Bulldog Rocketry

Preliminary Design Report

2016-2017 NASA Space Grant Midwest High-Power Rocket Competition

Faculty Advisor
Jose Carrillo
jcarrill@d.umn.edu

Level Two Mentor
John Christopherson
chris420@d.umn.edu

University of Minnesota Duluth
1049 University Dr, Duluth, MN 55812

Table of Contents

Table of Figures

Table of Tables

Executive Summary

The Minnesota Space Grant Consortium operates and organizes the Space Grant Midwest High-Power Rocket Competition, of which draws teams throughout the Midwest United States to test and display their engineering abilities in the form of rocket science. The University of Minnesota-Duluth team, Bulldog Rocketry, plans to attend and compete with a fully designed and thoroughly tested high-power rocket. The team consists of 50 active members, some of whom are outlined in the team summary.

The purpose of the competition is to develop a high-power rocket with an adaptable motor system which allows a J-class and K-class motor to reach the same altitude. Bulldog Rocketry will be utilizing an Aerotech J-135 and Aerotech K-2050 to prove the adaptable motor design. The avionics package will include a custom-built pitot tube which will act as an active data recording device which will directly record velocity. The rocket will be fitted with an on-board, downward and upward facing cameras, providing visual data of deployment events. The launch scoring will focus primarily upon the accuracy and precision of the rockets ability to reach similar altitudes with different motors.

A full recovery package, consisting of a dual deployment parachute mechanism (integrated with on-board avionics) will allow the rocket to safely descend from its peak flight altitude to land and be collected. The recovery altimeter is commercially made and has documented performance characteristics.

A full test-flight is planned to take place in early spring of 2017, where a complete, comprehensive performance analysis of the rocket will be conducted. The test flight will aid in further design and mechanical enhancements. Analysis of the test flight will be used to form a flight readiness report which will show the rockets flight worthiness. On May 21st, the rocket will be flown at the competition in North Branch.

The combination of manual calculations and computer aided simulations on SolidWorks, and OpenRocket are used by Bulldog Rocketry to design the best possible rocket. By using analytical engineering methods, the team is able to determine the rockets most essential dimensions including body length, nose cone design, and fin length.

Throughout the design and testing phase, team and public safety has been, and always will be, of the utmost concern.

Bulldog Rocketry Team Summary

The Bulldog Rocketry Team is a registered student organization at the University of Minnesota Duluth that includes students from the mechanical engineering, industrial engineering, electrical engineering, computer science, civil engineering, and physics departments. Only the team leads are included since there are so many active members.

Project Manager: Ethan Vought vough004@d.umn.edu
Air-Brake: Chet Peterson (Lead)
Airframe Design: Stefan Nelson (Lead)
Avionics Design: Logan Hotek (Lead)
Recovery: Jake Gartzke (Lead)
Video: David Ries (Lead)
Simulation: Evan Boncher (Lead)
Aesthetics: Paul Cerar (Lead)
Financial: Kalli Anderson (Lead)

Rocket Design Objective

Design and construct an "adaptable" single stage, dual deploy high-power rocket system that will fly to the same highest possible altitude on two motors that are as different as possible from one another. The rocket must be recovered safely and in flyable condition. Each team must predict the rocket's flight performance and construct a non-commercial on-board data collection package for the rocket that will directly measure velocity versus time, for comparison with data collected by a commercial rocketry altimeter. The team must also log airframe separation and parachute extraction from the airframe for both drogue and main parachute deployments, and also collect up and down video from outside the airframe to certify expected drogue and main parachute full deployment.

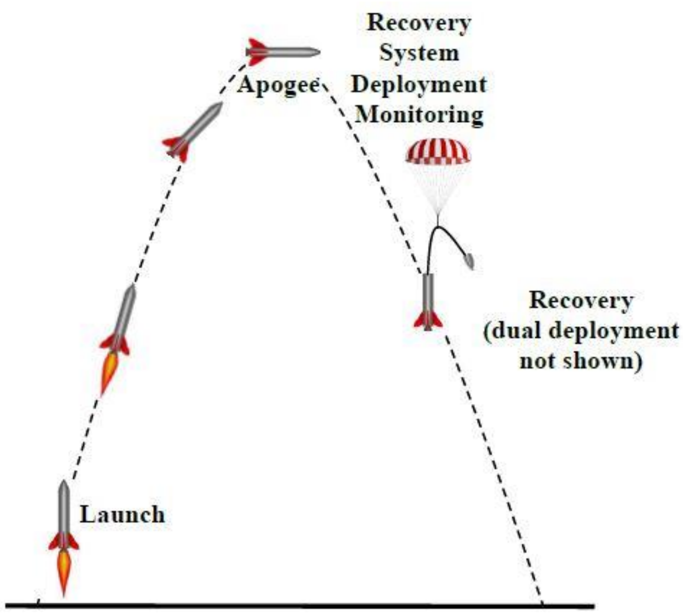


Figure 1: Events during rocket flight.

Competition Engineering Parameters

Flight Mission

- Use an adaptable motor system to attain the same altitude on each flight with one I-class and one J-class, or one J-class and one K-class motor.
- Document the state of the deployment system with your on-board logging system and up and down video. Collect sensor data to measure velocity versus time directly.

Rocket Recovery

- Electronic ejection of a recovery system no earlier than apogee using a commercial rocketry altimeter is required
- Dual deployment recovery system is required
- Motor ejection backup (post-apogee) is required
- Use of Drogue parachute (deployed no earlier than apogee) and Main parachute (deployed between 1500 and 500 feet above the ground) is required
- Landing speed < 24 ft/sec.

Rocket Constraints

- Each team must prepare a mounting location for a competition-provided “Altimeter Two
- Each team must be able to fully prepare their rocket for flight within one hour and fly at least twice during the launch window.
- The static margin of the rocket must be greater than or equal to 1 and less than or equal to 5 during the entire ascent, with drag system both engaged and stowed.

Model Rocket Demonstration Flight

- Purchase, assemble, fly, and successfully recover a “model” rocket.

Required Pre-Competition Test Flight

- Each team must assemble, fly, and successfully recover their fully-functional competition rocket at least once prior to attending the competition.

Rocket Design and Safety Reviews

- Participate in a safety review the day prior to launch.
- Present analysis of non-prequalified components at safety review.
- Additional safety review recommended.
- Rockets must pass Range Safety Officer’s Inspection on launch date.
- Analysis of non-“pre-qualified” components must accompany the rocket at the Design Safety Review.

Educational Outreach

Each team must share information pertinent to their competition rocket design/build/fly experience with at least one non-rocketry group.

Successful Flight Characteristics

- Launch at least two flights – first with smaller motor to establish the base apogee then with larger motor to achieve the equivalent-apogee goal
- Rocket flies vertically
- Rocket is stable throughout the flight
- Landing descent rate is deemed reasonable (< 24 ft/sec)
- All rocket components remain attached together throughout the flight
- Rocket must be recovered in flyable condition

Scoring

Preliminary Design Report (written)	30
Flight Readiness Report (written)	15
Flight Readiness Presentation (oral)	15
Competition Flight Performance	20
Post-Flight Performance Evaluation and Data Collection Report (Written)	20
Total:	**100**

Table 1: Scoring weight of competition requirements.

Mechanical Design

Precision and accuracy are absolutely essential in high power rocketry construction to ensure proper functionality and safety. A four-month design and brainstorming period ensured that manufacturing, testing, and performance would go as planned. Bulldog Rocketry has developed an adaptable motor system that allows the rocket to achieve the same altitude regardless of the J or K motor type. Each dimension listed was carefully determined through simulation with OpenRocket, SolidWorks and ANSYS Fluent. The lengths, thicknesses, weight, and general locations of each part shown in the figures below are strategically placed to optimize performance, stability, and functionality. The following sections will outline the mechanical design.

Dimensional Specifications

The total length of the rocket from tip to base is 55.00”. The nose cone from tip to shoulder is 8.00”, and the engine casing is 16.00”. The fin is 5.00” tall which incorporates the airbrake. The airbrake surface used to control the altitude is 3.00” x .50” The air-brake hides underneath the fin in order to reduce drag during flight. All pertinent dimensions can be seen in Figure 2. The total rocket mass is approximately 2800 grams without motors and 4400 grams with the motors

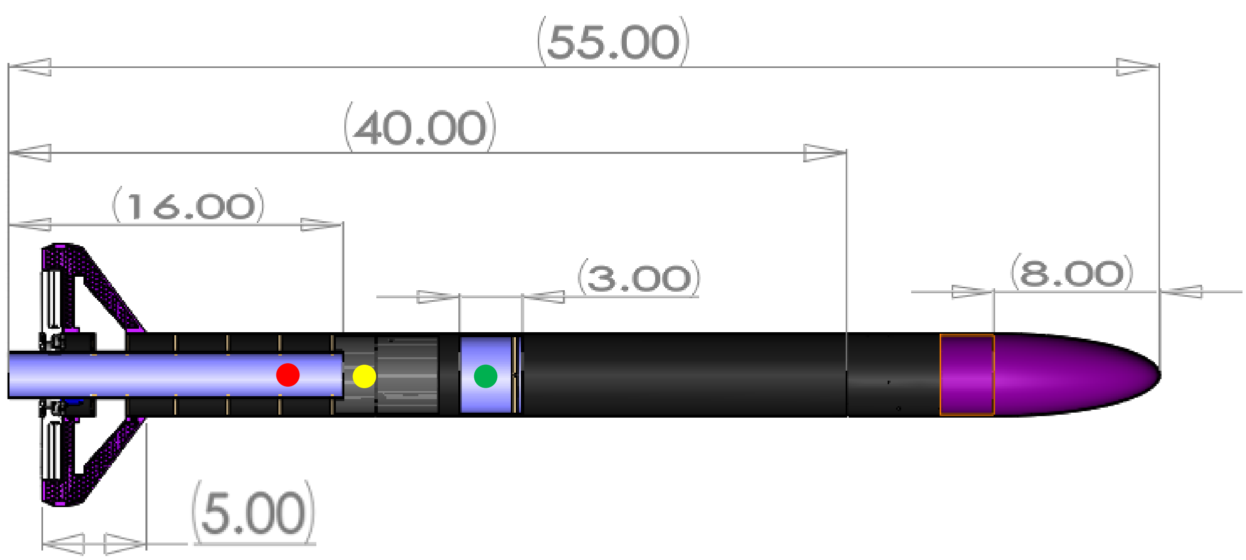


Figure 2: Rocket and dimensions.

Center of Pressure and Center of Gravity (Stability Analysis)

Designing a rocket that has a stable flight depends highly on the placement of the center of pressure and center of gravity. In Figure 2 the center of pressure and center of gravity are denoted by three colored dots on the model. The center of pressure is denoted by the red dot and the center of gravity before and after burnout are yellow and green respectively. The center of pressure is 41.12” from the tip and the center of gravities for the J-135/K-2050 flights are 36.36” and 35.88” from the tip respectively. After motor burnout, the center of gravity shifts towards the tip of the rocket by approximately 6” (30.60”).

Observing the rocket from tail to nose, the center of gravity is above the center of pressure. The stability is 1.19/1.31 caliber before burnout with the J-135/K-2050 and 2.63 caliber after burn-out. The competition requires that the caliber be between 1 and 5 during ascent. The location of the fins and the lengths of the body tube were designed to place the center of gravity and pressure where they would provide optimal stability.

Airframe Design

Every component starting from the nose cone to the fins were specially made in order to meet the requirements and constraints for the rocket. The airframe is comprised of 3 sections of blue tube which are 4.00” OD. The engine casing is also made of blue tube which is 2.56” OD. Blue tube was selected because of its low cost, high strength, proven durability, and ease of manufacturing. The engine casing and the body tube are joined by centering rings which can be seen in Figure 3.

The centering rings are water jet cut from 3/16” aircraft grade birch plywood which has a transverse tensile strength of 6400 psi [1]. In order to determine how many centering rings would be required for flight, a mock assembly with two centering rings joined by two 3/16” aluminum rods were made and placed in a tensile tester to determine the yield strength. From simulation, the rocket is expected to experience a maximum of 60 G’s of acceleration which equates to approximately 530 lbf on the centering rings.

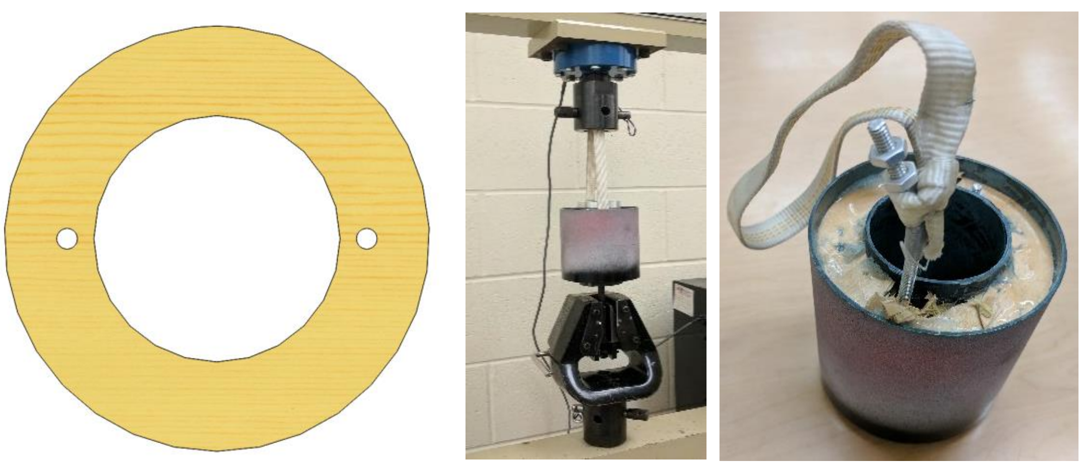


Figure 3: Centering ring and tensile test.

During the tensile test, the centering rings did not begin to fail until 350 lbf, and did not completely fail until around 570 lbf. The failure point of this design was the rods pulling through the centering rings. From the test, it was determined that each centering ring could handle approximately 285 lbf. The actual rocket will have 6 centering rings, whereas the test section only had two. The same 5-minute epoxy used in the test will also be used on the flight rocket. Our team predicts that the rocket will be able to withstand over 1710 lbf which is a factor of safety of approximately 3. The graphical results can be seen in Figure 4.

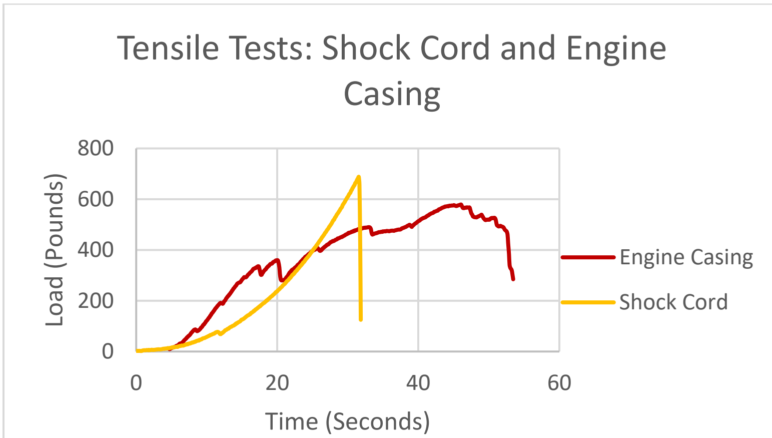


Figure 4: Engine case tensile test results.

Next, the fins were in consideration. In order to accommodate for the air-brake system, fiberglass and a 3-D printed prosthetic will be used to form a fin. The fin tab which holds the fin is made from 3/16" G-10 fiberglass which was waterjet cut to the desired shape. The 3-D printed portion of the fin tapers to a thickness of .50" which the airbrake hides behind. Fin design will be detailed later in the report.

A four-fin design was selected because of the added stability and due to the 90-degree separation which increases the ease of manufacturing. Since the design is simple, this made finding the center of pressure and gravity relatively easy.

Nose Cone Design

There are a number of nose cone styles which each have various advantages based upon the speed of the rocket. Some designs have better performance in the subsonic regime, while others have better performance in the supersonic regime. Figure 5 plots various nose cone styles and ranks their performance based on the cone's Mach number. The scoring scale goes from 1 (excellent) to 4 (inferior)

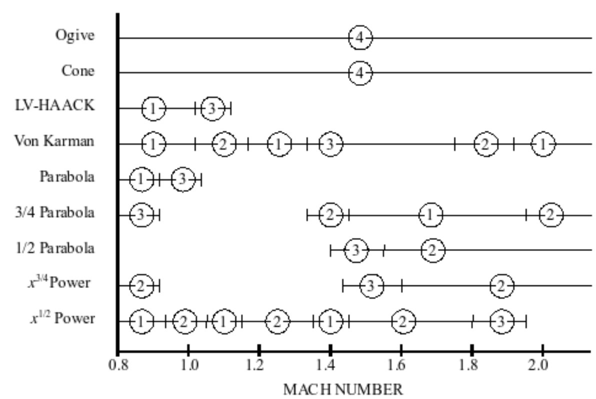


Figure 5: Nose cone performance plot.

Since it is known that the rocket will be flying subsonic speed for the majority of the flight, the following nose cone styles were considered for analysis: LV-HAACK, LD-HAACK (Von Karman), Conical, ½ Power, and elliptical. These cone designs were modeled in SolidWorks using their respective profile equations. Similar to the fin design selection, the nose cones were run through an ANSYS Fluent CFD simulation to determine the drag force experienced by each design. The boundary conditions that were used with this simulation will also be very similar to those used for the fin study. A velocity inlet will set the incoming air velocity. The walls of the nose cone were constrained using a specified shear stress. The outlet of the system was modeled with a set pressure. Since the bottom face of the nose cone is not exposed to the air, the pressure was set to atmospheric pressure.

The results of the various simulations can be seen in Table 2. The elliptical style cone showed the lowest drag force of the group of designs.

Table 2: Nose cone drag force data.

Design Style	Pressure Drag (N)	Viscous Drag (N)	Total Drag (N)
½ Power	46.59	1.38	47.97
LD-HAACK	45.61	0.94	46.55
LV-HAACK	44.25	0	44.25
Ellipse	28.51	2.82	31.32
Conical	56.20	0.98	57.18

Once the ideal design style was selected, the model that was created for the study was modified to fit the dimensions of the rocket and given a shoulder so that it can easily slide into the body tube. Since none of the major suppliers for rocket parts have this style of nose cone in the required dimensions, the part will be 3-D printed from carbon fiber filled nylon-11. A structural analysis of the nose cone is still in progress.

Recovery Design

The recovery portion of the flight commences when the rocket reaches apogee. The recovery system is a dual deployment system, which means that there will be two parachutes. The first deployment, called a drogue, will deploy at apogee and is the smaller of the two parachutes. Then at a lower altitude a larger main parachute will release bringing the rocket to a lower velocity, and land set the rocket down on the ground safely. Two ejection canisters filled with 2 grams black powder each are the primary source for ejection. In the event neither of these canisters ignite the engine deployment charge will fire and force out both of the parachutes. The weight of the charge is determined by entering the diameter and length of the section of the rocket containing the parachutes into a charge calculator on rockethead.net.

A piston constructed from coupler tube is used in the deployment of the parachute. The piston will help protect the parachute from any burns caused by the charges and will also help harness the explosion from the canisters. The altimeter will deploy two separate charges one second after apogee along with the engine back up to ensure parachute deployment. The drogue chute will open, while the main chute is released at 650 feet. A chute release is a small altimeter that holds a parachute closed with a rubber band. Bulldog Rocketry is using a chute release made by Jolly Logic which is seen in Figure 6. Bulldog Rocketry decided to use this method instead of having two charges that deployed the drogue and main chutes separately due to the unreliability of the charges. Since both chutes are pushed out of the rocket by one charge, the risk is of one of the parachutes not deploying is significantly lower. Additional specifications are discussed in the avionics design.

Figure 6: Chute release.

The rocket is equipped with two parachutes, both of which are manufactured by Fruity Chutes. Bulldog Rocketry decided to use a compact elliptical 18 inch parachute for the drogue. With a drag coefficient of 1.5 to 1.6 according to the manufacturer, the drogue chute is rated for 20 ft/sec with a 1.2lb load. The main parachute is an Iris Ultra Compact 48 inch parachute from Fruity Chutes with a manufacturer given drag coefficient of 2.2. It is rated for a 12.5lb rocket to descend at 20 ft/sec. The parachute is toroidal shaped and has 8 gores with shroud lines made of #400 Spectra. It is bridled with a ¼ inch Kevlar cord with no swivel. A 15 ft Kevlar shock cord with a diameter of 2 mm, rated for 750 lbs of force, attaches the upper and lower sections of the rocket. After testing a square, bowline, fisherman's, and a figure 8 knot on a tensile tester, the figure 8 knot was found to be the strongest, as it was the only one that did not break on the knot. The figure 8 knot test failed at 690 pounds. The cord will be anchored to the rocket using a kevlar loop, rated at 1500 pounds, that goes through two slots in the first centering ring of the engine mounting and ties onto the rods.

Fin Design

Proper fin design is integral to the stability of any rocket flight. The first step in the design process was to develop a basic fin shape. A clipped delta - style geometry was selected based on its efficiency within the subsonic regime. A diagram of this geometry can be seen in Figure 7.

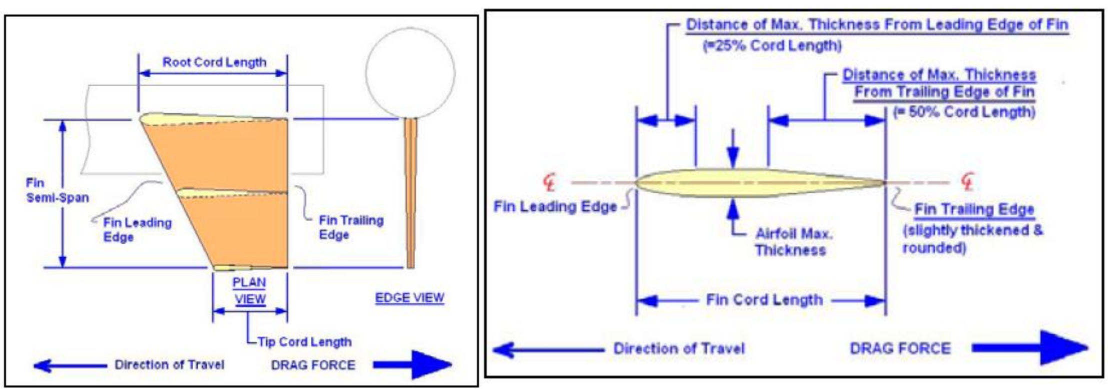


Figure 7: Clipped-delta fin geometry.

The fin's semi-span was determined by the surface area required by the airbrake to achieve the desired altitude reduction. Once the basic fin geometry and semi-span was determined, the root and terminal cross sections were created. Multiple fin iterations were built with varying cross-sectional dimensions based upon the drawing shown in Figure 7. A table of these dimensions can be seen in Table 3. The end of the fin was rounded to eliminate the sharp edge along the fin tip and reduce possible turbulence.

To determine which of these various fin iterations would perform most efficiently in a flight scenario, ANSYS Fluent CFD simulation was performed on each fin. The total drag force was measured to find which had the least amount of drag. To properly constrain the problem, a number of boundary conditions were used, the first of which was a specified inlet air velocity. This simulated the effects of the air resistance the fins and the rocket will experience while in flight. Next, the condition used to constrain the fin surface was zero shear stress due to the air passing over. Finally, for the system outlet, a static pressure was established. Since the rocket flows through the air and does not create considerable turbulence far beyond the fin, the pressure was set to atmospheric pressure.

The simulation determined that iteration 3 had the lowest total drag force. The following table shows the drag data for all iterations.

Table 3: Fin length and drag force on various fin iterations.

Iteration	Root Cord Length (in)	Tip Cord Length (in)	Pressure Drag (N)	Viscous Drag (N)	Total Drag (N)
1	5	2.5	1.79	0.75	2.54
2	5	2.25	2.04	0.74	2.78
3	5	2	1.16	0.86	2.02
4	5.5	2.5	1.53	0.81	2.34
5	6	2.5	1.18	0.87	2.05

Since this fin is relatively wide (0.6 in at root), having it constructed as a single solid piece did not seem to be practical for this design. It was decided that the fins should be honeycombed to reduce weight. According to hand calculations, the force that each fin would be seeing due to air resistance was about 40 pounds. Another consideration that had to be accounted for was that to 3-D print the honeycomb feature the fin could not be one solid body. The fin was split into two halves and joined at three points along the exterior of the fin. Figure 8 shows the final fin honeycomb. The addition of this feature caused a 22% reduction in total fin weight. The major cavity in the center of the fin is for the key that attaches the fin to the rocket body.

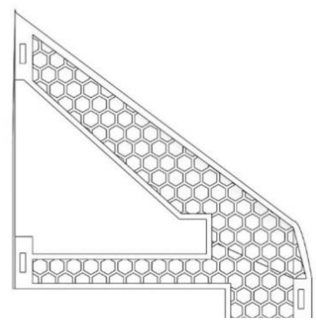


Figure 8: Fin half with honeycombing.

Air Brake Design

The air-brake was designed for this rocket to match the apogee of the larger motor to the smaller motor. The air-brake assembly consists of a top and bottom retaining ring, a center brake ring, two extension springs, two servos, two custom servo horns, and a thrust bearing Figure 9. All three rings and the servo horns are manufactured from Carbon Fiber filled Nylon-11 using a 3D printer. The entire assembly sits on the aft end of the rocket around the engine casing and is secured to two aluminum 10-24 threaded rods which run the length of the engine. The bottom retaining ring houses a thrust bearing that the center brake ring rotates on for frictionless operation even under a large axial force. The top retaining ring fits inside the body of the rocket doubling as a centering ring and holds two servos firmly in position above it. The bottom and top retaining rings retain the center brake ring in place while applying no compressive forces to it and allowing the center retaining ring to rotate freely. A low friction system is achieved by nesting a column from the bottom retaining ring inside a column from the top retaining ring acting as a spacer so that the brake may be firmly compressed without applying friction to the center. In this way, the center brake ring can spin while still being safely secured. The entire assembly was designed to be removable from the tail of the rocket by removing two lock nuts.

The lock nuts allow for any repairs or maintenance to easily be completed while ensuring that the air-brake is securely fastened.

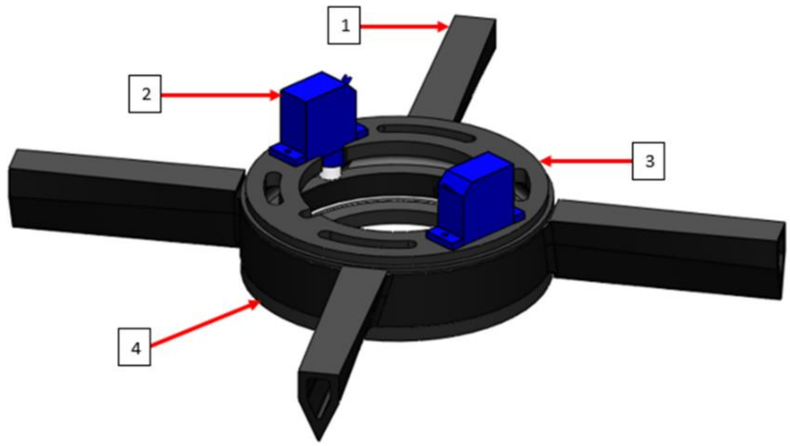


Figure 9: Air-brake exterior components.

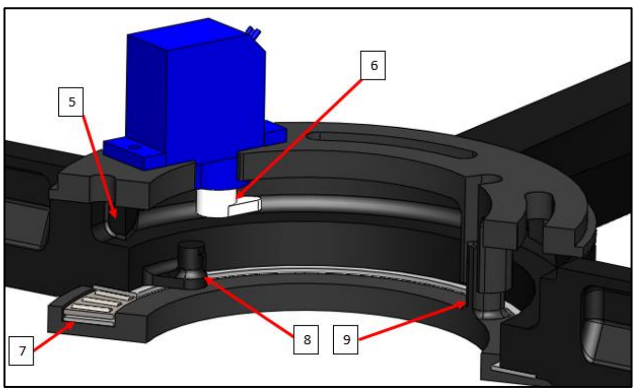


Figure 10: Air-Brake interior components.

Call-out components:

1. Center brake ring
2. Servo
3. Top retaining ring
4. Bottom retaining ring
5. Internal riser
6. Custom servo horn
7. Thrust bearing
8. Spring peg
9. Second spring peg and nested columns as spacers

Extension springs located inside the assembly provide the torque to engage and stow the air-brake. The springs must be put in tension by clocking the brake ninety degrees where the servos will then hold it in place. To avoid unintentional drag, the brake is stowed behind the fins when it is inactive (Figure 11). The brake profile is cut directly from the optimized fin design to ensure that the brake has the lowest impact on the flight of the rocket as possible when stowed. Once the avionics program determines that the brake should be engaged, the first servo is energized, rotating the servo horn out of the path of an internal riser inside the center brake ring and allowing it to rotate forty-five degrees before hitting the second servo horn. The air-brake is now engaged and four flat faces are introduced into the air stream causing drag. Once the avionics program determines the

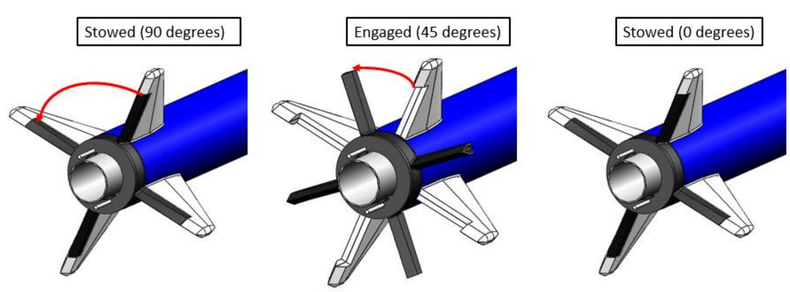


Figure 11: Drag system engage and stow cycle.

velocity has been reduced sufficiently, the second servo will rotate a servo horn and allow the center brake ring to rotate another forty-five degrees to a stowed position.

All four faces of the center brake ring will experience about 60 lbs. of drag force on each face Figure 12. A combination of Finite Element Analysis (FEA) and OpenRocket simulations were used to size the Air-Brake and determine the critical dimensions. The team has used OpenRocket in the past to model air-brakes and found it to be an excellent predictor of air-brake performance. The brake was modeled as a square fin at the aft end of the rocket, and simulations were run with and without the brake while maintaining a constant rocket weight. This method lead the team to conclude that four flat faces, three inches long and half an inch wide, were ideal. Through many iterations of this method a brake size was chosen to produce 1.5 times the amount of drag that was estimated to be necessary. A factor of safety will allow for a number of things: latency in the avionics triggering, unintentional under sizing of the air-brake, and the variable thrust and burn time of commercial engines. FEA was used once a SolidWorks model was built to ensure that the brake would have enough strength to withstand the anticipated drag forces. Based on hand drag calculations and previous results, a forty-pound load was applied to each face over time to observe the effect of continuous loading. The brake was designed to have a factor of safety of two under these conditions.

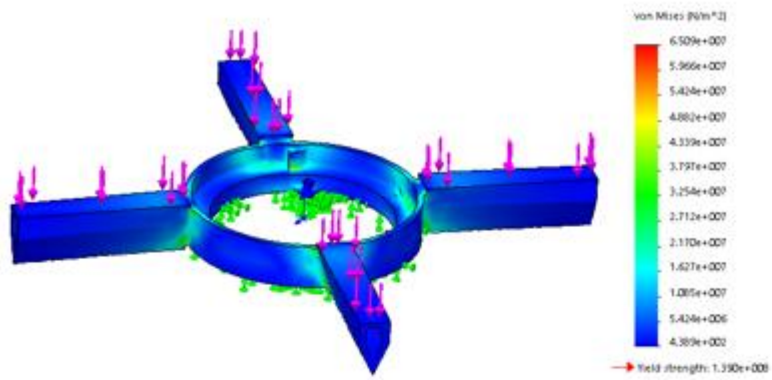


Figure 12: FEA analysis for air-brake.

Avionics Design

The avionics payload features two micro controllers: one is an Arduino Feather MO with a built-in radio packet and the other is an Arduino Feather MO datalogger. The avionics payload also features two Inertial Measurement Units (IMUs), a standard mV output pressure sensor, and an 8 GB SD card reader/writer. The IMUs record gyro, acceleration, barometric pressure, altitude, and temperature. The pressure sensor records differential pressure from a custom-built pitot tube using mV output readings. The pitot tube is Bulldog Rocketry's way of directly measuring velocity from a custom build system. Together the components collect, calculate, and record data. Along with recording data, the Arduino Feather MO with a built-in radio packet was specifically chosen for its live telemetry capabilities. The Arduino datalogger tasks are recording data on board the rocket and to operate the drag deployment system. The avionics payload also includes a parachute deployment altimeter and an Altimeter Two for standardizing each team's flights.

Control Design

While the Arduino Feather MO datalogger is recording the flight data and measuring the rocket's velocity, acceleration, and altitude to determine drag system deployment, the Arduino Feather MO with a built-in radio packet sends data back to the ground station through a uFL antenna setup. To determine the best time to actuate the drag system, the Arduino Feather MO datalogger will take 10 measurements per second. When the statements written in the Arduino's code determine the rocket has ended boost phase, the Arduino will send a signal to the servo motors to activate the drag system on the second flight. Using the current altitude, velocity, and drag, the Arduino Feather MO datalogger will then determine when to recover the drag system to be closest to the first launch altitude. In addition to the flight operations, the Arduinos will also perform pre-flight checks to determine that all functions are operating correctly. The pass/ fail checks will be visualized by a set of LEDs that can be seen from outside of the rocket.

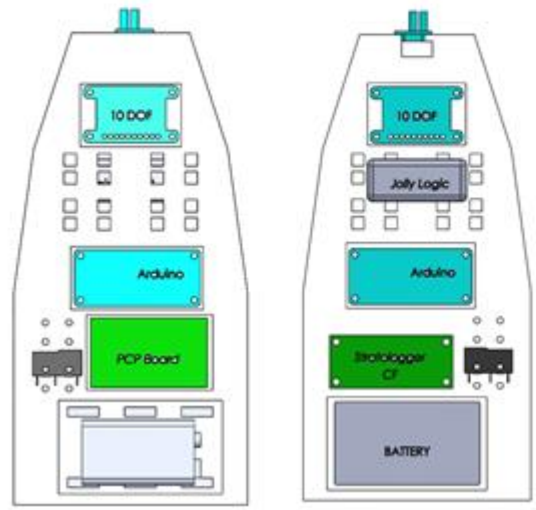


Figure 13: Avionics mounting design and layout.

The 3.3V Arduinos were chosen because of their fast processing speeds of 48MHz for each Feather, their small size and weight, and because they operate at the same voltage as the IMU/ SD card writer (3.3V). The 10 DOF IMU and the TE Connectivity 1230 Standard mV output pressure sensor were selected because of the reliability, ease of use, and accuracy of the data. To store the data on board the rocket, the most reliable and easy-to-operate micro SD card was chosen. The 433 MHz bandwidth was chosen for its reliability and imposed regulations to send the data over radio. Together the components can record and send data near real time, operate at a safe voltage, draw minimal current, and deploy/ recover the drag system.

The power supply for the avionics payload will be a 3.7V 2000 mAh lithium polymer battery. The Arduinos, and IMUs feature voltage level shifters to accommodate the 3.7V supply. The standard mV output pressure sensor has a fixed current setting and needs a series of resistors to step down the voltage. The total predicted current draw for the complete avionics payload is estimated at 250 mA giving the Arduinos well over 5 hours of battery life on a single charge. To power the servo motors for the drag system, there will be one 9V battery.

To ensure accessibility of the avionics payload, all the electronics are connected to a single board so the electronics bay can be removed from the rocket which is seen in Figure 13. Two plunger switches are used so the pins can be removed on the launch pad to access and turn on the Arduinos. The Arduinos also use a series of blinking LEDs that can be seen from the outside of the rocket to ensure they are operating correctly.

The Avionics payload will be in the nose cone of the rocket. This position provides optimal center of gravity and center of pressure. All components will be securely fastened, soldered, and dampened to avoid failure during the extreme forces due to launch.

Direct Velocity Measurement Design

The standard mV pressure sensor connects to a tube that runs to the tip of the rocket just outside the nose cone. As the rocket moves through the air a pressure buildup happens inside the tube. As the air velocity increases then the pressure inside the tube increases. The pressure sensor outputs the pressure change to an analog pin on the Arduino which records the voltage change. The voltage change can be correlated with a known pressure which can in turn be calculated to show velocity. An example of how the pitot tube calculation will be used can be seen in Figure 14. The accuracy of the pressure sensor is .2 psi which allows for a reliable velocity measurement. The direct velocity measurement happens at a rate of 10 times a second which is used to determine the deployment of the drag system to allow the rocket to achieve a desired altitude.

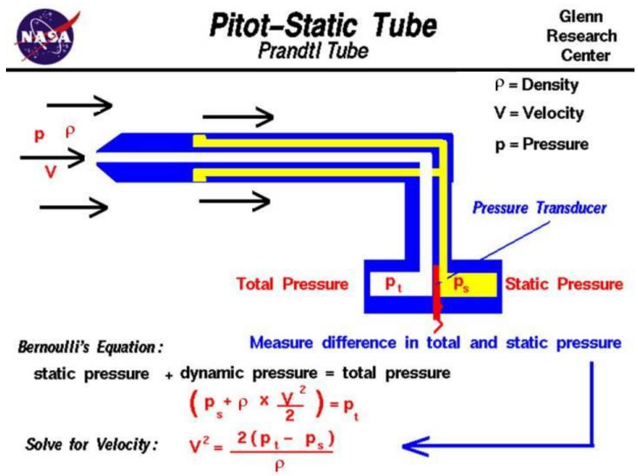
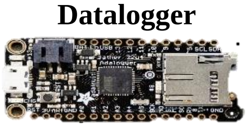
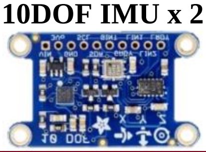


Figure 14: Pitot tube design calculations.

Table 4: Avionics component description.

Hardware Name / Picture	Description	Voltage Rating	Current Draw	Power Supply Information
Arduino Feather MO Datalogger 	- Microcontroller based on ATSAMD21G18 - Integrates sensors/ SD card - Cycles drag system	3.3V	50mA	2000 mAh lithium polymer battery
10DOF IMU x 2 	- 3 axis accelerometer, gyroscope, magnetometer - barometric pressure - temperature sensor	3.3V	20mA	2000 mAh lithium polymer battery
Pressure Sensor 	- Differential pressure reading from pitot tube	3.3V	1.5mA	2000 mAh lithium polymer battery
StratoLogger CF 	- Uses one charge for parachute deployment - Records Altitude and Maximum velocity - Audible beep to assure operation	4V to 16V	1.5mA	200 mAh lithium polymer battery
Altimeter Two 	-Competition supplied altimeter -Records max altitude based on barometric pressure	NA	NA	Internal battery

Separation Avionics

The rocket must have electronic deployment of a parachute recovery system ejected at or after apogee using a commercial rocketry altimeter. The rocket will use a Stratalogger CF to deploy the parachute. To deploy the parachute, the altimeter detonates one charge; the charge will deploy at one second after apogee to ensure parachute deployment. The software is easily programmed using a computer and will also provide the data to confirm the accuracy of the custom-built data recording package. In addition to both gunpowder charges, the delayed motor ejection will be the third fail safe to ensure that the parachute deploys. Once the rocket has separated, a radio tracking beacon will be used to follow the rocket to its landing point.

Competition Provided Avionics

To standardize every flight, the competition will supply a Jolly Logic Altimeter Two. The Jolly Logic Altimeter Two records max altitude, top speed, thrust time, peak acceleration, average acceleration as well as parachute deployment altitude. The avionics payload will accommodate an accessible location for the altimeter to be quickly and easily removed before and after flight.

In-Flight Video

The camera's role is to record the air brake deployment and recovery. To record quality, two cameras are utilized for this year's competition. They run independent from the rockets electronics bay, meaning they run on their own batteries and have their own storage devices. One camera is facing upward (seen in Figure 15) and the other camera is facing downward to record both deployment events. Each camera is inserted from the bottom of the doghouse and retained by an aluminum plate. The doghouse is designed so there can always have a perspective of the ground. Also, with the cameras being housed on the exterior of the rocket, the team needs two of them to balance out.

Figure 15: HD camera for recording dual deployment recovery system.

The Foxeer Legend camera (Figure 15) only weighs 45 grams while still providing Ultra High Definition video. For the K-2050 engine the burn sequence will take last less than a second so the lower resolution around 720p will be used to increase our frame rate from 24 to 120. The camera can even connect to a cell phone to download the video remotely. Fully charged with new batteries, the camera is rated to run 6 hours non-stop. Bulldog Rocketry already anticipates on having charge time in between each launch because it is possible and the team doesn't want a potential battery shortage. The camera's will be running during the entire duration of the flight.

Construction Solutions and Techniques

Machine work will be done with the help of UMD's machinists to ensure high quality and safety. The rocket will be assembled using a custom-built jig to assure alignment during the fin assembly of the rocket. 3D printers will be used to design and develop custom made parts for rapid prototyping. Test fitting will be done extensively to ensure all parts in the right place when the epoxy starts to set up. Safety wire will be used to hold on any components that could possibly be dislodged during flight. A more in depth look at how the rocket will be assembled can be seen below.

Planned Construction Procedure

1. Purchase all necessary materials
2. Machine and cut parts:
    - 6 centering rings, 3 body tube pieces, motor tube, and 4 fin tabs
3. 3D print specific parts:
    - 2 doghouses, air-brake assembly, 4 prosthetic fins
4. Test fitting of all parts (sand as necessary)
5. Mount parts into body using 5-minute epoxy
    - Straight edge jig used to install fins accurately
    - Allow to fully cure
    - Thorough inspections throughout epoxy process
6. Insert wiring for Avionics
7. Fasten all sections together
    - Nose cone, Electronics bay, Upper half (shear pins)
8. Inspect and test full assembly for functionality
9. Apply coats of paint in well ventilated area
10. Prep with pre-launch procedure

Flight Performance Characteristics

The basic concept for the competition is to fly a rocket with two separate motors that have vastly different thrust and impulse characteristics to a similar apogee. Equation__ outlines the exact scoring criteria for both flights.

$$\text{Figure of Merit (FM)} = Apogee_{avg} * \frac{\left(\frac{Total\ Impulse_{max}}{Total\ Impulse_{min}}\right)\left(\frac{Avg\ Thrust_{max}}{Avg\ Thrust_{min}}\right)}{\left(\frac{Apogee_{max}}{Apogee_{min}}\right)^2\left(\frac{Initial\ mass_{max}}{Initial\ mass_{min}}\right)}$$

This figure of merit is then compared to the competition maximum and given a percentage of the 70 point maximum based on performance. Additional points are added or taken away based on if the apogee of the flight reaches or exceeds 3000 feet.

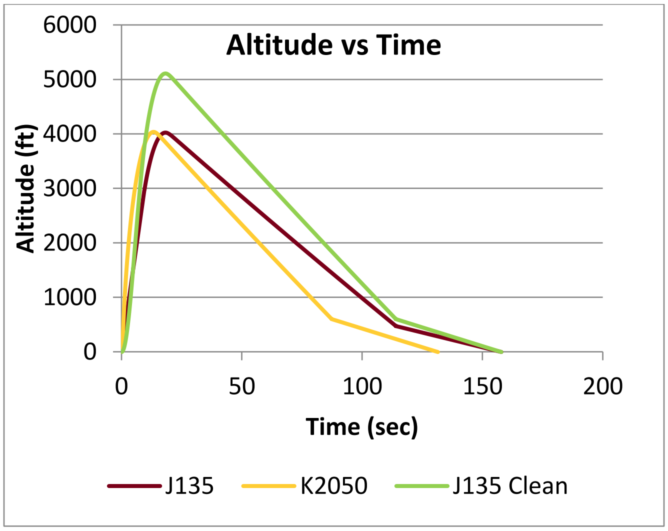
Motor data from all Cesaroni, AeroTech, Gorilla, and Loki engines in thrust class I-K was collected and organized into an Excel spreadsheet. Based on this data and expected rocket mass and drag coefficient data, a number of hand calculations were performed to find the predicted apogee, burnout velocity, and time to apogee. The results of these calculations were then appended onto the motor data table. These data tables were then cross-referenced, pairing all 5000 combinations of I/J-class and J/K-class motors together. Using Equation__, each motor combination was given a figure of merit and also a number of bonus points depending on if it reached or exceeded a 3000-foot apogee. A majority of the highest figure of merit combinations did not reach the minimum apogee, and therefore, would not be ideal choices. This lead to the choice of the following combination: AeroTech J-135 and K-2050. This combination offered one of the highest figures of merit while still attaining an apogee that would not lose points.

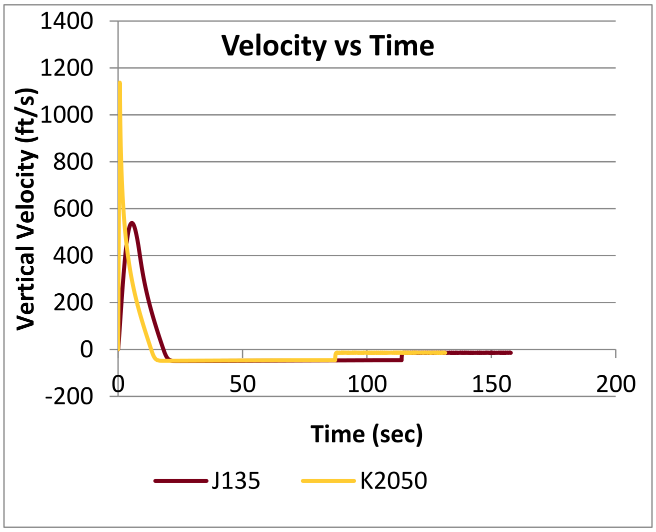
Launch Analysis

The rocket is launched and will ascend vertically. The pre-constructed on-board data collection package will characterize the coefficient of drag over time, and the on-board cameras will document the state of the drag system. After motor burnout, the rocket will activate its drag system and will then deactivate before reaching the apogee. The rocket will then begin to descend. The drogue parachute will be launched and will allow the rocket to descend at a steady rate of 46 ft/s. The main parachute will deploy once the rocket descends to an altitude of 650 ft and decreases to a final approach velocity of 13 ft/s. The dual-stage parachute system will allow the rocket and its contents to be safely recovered in reusable condition. This will be repeated for the second launch and will also include the activation of the air-brake immediately after motor burn out. The avionics will retract the air-brake when braking has been calculated to be sufficient and the chute will again be deployed at apogee.

Flight Analysis

Using OpenRocket against hand calculations, Bulldog Rocketry predicts the launch using the J-135 motor will achieve a maximum altitude of 5108 ft, maximum velocity of 539 ft/s, and a maximum acceleration of 6 g’s. Similarly, the launch using the K-2050 motor will achieve a maximum altitude of 4036 ft, maximum velocity of 1137 ft/s, and a maximum acceleration of 60 g’s.. Both motors have a rail exit velocity at 8 ft of greater than 45 ft/s. Figures 16 compare the flight characteristics of these two motors in detail. According to the difference in projected apogees, the air brake will have to create a 22% reduction in altitude on the J-135 flight to achieve a similar apogee to the K-2050 motor. The airbrake was designed to achieve the necessary reduction in altitude.





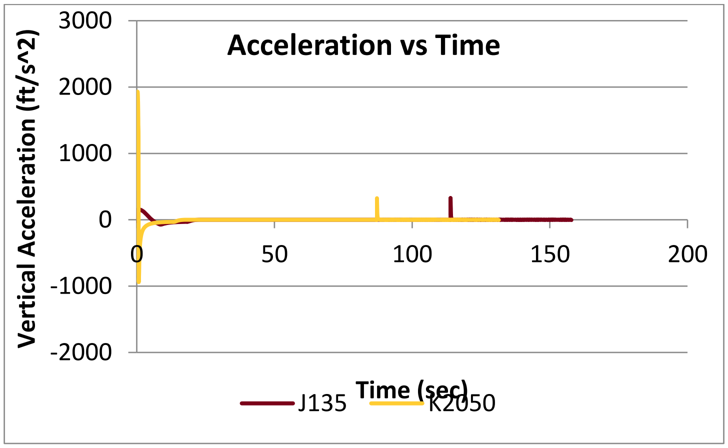


Figure 16: Flight performance simulation results.

Recovery Analysis

The recovery portion of the flight will begin one second after apogee when the ejection canisters discharge and end when the rocket touches the ground. Figure 16 is a simulation plot from OpenRocket of the initial portion of the recovery phase using the Iris Ultra Compact 48- Inch parachute. The lines plotted are respective altitude, velocity, and acceleration. From this simulation, a descent velocity was computed. The descent rate is the same for both flights, but the total flight time is different due to different altitudes. The total time the rocket spends in descent will be approximately 260 seconds. The descent rate was also checked against the Fruity Chutes descent rate calculator using the estimated weight and both the drogue and main parachute. Fruity Chutes calculator predicted the descent rate of the drogue parachute at an estimated 3400 grams to be 44.3 feet/sec. The descent rate of the main parachute was calculated to be 13.95 feet/sec at 3400 grams.

Environmental Conditions

Using weatherspark [3] the average conditions for the launch on May 21st are as follows. The probability of precipitation is 9%, the average wind speed is 6 mph in the morning and 12 mph in the afternoon as seen in Figure 17. The wind direction is generally out of the east. The cloud cover is 51% in the morning and 67% in the afternoon. The temperature is 53°F in the morning and 69°F in the afternoon.

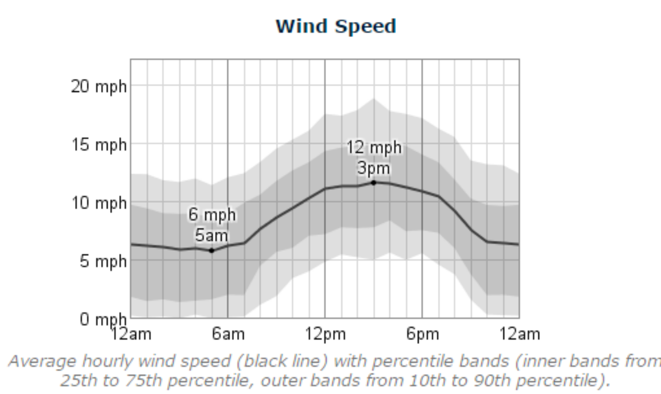


Figure 17: Wind speed estimation for launches.

The environmental data is brought into consideration for our design and launch. Due to favorable conditions in the morning, Bulldog Rocketry will try to do their launches earlier in the day.

Innovation

The requirements of the competition necessitate problem solving and innovation to meet the design constraints. The three largest innovations for this rocket are the air-brake, electronics, and the video sections.

The air-brake was designed to be able to reduce the rockets altitude by 1,500 feet, 50% more than necessary, to compensate for the difference in engine size, environmental factors, and manufacturing tolerance in each engine. To achieve this, the air-brake was designed as four, equally spaced, flat faced "fins" that are 0.50” x 3.00”. These fins will rest underneath a prosthetic that hides the flat face from the airflow until a servo allows spring force to rotate the brake 45 degrees and into the airstream. This method was selected because the mechanism is extremely simple and left few possibilities of failure. A thrust bearing is nested beneath the brake to absorb the drag force while maintaining nearly frictionless rotation. Because the fins are all attached to the same ring, this also ensures that every face will enter the airstream at the exact same time eliminating any possibility of causing the rocket to lose control.

The method for collecting video is relatively original as well. Small USB sized cameras were purchased for their low profile and high definition video quality. Doghouses were designed to house an upward and downward facing camera on the outside of the rocket. These doghouses were also designed to act as small stabilizing fins toward the top of the rocket. The cameras are easily removed for download and making them very easy to use. Again, this method was chosen for its simplicity and effectiveness.

Finally, the method of data collection and drag deployment features two Arduinos. Initially one Arduino was going to be used but a problem with latency arose. To combat the latency, two Arduinos will be used to build a functional drag system and data collection system. In addition to the multiple Arduinos, a well thought out mounting board was designed and printed to ensure easy emplacement and repair should that be the case.

Safety Features and Construction Considerations

The contents of the detailed pre-flight and post-flight procedures are listed later below. As the rocket is built and tests are conducted the pre/post-flight inspections will be modified to suit the rocket. To ensure the safety of the manufacturers, all machining will be done by qualified operators and eye protection will be required. Gloves will be required whenever epoxy is handled and all painting will be performed in a well-ventilated area.

Pre-Launch Procedure

Initial Rocket Inspection

1. Inspect rocket nose cone and body for damage.
2. Inspect fin prosthetics for any cracks or damage.
3. Ensure the separation area does not bind or catch.
4. Inspect shock cord connection points.
5. Ensure camera, altimeter, Arduinos, and circuit boards are OFF.

Drag System Inspection

6. Ensure drag system is properly torqued.
7. Ensure end caps for drag system are properly secured.
8. Verify the drag system does not bind when the springs are loaded.
9. Check that the servos are catching on the risers of the brake.

Avionics Inspection

10. Connect the 3.7V and 9V batteries to the Arduino, circuit board, and altimeter.
11. Run a test cycle of the drag system to ensure proper operation.
12. Check status LEDs to ensure no anomalies.
13. Pull the SD card to see if test data is recorded.
14. Replace SD card.
15. Turn on parachute altimeter and ensure proper operation.
16. Install Altimeter Two and ensure proper operation.
17. Stow avionics package and ensure the package is secure.
18. Turn off Arduinos and altimeter after proper operation is assured.

Assembly Inspection

19. Perform continuity check on ejection charge.
20. Pack and secure ejection charge inside piston.
21. Ensure the shock cord is securely attached to both sides of the rocket.
22. Inspect and fold parachute and attach to shock cord with quick link.
23. Install piston, shock cord, and parachute.
24. Assemble both sides of rocket and assure no binding or catching.
25. Install cameras in doghouse and ensure they are secured.

Launch Pad Inspection

26. Install motor.
27. Place rocket on launch rail.
28. Turn on Arduinos, altimeter, radio beacon, and cameras.
29. Ensure test cycle runs correctly on Arduinos and the altimeter follows proper beeps.
30. Altimeter - 4 sets of 3 short beeps indicates success, any long beeps denotes failure.
31. Final visual inspection.
32. Launch

Post-Launch Procedure

Tracking

1. Track the rocket using the radio device.
2. Follow the radio signal to the rocket and have “heads up” awareness.
3. Approach the rocket with caution and do not attempt to catch the rocket if it is still descending.

Rocket Inspection

4. Record altimeter altitude based off of series of beeps.
5. Turn off Arduinos, altimeter, and cameras.
6. Collect all components.
7. Return to the judge’s booth.

Judges Inspection

8. Present the rocket and all components to the judges table.
9. Remove the camera and SD card and present video and data.
10. Return Altimeter Two so altitude can be recorded.

In-Depth Rocket Inspection

11. Inspect motor, shock cord, parachute, body, fins, drag device, and nose cone.
12. Download camera video and SD card data.
13. Download data from Altimeter.
14. Replace all components to standard configuration.
15. Follow Pre-Launch Procedures for next launch.

Risk Assessment

Table 5: Risk assessment analysis and mitigation.

Risk Assessment					
Risk Factor	**Risk Statement**	**Likelihood**	**Impact**	**Level**	**Mitigation Strategy**
Rocket Construction	Rocket construction will involve the use of power tools, soldering irons, and hand tools. There is inherent risk to bodily injury using these tools.	M	H	H	Wear proper PPE and have facility supervision for difficult tasks. Have machinist build difficult parts.
Gluing and Painting	Epoxy and paint will be used to assemble the rocket. These products produce fumes that are harmful to the lungs and eyes.	M	H	H	Wear proper PPE including safety goggles, gloves, and a mask if necessary. Have faculty suggest best location for these tasks.
Recovery System	The recovery system is responsible for safely deploying a parachute for smooth descent after flight. If the recovery fails, the rocket will fall unrestricted.	M	H	H	Use electronic commercially available parachute deployment system, use flame retardant parachute, do not remove moto backup deployment charge, and test system to ensure operation.
Motor	Motors are highly flammable and pose a risk to everyone near the motor.	L	H	M	Keep all flames away from motor, only install motor on launch pad before launch, and do not tamper with motor.
Launch Pad	The launch pad can have debris, materials, and personnel that obstruct a safe launch of the rocket.	L	H	M	Clear all debris from launch pad prior to launch, check launch rail for any binding or catching, ensure launch pad is clear of people before launch, countdown before launch.
Drag System	The drag system is custom designed and could fail in the air resulting in rocket failure	M	H	H	Use computational analysis to ensure components will not fail, test redundancy of system, and design so a failure will not interrupt a safe flight.

Project Timeline

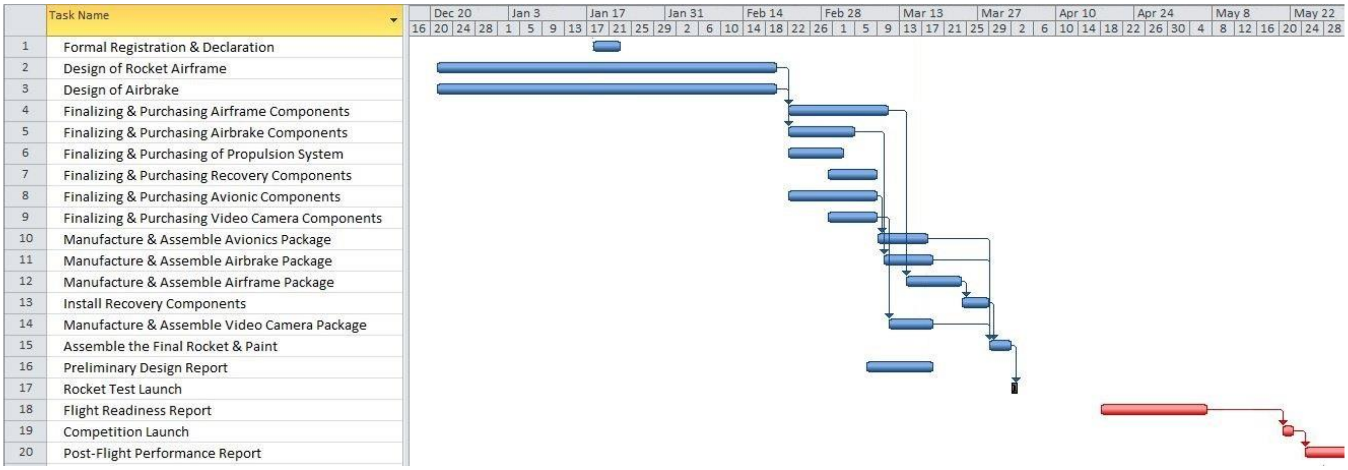


Figure 18: Project timeline.

Budget

Many of the parts necessary to construct the rocket of our choice were available from previous years and did not need to be purchased, these have been filled with "-" to indicate the lack of expense. In some cases, multiple parts were pulled into sections for simplicity (i.e. Hardware).

Expenses	Cost
Air-Brake	
Springs	$ 13.71
Servos	$ 8.76
Printing	-
Aluminum Rod	$ 5.54
Airframe	
Centering rings	$ 22.60
Fiberglass	$ 96.00
Hardware	$ 26.24
Fasteners	$ 35.25
Nose Cone	-
Body tubes	-
Competition	
Travel/Hotel Estimate	$ 300.00
Midwest Competition	$ 400.00
Motor	
4-Grain Case	$ 89.98
Retainer Ring	$ 31.30
J-135/K-2050 (5 engines)	$ 504.30
Recovery	
Parachute	$ 182.70
Kevlar cord	$ 26.80
Video	
Printing	-

Cameras	$ 103.53
Arduinos	$ 24.55
Micro SD Card	$ 35.54
Stratalogger Altimeter	-
Mini-Lipo Battery	$ 10.45
IMU and Pressure sensor	$ 110.86
Total	**$ 2036.89**

Table 5: Budget for rocket competition.

Conclusion

Bulldog Rocketry will launch a rocket at least twice during the competition while meeting or exceeding all competition requirements. Students with help from mentors and faculty will use simulation analysis, extensive testing, and applied engineering to build a safe, quality, and innovative rocket. Bulldog Rocketry will have a competitive and successful rocket for the 2017 Space Grand Midwest High-Power Rocket Competition.

References

[1] "Rules for Surveying and Testing of Plywood for Aircraft." (1953): n. pag. www.aircraftspruce.com. Germanischer Lloyd. Web.

[2] "Pitot Tube." NASA, n.d. Web. 10 Mar. 2017

[3] “May Weather in Minnesota.” Weatherspark. Web. 10 Mar. 2017