University of Nebraska Lincoln

Department of Mechanical Engineering

Preliminary Design Report

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1 Executive Summary

NASA's Space Grant Midwest High-Power Rocket Competition presents a unique and exciting challenge to competing design teams. Each team must launch a rocket to an apogee of at least 3000 ft. and recover it. This is followed by a second launch, during which an active drag system must be deployed to reduce the rocket's apogee to 75 percent of the original apogee. In order to achieve this, our team worked to determine a rocket length and diameter at which we could comfortably attain such an original apogee and still maintain a sufficient amount of room to create an active drag system. Through modeling and testing in SolidWorks and OpenRocket, we found that a diameter of $10.16cm$ and an overall length of $234cm$ would suit our needs. Specific dimensions regarding the rocket's internal components will be discussed further in the report. With these dimensions, we were able to model a rocket that OpenRocket predicts will reach an apogee of $1325.5m$. Analysis also shows us that it will remain stable for the entire initial flight. We chose to put our drag system as close to the computer-calculated center of pressure as possible, since fluctuations in surface area at this point would change the center of pressure the least. Thus, our rocket will remain stable during its second, air brake enabled flight as well. Recovery will be accomplished using a dual-deployment system. This involves several StratoLoggers firing ejection charges for both a drogue chute at apogee to slow the rocket down and a main parachute at $305m$ for full recovery. For both flights, we will be using a Cesaroni K-711 as our propulsion system. This K-711 is one of the available motors specified by the competition. With the motor loaded, our mass is expected to be approximately $12.469kg$. Using internal control systems and given data from simulations and calculations, the drag system will be deployed during the second flight to reach our second target apogee, approximately $994.125m$.

2 Introduction

The NASA Space Grant Midwest High-Power Rocket Competition allows teams like ours to come up with their own design to try and meet this year's objectives. We have designed a rocket that can be launched to an apogee of greater than $914.4m$, safely recovered, and then launched again. The main goal is to reduce the apogee of the second launch to 75 percent of the first, using a drag system that we have designed. We have used programs such as SolidWorks 2015 and OpenRocket 15.03 to predict the rocket's flight performance and to show that our drag system will meet the goals of the competition. The majority of the design was performed using OpenRocket, with the components modeled using SolidWorks. This report details the design of our rocket and the drag system and its predicted flight performance.

3 Rocket Structural Design

3.1 Mechanical Design

3.1.1 Rocket Body and Motor Housing

In addition to the deployment can and the avionics bay, which will be explained in detail in a later section, the body of the rocket will contain three main sections: the nose cone, the drogue section, and the main section. The nose cone is made of filament wound fiberglass with a length of $58.4cm$, a base diameter of $10.2cm$, and wall thickness of $2.29mm$. It is a Von Karman cone, which is part of the Haack series, and is designed to minimize the drag that the rocket experiences. The drogue section is made of $102mm$ Blue Tube with a wall thickness of $1.4mm$ and length of $35.6cm$, and will contain the drogue chute for the rocket. The main section is also made of $102mm$ Blue Tube with a wall thickness of $1.4mm$ and length of $38.1cm$, and will contain the main parachute of the rocket.

The motor housing is made of $102mm$ Blue tube with a wall thickness of $1.4mm$ and a length of $82.6cm$. The interior of the motor housing will contain the integrated drag system as well as the K-711 motor. On the exterior of the motor housing, three fins are made of fiberglass and arranged in a triangular pattern around the outside of the motor housing. They have leading angle of $26.53°$, a root chord of $30.5cm$, a tip chord of $10.1cm$, a mid-chord length of $11.7cm$, and a thickness of $7.62mm$. All sections, excluding the deployment can and avionics bay, will be wrapped in carbon fiber. A computer CAD model of the rocket from the side and front is shown below in Figures 1 and 2.

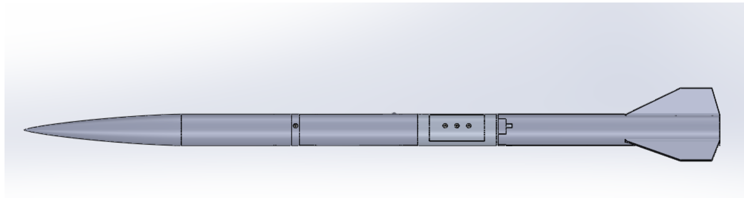


Figure 1: A side view of the rocket modeled in SolidWorks

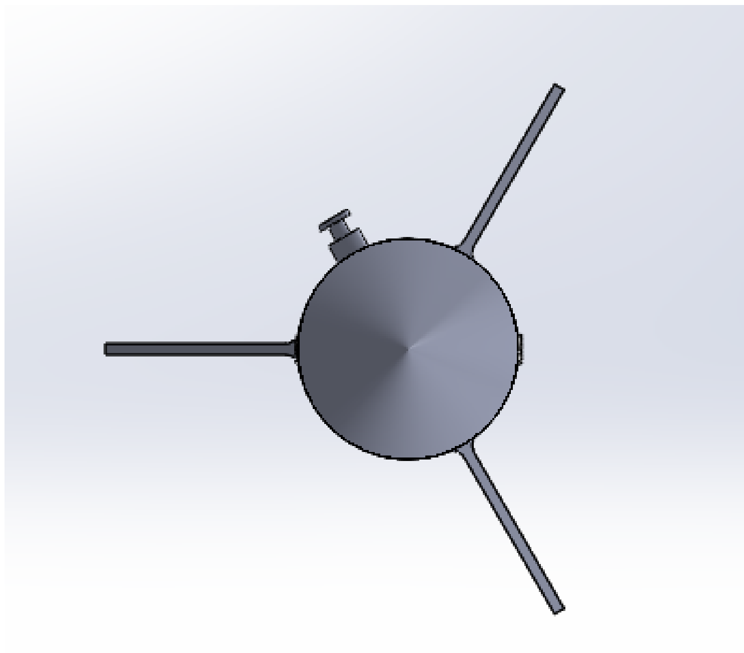


Figure 2: A front view of the rocket modeled in SolidWorks. The large protruding cylinder is a launch lug.

3.1.2 Avionics Bay and Deployment Can

In order to safely recover the rocket during a high speed descent, we have incorporated a dual-deployment parachute system. Modeling this in OpenRocket quickly confirmed that there must be a separate set of deployment electronics between the drogue and main sections of the rocket, to avoid upsetting the stability of the rocket. This was done so the drag system could remain as far back as possible, near where the center of pressure of the rocket was evaluated, while electronics could still be placed in the forward half of the rocket for ease of construction and deployment.This forward deployment can is pictured in Figure 3.

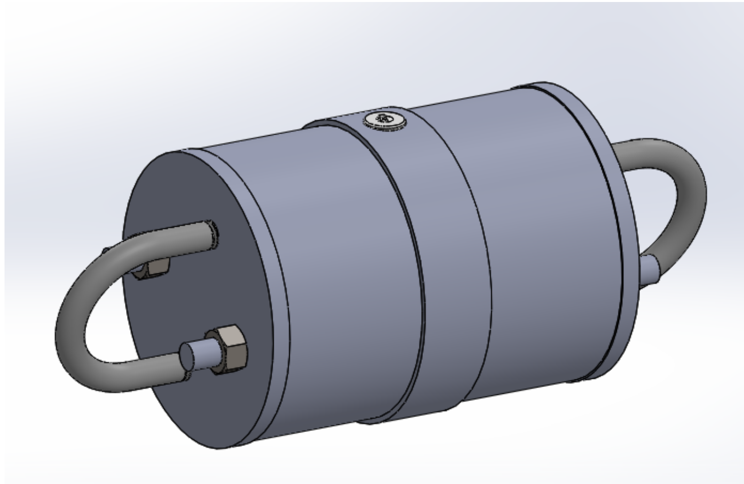


Figure 3: The deployment can

From end to end, the can is 13.97*cm* long, and is held together by .9525*cm* all thread. On each end, a .9525*cm* thick u-bolt is secured with nuts to a capping disk. From end to end, the can is 13.97*cm* long, and is held together by .9525*cm* all thread. On each end, a .9525*cm* thick u-bolt is secured with nuts to the disk. The can's cylindrical shell is made from an aluminum tube with an outer diameter of 10.16*cm* and an inner diameter of 9.2075*cm*. The end caps of the deployment can will be made of plywood laminated with carbon fiber. Each is 1.275*cm* thick. This deployment can contains the necessary electronics to deploy the ejection charges for recovery.

A second bay in the main section of the rocket holds all other electronics, such as the provided altimeter and controls for the drag system. It is pictured below. This AV bay is made from the same aluminum tubing as the deployment can. It is also similarly anchored on one side, with a u-bolt and all thread of the same diameter as those in the deployment can. This all thread runs the complete length of the AV bay, through the drag system (pictured on the back of AV bay in Figure 4) into the engine block (the right-most component visible in Figures 4, 5, and 6). Rather than being completely contained like the deployment can, this AV bay has an access door on which resides three key switches. This door can be easily removed to access electronics if such an action is required.

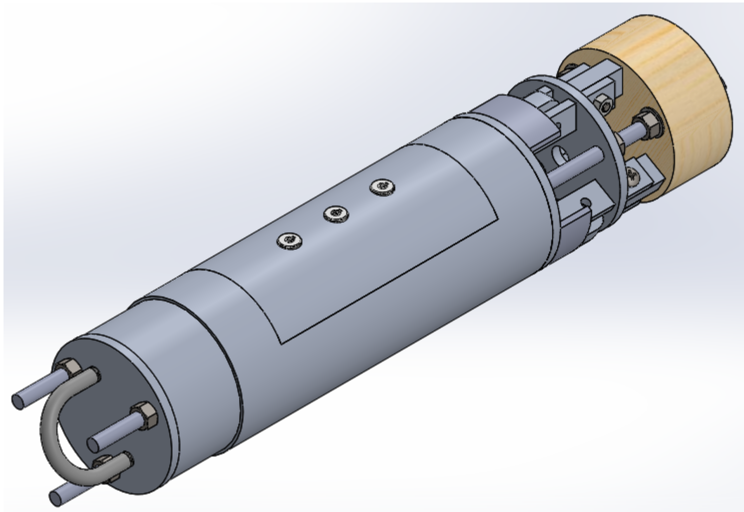


Figure 4: The main body AV bay

3.1.3 Drag System

The rocket's drag system is pictured below in an retracted, or stowed, state. The attached AV bay is hidden in this assembly.

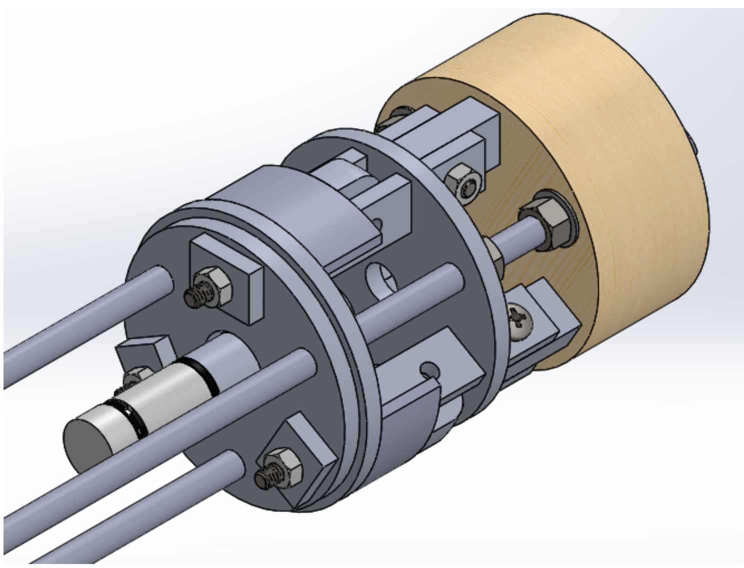


Figure 5: An overview of the drag system

The brakes operate by increasing the cross sectional area of the rocket. This is done by actuating panels that, when closed, conform to the same curve as the diameter of the rocket. When deployed, they protrude perpendicular to the rocket, as shown below in Figure 6.

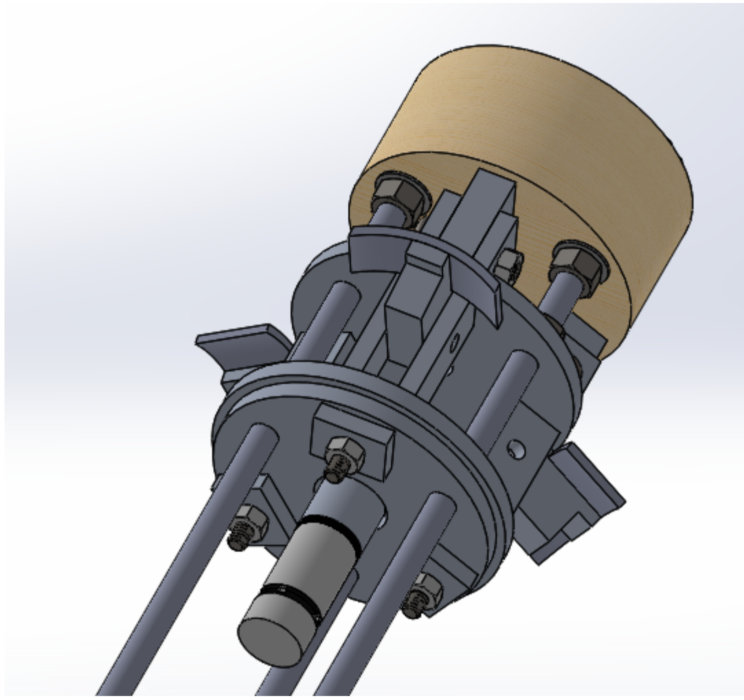


Figure 6: The drag system with the brake panels extended

This actuation is performed by a motor rotating a spool with three chords, which attach to a brake panel individually. A small amount of current is applied to the motor, keeping the doors closed. When signaled, the motor will turn the opposite direction, coiling cord on a different spool in order to open the brakes. Likewise, the motor will rotate in the opposite direction when needed, retracting the panels before apogee. A side view of the drag system, showing the motor and spool, is below in Figure 7.

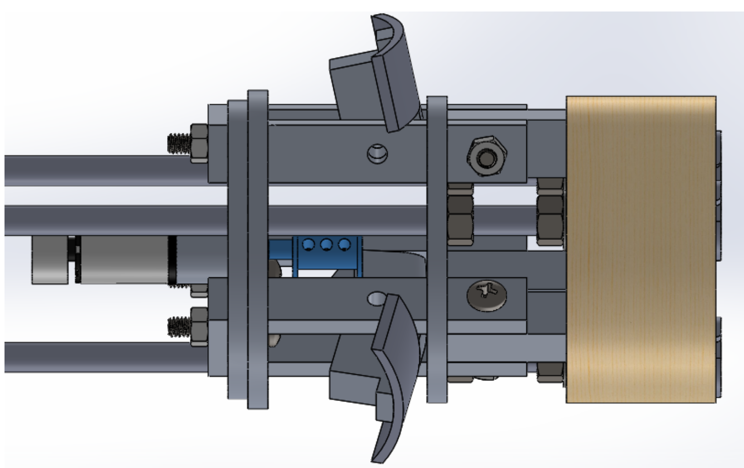


Figure 7: A side view with the cable spool highlighted in blue

All structural components in the drag system will be made out of aluminum. All of the fasteners inside the drag system are steel .635cm diameter bolts and with appropriate nuts. The drag system is fastened to the engine block with the same .9525cm diameter all thread that runs through the AV bay. It is secured to the engine block with .9525cm nuts and washers.

3.2 Electrical Design

3.2.1 Launch Control

The rocket will be switched on with multiple key switches for each specific major electrical system. Having verified that all systems are working correctly, launch will be electrically initiated using a FireWire ignitor.

3.2.2 Drag System Analysis and Control

For the analysis and logging of the entire flight, an Arduino Teensy or Micro will be used as the main microcontroller that will handle data interpretation and execution of electrical commands to the servo motors that control the braking flaps. The Stratologger has an RS232 data transmission and reception header, which will be interfaced to the Arduino to interpret transmitted data from the Stratologger. The data derived from the Stratologger will control when and how fast the flaps deploy. This will be done via interaction with a motor controller, which will monitor the motor's state, thereby allowing calculation of the force caused by the air on the air brakes. This will be used in conjunction with the data from the Stratologger to estimate the progress of the rocket and adjust brake control as necessary to achieve the desired height.

3.2.3 Recovery System

Two Stratologgers will be used to control the deployment of the two different chutes, which deploy at apogee and the determined height of 305m for recovery. There will be four Stratologgers, two for each chute for redundancy, and they will be independent of the main avionics bay systems, so that the effectiveness of chute ejection will not be affected by wiring connections.

4 Propulsion System

Our rocket uses a K-711 motor from the manufacturer Cesaroni. For this competition we were given a variety of motors that we could use. With analysis from OpenRocket, we decided that the K-711 is the most effective motor for our rocket design. Below we have included plots of motor mass and thrust versus time.

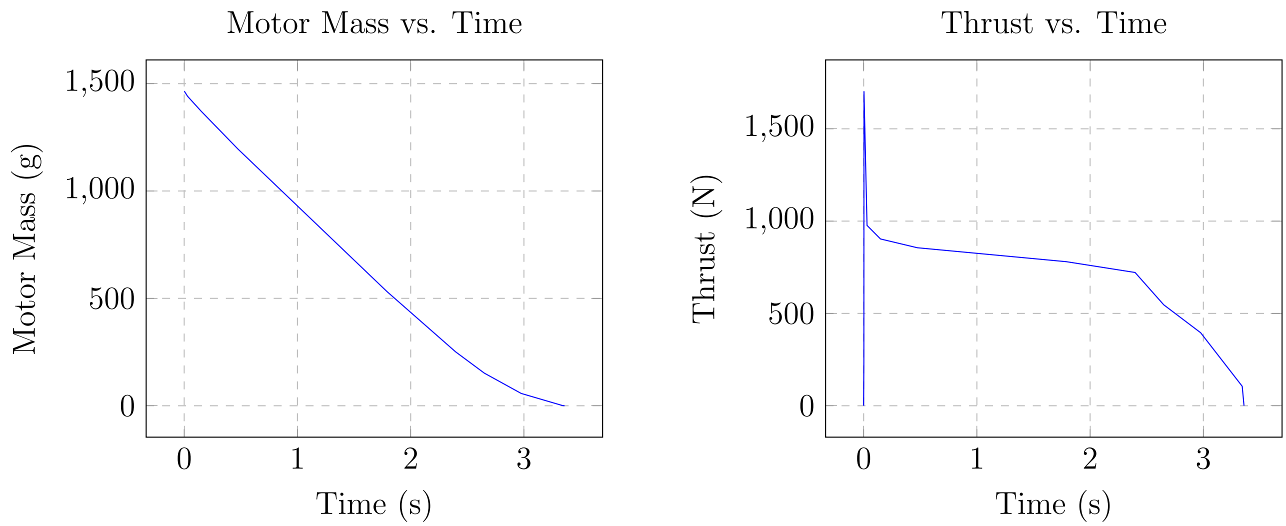


Figure 8: Motor data was retrieved from Thrustcurves.org.

4.1 Parachute Ejection System

The rocket design we have created incorporates two parachutes: one drogue parachute and one main parachute. The drogue parachute will deploy first at apogee. According to linear kinematics, the rocket would, in theory, travel straight up, come to a stop and come down. In reality, the rocket will follow a parabolic path due to wind, instability, and other factors. This resulting horizontal velocity means the rocket will not come to a complete stop where the main parachute could be safely deployed. Instead, the drogue parachute is deployed at apogee, because it can withstand deployment at a much higher velocity. The drogue parachute that we will be using can be deployed at velocities up to Mach 1. This rocket, at maximum velocity, will be traveling at Mach 0.47, and will have slowed completely at apogee. Once the drogue parachute is deployed, the rocket will descend at a velocity that is safe to deploy our main parachute which is $3.66m$ in diameter at the altitude of $304.8m$. This will allow our rocket to land on the ground at a safe velocity of $5.06m/s$. The Electronics bay located in between the two parachutes will contain the electronics used to detect the desired altitude, and the ejection mechanisms to deploy our parachutes.

5 Construction Techniques

5.1 Mechanical Construction

5.1.1 Rocket Body and Motor Housing

First, all the necessary parts will be cut according to our SolidWorks and OpenRocket model dimensions. These parts include our Blue Tube, which makes up the basis of the rocket's body, the phenolic tube that makes up the rocket's motor sleeve, our centering rings and engine block, which mount the motor in place, the fins, and any non-aluminum bulkheads. The bulkheads, centering rings, fins, and engine block can all be laser-cut for the most precision possible. It is important to note that the engine block is not all one piece. It is constructed by cutting several disks of plywood to the inner diameter of the Blue Tube and using resin to cement them together. This method has been used for many of the previous rockets constructed at UNL, and has not failed in any previous design. Once this is completed, holes can be drilled through the engine block for the attachment of all thread and the drag system, which will be discussed in the next section. Resin will also be used to secure the centering rings in place around the phenolic tube. Slots will be cut every 120 degrees around the rear tube to allow the attachment of fins. Once these fins are inserted, all of the Blue Tube sections will be wrapped in carbon fiber. Under the carbon fiber at the root of the fins' attachment point will be a small amount of fiberglass, carbon fiber, or other suitable extra material. This is to allow the side edge of the fin and the contour of the rocket body to be filleted, rather than attached at a sharp corner. This entire carbon fiber wrap will also be secured with resin.

5.1.2 Aluminum Components

The only aluminum components in the rocket make up the forward deployment can and the rear drag system/ AV bay. These parts will be machined based on multi-view diagrams with dimensions that were created from our SolidWorks models. One such diagram of the deployment can's outer shell is shown in Figure 9

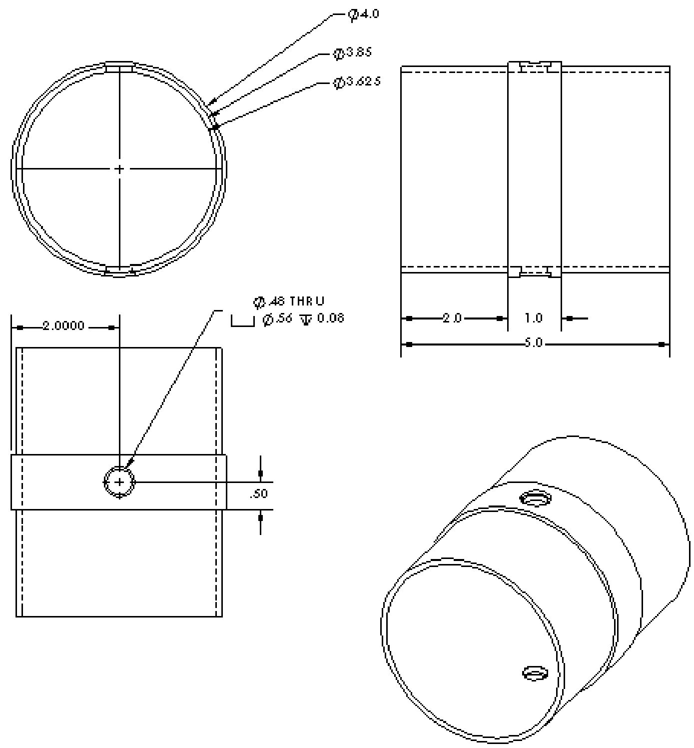


Figure 9: The deployment can's outer shell. All dimensions are in inches, for ease of machining.

After the parts are machined, they can be assembled according to our models made in SolidWorks and OpenRocket. At this point, they can be compression-fitted with all thread as shown in Figures 4 and 3. The aluminum deployment can with be inserted into the joining of the forward parachute tubes. The AV bay and attached drag system will be anchored to the motor mount with all thread, again as shown in Figure 4.

5.2 Electronic Components

Inside the AV bay and deployment can will be placed sheets of acrylic that are laser-cut to fit in their respective spaces. These sheets, running parallel to the all thread inside these bays, will hold our electronic components. In the deployment can, four StratoLoggers and four 2s LiPo batteries will be mounted to the acrylic with zip-ties, nylon standoffs, adhesive, or a combination of all three. The power between the voltage sources and the StratoLoggers will be controlled by two key switches, visible in Figure 3.

Similar key switches are used to power up the electronics in the AV bay and attached drag system, as seen in Figure 4. These components include a Raven altimeter, an Arduino microcontroller, the competition-provided altimeter (and its power source), and the motor that controls the drag system doors. These electronic components (except for the motor) and the necessary LiPo batteries will be secured in a similar manner to that of the deployment can. The motor has mounting holes for M2 machine screws, and is attached with these to the first of the disk plates in the drag system as shown in Figure 6

6 Performance Estimation

6.1 Structural Analysis

6.1.1 Deployment Bay End Cap

Our rocket will have a shock-cord that connects each piece of the rocket during parachute ejection. Due to the double-ejection configuration of the rocket, there will be a length of shock-cord from the nose cone to the deployment can, and from the deployment can to the avionics bay. The deployment can has two pieces of all thread running though it and 3-ply birch plywood caps with U-bolts. The weakest point of this system is the 3-ply plywood. It has to hold together the two pieces of all thread and the u-bolt. To test the strength of this connection, we performed a Static FEA simulation in SolidWorks with 890 Newtons of force. The maximum possible force that these points would need to withstand is 890 Newtons with the deployment of the parachute. This test showed that at the weakest point the plywood bent by only half a millimeter. This is reasonable because this is the worst case scenario and we will cover these connections with carbon fiber. To calculate the safety factor the equation is $f_s = S_y/\sigma_m$, or Safety Factor=Yield Strength/Max Stress. The safety factor for the deployment bay end cap is 2.6, and the minimum requirement for aerospace is a safety factor of approximately 1.4.

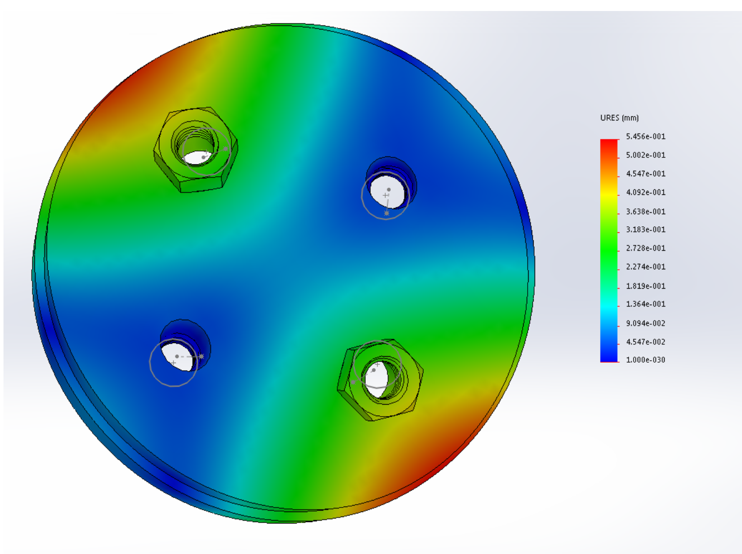


Figure 10: This shows the displacement of the Deployment Bay

6.1.2 Avionics Bay and Drag System Structure

As stated in Section 6.1.1, there are several bays which the shock-cord must pass through. Using the same method, with 890 Newtons of force we determined the displacement of the avionics bay end cap is approximately 2 micrometers. The safety factor for the avionics bay end cap is 5.89 which is well above the minimum requirement for aerospace structures. For our motor mount, we are using a tested technique that has never failed before. This is further discussed in our rocket construction and assembly sections.

6.2 Flight Parameter Analysis

6.2.1 Center of Pressure and Center of Gravity

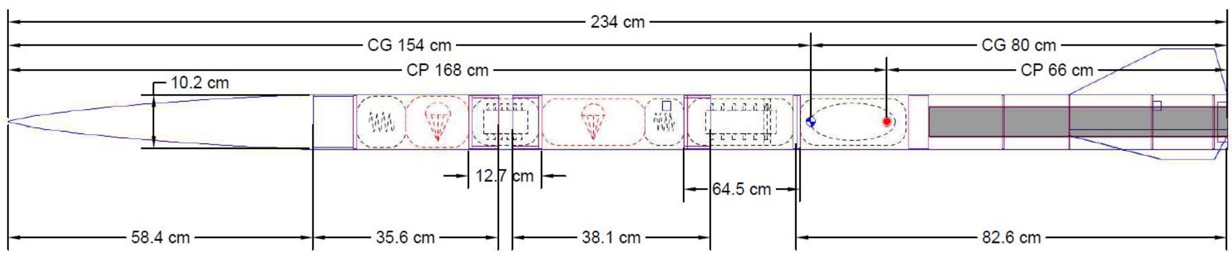


Figure 11: Rocket Dimensions

The relationship between the center of pressure and center of gravity can be seen in Figure 11. In the clean configuration, with the drag system retracted, the center of pressure is located $154cm$ from the tip of the nose cone, and the center of gravity is located $168cm$ from the same position. This difference of $14cm$ results in a stability of 1.44 body diameters, or calibers, at Mach 0.30 ($103m/s$) The goal for the design of this rocket is a stability of between 1.3 and 2.0 calibers at Mach 0.30, so this value is acceptable. During the launch phase, the mass of the motor decreases, shifting the center of gravity forward to $140cm$. As the center of pressure remains constant, the stability increases to 2.14 calibers at motor burnout. The rocket remains stable throughout its ascent to apogee.

6.3 Flight with Drag System Closed (Standard Flight)

The analysis of the standard flight performance with the drag system closed was performed using OpenRocket.

6.3.1 Simulation Parameters

The simulation options within OpenRocket allow more accurate simulations, using real-world data. Our simulation assumes the average weather conditions in North Branch, MN during the month of May, and takes into account the physical properties of our launch and recovery equipment. The simulation assumes:

- The launch rod is $3.05m$ long.
- The launch site is located at N 45.3°, W 92.6°.
- The launch site is at an elevation of $274m$ AMSL.
- The drogue and main parachutes have drag coefficients of 0.80 and 1.50 respectively.
- The drogue chute deploys at apogee, and the main chute deploys at $305m$ AGL.
- Average wind speed is $2.9m/s$, with a standard deviation of $0.29m/s$.

6.3.2 Launch Analysis

The launch phase of the flight occurs between motor ignition and burnout. The Cesaroni K-711 burns for $3.35s$, with an average thrust of $709N$. At motor burnout, the rocket has been accelerated to a maximum vertical velocity of about $158.22m/s$, at an altitude of $300.75m$.

6.3.3 Flight Analysis

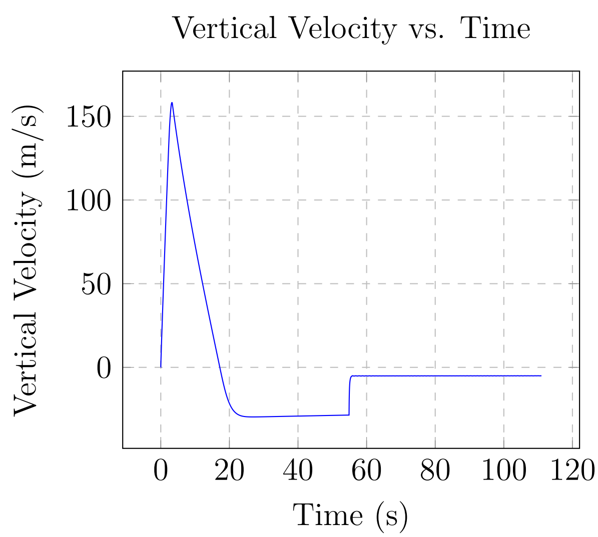
At this point, in a drag-limited flight, the drag system would deploy, slowing the rocket. In this clean configuration, the rocket decelerates normally under gravity, climbing to an maximum altitude of $1325.5m$, $17.2s$ after ignition. As stated above, the rocket remains stable throughout flight, shifting from 1.44 to 2.14 calibers during ascent.

6.3.4 Recovery Analysis

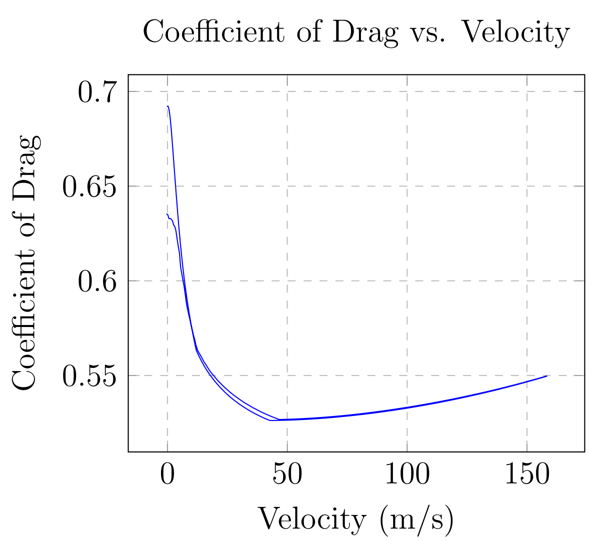
At apogee, the dual deployment system is engaged, deploying the $45.72cm$ drogue parachute, which has an estimated coefficient of drag of 0.80. This slows the initial descent of the rocket to $28m/s$, to allow safe deployment of the main parachute at a lower altitude. The $3.6576m$ ($12ft$) diameter main parachute has an estimated coefficient of drag of 1.40. This parachute deploys at $305m$, $54s$ into the flight. This slows the rocket to a safe $5m/s$ descent, in order to allow safe recovery, and to comply with the $7.31m/s$ ($24ft/s$) landing speed limit.

6.3.5 Anticipated Performance

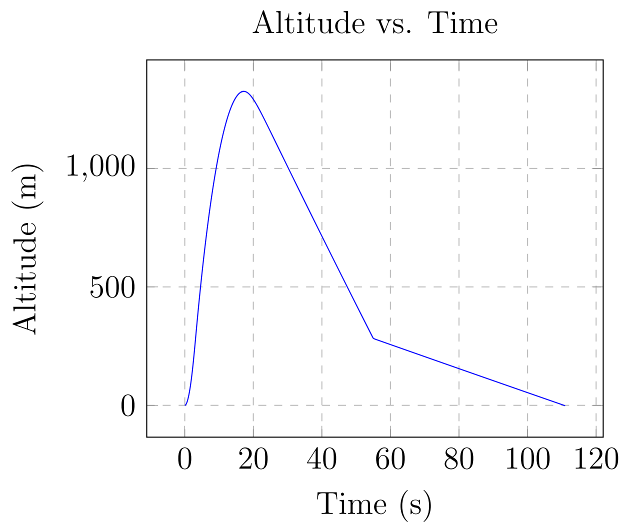
The vertical velocity increases as shown in the graph below until the motor burns out, at which point it decreases and becomes negative until the parachute is deployed, which causes the vertical velocity to become constant, as there is no more acceleration.



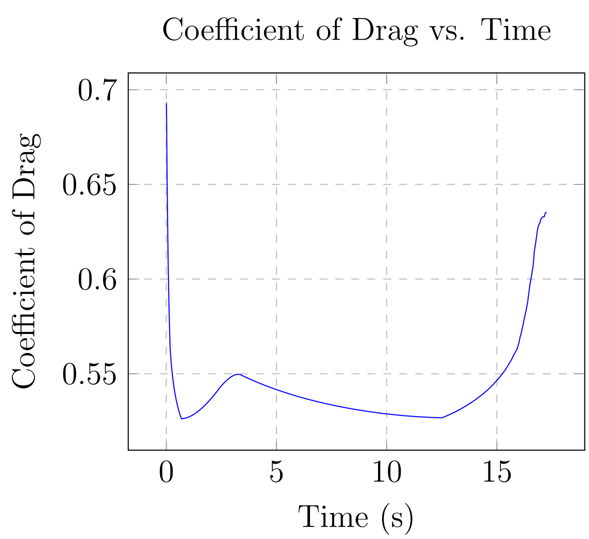
During the course of the flight, the coefficient of drag changes with variations in the velocity of the rocket, the density of the air, and the effective surface area of the rocket. This graph demonstrates this phenomenon. This graph uses data from the OpenRocket simulation during ascent.



The following graph shows when the rocket will reach its projected apogee of $1325.5m$, when the parachute will deploy, and when the rocket hits the ground.



Lastly, the following graph plots the simulated coefficient of drag over the course of the flight.



6.4 Difference in Flight due to Drag System Deployment

As far as we could tell, not much of the literature has been devoted to in depth studies of the effects of air brakes on fluid flow. Typically, people are interested in making rockets or planes more efficient, not slowing them down mid-flight. Thus, the techniques we have used initially may not produce an accurate model of reality. For this purpose, we decided to investigate the effects of air brakes through a variety of methods, to get a better idea of what will actually happen.

The most simplistic, and therefore the least accurate, estimate is to assume that the coefficient of drag is constant throughout the flight. Because both flights (with and without drag) should behave the same way while the motor is burning and after we reach apogee, we only care about comparing the part of the flight between these events. Throughout this region of time, the only forces acting on the rocket will be gravity and drag.

Since we already had the rocket modeled in SolidWorks and the program has a built-in fluid simulator, we thought we would run a simulation at various air speeds to determine a rough value of coefficient of drag, when the air brakes are fully open. Recall that OpenRocket predicted values of around 0.55 (except at very low velocities).

Velocity ($\frac{m}{s}$)	Dynamic Pressure (Pa)	Drag Force (N)	Coefficient of Drag
40	955.22	6.6339	0.57971
80	3832.25	26.8928	0.58577
120	8594.07	59.0538	0.57358
160	15336.16	98.8015	0.53776
		Average:	0.56920

Table 1: Simulated values for coefficient of drag with air brakes fully open.

It is clear from the above table that the values of coefficient of drag from SolidWorks, with the brakes fully open, do not differ as greatly from the values predicted by OpenRocket (with air brakes not deployed) as one would expect. This possibly suggests an error in the simulation methods of either OpenRocket or SolidWorks that must be fully explored. Also, it is clear from both sources of simulations that the coefficient of drag is not constant over time, but clearly depends on velocity.

To improve the simulations and resolve some of the issues discussed above, we plan on modeling the performance with air brakes open much more thoroughly. We spent most of the first semester learning the basic principles of aerodynamic drag, locating good sources, and establishing connections with experts in the field. Because our institution lacks any sort of aerospace program, many of us were largely unfamiliar with just how complicated drag forces and fluid dynamics can be. Luckily, we recently came across a number of resources.

We obtained access to Star CCM+. This is a computational fluid dynamics simulator that will be able to take into account all of the subtleties of fluid flow that are too complicated to analyze by hand. This is professional grade software, and we plan on running extensive simulations to accurately characterize the coefficient of drag. One draw back of using such a program is that it is entirely closed source. This means we have no idea how the results are produced, which means we are unaware of possible sources of error. Additionally, it gives little physical intuition into what is really happening, so that many simulations must be performed to see a pattern. Therefore, we decided not to rely entirely on Star CCM+.

Another method of predicting flight performance is to use the equations given in `http://web.aeromech.usyd.edu.au/AERO2705/Resources/Research/Drag_Coefficient_Prediction.pdf`. This document comes from the official University of Sydney website, and was written by a professor there. It seems to be used in the course AERO2705, Space Engineering I. In this document, the author explains that the equations combine some fluid theory, equations from the US Air Force Data Compendium, and the author's own experience of working with rockets over many years. These equations include a section on "proturbance drag." This is drag caused by objects jutting out of the main body of the rocket. It was designed primarily to predict the effect of launch lugs, but we believe it can be easily adapted to model our air brakes. This will give us another way of computing the effect of the air brakes on flight.

Our final form of analysis will be more custom made. We have recently been working with the guidance of Doctor Adam Larios. Dr. Larios is an Assistant Professor of Mathematics here at the University of Nebraska who specializes in fluid dynamics. We plan on using a combination of code that Dr. Larios has produced previously for fluid simulations, only modifying it to fit our purposes. Unlike the other methods which are based primarily on empirical data and approximations, this method will rely only on the pure theory of fluid dynamics. It will therefore be interesting to compare these results to those obtained through other methods.

For the part of the flight that we are interested in (after motor burnout, but prior to apogee; when the air brakes will be deployed), the only forces acting on the rocket are gravity and drag. We have previously determined how gravity and air density change with altitude. All that remains is to describe coefficient of drag as a function of altitude and velocity. Although we have not accomplished this so far, we have specific plans on how to go about achieving this, and we have all the necessary resources. Thus, a much more detailed analysis of drag will be present in our next report.

7 Safety Considerations

The building and testing of a high power rocket presents several safety hazards, so it is important that certain safety measures are taken.

7.1 Design Considerations for Safe Flight and Recovery

The rocket has several general safety features integrated into the design. The rocket is equipped with two parachutes, the first being a twelve foot diameter main parachute. Our rocket could land safely with an eight foot parachute, but having a larger parachute allows for a more safe and stable decent. The other parachute is a 45.72cm drogue parachute, to initially slow the rocket so that the main parachute does not damage the rocket during deployment. The rocket has been designed for stability, as well as performance. The relationship between the center of pressure and center of gravity, as noted in 6.2.1, is to ensure that the rocket flies safely,, as well as meeting the stability requirements set for the competition.

7.2 Material-Handling Procedures

Since several of the materials we are working with are potentially dangerous, several precautions must be taken to ensure safety for team members. One such material is carbon fiber, which consists of very fine fibers. If stretched or strained too much, these fibers can begin to "fuzz" on the surface of the wrap or can get into the air. Naturally, this will also happen when cutting the carbon fiber. Therefore, it is important that team members working with carbon fiber always wear appropriate gloves (thick enough so that the fibers can't poke through), proper eye protection, ventilators, and work in a well ventilated area as to avoid inhaling the fibers.

Another potentially dangerous substance team members will be working with is resin. Since the resin team members will be working with has hazardous fumes, necessary precautions must be taken to ensure safety. When applying resin or sanding resin, team members must do so in a fume hood and wear proper goggles to ensure safety. Lastly, team members will be using saws to cut materials such as blue tube, plywood, and fiber glass. Since dust and debris will be produced when cutting these or any other materials, it is critical that team members wear appropriate safety goggles or glasses while operating any of the saws or other cutting devices.

7.3 Assembly Procedures

- Assemble aluminum components of the drag system as specified in the SolidWorks model
- Insert electronic components into AV and deployment bays
- Attach AV bay/ drag system to the engine block with all thread as shown in **??**
- Close drag system and AV bay by securing bulkheads and u-bolts to their open ends
- Using all thread running through the nosecone, attach a bulkhead and u-bolt to the Von Karman nosecone
- Secure the tube that holds the drogue parachute to the nosecone
- Secure the tube that hold the main parachute to the end of the AV bay that is not attached to the engine block
- Drill holes for and attach the launch lugs
- After laying all pieces out in order, tie one length of shock cord to the nosecone u-bolt and one end to the deployment can u-bolt
- Tie a second length of shock cord to the opposite deployment can u-bolt. Tie the other end to the AV bay's u-bolt

- Secure the drogue chute to the first shock cord length and the main parachute to the second
- Wrap the shock cord and fold the parachutes to a size that will in the tubes
- Slide the tubes that hold the drogue and main parachute over the thinner sections of the deployment can to complete the rocket's body

7.4 Pre- and Post-Launch Procedures

To prepare the rocket for take of check over all of the electronics. Check batteries, connections, and sensors. Then fold the main parachute and insert into the the main chute tube. Perform the same procedure for the drogue chute. After this place the k-711 motor into the motor tube, secure it and prep the motor. Then put on launch rail and position the launch rail. Clear the area and do last minute checks. Then launch the rocket. After launch use the GPS to find the rocket with a recovery team. Recover the rocket and prep it for the next launch.

7.5 Pre-Flight Checklist

1. Flight Computers
   Verify flight computer configurations
   Replace flight computer batteries
   Check battery voltages
   Check flight computers
   Wire e-matches
   Set charges
2. GPS
   Check battery voltage
   Connect antenna to receiver
   Mount antenna to receiver
   Connect receiver to laptop's serial connection
   Place transmitter in casing and in Deployment bay
3. Avionics Bay
   Rewire flight computers to key switches
4. Recovery System
   Insert Nomex wadding
   Prepare main parachute
     Fold
     Place in main parachute tube
   connect main chute to nosecone
   Place drogue in drogue tube
   Gather shock cord in airframe
   Position nosecone and insert shear pins
5. Loading Motor

Place motor in motor mount tube
Lock engine retainer ring
Insert igniter rod through center of grains to top
Tape igniter rod into place
Confirm ignition system disconnected (safety)
Disconnect leads and connect to ignition system

6. Launch Procedure
   Load vehicle on Launch rail
   Angle launch rail to vertical
   Activate flight computers
   Clear launch pad
   Confirm continuity
   Signal Launch-readiness

7.6 Post-Flight Checklist

1. Recovery
   Visually mark touchdown location
   Distribute walkie-talkies
   Deploy recovery team
   Guide recovery team to rocket
   Confirm recovery of rocket with GCS

8 Innovative Components and Systems

The most innovative component in the rocket is the drag system. Most of the other components of the rocket are based on conventional designs and rules of thumb that our university has developed over several years of rocketry competitions. However, since the competition's requirements are somewhat unusual, we have sought an unusual solution. The drag system actuated by cables has, to our knowledge, not been down before. We believe that this system will suit our needs sufficiently, as it is relatively easy to manufacture and operate. In addition, it is easily integrated into the AV bay that we designed for the rocket. Integrating in this manner is another innovative feature of the drag system. Rather than having one electronics bay control the deployment of the parachutes and the drag system, which would need to have wires running through most of the length of the rocket, we chose to split the electronics up. The forward deployment bay's wiring is localized, as is the wiring of the AV bay/ drag system. Integrating half of the electronics and the drag system while keeping the recovery electronics separate means that we will not have to run wires through any length of the rocket, simplifying a complicated system.

9 Project Budget

Item	Part Cost	Number	Total Cost
Carbon Fiber Skin	$330.00	1	$330.00
Garolite (G10) Fiberglass	$64.00	1	$64.00
All-Thread	$7.00	3	$21.00
Jolly Logic Altimeter 2	$70.00	1	$70.00
Phenolic Tube	$15.00	1	$15.00
Sections of Tubular Nylon	$2.10	27	$56.70
Epoxy	$75.50	2	$151.00
Firewire Initiators	$2.00	30	$60.00
Stratologger CF Altimeter	$50.00	2	$100.00
USB Data Transfer Kit	$25.00	2	$50.00
Various Hardware	$50.00	1	$50.00
Keylock Switches	$13.00	6	$78.00
Machining	$1,800.00	1	$1,800.00
Arduino	$50.00	1	$50.00
Li-Po Battery for Controls	$12.50	8	$100.00
Drag System Spring	$15.00	2	$30.00
Motor Retainer	$41.00	1	$41.00
Electric Motor w/ Encoder	$50.00	1	$50.00
Battery for Electric Motor	$80.00	1	$80.00
GPS	$40.00	1	$40.00
Radio	$40.00	1	$40.00
Competition Motor	$103.00	2	$206.00
Rocket Tracking Unit	$200.00	1	$200.00
Vehicle Rental	$300.00	2	$600.00
Hotel	$90.00	10	$900.00
Arduino Beginner Kit	$50.00	2	$100.00
Raw Materials (Aluminum, et	$800.00	1	$800.00
		Total	$6,083

Figure 12: Cost Budget for the UNL Rocketry Team

Income Source	Amount
NASA Nebraska	$6,000
ESAB	$1,800
NU Foundation	$130.00
Total Current Inc.	$7,930

Figure 13: Funding Budget for the UNL Rocketry Team

This is the total budget for both current and projected costs as well as income. As shown, there is considerable room for error and also allowing the option of more accurate, and often more expensive, components as needed.

10 References

Single reference is sourced by hyperlink in the text.