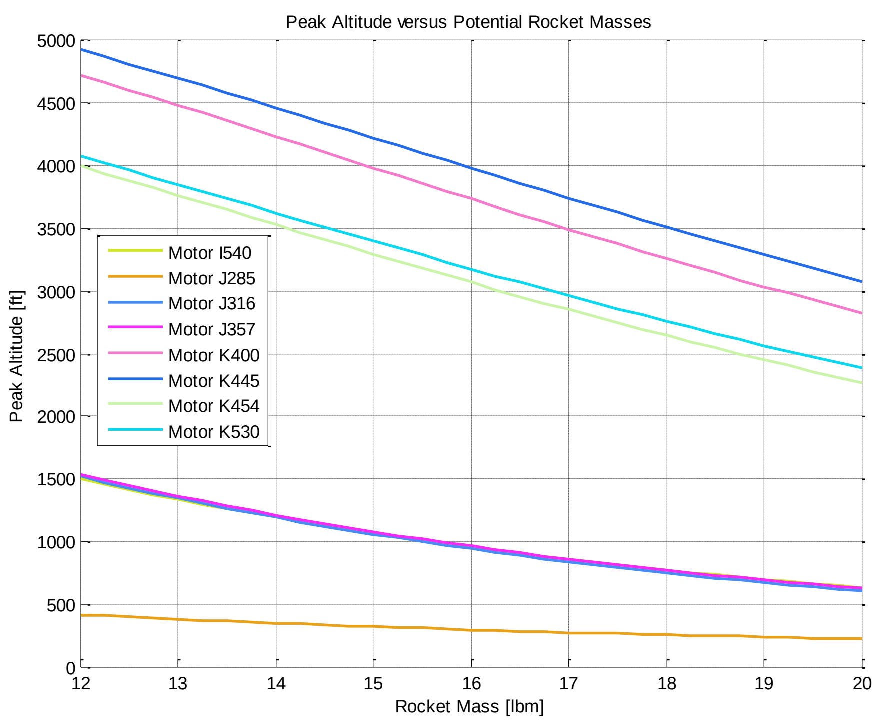


Figure 1: Altitude versus Rocket Mass for Each Motor Option

Body Tubes and Length

The body tubes 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 body tube diameter was determined using the same MATLAB code used to determine the motor. The possible rocket body diameters for the competition were between 4 to 6 inches. Since the body tubes are normally available in one inch increments, diameters of 4, 5, and 6 inches were run along with the MATLAB code. It was determined that a 5 inch diameter body tube would cause the rocket to have an apogee closest to 3000 feet and still be flexible with the mass of the rocket. Unfortunately the team was unable to find cardboard tubing that was available at 5 inches in diameter. The closest to the 5 inch diameter tubing without going down to 4 inches or up to 6 was 5.54 inches in diameter. Inputting 5.54 inches into the program still proved this to be a viable option, so this was chosen for the rocket.

The body tube lengths were heavily dependent on the design restriction of a maximum total rocket length of 84 inches. OpenRocket, a free rocket design software program, was the primary software used to design much of the rocket. OpenRocket was used to calculate optimum body tube lengths. It was found that the lower body tube (to house the motor mount and drogue parachute) would have a length of 25.5 inches. The upper body tube (to house the main parachute) would have a length of 16.5 inches. The AVMS would add another 8.5 inches to house the device. These lengths help to bring the rocket to an apogee of approximately 3000 feet, with favorable centers of gravity and pressure. The total length of the rocket is 65.5 inches, which is below the 84 inch restriction.

Nose Cone

After choosing body tube size of 5.54 inch, nose cone options were limited to a 5.38 inch diameter. Only two durable plastic options were found with an ogive shape, both made by LOC Precision Rocketry; the PNC Short and the PNC Long. With the short length measuring 13 inches and the long length measuring 21 inches, the 13 inch length was chosen in order to maximize the available space for electronics bays, parachutes, and other miscellaneous items while remaining inside of the max overall rocket length. The ogive shape was chosen because it has a low coefficient of drag which will allow for a higher apogee with the increased weight of the payloads.

Fins

According to Barrowman's theory, the fins are the main component on a rocket that determines the center of pressure. The nosecone 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 and body tube sizes, the fins were designed using an iterative method in OpenRocket.

Since the rocket uses a K454 motor this year and is about twice the weight as last year's rocket, thicker and larger fins were required, so the Public Missiles C series fins were evaluated. The stability caliber and maximum altitude were monitored as different fins were placed into the model. Because large fins lower the overall lift force (applied at the center of pressure), long, triangular fins produced a highly overstable rocket with the center of pressure too near the bottom of the lower body tube. As fin designs were narrowed down, the C-08 fins were found to produce a stable rocket at ignition and burnout along with an acceptable maximum altitude around 3012 feet for a rocket weight of about 17 pounds. This was for 4 fins. With 3 fins, the center of pressure moved up the rocket, producing an understable rocket, and the drag contribution of the fins was lowered, increasing the maximum altitude.

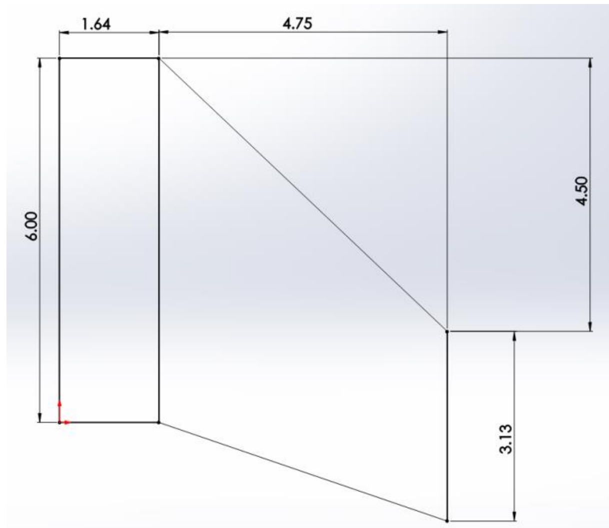


Figure 2: Fin Dimensions

Therefore, the chosen fins were C-08 G-10 prism fiberglass fins from Public Missiles with a thickness of 0.093 inches. The fin dimensions are shown in Figure 2. Four fins were chosen to meet the stability and apogee requirements. The fins were attached to the rocket by placing them through fin slots in the lower body tube and using epoxy to attach them to the motor mount tube and the outer and inner surfaces of the body tube.

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.

Many assumptions were made during the derivation of Barrowman's theory for predicting the center of pressure, including: the flow over the rocket is potential flow, the point of the nose is sharp, fins are thin flat plates, the angle of attack is near zero, the flow is steady and subsonic, the rocket is a rigid body, and the rocket is axially symmetric.

The rocket design does violate some of these assumptions, because the rocket is not rigid, the nosecone is not sharp, and the rocket is not perfectly axially symmetric. However, the theory was still applied with the understanding that minor uncertainties will be present as a result. Details can be found in Appendix B.

Table 1 shows the locations of the CP and CG and the caliber stability at ignition and at burnout according to the OpenRocket simulation.

Table 1: Locations of CP and CG (In Inches from Nose Cone Tip)

	CP	CG	Stability (Caliber)
Ignition	47.9	41.4	1.16
Motor Burnout	47.9	39.4	1.52

From this analysis, it can be concluded that the rocket will be stable during the entire ascent portion of the flight.

Pressure Relief

The two barometric altimeters used to deploy the drogue and main parachutes require static pressure port holes. Static port holes are required for pressure equalization between the air inside the bay and the outside air during flight. This is very important since the parachutes could be deployed too early or too late if the static port holes are not the correct size. The general rule for port hole sizing is to use a ¼ inch diameter hole (or equivalent area if multiple smaller holes are used) for every 100 cubic inches of bay volume. It is also recommended to use at least three holes spaced evenly around the body tube to help negate the effects of crosswinds. Pressure relief holes should not be drilled in-line (180°) from each other as this would negate the relief. The RRC2 mini user manual recommends the use of the following equations for port hole sizing.

The diameter of a single port hole:

$$Single\ Port\ Hole\ Diameter = 2\sqrt{\frac{Volume\ of\ Bay}{6397.71}} \tag{1}$$

The area of a single port hole:

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

The diameter of multiple port holes:

$$Multiple\ Port\ Hole\ Diameter = 2\sqrt{\frac{Single\ Vent\ Area}{(\#\ of\ Holes)(\pi)}} \tag{3}$$

The diameter of the top payload bay is 5.38 inches and the inner length of the bay is 5.75 inches. This yields a volume of 130.7 cubic inches. The diameter of a single port hole is equal to 0.24 inches with an area of 0.047 square inches. Three holes were drilled into the payload bay each with a diameter of 0.141 inches spaced 120 degrees apart.

During the rocket's ascent the atmospheric pressure surrounding the rocket decreases. In order to relieve the pressure, a quarter inch hole was drilled into both the upper and lower body sections of the rocket. If these holes are not present the higher pressure inside the rocket could cause the rocket to separate and deploy its parachutes early.

Parachute Design

The rocket will use a dual deployment system. This means the rocket will deploy a small drogue parachute at apogee and then a main parachute at a lower altitude to minimize the drift of the rocket allowing easier retrieval of the rocket. The chosen parachute to be used is a 24 inch drogue chute that will deploy at apogee and a 60 inch main SkyAngle Classic parachute that will deploy at 600 feet. The rocket will have a descent rate of 18 feet per second once the main cute has opened. Two altimeters will be used for redundancy to ensure the parachutes deploy. The parachutes are shown in Figure 3.

Figure 3: Drogue and Main Parachutes

Lower Payload Bay Design

The Lower Payload bay was made from a 5.372 inch OD tube that is reinforced with a 5.24 inch OD stiffy tube. It is 6.5 inches long and since the outer diameter of is 5.372 inches, it fits perfectly into the 5.38 inch ID airframe. A small piece of airframe, measuring 1.5 inches in length, was cut from a body tube and epoxied in the center of the payload bay to turn the bay into a coupler. Two barometric altimeters were used in the payload bay a RRC2 mini used in previous years and an ALTS25 given to the team at the Altimeter Conference. These altimeters will be used to deploy the drogue and main parachutes as well as record the altitude of the rocket. The payload bay also holds the Raven III (WSGC flight data recorder) along with two 9 volt batteries that will power the previously mentioned electronics. Two key switches were placed 180 degrees apart on the payload bay to allow easy arming of devices on the launch pad. One key switch is for turning on the WSGC flight data recorder and the other is for arming both altimeters. Terminal blocks were placed at either end of the bay to allow easier attachment of black powder charges on launch day. The assembled payload bay is shown in Figure 4.

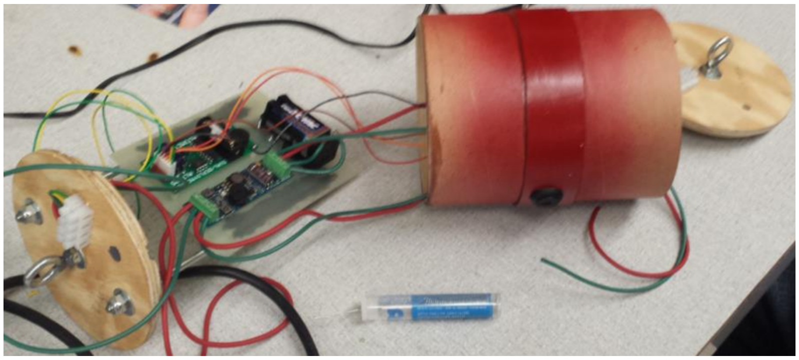


Figure 4: Lower Payload Bay Assembly

Alternate Velocity Measurement System Design

A requirement of this year's competition was to record data that can be used to find the rocket's velocity and acceleration during its ascent using a device other than the altimeters used for electronic deployment of the parachutes.

Several ideas on how to create an Alternate Velocity Measurement System (AVMS) were conceived which included using a hot wire anemometer, a pitot tube, and a pressure sensor. After reviewing a hot wire anemometer, it was considered to be too expensive and too fragile to handle a rocket launch. Next, a pitot tube was considered but the response time of roughly one second would prove to be too long; it would not be able to provide sufficient data points to calculate the velocity. The final idea of using a pressure sensor that would be activated using the force from drag on the rocket and equating the velocity from the drag force equation was determined to be the best choice.

Two tandem designs were then created, and a decision matrix was assembled in order to determine the most feasible option. The first option involved having a split nose cone attached to a lever which would act just outside of the boundary layer. The main disadvantages of this were the added drag (and calculating this drag) due to the external features that extrude outside of the main rocket, the attaching arm would have a lot of stress applied to it, and the design needed an inner platform inside of the electronics bay which would separate the bay halves. The advantage was its ease of assembly. The second option involved the main nose cone activating the pressure switch with the use of an aluminum rod that passes through the top end of the electronics bay. The main disadvantage of this design was the difficulty of assembly since the measurements need to be precise. The advantages of this design were that the drag would be greatly reduced and the risk of failure would be low. Shown in Table 2 is the decision matrix for the 2 designs.

Table 2: Alternate Velocity Measurement System Decision Matrix

		Split Side Nosecones		Main Nosecone	
Decision Factor	**Weight (1-5)**	***Rank****	***Score***	***Rank****	***Score***
Ease of Assembly	4	3	12	4	16
Drag Contributions	2	5	10	1	2
Complexity	5	4	20	3	15
Risk of Failure	5	4	20	2	10
Ease of Velocity Calculation	3	3	9	2	6
Total Score			***71***		***49***

**Rank: 1 = most beneficial, 5 = least beneficial*

The design that was chosen was the one involving calculating the velocity using the force applied to the main nose cone. The device works using a pressure sensor that can read between 0 and 1000 pounds of force depending on the size of the resistor used in its amplifier circuit. The pressure sensor is a variable resistor that will decrease in resistance as the force applied to the sensor (with an active sensing area of 0.375 inches in diameter) goes up. The pressure sensor feeds into an analog pin on an Arduino Uno board with an Ethernet shield attached to it. The pressure sensor is shown in Figure 5. The Arduino Uno reads the voltage across the pressure sensor and then saves it to a micro SD card inserted on the Ethernet shield. This voltage has a known relationship to the force being applied to the pressure sensor, which was calibrated. The Arduino Uno also has a piezo buzzer attached to one of its digital pins that beeps at a regular interval to show the force sensor is connected and recording data.

Figure 5: Pressure Sensor for AVMS

The payload bay that houses the AVMS has 2 fiberglass boards in it to support the electronics. The electronics that are housed in the upper bay are the force sensor, the force sensor’s amplifier circuit, the Arduino Uno with attached Ethernet Shield, the Garmin GTU 10 Global Positioning System, and three 9-Volt batteries: two used for the force sensor’s amplifier circuit, and one used to supply power to the Arduino Uno. The force sensor’s amplifier circuit and the Arduino Uno will be turned on at the launch pad using key switches. The boards are centered around the aluminum rod running from the nose cone down to the force sensor. Conduit is attached to the bottom bulkhead to guide the aluminum rod in the bay. The nosecone is free to move down one eighth of an inch but a removable pin in the aluminum rod stops the nose cone from going upwards. A diagram of the upper bay is shown in Figure 6.

The voltage across the pressure sensor will be recorded which will lead to the drag force on the nose cone. The velocity will be found using the drag force equation shown in Equation 4.

Figure 6: AVMS Setup

$$F_d = \frac{1}{2}\rho V^2 C_d A \tag{4}$$

where F_d is the drag force on the nose cone, ρ is the density of air, V is the velocity of the rocket, C_d is the coefficient of drag of the nose cone, and A is the frontal area of the nose cone. The velocity can be solved for as shown in Equation 5.

$$V = \sqrt{\frac{2F_d}{\rho C_d A}} \tag{5}$$

Using Equation 5 and the recorded data on the SD card, the velocity of the rocket's ascent can be determined. The acceleration of the rocket can then be determined by taking an integral of the velocity data. This velocity and acceleration data will be compared to the data from the competition flight data recorder.

Rocket Recovery Considerations

Previous competitions have shown that recovery time can be frustratingly long, preventing smooth progression through the competition launch day. Without provisions taken to reduce this time, rockets can become lost indefinitely. To prevent this, several recovery precautions were implemented:

1. A Garmin GTU 10 GPS locator was chosen to provide up-to-date transmitted location information on the rocket. This was placed in the upper payload bay in order to prevent signal interference with the altimeters in the lower payload bay.
2. A drift calculator on the freeware software "Rocketry Tools" by Jack Anderson (see Reference page) was used to estimate the drift distance of the rocket under certain conditions. It takes into account wind speed, maximum altitude, descent rate for drogue only, descent rate with all parachutes open, and altitude for main deployment. For a wind speed of 10 MPH, a drift distance of 0.21 miles is predicted. The wind speed on the day of the launch will be incorporated into the drift calculator.
3. The rocket paint colors were chosen to be red and yellow. Last year, the team chose black for the lower body tube, which was not a good choice because the rocket landed in water with only the black tube above the surface, making it very difficult to find. Red and yellow are stark colors which will be easy to spot.
4. The team will bring several people and cars to have a split-up formation during the launch. People spread around a radius of the drift distance will be stationed with cameras to watch the rocket as it comes down. If rockets launched before this rocket tend to drift in a certain direction, the people will be stationed mainly in that direction.

These precautions will greatly reduce recovery time.

Rocket Construction

Using OpenRocket, the design was determined and calculations proved the performance of the rocket to meet the specifications of the competition. Taking the results from OpenRocket, the parts and supplies were then purchased from certified rocketry vendors and the construction of the rocket began.

It had been determined to utilize cardboard as the team members had worked with this material in previous years. This material allowed for the ability to cut tube lengths, fin slots, holes for key switches and to apply epoxy and paint easily. The team also knew the performance that it would provide. Two body tubes were purchased and then cut to the specified lengths determined in OpenRocket. It was determined that a hack saw provided a more accurate cut rather than the band saw on the first attempt in the MSOE machine shop. After cutting a section of tubing, it was sanded to insure a smooth finish. Once the two sections of body tubes and the coupler were cut to 25.5, 16.5, 8.5 and 1.5 inch pieces, the sizes were confirmed and each section was slid together to get an idea for the size of the rocket. Once all measurements were confirmed the 1.5 inch piece of body tube was glued in the middle of the coupler using a two part two-ton epoxy. The coupler houses the altimeter bay with all altimeters, data recorders, batteries, and electronic key switches to turn all these devices on before the launch of the rocket. The motor side and nose cone side of the body tubes were then placed onto the coupler to confirm all fits remained the same.

Figure 7: Motor Mount with Added Weight

A decent portion of time was devoted to determining where weight could be added to the rocket. It was decided that weight would be placed around the motor mount tube in a symmetric fashion. This method of attachment was a very secure method to add a large amount of weight. A length of steel rod was found that would provide enough weight. The rod was cut into two 1.5 pound sections that were mounted between the centering rings of the motor mount tube. The rod was mounted by drilling and tapping a hole in each end. Then bolts were fed through the centering rings and secured with JB Weld. A photo of the completed motor mount with additional weight is shown in Figure 7.

Throughout the construction process, careful work was done on the aluminum rod in the AVMS. The aluminum rod provides an extension from the nose cone that will contact the force sensor. The aluminum rod was machined to the proper diameter by a lathe in the MSOE machine shop. A photo of the machining process is shown in Figure 8.

The end of the rod that is opposite the force sensor is inserted into the nose cone. To insure the rod end will stay in the nose cone, the rod is threaded and will be secured with a nut and JB weld.

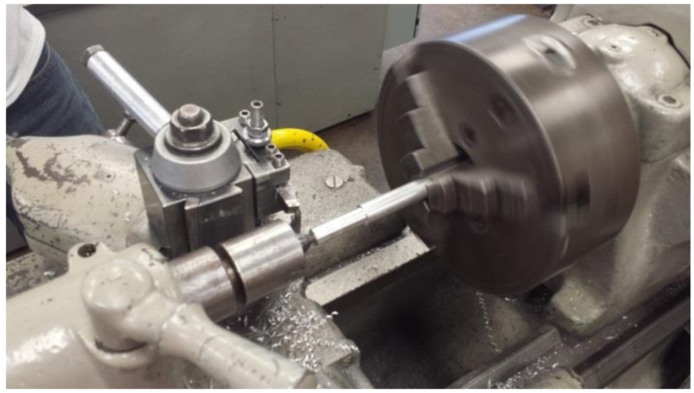


Figure 8: Aluminum Rod Machining for AVMS

In the design of the rocket it had been determined that 4 C-08 fins, would then be placed evenly around the body tube at 90 degree intervals and with no angle applied. The locations of the fins will be marked on the body tube with pencil and then the slots 6 inch tall and 0.093 inch wide will be cut using a razor blade to allow for a snug fit. With each of the 4 fin slots cut, the motor mount and centering ring will be placed into the end of the body tube and epoxied with the same two part two ton epoxy used in the coupler. Once the motor mount dries and is in place, each fin will be placed into position and epoxied. This process will be repeated for each fin. Once all four fins are epoxied, the last centering ring will be epoxied and the motor retainer will be JB welded to the motor tube. This will allow for a strong and secure bond under the strong forces and heat that the motor will produce during launch.

Team Whoosh decided that the rocket will be painted with a yellow fading into red paint theme. Additionally, white a vinyl decal saying “Whoosh” will be placed on the lower body tube. This will be done in the MSOE paint booth located in the student center campus building. With the rocket painted, the switches will be placed into the coupler, the shock cord, drogue chute, and parachute will then be attached to the eye bolt on the nose cone and the U-bolt placed on the top centering ring of the motor mount. With all the chutes, cords, altimeters, data recorders, and locating devices placed in the rocket assembly, the construction of the Team Whoosh Generator rocket will be finished. A photo of the completed rocket is shown in Figure 9.

Figure 9: Completed Rocket

ANTICIPATED PERFORMANCE

The anticipated performance of the rocket was simulated using two programs: MATLAB and OpenRocket. The results of both simulations were compared to estimate the performance of the rocket on launch day. The following sections detail these simulations.

Assumptions and Limitations

The motor thrust curve for the Cesaroni K454 motor used for the competition is shown in Figure 10, made available from ThrustCurve.org.

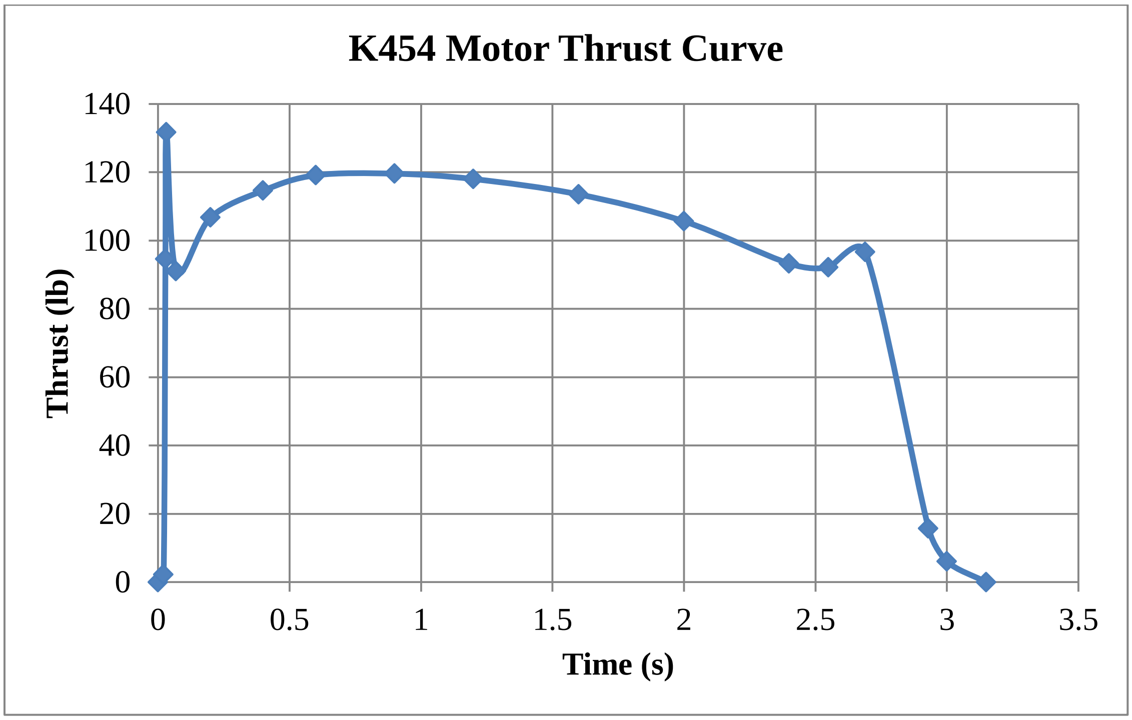


Figure 10: Motor Thrust Curve

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 thrust curve is accurate was used for the simulations.

For MATLAB, the primary assumption for the simulations was that the rocket would be launched vertically and would 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. Other forces, such as from wind, are not taken into account. For OpenRocket, however, these parameters can be taken into account.

There are, of course, factors that could not be taken into account in these simulations, such as stability, rotation, and deviation from vertical flight. However, upon arrival to the launch site, further available data (wind speed and direction) is then taken into account in the OpenRocket simulation. Any last minute weight is added or removed to optimize performance.

MATLAB Simulation

MATLAB was used to estimate the desired weight of the rocket to reach an apogee closest to 3000 feet. A MATLAB program written and revised through previous year's competitions was used to find this. Figure 11 shows the outcome of this simulation.

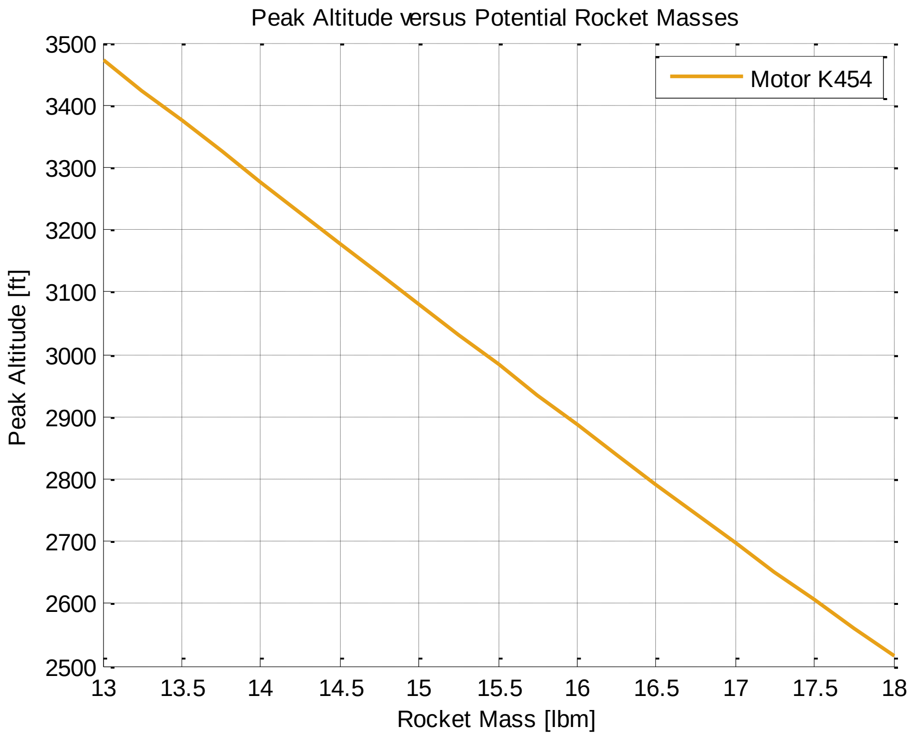


Figure 11: Simulation of Peak Altitude as a Function of Rocket Mass

As seen from the Figure 11, to reach a simulated altitude of around 3000 feet, the rocket mass (total without propellant) must be around 15.5 pounds. This is useful for finalizing the weight on launch day, as well as cross-checking the results from the OpenRocket and MATLAB flight simulations. As will be seen later, both the OpenRocket and MATLAB simulations show that a rocket mass around 15.4 pounds produces favorable flight outcomes (including apogee near 3000 feet).

A MATLAB simulation for the rocket flight performance was then developed using numerical methods. The main function and the simulation program itself were used is from previous years of rocket competitions. The function 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 Equation 6.

$$m_i v_i + F_i \Delta t = m_{i+1} v_{i+1} \tag{6}$$

Where F_i is the net force acting on the rocket and Δt is the time step between calculations. The net force acting on the rocket during accent is expressed in Equation 7.

$$\begin{aligned} F_{net} &= F_{grav} + F_{drag} + F_{thrust} \\ &= m_i g + \frac{1}{2}\rho v_i^2 C_d A + T_i \end{aligned} \tag{7}$$

Where:

ρ 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 Equation 7 into Equation 6 and solving for v_{i+1} yields:

$$v_{i+1} = \frac{1}{m_{i+1}}\left[v_i m_i + \frac{1}{\Delta t}\left(T_i - m_i g - k v_i^2\right)\right] \tag{8}$$

Where:

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

Acceleration was calculated using Newton's 2nd law which is expressed in Equation 9:

$$a_i = \frac{F_i}{m_i} \tag{9}$$

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 0.43. These versus time were then plotted against the OpenRocket simulation results. These plots are shown in the Flight Predictions section.

OpenRocket

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 were also be approximated.

OpenRocket was the main resource 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.

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 10 mph produced an apogee altitude difference of only 49 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 3012 feet.

Figure 12 shows the full assembly of the rocket, as modeled in OpenRocket, with a side cross-section view and a 3D component view.

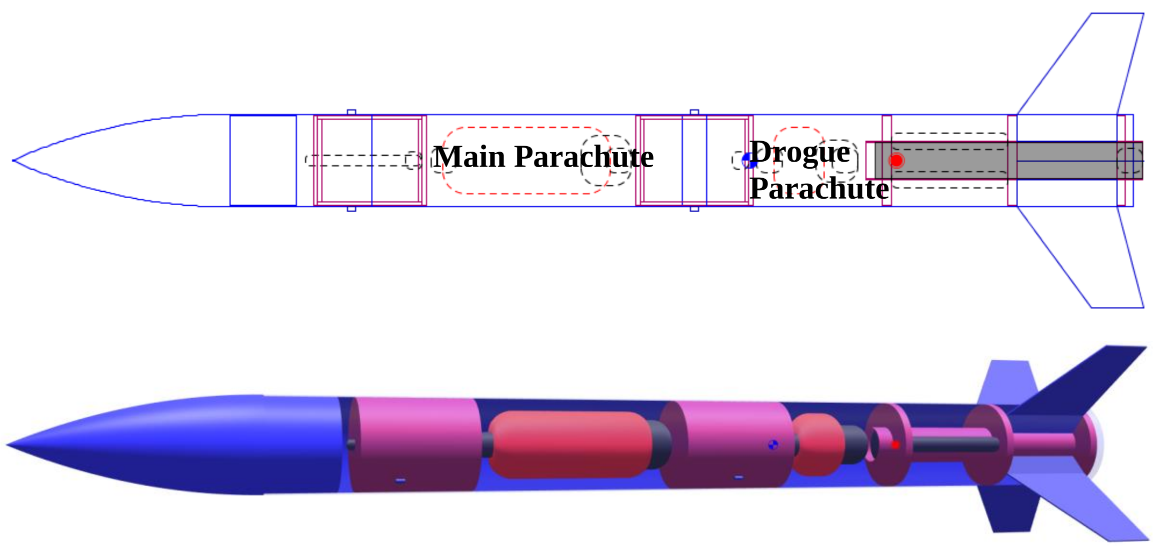


Figure 12: Full Rocket Assembly with Side Cross-Sectional View and 3D Model

Flight Predictions

Altitude, velocity, and acceleration predictions to apogee from MATLAB and OpenRocket are compared in Figure 13. Time to apogee is approximately 14 seconds. The peak altitude, acceleration, and velocity for both simulations are shown in Table 3. Because last year's rocket was designed in a similar way with apogee predictions close to 3000 feet, designing this year's rocket very close to 3000 feet as well was chosen. As seen in Table 3, OpenRocket and MATLAB's simulations produce similar values for altitude velocity, and acceleration. The acceleration is about 300 ft/s^2 less than last year, which is great from a safety standpoint. The motor this year has a low impulse burning over a longer period of time (which allowed the team to use cardboard tubing instead of a more shock resistant material), producing a lower acceleration.

Table 3: Maximum Flight Predictions

	OpenRocket	**MATLAB**
Altitude (ft)	3012	2996
Velocity (ft/s)	461	465
Acceleration(ft/s^2)	201	197

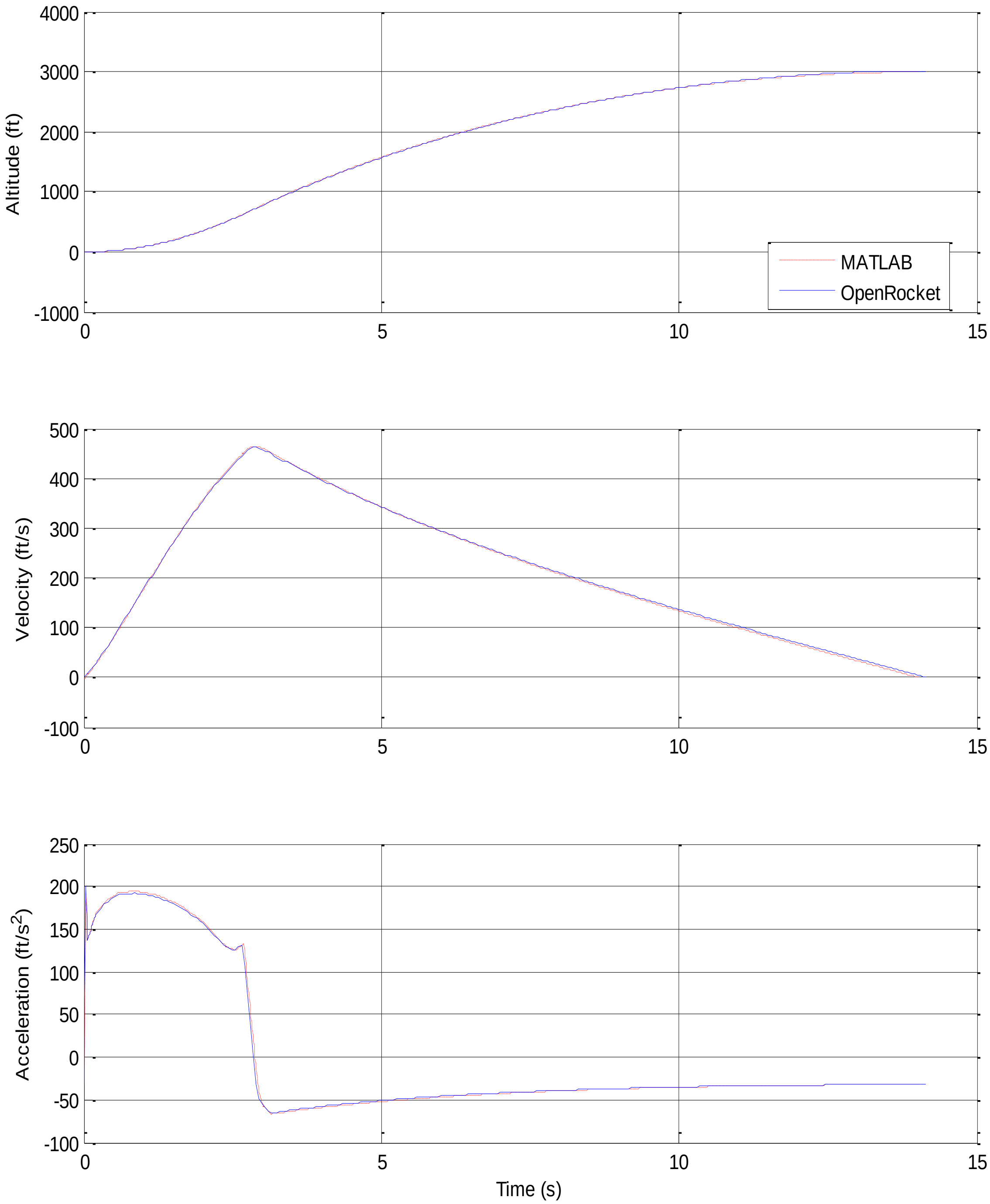


Figure 13: MATLAB and OpenRocket Predictions of Altitude, Velocity, and Acceleration

CONCLUSION

This rocket design will provide a safe and effective flight in which the objectives set by the competition are achieved. The rocket will reach an apogee of approximately 3000 ft where it will then descend by drogue chute to approximately 600 ft where a main parachute will deploy for a safe landing. Complying with the rules, the length of the rocket is 65.5 inches, the diameter is 5.54 inches, and the motor is a K454 motor. The rocket weighs about 17 pounds (with propellant). These parameters were designed using OpenRocket and MATLAB, which modeled and simulated the rocket and launch.

The Alternate Velocity Measurement System (AVMS), as required by the competition, was designed as a nosecone pressure sensor system. The drag force on the nosecone pushes on a pressure sensor, which records a voltage onto an SD card connected to an Arduino board. This voltage corresponds to a force, which is used to find the velocity and acceleration of the rocket. Also, a quick recovery of the rocket will be achieved with a GPS system, drift calculation on the day of the launch, bright paint colors, and many cars stationed throughout the landing area.

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

Item	**Cost ($)**
Fexiforce Pressure Sensor	19.95
Nylon 9 Volt Battery Holder 3x	12.00
Key Switch 5x	30.00
Remove Before Flight Tag 2x	12.00
5.38 inch Body Tube 2x	73.51
Rail Buttons 2x	5.84
5.38 inch Nose Cone	54.95
54 mm Motor Mount tube	7.35
54 mm Motor Retainer	36.38
1500# Kevlar Shock Cord 30ft	27.60
5.38 inch LOC Coupler 2x	16.50
5.38 inch LOC Stiffy TC stiffener 2x	19.90
Arduino Uno + Ethernet Shield Combo Pack	63.95
1 square foot of 1/16 inch G-10 fiberglass board	10.00
Prism Fins 4x	59.55
Nylon Shear Pins 2x	5.90
60 inch Sky Angle Parachute	105.00
Second Motor	116.00
Lettering and CP/CG Decals	9.90
Terminal Block	3.69
1 year of GPS tracking for Garmin GTU 10	49.99
Plywood for Centering Rings	20.00
Epoxy and Misc. Hardware & Expenses	114.83
Tax/Shipping	108.52
Total	**983.31**

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).

The computation of CP isn't as hard as it looks at first. Check out the spreadsheet example at the bottom of this page.

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 stability caliber".

Terms in the equations are defined below (and in the diagram):

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

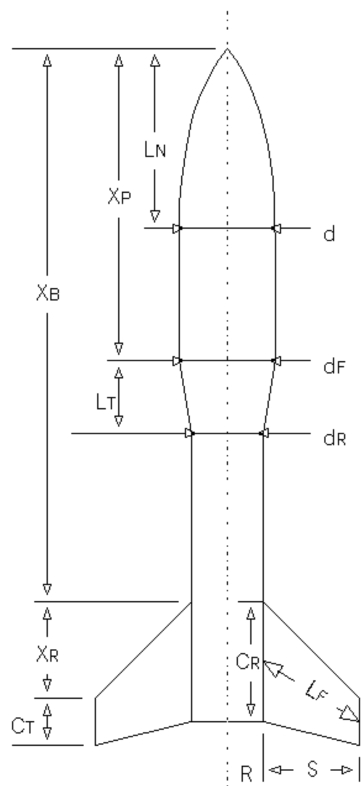
S = fin semispan

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: $\left(C_N\right)_N = 2$
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

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

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

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:

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

http://my.execpc.com/~culp/rockets/Barrowman.html

APPENDIX C: RESOURCES AND ACKNOWLEDGEMENTS

Black Powder Charge Calculator

http://www.info-central.org/?article=303

http://archive.rocketreviews.com/tool_black_powder.shtml

Model Rocket Parachute Descent Rate Calculator

http://www.onlinetesting.net/cgi-bin/descent3.3.cgi

http://www.info-central.org/?article=271

http://www.rocketreviews.com/descent-rate-calculator.html

Static Port Hole Size

http://www.vernk.com/AltimeterPortSizing.htm

RR2 User Manual

http://www.missileworks.com/user_downloads/RRC2X_RevC.pdf

Rocket Competition Manual

Collegiate Rocket Competition Handbook – Courtesy WSGC

Barrowman's Theory Information

http://my.execpc.com/~culp/rockets/Barrowman.html

Drift Calculator

http://www.thefintels.com/aer/software.htm

Acknowledgments

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