Bulldog Rocketry

Flight Readiness 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, land, and be collected. The recovery altimeter must be commercially made and have documented performance characteristics.

A full test-flight took place in the spring of 2016, where a complete, comprehensive performance analysis of the rocket was conducted. It is this test flight which will aid in further design and mechanical enhancements. Analysis of the test flight will be outlined in this 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
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.

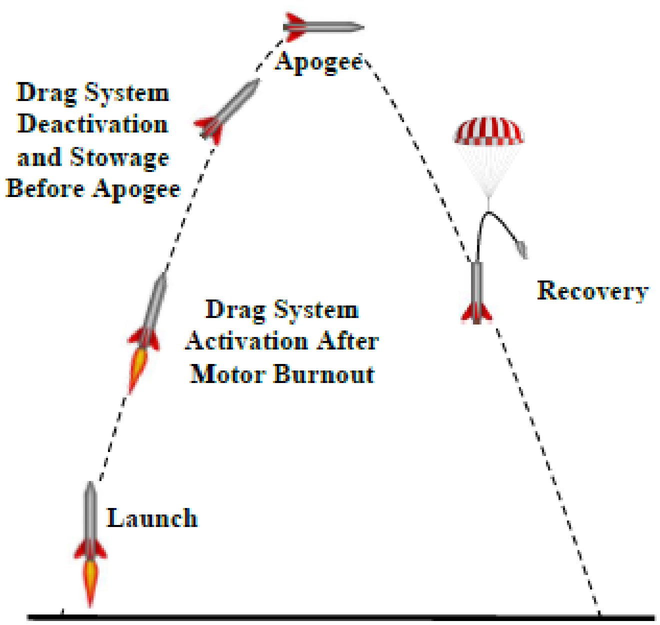

Figure 1: Events during rocket flight.

Mechanical Design

Precision and accuracy are absolutely essential in high powered rocketry construction to ensure not only proper functionality but safety as well. 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 1.32 caliber before burnout and 2.22 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 stowed 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 24 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 ample 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 64.5 inches in length. The fin itself is 3 inches long 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 chosen. The air-brake needs to stow 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.

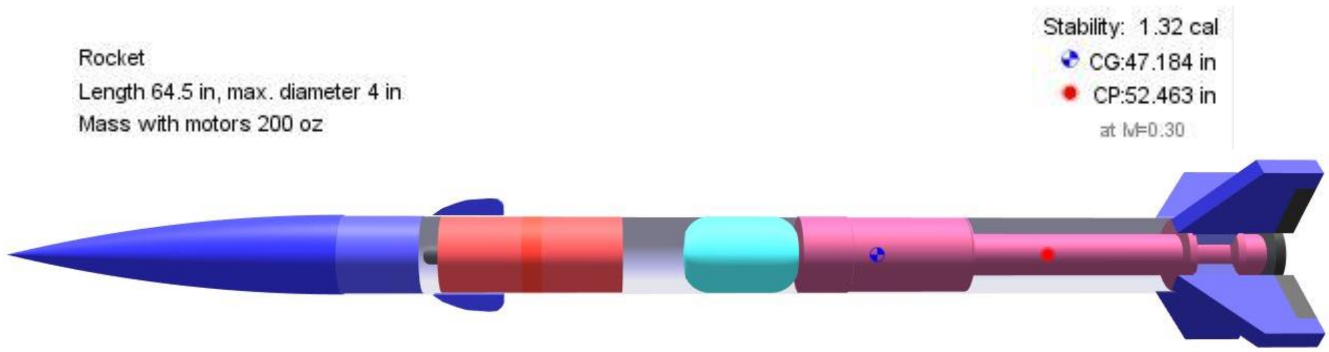

Figure 2: Rocket dimensions.

Stability Analysis

The center of gravity is located directly below the piston and about 4 inches above the top of the engine. With a caliber of 1.32 we fully expect a stable flight given the current center of pressure and center of gravity. Once the engine has entirely burned, the stability will increase to a caliber of 2.22. Both of these stabilities are well within the acceptable safety range.

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.

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 1/8" 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 two 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 3). 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.

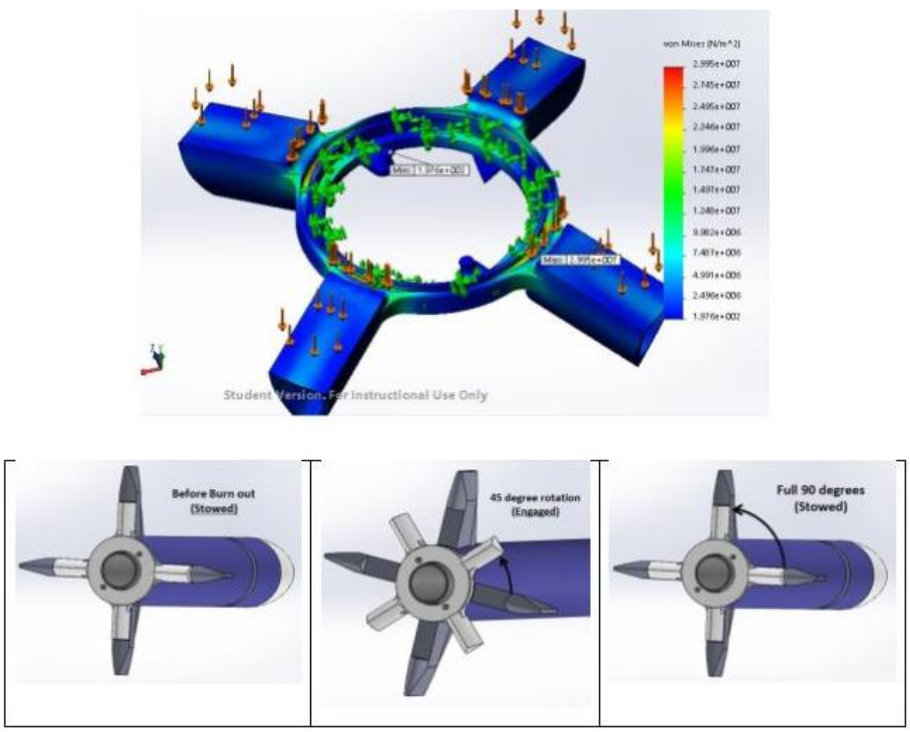

Figure 3: Drag system stress analysis and visual representation.

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 1.5 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. 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 parachute equipped is an Iris Ultra 48 inch from Fruity Chutes with a manufacturer given drag coefficient of 2.2. 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.

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 1667 meters.

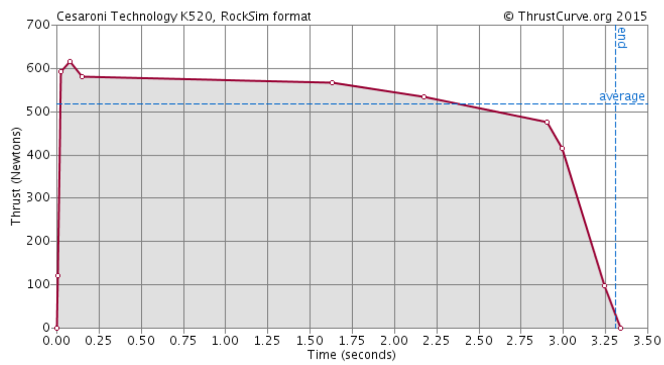

Figure 4: Thrust curve for Cesaroni K520.

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.

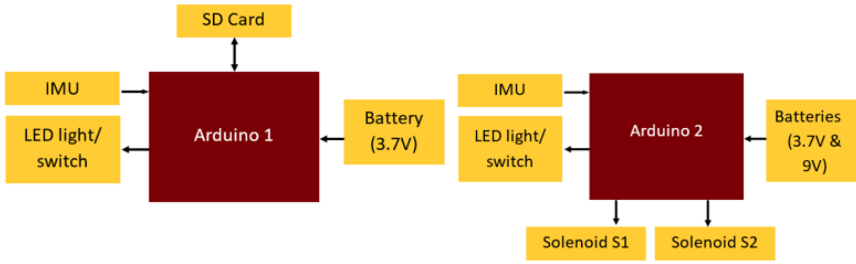

Figure 5: Arduino control design.

Arduino Control Design

While one Arduino is recording the flight data, the other Arduino will be measuring the rocket's velocity, acceleration, coefficient of drag, 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 has ended boost phase, the Arduino will send a signal to a transistor which will send power to the solenoids and 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 as well as through audible beep sequences.

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.

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, each with 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.

Changes since Preliminary Design Report

The AIM USB 3.0 deployment altimeter has been replaced with a Stratologger CF due to hardware failure. The dimensions have slightly changed due to a rebuild which are detailed in the sections below.

Construction Methods and Pictures

The construction of the rocket was completed over the course of over three hundred man hours of which many members of the Bulldog Rocketry club contributed. Below are pictures of the construction process with descriptions of what tasks were performed and how they were executed.

Figure 6: Body tube prep.

Figure 6 from left to right: Chet measuring bulkheads to ensure alignment. Ethan rounding the fins for better aerodynamics. Kalli using body filler on the tube for a high quality finish. The engine mount consisted of three centering rings and two threaded rods. The centering rings were slid onto the threaded rods and were secured in their proper location by lock nuts. The fins were test fit into the centering rings slots multiple times. The entire assembly was test fit into the body of the rocket multiple times before it was epoxied and inserted to ensure precise alignment. The fiberglass fins were cut from a waterjet cutter and rounded on the top face to create an aerodynamic body. The entire exposed body tube of the rocket was filled with body filler and sanded multiple times to hide any of the spirals that come with blue tube.

Figure 7: Mating of components.

Figure 7 from left to right: Christopher putting the finishing touches on the fin assembly. Joel epoxying the top bulkhead and wiring. Joel aligning the camera dog houses to ensure alignment with fins. The engine mount was coated in epoxy, slid into the body, and then the fins were inserted into the exact right spot. Extra epoxy was added to the top centering ring to ensure extra strength to support any of the force exerted on the U-Bolt. To add the camera doghouses, a custom designed jig was used to ensure alignment, then a plum-bob was used to ensure that they were equidistant between the fins and each other.

Figure 8: Testing and assembly of avionics and fins.

Figure 8 from left to right: Kevin pressure testing the electronics to verify proper operation. Jake and Andy “eyeballing” the doghouse’s as the epoxy sets up. Chet applying epoxy and body filler to smooth out the prosthetic fins. The electronics were tested in a pressure vessel to verify that the programs and sensors were working properly. These series of test were performed multiple times with varying pressures and conditions to ensure operation. Underwater epoxy was added to the sides of the fins to create fillets. These could then be formed and sanded to create an aerodynamic and aesthetically pleasing fin profile.

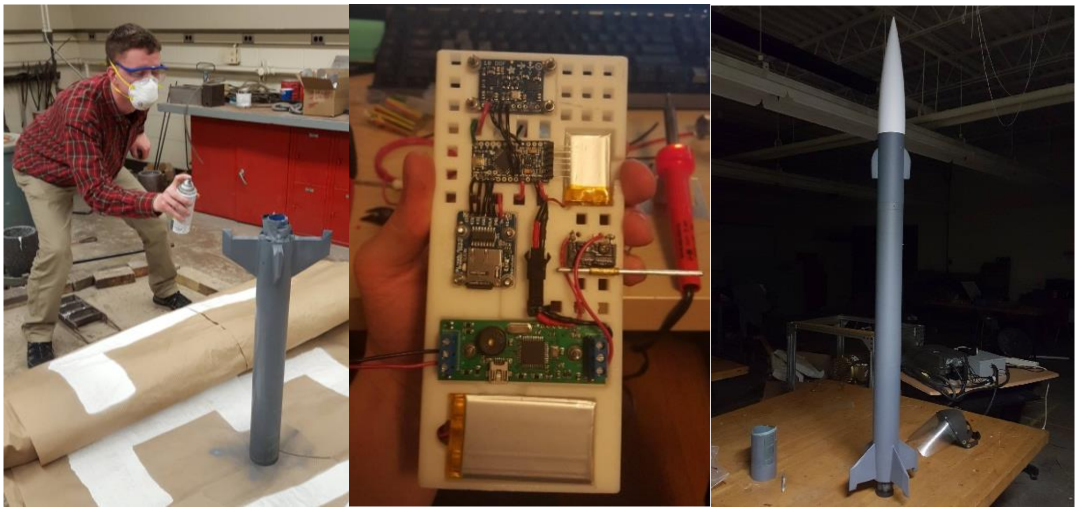

Figure 9: Painting and assembly of rocket.

Figure 9 from left to right: Ethan priming the rocket. A completed side of the avionics board. The complete rocket assembly after test launch’s. The rocket was spray painted in a properly ventilated area with proper protective equipment. The avionics were assembled and soldered in a clean and functional lay out to simplify field repair. Externally removable arming pins were added to ensure that the rocket could be armed in a safe and quick manner on the launch pad. The rocket was assembled and many ground tests of the recovery system followed.

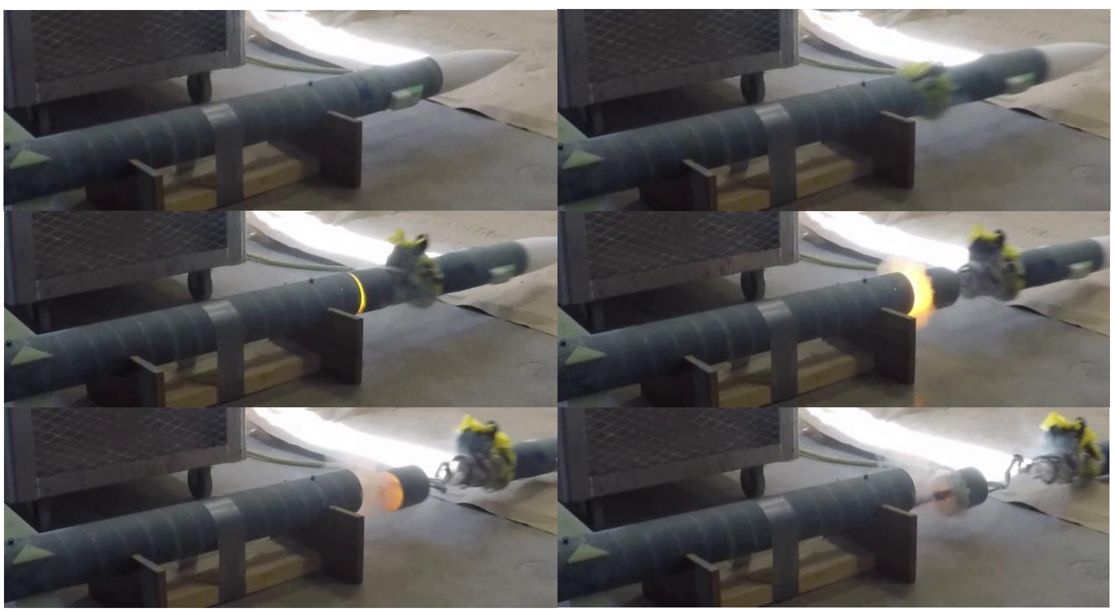

Figure 10: Frame by frame recovery test.

Overview of Test Launches

Three test launches were performed on the 16^{th} of April in North Branch, MN under the supervision of Gary Stroick. Throughout the day the temperature was hovering in the 30 degrees Fahrenheit. The wind was coming out the southwest at a brisk speed with gusts up to 15 mph. The team set up a work station and began to go through the preflight checklist. Each step in the list must have a signiture confirming that the step has been completed properly. Once the checklist was completed and we had confirmed that every procedure was done properly the rocket was presented to the RSO and then brought to the launch rail. Arming pins extending out of the airframe ensure that the avionics and parachute ejection sytems are not armed until the pins are pulled. Once the rocket was on the rail and oriented upwards the pins were removed and the engine was wired for launch.

Figure 11: Bulldog Rocketry braving the cold and prepping the rocket.

The first launch reached an apogee of about 1400 meters with a maximum velocity of approximatly 440 m/s. This was a “clean launch” in which the air-brake was not activated. The parachute deployed at apogee and the rocket descended at approximatly 7 m/s. Every aspect of the first flight went as planned except that one of the two downward facing cameras did not function properly. The camera did not record video because the power button was bumped as as it was installed in the doghouse. The breeze carried the rocket to a nearby field where it was recovered with no damage to any of the components.

Figure 12: Bulldog rocketry’s first test launch.

After the rocket was recovered, the team prepared for the next launch in under an hour. In this time the team went through the preflight checklist again and found a field solution to ensure that camera failure would no longer be an issue. The second test flight went much the same as the first. Again, the air-brake was not activated in order to determine the clean coefficent of drag which the deployment system heavily depends on. The apogee was about 1450 meters with a maximum velocty of 480 m/s and a decent rate of 7 m/s. Unfortunaly the rocket landed on a patch of asphalt and broke a piece of the prosthetic fin off. The fin was easily fixed with some sanding and crazy glue. The only concern from this launch was the fact that the primary ejection canister did not fire and the motor backup ejection actually forced out the parachute. Upon realizing this the team tested the ejection charge separate from the avionics bay and found that the ejection canister was a dud. Although the deployment charge had continuity, the canister still failed to detonate.

Figure 13: Rocket landing pictures.

After repairing the fin and troublshooting the deployment system, the team went through the checklist a third time and presented the rocket to the RSO. This launch was programmed to engage the air-brake and recover the air-brake once the rockets speed was below 15 m/s. The reason for not utilizing the 75% calculations was to test the maximum performance of the airbrake while still recovering the drag system before apogee. The operation of the air-brake during this flight can be seen in figure 14. The air-brake deployed at the correct time but was slow in doing so. The airbrake had trouble overcoming the force of the air, this was due to using weaker springs then planned. Despite the air-brake only being exposed for about half the time we planned, it still decreased the apogee by 17%.

At apogee, the ejection cannister exploded but the rocket did not separate. We believe this is most likely due to the massive accelaration lodging the ejection piston into the bulkheads epoxy. Because the air-brake had shortened the flgiht time, the rocket went into a nose dive for around four seconds before the motor ejection forced the parachute out. The speed at which this happened caused the rocket to zipper up the side and brake the quick-link, rated for 500 lbs, which connected the parachute to the shock cord. The rocket went into a free-fall for about 1000m at a rate of 27 m/s. Due to the heavy-duty contruction techniques, the rocket actually sustained no damage from the fall and impact, aside from the nose cone insert which held some comercial avionics that we used to correlated the data with our own. All essential components remained intact and the parachute was recovered undamaged in a nearby field. Unfortunally, all the custom data was lost likely due to a voltage spike on impact.

Launch Analysis

All three test launches provided excellent data on the functionality of the rocket. In the first launch the boost phase lasted for 2.4 seconds and provided a maximum acceleration of 29 g's. With this acceleration the rocket was able to reach a maximum velocity of 442 m/s according to our data package, approaching Mach 1.3. The second flight went similarly to the first. The boost phase lasted for 2.6 seconds and provided a maximum acceleration of about 25.4 g's. This time the rocket reached a maximum velocity of around 488 m/s, which is about Mach 1.42. We expect some discrepancies in the velocity data due to the pressure changes from approaching Mach 1, for this report we will be analyzing the data according the custom data package. Unfortunately, the rough landing of the third launch corrupted some of the data including the length of the boost phase. The maximum velocity on the third flight was around 429 m/s with a maximum acceleration of 28.3 g's.

Coast Analysis

The coast phase of the first two flights began with engine burn out and ended with parachute deployment. The air-brake was not deployed on the first two flights. For the first flight the coast phase lasted 10.2 seconds and had a starting velocity of 442 m/s. The acceleration actually began to decrease before the rocket had finished boost phase entirely, but for the coast phase overall the max negative acceleration was 18 g's. The second flight was similar with a length of 10 seconds, a starting velocity of 488 m/s, and a max negative acceleration of 20 g's. The third launch utilized the air-brake immediately after boost phase had ended. The air-brake had some minor functionality issues and was not able to engage fully when it was meant to but did eventually rotate into the air stream. This reduced the altitude by 17%, indicating the air-brake had a significant effect. Although the ejection canister failed, the rocket again would have ejected the parachute at apogee.

Drag System Analysis

In Figure 14 the drag system can be seen in operation. At image 1 the rocket is moments away from lift off. In 2 the rocket is ending boost phase where the acceleration is equal to zero and triggers the deployment of the drag system which is seen in 3. In 4 the drag system is fully deployed and stays in this position until the Arduino's determine that the drag system should stow. Bulldog rocketry would prefer not to detail how the calculations work since it gives our team a competitive edge. In 5 the rocket begins to stow the drag system, which can be seen fully closed at apogee in 6.

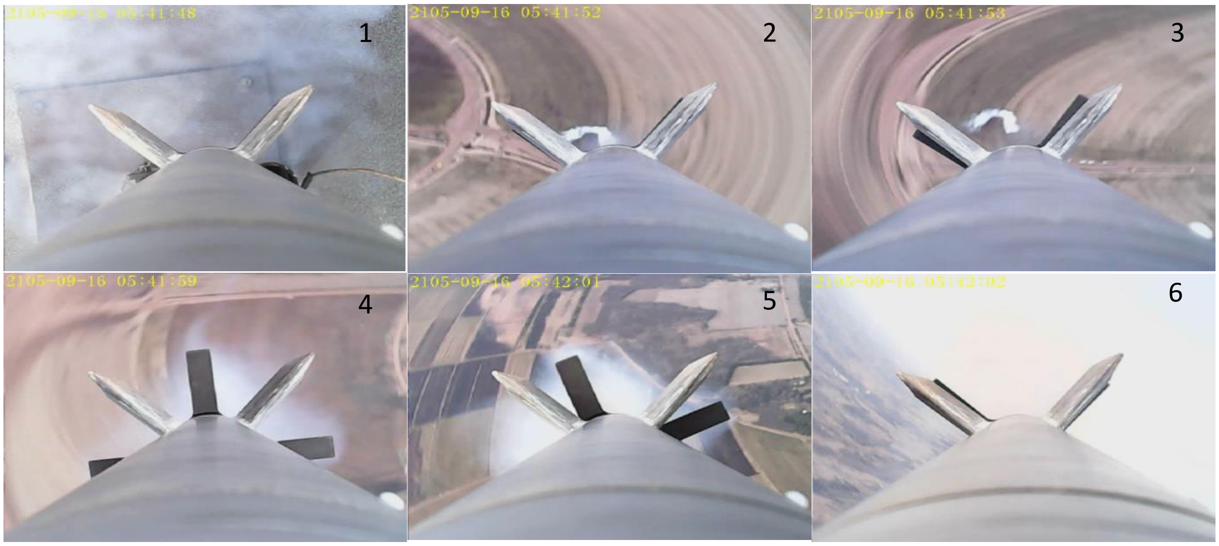

Figure 14: The drag system throughout a test launch.

Although the drag system deployed and stowed as designed, there was an issue with turning the first 45 degrees of the deployment. The springs were not able to overcome the force of the air resistance thus resulting in a slow deployment costing nearly 4 seconds of full drag deployment. Solving the drag force we were able to determine that the springs will have to overcome nearly 40 lbs. of force at peak velocity. In order to correct the problem Bulldog Rocketry will implement stronger springs and smoother sliding surfaces that are contacting one another. Also the team plans to use graphite to lubricate the contact surfaces. Through testing with weights in the lab we will be able to determine if the corrections will overcome the drag force.

Recovery System Analysis

As seen in table 1 and Figure 15 the rocket had an average decent rate of -7 m/s (-24 ft/s) for the first two flights. During the third flight the decent rate was uncontrolled at -27.1 m/s which was due to a failure to deploy the commercial system which is mentioned earlier in the report. For the successful deployments the rocket drifted 1,200 m to the northwest. For the uncontrolled decent the rocket landed approximately 20 m from the launch site. If anything this shows how stable the rocket was even with the gusty winds. Improvement's that will be made to the drag system include new deployment charges, lower friction in the body tube by sanding, a means to block the ejection piston from wedging into the bulkhead, and a stronger quick link to secure the parachute.

Pre-flight / Post-flight Procedure Analysis

The pre-flight / post-flight procedure was successful and did not require any major modifications. The team decided to add a second signature line to each task. This was done just as an added safety precaution even though it was not an issue that was encountered. No additional changes will be made to the procedure since the team was very successful in recovery and had and average recovery / recycle time of 50 minutes to prepare for the next launch. Even with troubleshooting and quick fixes to the rocket the team was able to meet the 1 hour deadline.

Data and Video Collection Analysis

Bulldog Rocketry performed extensive tests of both the avionics and video collection packages before the test flights to ensure best practice and operation. During the first test flight, one video camera turned off when inserted into the doghouse. This issue was resolved by sanding the cameras buttons flush to the camera body which ensures the cameras will not turn off when inserted into the doghouse. The video from the three test flights turned out great and will require no addition modifications for the competition.

The custom data collection package performed superbly on the first two launches and output smooth, and easy to read data. The team was amazed to see how closely the data lined up with the Altimeter Two and the Stratologger. In addition to the smooth data, the coefficient of drag output was great on the first two launches and provided valuable data for the competition. On the third launch the data was lost likely due to a voltage spike on ground impact which corrupt the data on the SD card. Later the data package was turned back on and everything functioned properly. The team plans to rebuild the avionics board to a more compact and sleek design. All data can be seen in the segments below.

Test Flight Predicted vs. Actual Performance

The data for the test flights can be found below compared against the predicted results. The first two launches were clean launches meaning that no drag system was deployed. The reason for two clean launches is because the internal calculations to deploy the airbrake depend heavily on the coefficient of drag of a clean rocket. By completing two clean launches we can be assured that the data is correct. The third launch was a drag system activated launch which was successful in deploying and recovering the drag system. Some of the data for the Altimeter 2 is shown as corrupt, we believe the hardware is failing on that device. The performance of all three flights will be shown in both graphical and numerical form below. Discrepancies in the data will be described below each graph.

Table 1: Numerical data of test launches vs predicted.

All Launches use Cesaroni K520	Launch One	Launch Two	Launch Three	Clean Predicted	Drag Predicted	Clean Accuracy	Drag Accuracy
Mass (kg)	4.1	4.1	4.1	4.1	4.1	100.0%	100%
Max Alt AGL CD(m)	1392.4	1453.9	Corrupt	1667.0	1250.0	85%	NA
Max Alt AGL SL (m)	1405.8	1453.1	1205.0	1667.0	1250.0	85%	72%
Max Alt AGL Alt2 (m)	1404.0	1454.0	1200.0	1667.0	1250.0	85%	72%
Max Velocity CD (m/s)	442.0	488.2	Corrupt	236.0	236.0	197%	155%
Max Velocity SL (m/s)	320.0	350.0	335.0	236.0	236.0	141%	142%
Max Velocity Alt2 (m/s)	Corrupt	Corrupt	429	236.0	236.0	NA	182%
Max Acceleration Alt2 (g's)	29.0	25.4	28.3	10.0	10.0	272%	283%

All Launches use Cesaroni K520	Launch One	Launch Two	Launch Three	Clean Predicted	Drag Predicted	Clean Accuracy	Drag Accuracy
Boost Time (sec)	2.4	2.6	Corrupt	3.3	3.3	75.8%	NA
Coast Time (sec)	14.4	14.0	10.0	14.0	10.7	101.4%	71%
Decent Rate (m/s)	-7.5	-7.5	-27.1	-6.1	-6.1	123.0%	445%
Reduction in Alt (percentage)	NA	NA	17%	NA	25%	NA	68.3%
Avg Coefficient of Drag	0.77	0.95	Corrupt	0.84	1.51	102.2%	NA

*CD denotes the custom data package, SL denotes the commercially available Stratologger, and Alt2 denotes the Altimeter 2. After the test flights we determined that the Altimeter two was reporting erroneous data in some cases. Bulldog rocketry also lost data on the third launch likely due to the hard landing.

Graphical Data of Test Launches

Below are the graphs from the test launches compared to the predicted performance. All test launch data was pulled from the custom built data collection package excluding the altitude of the third launch which was pulled from the surviving Stratologger. Due to the uncontrolled freefall there was a voltage spike in the custom avionics which corrupted the SD card data. Therefore the third launch drag data will not be detailed in the graphical data besides altitude.

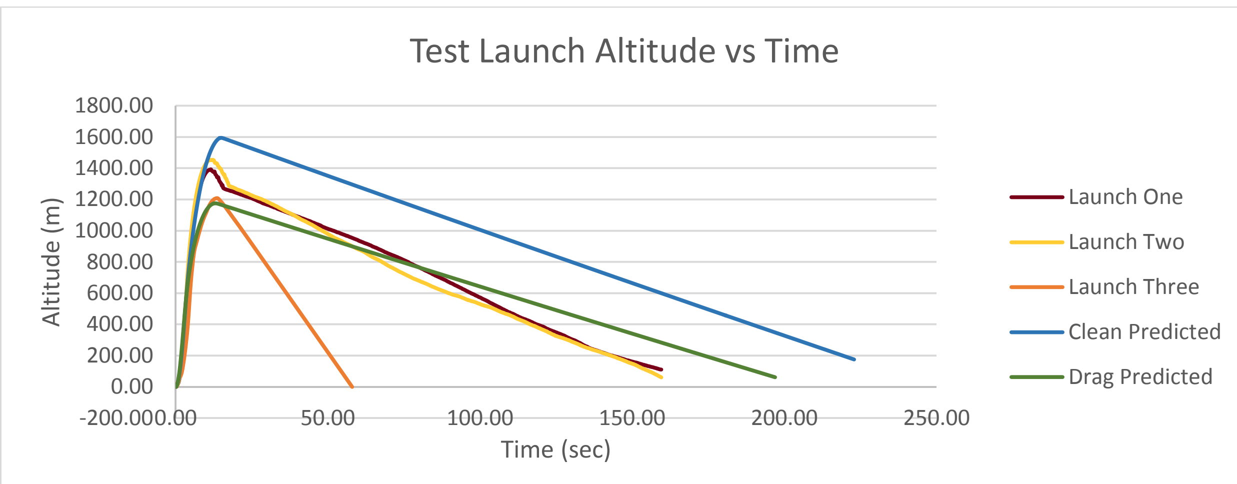

Figure 15: Test launch altitude vs predicted.

The first two launches did not achieve their predicted altitude. This is likely due to the airbrake peeking out just a little bit from behind the fins, also due to the rocket not having its final finish applied. The team plans to nail down the alignment of the fins before competition and we plan to achieve the predicted altitude of 1667 meters. The drag system altitude was nearly what was predicted but we were not shooting for 75%. The third launch was to determine the max effectiveness of the airbrake. Due to the slow deployment the team did not achieve 75% but with modifications, we plan on easily hitting the 75% target.

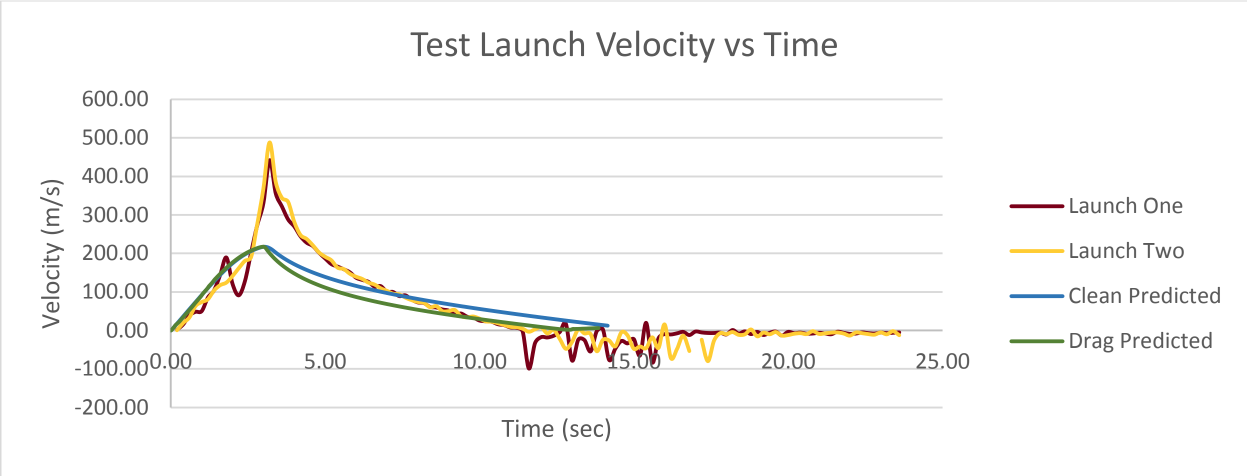

Figure 16: Test launch velocity vs predicted.

The predicted velocity and actual velocity show a very large error. The inaccuracy is likely due to the thrust curve of the Cesaroni K520 motor in OpenRocket not being modeled correctly. There is also noticeable difference between the Stratologger data and the custom data, we believe the error is likely due to the rocket approaching Mach 1 and causing false pressure readings. We believe that the custom data is reliable due to the alignment of the first two launches and being compared against the altitude change.

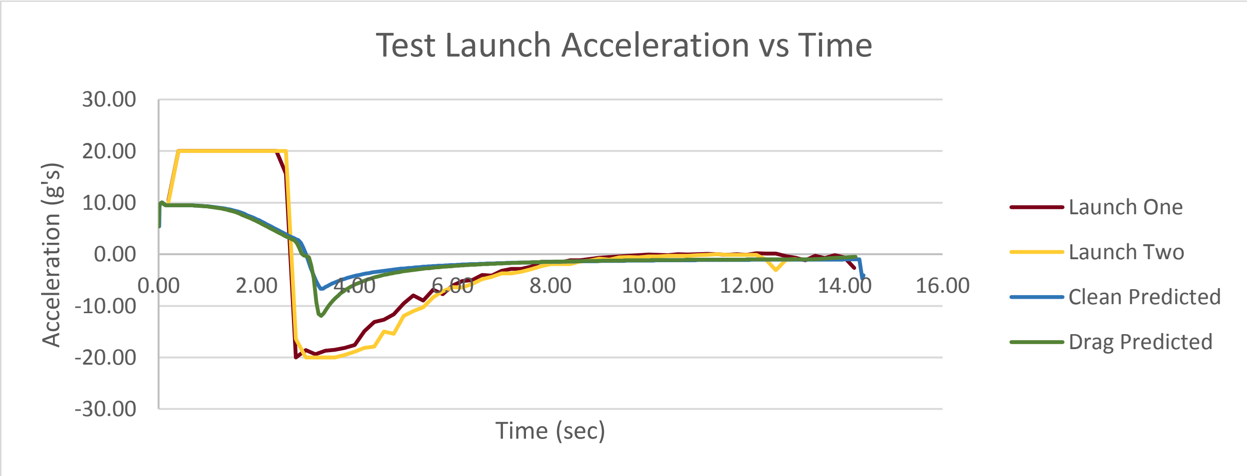

Figure 17: Test launch acceleration vs predicted.

The acceleration also had notable error between predicted and tested which is due to the thrust curve being incorrectly modeled in OpenRocket. It is apparent that the acceleration in the custom data package peaks out at 20 g's. The limit of the data package was known ahead of time and was not a concern to the team because it will not affect how well the team competes.

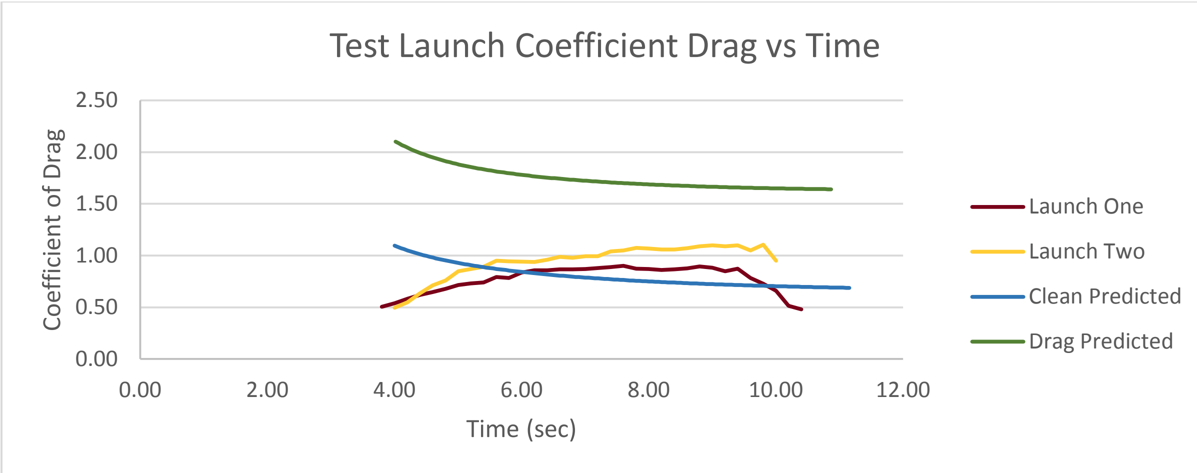

Figure 18: Test launch coefficient of drag vs predicted.

The team is extremely proud of the results from the coefficient of drag sensor readings. The predicted clean average coefficient was calculated to be .84 and we found the average clean coefficient of drag at .86 during the first two test launches. The relationship for the predicted results shows a decreasing trend as time goes on and the tests show an increasing trend. We are still trying to work out the difference between the findings. Due to the corruption of the data on the drag flight we cannot show the coefficient of drag results but we fully expect the data to line up with the predicted results. The team will opt not to discuss how the results were calculated since we believe it gives us a competitive edge.

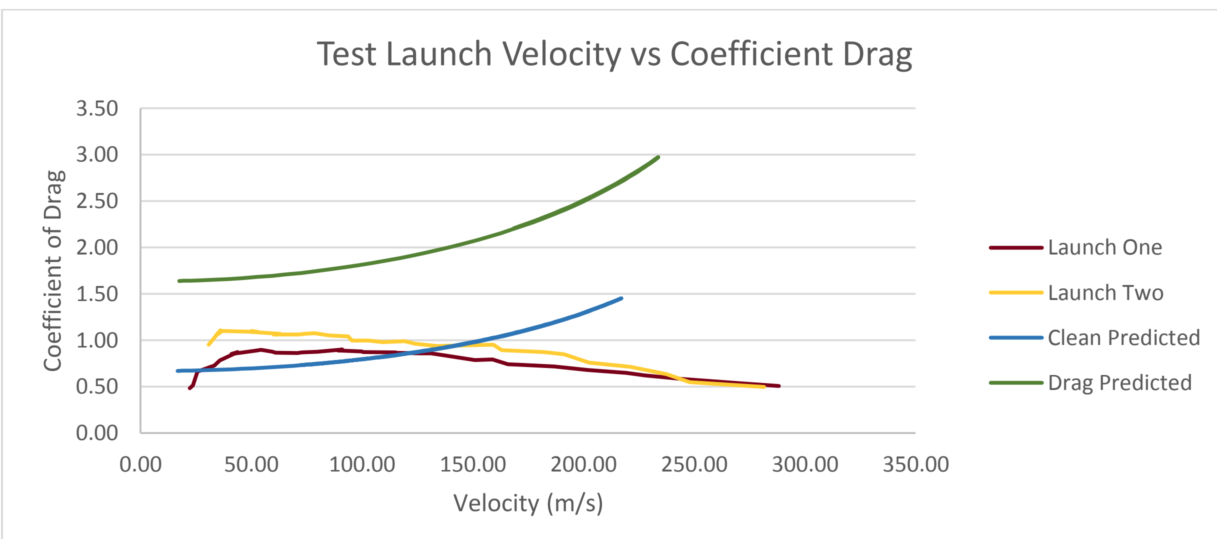

Figure 19: Test launch coefficient of drag against velocity vs predicted.

The velocity vs coefficient of drag graph also shows the predicted vs test trend to be opposite, the team is still working out why this is happening.

Rebuild

There was damage to the rocket due to the ejection problem from the third test launch. The damages were from the failed ejection that zippered up the side of the rocket body approximately 7 inches. No essential components of the rocket were destroyed from the fall. The damaged body was cut off and replaced by epoxying a coupler tube to the bottom of the rocket which new upper body is bolted to. The avionics bay was slightly damaged in the flight and was rebuilt to better accommodate the avionics. A new nose cone was also purchased and installed. These alterations actually increased the rocket's functionality and ease of reset for the next flight. In the previous design the piston could be forced down and wedged into the epoxy of the top centering ring causing the first ejection charge to fail parachute deployment. With the new design the piston can rest on top of the coupler tube eliminating the issue. Also the main body tube can be removed and cleaned between flights.

Planned Changes before Competition

The air-brake did not deploy as well as was expected during the test launch. This was most likely because the amount of drag force on the open face which created friction that the springs could not overcome. To combat this, the team will be adding small ramps to the edge of the airbrake. The idea is that the ramps will deflect the air, divert it, and create an extra force to aid the air-brake in rotating out the initial forty-five degrees.

Key Findings/Potential Design Improvements

If there was time the air-brake would be redesigned to utilize a ball bearing system. Most of the issues in functionality were due to friction and we believe using a bearing system could eliminate the problems associated with overcoming the drag force.

Budget

Many of the parts necessary to construct the rocket 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). Rows marked with an asterisk indicate places where the actual expense of the build differed from the predicted expense. Most of these were the results of additional purchases that were made to rebuild the top portion of the rocket after the third test launch.

Expenses	Predicted	Actual	
Air-Brake			
Springs	$ 13.71	$ 13.71	
Solenoids	$ 8.76	$ 17.52	*
Printing	-	-	
Stainless Steel Tubing	$ 5.54	$ 5.54	
Airframe			
Centering rings	$ 22.60	$ 22.60	
Fiberglass	$ 96.00	$ 96.00	
U-bolt	$ 8.78	$ 8.78	
Hardware	$ 26.24	$ 26.24	
Fasteners	$ 35.25	$ 35.25	
Nose Cone	-	$ 34.21	*
Body tubes	-	$ 38.95	*
Avionics Bay	-	$ 20.98	*
Competition			
Travel/Hotel Estimate	$ 300.00	$ 300.00	
Midwest Competition	$ 400.00	$ 400.00	
Motor			
4-Grain Case	$ 89.98	$ 89.98	
Retainer Ring	$ 31.30	$ 31.30	
K520	$ 504.30	$ 464.75	*
Recovery			
Parachute	$ 182.70	$ 182.70	
Kevlar cord	$ 26.80	$ 26.80	
Video			
Printing	-	-	
Cameras	$ 103.53	$ 103.53	
Avionics			
Arduino Mini Pro	$ 24.55	$ 24.55	
Micro SD Card	$ 35.54	$ 35.54	
AIM USB Altimeter	-	-	
Mini-Lipo Battery	$ 10.45	$ 10.45	
IMU	$ 20.86	$ 20.86	
Total	**$ 1946.89**	**$ 2010.24**	

Table 2: Budget for rocket competition.

Conclusion

Bulldog Rocketry will launch a rocket twice during the competition while meeting or exceeding all competition requirements. Students, with the help of mentors and faculty, used simulation analysis, extensive testing, and applied engineering to build a safe, quality, and innovative rocket. Students have put in hundreds of man hours into this design purely due to a passion for high power rocketry and the satisfaction that comes from creating an elegant design. Bulldog Rocketry will have a competitive and successful rocket for the 2016 Space Grand Midwest High-Power Rocket Competition.