Bulldog Rocketry

Preliminary Design Report

2015-2016 NASA Space Grant Midwest High-Power Rocket Competition

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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 basic rocketry science. The University of Minnesota-Duluth team, Bulldog Rocketry, plans to attend and compete with a fully designed and thoroughly tested rocket. The team consists of 21 members whom are outlined in the team summary.

The purpose of the competition is to develop a high-powered rocket with an active data recording device along with a drag system that will reduce the altitude of the rocket during a second, successive launch to 75% of the original recorded altitude. The rocket will be fitted with an on-board, downward-facing camera, providing visual data that will be used in final analysis. The competition scoring will focus primarily upon the accuracy and precision of the air-brake mechanism's ability to launch the rocket to the desired altitude.

A full recovery package, consisting of a 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 must be commercially made and have documented performance characteristics.

A full test-flight is planned to take place in the spring of 2016, where a complete, comprehensive performance analysis of the rocket will be conducted. It is this test flight which 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.

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 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 that includes students from the mechanical engineering, industrial engineering, electrical engineering, and physics departments.

Project Manager: Chet Peterson
Air-Brake: Chet Peterson (Lead), Ashton Lebrun
Airframe Design: Lee Vest (Lead), Christopher Kleinjan, Peter Guski, Nicholas Zeman,
Avionics Design: Ethan Vought (Lead), Kevin Victoria, Logan Hotek, Stefan Nelson
Recovery: Joel Stomberg (Lead)
Video: Joseph Kaiser (Lead), Jake Klinkner, Andy Miller, Alex Colbert
Simulation: David Ries (Lead), Zach Ludwig (Lead), Zach Claassen
Construction: Joseph Sygulla
Aesthetics: Kalli Anderson (Lead)

Rocket Design Objective

Design and construct a high-power rocket with an active drag system that will reach an apogee of at least 3000 ft. above ground level and be recovered safely and in flyable condition, predict its flight performance (both with and without the drag system engaged), and construct a non-commercial on-board data collection package for the rocket that will characterize its coefficient of drag over time and use an on-board video camera to document the state of the drag system.

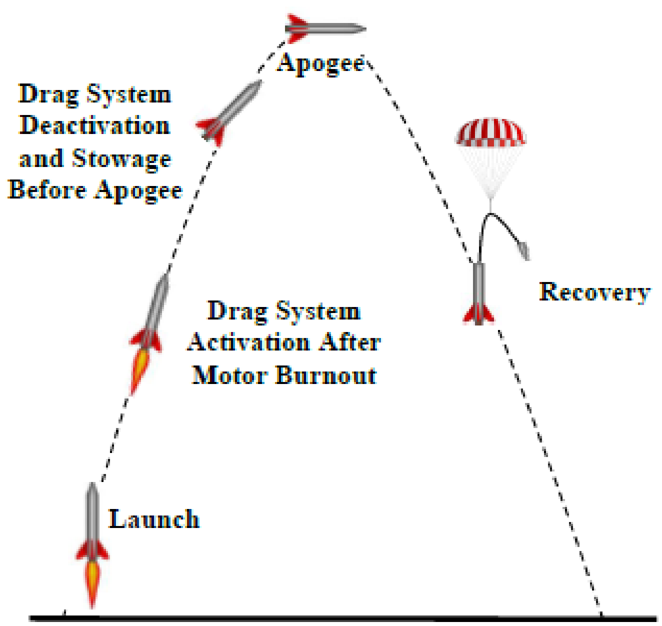


Figure 1: Events during rocket flight.

Competition Engineering Parameters

Flight Mission

- Use an active drag system to attain an altitude of exactly 75% of the not-deployed apogee with the same rocket flown on the same motor.
- Document the drag system with on-board video and collect sensor data to characterize drag as a function of time.

Rocket Recovery

- Electronic ejection of recovery system no earlier than apogee using a commercial rocketry altimeter.
- Motor ejection backup required.
- Apogee/Main Parachute required
- Ejection of recovery parachute during ascent prohibited.
- Ejection of recovery system while drag system is still activated/deployed is prohibited.
- Landing speed < 24 ft/sec.

Rocket Constraints

- 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, one with drag system deactivated, and one with drag system activated to achieve reduced-apogee goal.
- Rocket flies vertically.

- Rocket is stable throughout the flight.
- Drag system is successfully activated after motor burnout and deactivated/fully retracted prior to apogee, as documented by on-board video and/or monitoring system.
- 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 powered rocketry construction to ensure not only proper functionality but safety as well. Each dimension listed below was carefully determined through simulation with OpenRocket and SolidWorks. A long period for design and brainstorming ensured that the final assembly functioned properly with very few minor alterations to the original design. 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 proper stability. Observing the rocket from tail to nose, the center of gravity should be in front of the center of pressure. Their distance provides stability and this rocket was designed to have a stability of 1.64 caliber before burnout and 1.70 caliber after burn-out. The fins provide a large portion of this stability. The fins consist of 3/16 inch G10 Fiberglass and a Carbon Fiber prosthetic that slowly transitions the fin out to a thickness of 1 inch over a length of 4 inches. This transition is essential for keeping the air-brake hidden until it needs to be engaged.

The air-brake is designed to rest underneath the fins, completely out of the air-flow until one of two solenoids allows it to rotate into the air-stream. The second solenoid, when energized, allows the brake to rotate back into a stowed position before apogee. Both Solenoids and the recovery system are controlled by the Avionics bay, which calculates the estimated apogee five times a second. It uses this information to activate the solenoids and initiate recovery. The recovery system will deploy shortly after apogee using a gunpowder charge and a piston. Once the chute is out the rocket should descend at about 20 ft/s. In the event that the blasting caps do not ignite, the delayed ejection charge of the engine will force out the parachute. A Cesaroni K520 engine was chosen for this competition based on the relatively short burn time but large thrust. This allows plenty of time for the air-brake to alter the velocity of the rocket before apogee. All these components work together to give the rocket stability, accuracy, and safety.

Dimensional Specifications

The most essential dimensions of the rocket were determined through iterative simulation on OpenRocket and SolidWorks. 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 rocket comes out to be 58.65 inches in length, about 4.9 ft. The fin itself is 3 inches tall along with the prosthetic bringing the total length to 6 inches. This provides enough fin surface to provide a stable and controlled flight. The approximate weight of the rocket including paint is 11.70 lbs. The air-brake was designed more intensely than any other portion of the rocket. The air-brake went through many iterations and dimensional changes in the design process but eventually a 3 inch by 1 inch area for each leg was choosen. The air-brake needs to hide underneath the prosthetic of the fin so an extra inch by inch tab was added to the end of the prosthetic to ensure that the air flow over the fins would be as uniform as possible during the period when the air-brake is stowed.

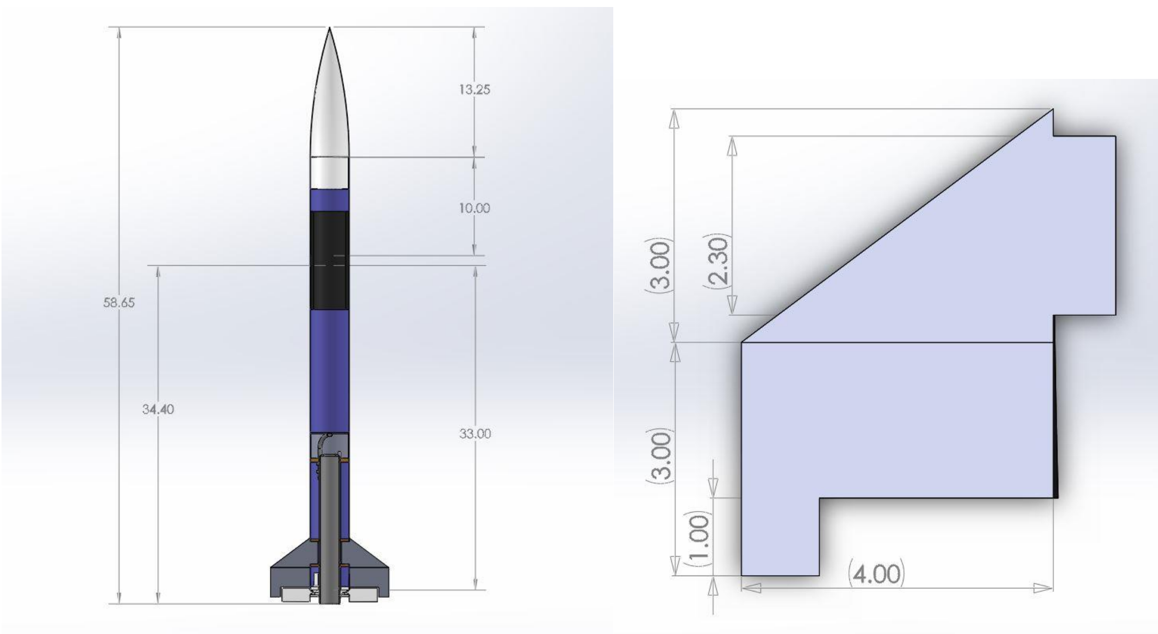


Figure 2: Rocket and prosthetic dimensions.

Center of Pressure and Center of Gravity

Designing a rocket that has a stable flight depends on the placement of the center of pressure and center of gravity. In Figure 2 the center of pressure and center of gravity can be seen on an OpenRocket simulation of the model. The center of pressure is denoted by the red dot and the center of gravity is denoted by the blue dot. The center of gravity is above the motor and about 6 inches above the center of pressure indicating that the rocket will have a stable flight.

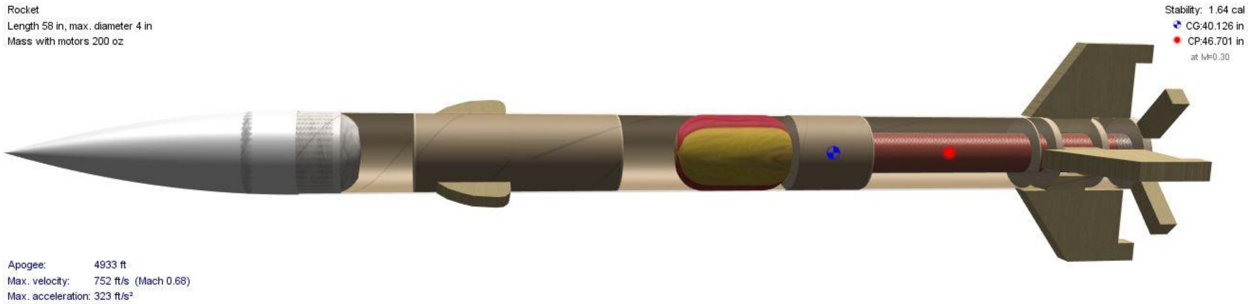


Figure 3: Rocket body.

Airframe

Designing the general airframe for the rocket took careful consideration, with many different approaches to the design; research was required to complete it. Previous UMD rockets were analyzed to aid in determining how the drag system should be designed. Every component starting from the nose cone to the fins needed to be specially made in order to meet the requirements and constraints for the rocket. In the past, the nose cone chosen happened to be ogive because of its aerodynamic shape. After a group discussion, it was decided the previous nose cone shape would be perfect for this rocket. Then the body material had to be chosen for this rocket. Recent years showed that blue tube performed well, therefore this year's rocket was made with the high strength blue tubing. Next, the fins were in consideration, they had previously been 3/16" fiberglass, but this year an air-brake was required for the competition. In order to accommodate for the air-brake system, fiberglass and a 3-D printed prosthetic will be used to form a fin. The 3-D printed portion of the fin tapers from 3/16" to 1" thick making it easier for the air brake to hide behind.

The design was chosen to reduce drag when the airbrake was stowed. A four fin design was selected because it would be the easiest to take measurements due to the 90-degree separation. Since the design is simple, this made finding the center of pressure and gravity relatively easy. After the design was finalized, the ideal motor for the flight was chosen. Many motors were analyzed and simulated in open rocket, and the final motor chosen was the Cesaroni 1711-K520-WH-17A.

Air Brake Design

The air-brake assembly consists of a top and bottom retaining ring, a center brake ring, two extension springs, and two solenoids. All three rings are manufactured from Carbon Fiber filled Nylon 11 using a 3D printer. The entire assembly sits on the end of the rocket around the engine casing. The top retaining ring fits inside the body of the rocket doubling as a centering ring and holds two solenoids firmly in position above it. The bottom retaining ring holds the center brake ring firmly in place while still allowing it to rotate freely. In this way the center brake ring is able to spin while still being safely secured. Any repairs or maintenance to the air-brake assembly will be easy because the entire assembly was designed to be removable from the tail of the rocket by removing four hex nuts.

Extension springs located inside the assembly provide the torque to activate and stow the air-brake. The springs must be put in tension by clocking the brake ninety degrees where the solenoids will then hold it in place. To avoid unintentional drag, the brake is stowed behind the fins when it is inactive (Figure 4). Once the avionics program determines that the brake should be activated, the first solenoid is energized removing an obstruction and allowing the center brake ring to rotate forty-five degrees before hitting the second solenoid. The air-brake is now activated; introducing four flat faces into the air stream causing drag. Once the avionics program determines that velocity has been reduced sufficiently, the second solenoid will be energized and allow the center brake ring to rotate another forty-five degrees to a stowed position.

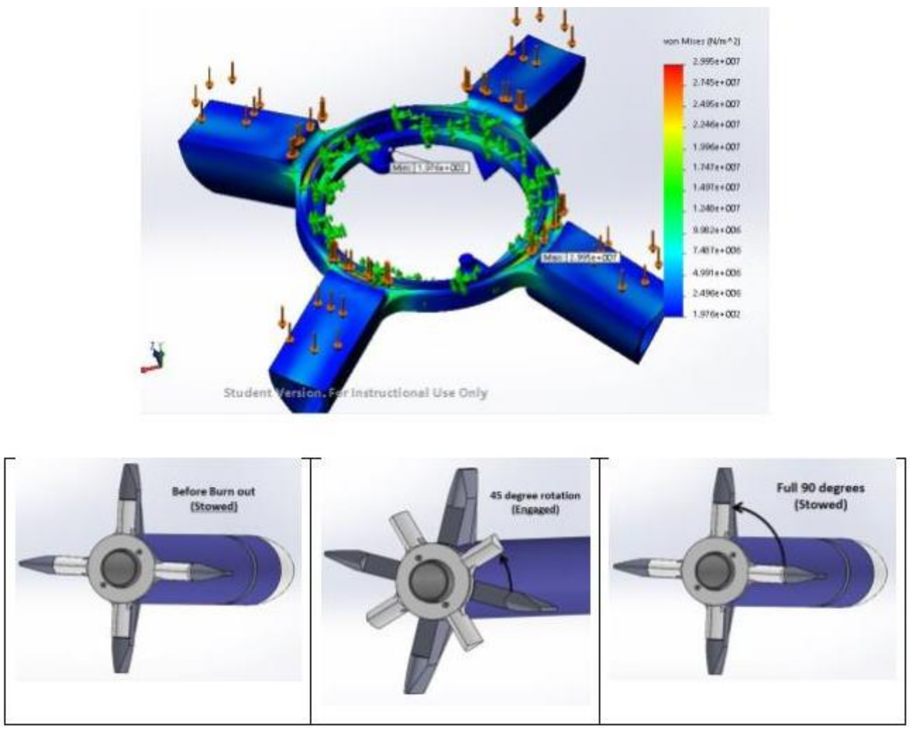


Figure 4: Drag system stress analysis and visual representation.

Major stress due to drag will be applied to all four faces during deployment of the air-brake so many simulations were run to test the structural integrity of the design (Figure 4). It was found that each face could withstand approximately 25.0 psi without structural failure. The simulations on OpenRocket give no reason to believe any face will be under that kind of pressure.

Multiple simulations were done on OpenRocket as well as CFD (Computational Fluid Dynamics) to ensure that this design would provide enough drag to cut the altitude of the rocket by twenty-five percent. Using the OpenRocket simulations the air-brake was designed to ensure it could reduce the rockets apogee altitude by forty percent. Having ample drag leaves enough time in which the air-brake can be deployed and stowed while still achieving the goal of a twenty-five percent reduction. This also allows there to be some latency in the avionics calculations without missing the target altitude at apogee.

Fin Design

The tail-fin design consists of a main-body which is fixed into the rocket frame itself and a 'prosthetic' covering, fitting the exterior body of the fin, providing proper aerodynamics and air-brake functionality. The fins are fixed to the body by running a 2.3 inch tab through the tube and into three centering rings as seen in the cross section of Figure 5.

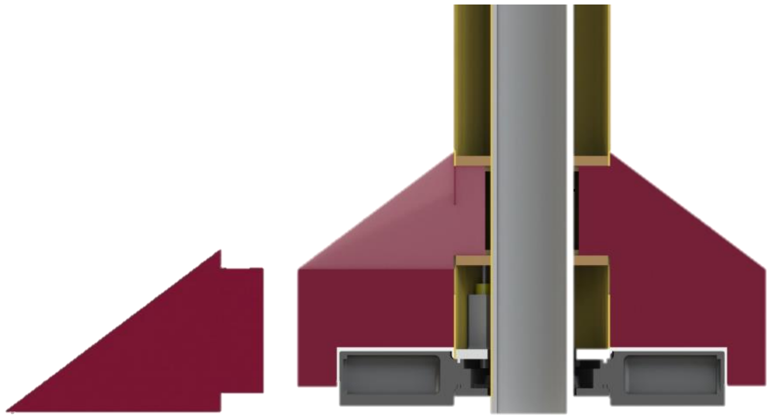


Figure 5: Fin and cross section of centering rings, motor tube, prosthetic fins, and drag system.

Recovery System

The recovery portion of the flight commences when the rocket reaches apogee. The recovery system is a single deployment system. 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 the parachute. The weight of the charge is determined by 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 charges are deployed using an AIM USB 3.0. This device, shown in Table 2, measures barometric pressure and can detect when the apogee is reached. The altimeter will deploy two separate charges one second after apogee along with the engine back up to ensure parachute deployment. Additional specifications are discussed in the avionics design.

The parachute equipped is an Iris Ultra 48 inch 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 15ft Kevlar shock cord, rated for 1500 lbs of force, attaches the upper and lower sections of the rocket. The cord will be anchored at both ends using U-Bolts.

Analysis of Custom Built Parts

Multiple parts of the rocket were designed and build by the members of the club. Each of these parts underwent some type of analysis to ensure that they would be able to handle each of the stresses they will encounter during flight. The fins specifically were manufactured from 3/16 inch G10 fiberglass which is more than strong enough for the stresses of flight. The air-brake was tested in SolidWorks to find the point at which force on the flat faces would cause fracture. Simulations of this type consistently returned about 25 psi on each face before fracture. Although it was determined that there was little chance of reaching this pressure, the air-brake was designed for more than twice that stress. Part of this test can be seen in Figure 4 above.

Propulsion System

The motor selected for the competition is a Cesaroni K520. The motor has a total Impulse of 1,710.2N with a burn time of approximately 3.3 seconds. For the rocket to have success with the designed drag system, maximum time is needed for the drag system to deploy. Since the K520 has a burn time of only 3.3 seconds, the rocket should have approximately 11.2 seconds to deploy the drag system. Using OpenRocket the predicted altitude due to the K520 will be 4976 ft.

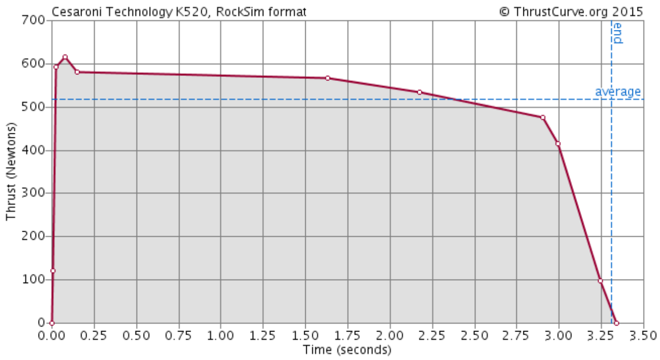


Figure 6: Thrust curve for Cesaroni K520.

Avionics Design

The avionics payload features two 3.3V Arduino Pro Mini microcontrollers, two Inertial Measurement Units (IMU), and an 8GB SD card reader/writer. The IMUs record gyro, acceleration, barometric pressure, altitude, and temperature. Together the components collect, calculate, and record data. In addition to the data recording, one Arduino has the specific task of drag system deployment. The avionics payload also includes a parachute deployment altimeter, and an Altimeter Two for standardizing each team's flights.

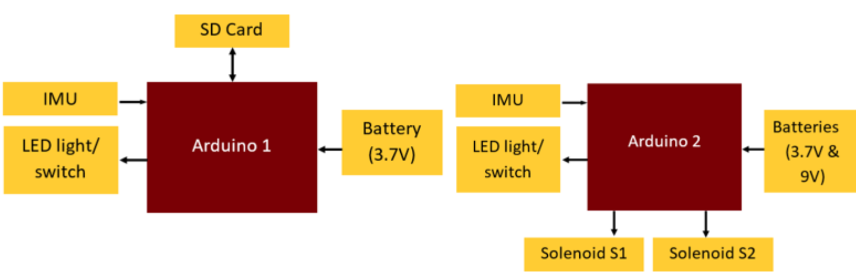


Figure 7: Arduino control design.

Arduino Control Design

While one Arduino is recording the flight data, the other Arduino will be measuring the rocket's velocity, acceleration, and altitude to determine drag system deployment / recovery. In order to determine the best time to actuate the drag system, the Arduino will take 5 measurements per second. When the statements written in the Arduinos code determine the rocket his ended boost phase, the Arduino will send a signal to a transistor which will send power to the solenoids which activate the drag system. Using the current altitude, velocity, and drag, the Arduino will then determine when to recover the drag system to be closest to 75% of 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 LED's that can be seen from the outside of the rocket.

The 3.3V Arduino was chosen because of the fast process speed of 8MHz, the small size, and because it operates at the same voltage as the IMU/SD card writer (3.3V). The 10DOF IMU was selected because of the reliability, ease of use, and accuracy of the data. In order to store the data, the most reliable and easy to operate SD card reader was chosen. Together the components are able to record data near real time, operate at a safe voltage, draw minimal current, deploy / recover the drag system, and output data that can be used to calculate drag as a function of time.

The power supply for the avionics payload will be a 3.7V 1200mAh lithium polymer battery. The Arduinos, IMUs, and SD card writer all feature voltage level shifters in order to accommodate the 3.7V supply. During testing the prototype Arduino setups drew on average 140mA. The total predicted current draw for the complete avionics payload is estimated at 180mA giving the Arduinos well over 4 hours of battery life on a single charge. To power the solenoids for the drag system, there will be two 9V batteries in series which will result in 18Vs of power. The 18Vs supplied should provide 10N of pull force to deploy and redeploy the drag system.

To ensure accessibility of the avionics payload, all of the electronics are connected to a single board so the electronics bay can be removed from the rocket. In order to turn on the Arduinos two plunger switches are used so that the pins can be removed on the launch pad. 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.

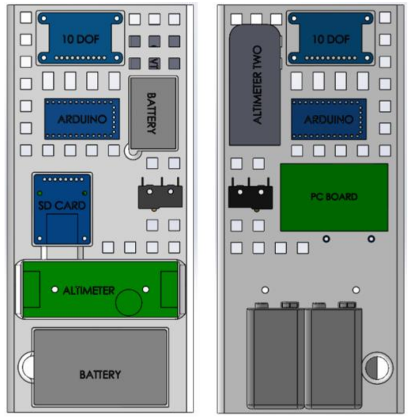


Figure 8: Avionics mounting design and layout.

The avionics payload will be located towards the top half of the rocket in a position that 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.

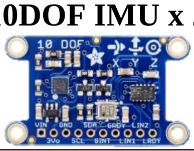
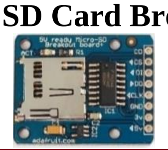
Hardware Name / Picture	**Description**	**Voltage Rating**	**Current Draw**	**Power Supply Information**
Arduino Mini Pro x 2 	-Microcontroller based on ATmega328 -Integrates sensor / SD card -Cycles drag system	3.3V	15mA	1200 mAh lithium polymer battery
10DOF IMU x 2 	-3 axis accelerometer, gyroscope, magnetometer -barometric pressure -temperature sensor	3.3V	20mA	1200 mAh lithium polymer battery
Micro SD Card Breakout 	-Records sensor data from 10DOF IMU -Utilizes 8GB memory card -Automatic level shifting	3.3V	35mA	1200 mAh lithium polymer battery
AIM USB 3.0 Altimter 	-Dual deployment -Records altitude and velocity -Audible beep to assure operation	3V to 14V	4mA	200 mAh lithium polymer battery
Altimeter Two 	-Competition supplied altimeter -Records max altitude based on barometric pressure	NA	NA	Internal battery

Table 2: Avionics component description.

Separation Avionics

The rocket must use electronic deployment of a parachute recovery system ejected at or after apogee using a commercial rocketry altimeter. The rocket will use an AIM USB 3.0 altimeter to deploy the parachute. In order to deploy the parachute, the altimeter detonates 2 separate charges. The first charge will deploy at one second after apogee and the second will detonate 3 seconds after apogee to ensure parachute deployment. The software is easily programmed using a computer and will also provide us with data to confirm the accuracy of our custom built data recording package. In addition to both of the 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.

Competition Provided Avionics

In order to standardize every flight, the competition will supply a Jolly Logic Altimeter Two. 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. In order to record quality reliable video, two 720p cameras were selected that has a built in battery and enough memory to operate independent of the other electronics. The reason for using two cameras is to have redundant recording and to balance the rocket. Having no wires running to the camera allows the video to be taken from almost any location on the rocket. The view angle and distance will be selected based on the camera's field of view and the aerodynamics team's choice of location.

Figure 9: 720p USB camera for recording drag system deployment and recovery.

Both cameras will be mounted on the outside of the rocket so that no modifications have to be made to the tubing. In order to mount the cameras on the outside of the rocket, a doghouse was designed to prevent excess drag and so the camera is secure to the side of the rocket. A prototype of the doghouse (Figure 10) was designed using SolidWorks. The doghouse will shelter the camera and still allow it to be easily accessible. The doghouse door will be friction fit to ensure the camera does not dislodge during flight.

Figure 10: Doghouse for USB camera, maroon represents cover, gold represents body.

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. Assemble all necessary materials
2. Machine and cut parts:
    - 3 Centering rings, Body tube, motor tube, and fins
3. 3D print specific parts:
    - Doghouses, Air-Brake assembly, Prosthetic fins
4. Test fitting of all parts (sand as necessary)
5. Mount parts into body using strong Epoxy
    - Straight edge 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 procedures

Predicted Performance

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 camera 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 main parachute will be launched and will allow the rocket to come to the ground at a safe and steady rate of less than 20 ft/sec. The rocket and its contents will all 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.

No-Drag System Flight Analysis

Using OpenRocket against hand calculations, Bulldog Rocketry predicts the first launch will achieve a maximum altitude of 5,470ft with a maximum velocity of 776ft/s. Figures 11, 12, and 14 show the flight characteristics in detail.

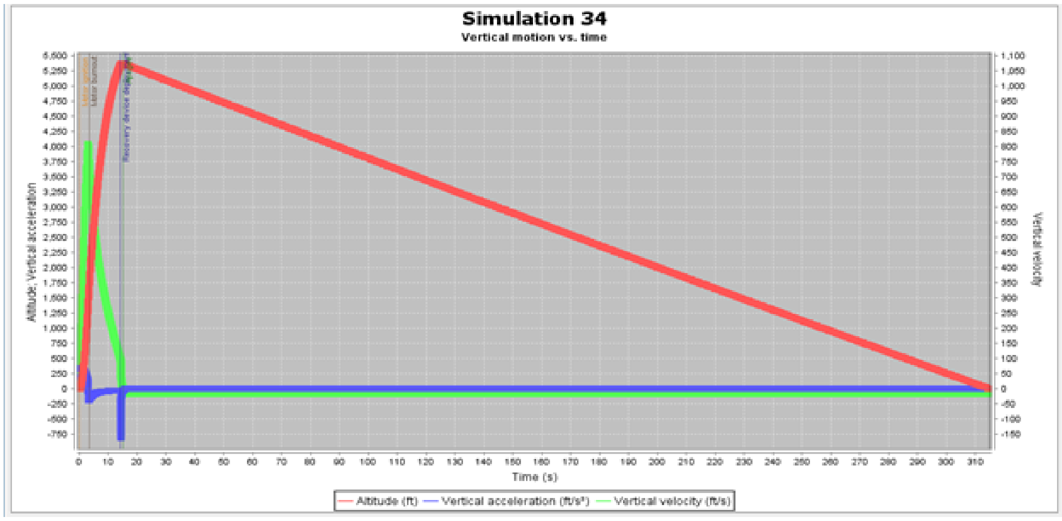


Figure 11: Flight simulation with drag system stowed.

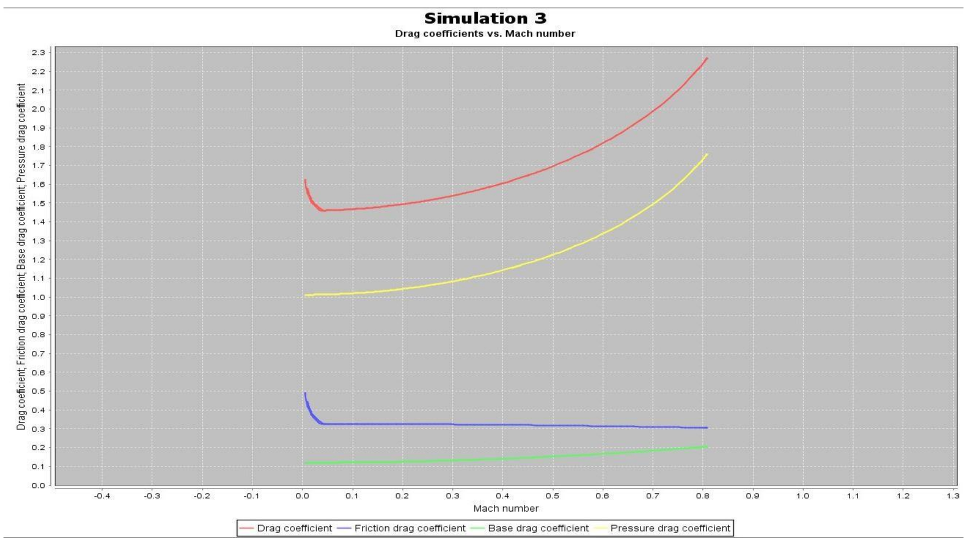


Figure 12: Launch with no drag, drag variables vs time.

Drag System Flight Analysis

Using OpenRocket against hand calculations, Bulldog Rocketry predicts the first launch will achieve a maximum altitude of 4,100ft with a maximum velocity of 776ft/s. The predicted altitude for the second launch is approximately 75% of the first launch. To account for engine variation the Arduino will deploy and redeploy the drag system using real time telemetry. Figures 13 and 14 show the flight characteristics in detail.

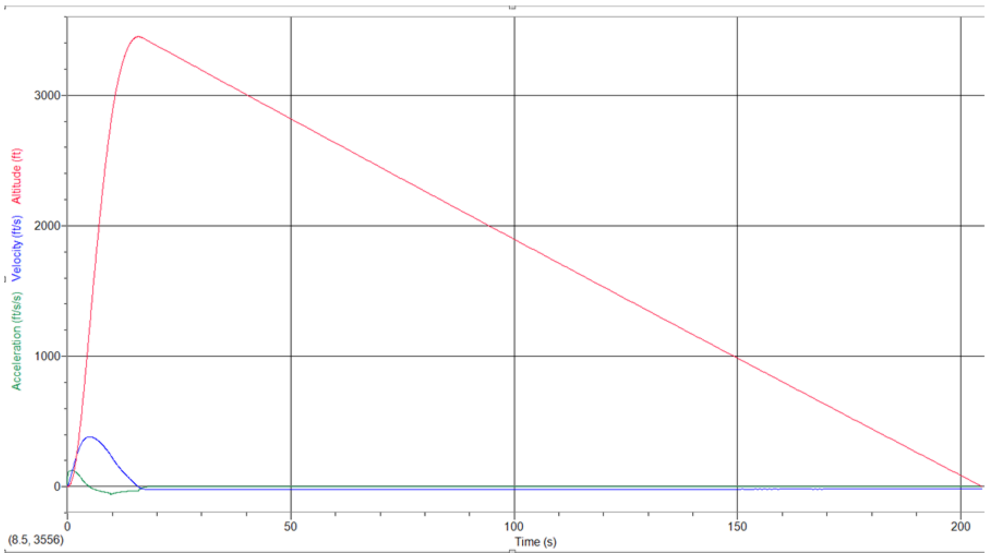


Figure 13: Flight simulation with drag system stowed.

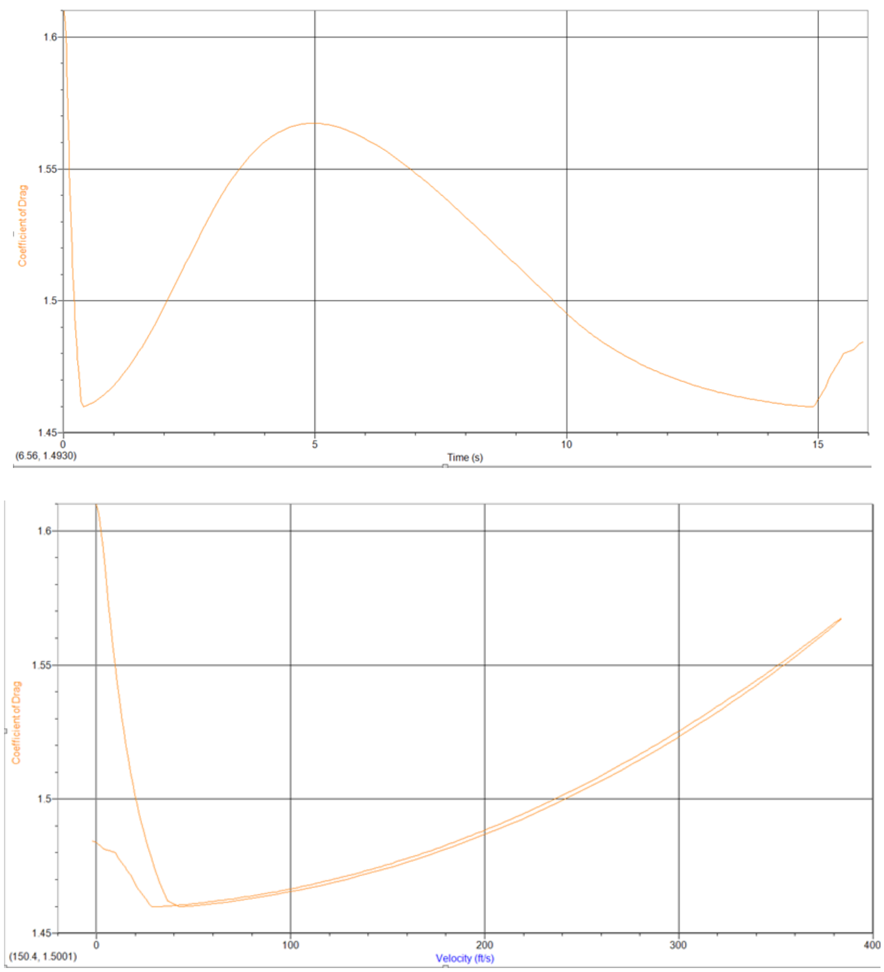


Figure 14: Launch with drag, drag variables vs time.

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 15 is a simulation plot from OpenRocket of the initial portion of the recovery phase using the Iris Ultra 48-inch parachute. The lines plotted are respective altitude, velocity, and acceleration. From this simulation, a decent velocity of 20ft/sec was computed. The decent 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 decent rate was also checked against the Fruity Chutes decent rate calculator using the estimated weight and parachute selected.

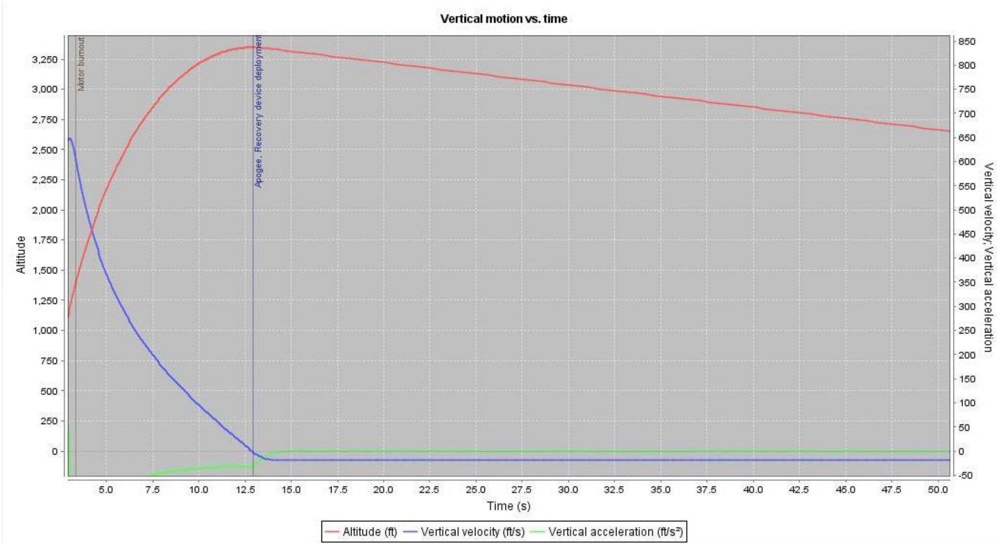


Figure 15: Predicted rocket descent.

Stability Analysis

The CFD solution iteration graph is shown in Figure 16 and can be seen to have steady iterations at the final result indicating that the numbers achieved for coefficient of drag are accurate. To reduce solution time, one set of fins was analyzed. The coordinate system is consistent through the simulations; air-flow is designated in the negative Y direction as to portray the actual flight of the rocket. The meshing of the rocket shown in Figure 17 is seen to be concentrated near the drastic changes within the rocket fins. This is important while using a finite number of elements to accurately calculate the drag force at harsh corners of the model. The analysis was completed to find the coefficient of drag of the rocket itself. Currently the coefficient of drag with the airbrake deployed is being calculated using CFD. The simulation for each scenario (with deployed air-brake and without deployed air-brake) are to be repeated several times, increasing the airspeed and comparing calculated drag coefficients. Calculating accurate drag coefficients for the rocket with and without the air-brake engaged is an ongoing process that is expected to yield useful information very soon.

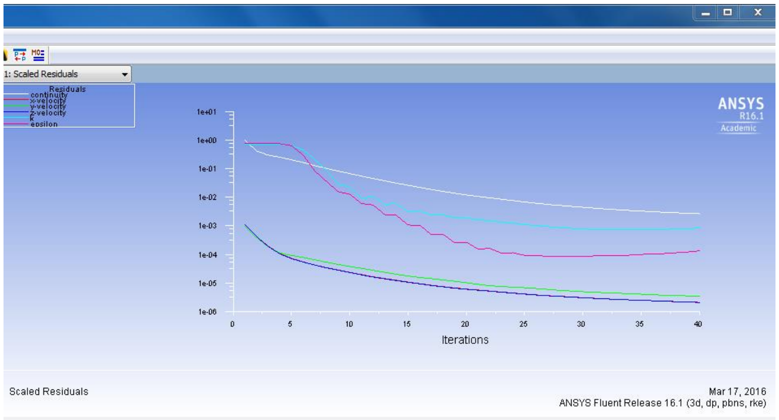


Figure 16 - Iterations Using CFD

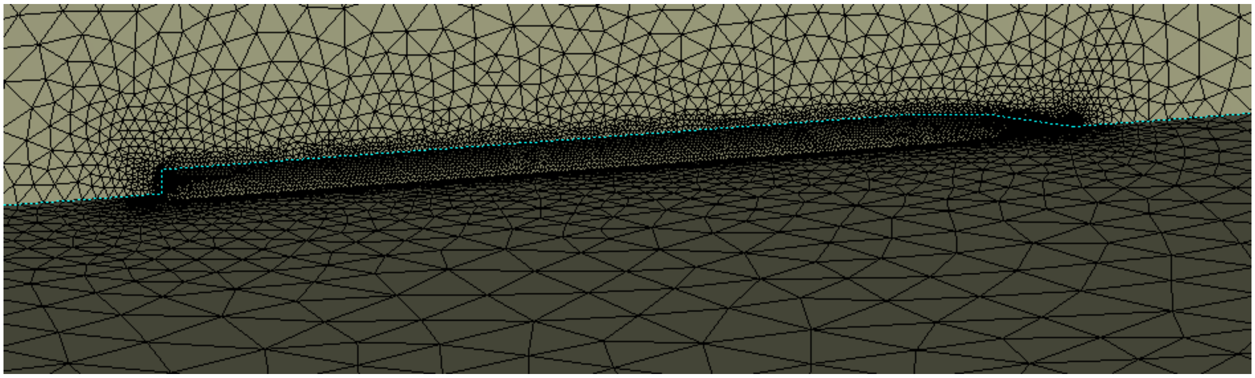


Figure 17 - Meshing of Rocket

Environmental Conditions

Using weatherspark.com the average conditions for the launch on May 16th are as follows. The probability of precipitation is 10%, the average wind speed is 7mph in the morning and 12mph in the afternoon. The wind direction is generally out of the east. The cloud cover is 39% in the morning and 71% in the afternoon. The temperature is 52°F in the morning and 67°F in the afternoon.

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 some problem solving and innovation in order 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 25% while not restricting the rockets flight during the first launch, engine burn, and after apogee. To achieve this the air-brake was designed as four, equally spaced, flat faced "fins" that are 1 x 3 inches. These fins will rest underneath a prosthetic that hides the flat face from the airflow until a solenoid allows spring force to rotate 45% and into the airstream. This method was selected because it was the simplest and thus there is less to go wrong. 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 video quality. Doghouses were designed to hold the cameras on the outside of the rocket facing toward the bottom. 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. So to combat the latency two Arduinos could 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 in Appendix A and Appendix B. 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. Construction procedures can be found in Appendix A.

Risk Assessment

Risk Assessment					
Risk Factor	**Risk Statement**	**Likelihood (H/M/L)**	**Impact (H/M/L)**	**Level (Derived)**	**Mitigation Strategy/ Contingency Plan**
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	The recovery system is responsible	M	H	H	Use electronic commercially

System	for safely deploying a parachute for smooth descent after flight. If the recovery fails, the rocket will fall unrestricted.				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.

Table 3: Risk assessment analysis and mitigation.

Project Timeline

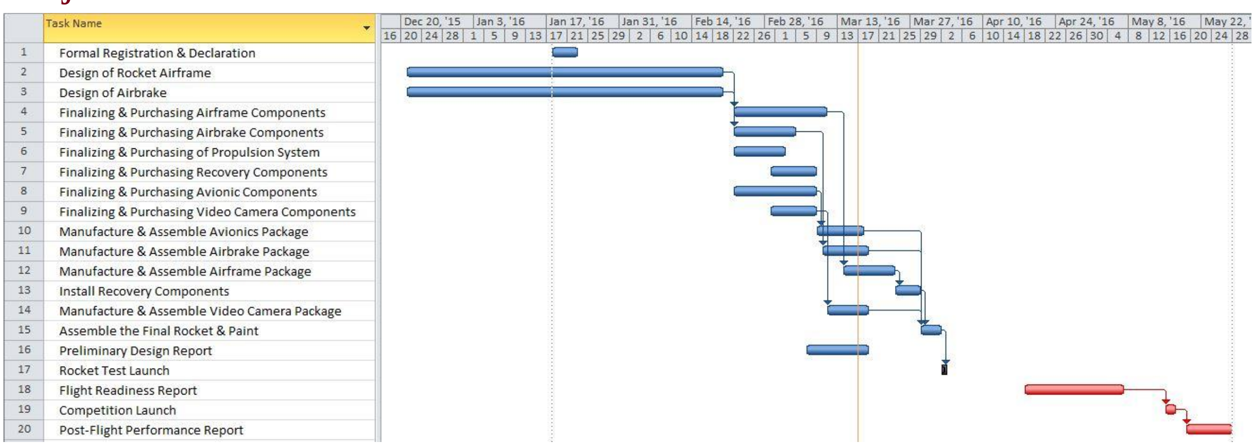


Figure 17: Project timeline.

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

Solenoids	$ 8.76
Printing	-
Stainless Steel Tubing	$ 5.54
Airframe	
Centering rings	$ 22.60
Fiberglass	$ 96.00
U-bolt	$ 8.78
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
K520	$ 504.30
Recovery	
Parachute	$ 182.70
Kevlar cord	$ 26.80
Video	
Printing	-
Cameras	$ 103.53
Avionics	
Arduino Mini Pro	$ 24.55
Micro SD Card	$ 35.54
AIM USB Altimeter	-
Mini-Lipo Battery	$ 10.45
IMU	$ 20.86
Total	**$ 1946.89**

Table 4: Budget for rocket competition.

Conclusion

Bulldog Rocketry will launch a rocket 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 2016 Space Grand Midwest High-Power Rocket Competition.

Appendix A: 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 solenoids are catching on the lips of the drag system.

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. Ensure the shock cord is securely attached to both sides of the rocket.
20. Inspect and fold parachute and attach to shock cord with quick link.
21. Install piston, shock cord, and parachute.
22. Assemble both sides of rocket and assure no binding or catching.
23. Install cameras in doghouse and ensure they are secured.

Launch Pad Inspection

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

Appendix B: 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 Drag Data as a function of time.
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 Appendix A for next launch.