Bulldog Rocketry

Post-Flight Performance 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, attended the competition on May 15th-16th with 12 of the 21 current members. The performance of the rocket and the team is outlined in the following report.

The purpose of the competition is to develop a high-powered rocket with an active data recording device and 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 the final analysis. The competition scoring will focus primarily upon the accuracy and precision of the air-brake mechanism's ability to decrease the rockets apogee on the second launch.

A full recovery package, consisting of a parachute deployment system (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.

On the 16th of April two successful test flights were performed by the team, where a complete, comprehensive performance analysis of the rocket was conducted. This analysis aided in trouble shooting all possible alterations to the design. The successful test flights themselves proved the rockets overall flight worthiness and design alterations were implemented wherever a fault in performance was noted.

A combination of manual calculations and computer aided simulations on SolidWorks and OpenRocket were used by Bulldog Rocketry to design the best possible rocket. By using analytical engineering methods and a general engineering methodology, the team was able to determine the optimal characteristics of the rocket, including: length, weight, engine size, and stability.

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

Please see our team's brief video from the competition in the following YouTube link!
https://www.youtube.com/watch?v=mxDdNn-pUbQ

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 (pete9558@d.umn.edu)
Air-Brake: Chet Peterson (Lead), Ashton Lebrun
Airframe Design: Lee Vest (Lead), Christopher Kleinjan, Peter Guski
Avionics Design: Ethan Vought (Lead), Kevin Victoria, Stefan Nelson
Recovery: Joel Stomberg (Lead)
Video: Joseph Kaiser (Lead), Jake Klinkner, Andy Miller
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, be recovered safely and in flyable condition, predict its flight performance (both with and without the drag system engaged), 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.

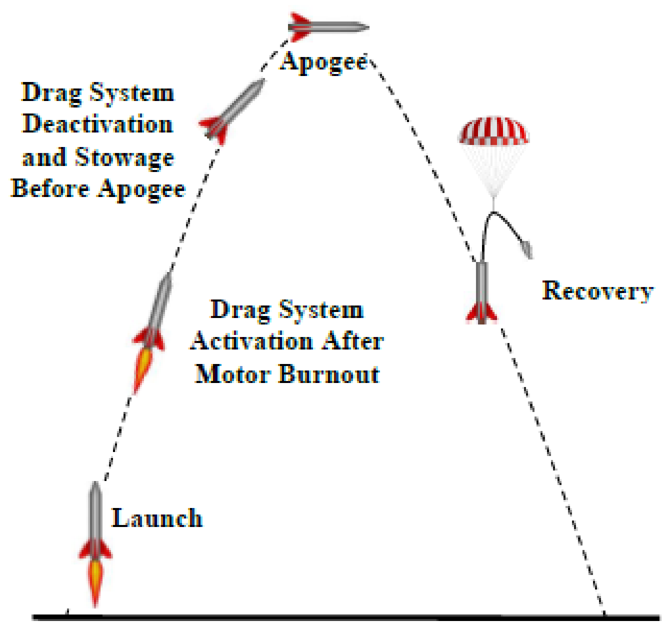

Figure 1: Events during rocket flight.

Flight Performance Characteristics

Table 1 – Physical characteristics of the rocket

Rocket Characteristics	Before burn	After Burn
Weight (lbs)	13.9	10.5
Length	69"	69"
Center of Pressure	55.5"	55.5"
Center of Gravity	50"	46"
Stability (caliber)	1.45	2.32

Figure 2: Competition "clean" launch.

Table 2 – Data from competition flights.

All Launches use Cesaroni K520	Launch One	Launch Two	Clean Predicted	Drag Predicted	Clean Accuracy	Drag Accuracy
Max Alt AGL CD (m)	1350.4	1057.7	1667.0	1250.0	81.0%	85%
Max Alt AGL SL (m)	1345.1	1058.0	1667.0	1250.0	80.7%	85%
Max Alt AGL Alt2 (m)	1364.0	1055.0	1667.0	1250.0	81.8%	84%
Max Velocity CD (m/s)	372.0	400.0	236.0	236.0	157.6%	169%
Max Velocity SL (m/s)	274.5	365.2	236.0	236.0	116.3%	155%
Max Velocity Alt2 (m/s)	NA	NA	236.0	236.0	NA	NA
Max Accel Alt2 (g's)	30.1	29.0	10.0	10.0	301.0%	290%
Boost Time (sec)	2.8	2.6	3.3	3.3	84.8%	79%
Coast Time (sec)	9.2	8.2	14.0	10.7	65.7%	77%
Decent Rate (m/s)	-6.6	-7.2	-6.1	-6.1	107.4%	117%
Reduction in Alt (%)	NA	22.7%	NA	25%	NA	91%
Avg Coefficient of Drag	0.88	2.07	0.84	1.51	104.3%	137%

*CD denotes the custom data package, SL denotes the commercially available Stratologger, and Alt2 denotes the Altimeter 2.

Rocket Operational Assessment

During the competition the Bulldog Rocketry team did not have any anomalies that significantly impacted the performance or safety of the flights. The details regarding launch, flight path (coast), drag system, recovery, and pre / post launch procedure are outlined below.

Launch Analysis

Both competition launches had excellent performance and provided the results that Bulldog Rocketry was seeking. In the first launch the boost phase lasted for 2.8 seconds and provided a maximum acceleration of 30.1 g's. With this acceleration the rocket was able to reach a maximum velocity of 372 m/s according to our data package, approaching Mach 1.1. The burnout happened at approximately 300 m. Due to the un-clocked airbrake peeking out for just a second there was a decrease in velocity / altitude due to unnecessary drag. As seen in figure 3, the airbrake spun out likely due to the centripetal force created by the spin of the rocket. This could have been prevented by installing a set screw for the first launch. Although the airbrake peeked out, figure 9 shows that there was not a significant increase in drag which made it possible to still have a successful reduction in altitude in the second flight.

Due to a decrease in velocity / apogee and an increase in drag, the team had to rely on data from test launches to program the rocket for the second launch. If the team had used the new data from the first launch the drag launch would not have been as successful because the coefficient of drag was no longer reliable. In reality, the airbrake peak out only created a challenge for Bulldog Rocketry. The team was forced to rely on simulations and the design of their rocket since their baseline flight was a bit lower in altitude than expected.

Figure 3: Air-brake slightly exposed during flight 1.

The second flight went similarly to the first. The boost phase lasted for 2.6 seconds and provided a maximum acceleration of approximately 29 g's. This time the rocket reached a maximum velocity of around 400 m/s, which is about Mach 1.16. The burnout happened at around 300 m similar to the first competition flight. During this boost phase the airbrake stayed in as required. In this launch the rocket shook a bit during the very end of the boost phase. We believe this was due to approaching Mach 1 sooner than usual which created pressure changes that caused instability in the rocket. The oscillations did not affect the overall flight of the rocket. Both flights flew in a very straight and upright flight path.

Coast Analysis

The coast phase of the two flights began with engine burn out and ended with parachute deployment. The air-brake was not deployed on the first flight but was deployed on the second flight. For the first flight the coast phase lasted 9.2 seconds and had a starting velocity of 372 m/s. The apogee of the first flight was 1364 m. The second flight was similar with a coast length of 8.2 seconds, a starting velocity of 400 m/s, and a max negative acceleration of 20 g's. The airbrake deployed .2 seconds after burnout and stayed open for approximately 2 seconds causing a peak coefficient of drag of 7.5. Having the airbrake out for only 2 seconds caused the apogee of the rocket to be 1055 m which was a 22.7% reduction in altitude.

Drag System Analysis

In figure 4 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 after 2.6 seconds where the acceleration is equal to zero which triggers the deployment of the drag system which can be seen in 3. The delay from boost to deployment was only .2 seconds providing the maximum time for the airbrake to cause drag. In 3 the drag system is fully deployed and stays in this position until the Arduino's determine that the drag system should stow. They determine the deployment time by predicting the apogee of the rocket if the air-brake was turned off at that moment. In the drag flight the brake only needed to be deployed for 2 seconds.

When the drag system stowed, the avionics predicted the rocket would apogee at 1027 m which was 4 m from the goal for 75% apogee. The actual apogee was 1055 m which was only 28 m from the Arduino's apogee prediction 4.8 seconds into flight. This reduction in altitude was 22.7% which Bulldog Rocketry is extremely proud of. In image 4 the rocket approaches apogee, reaches it at image 5, and deploys the parachute using the main deployment charge in image 6.

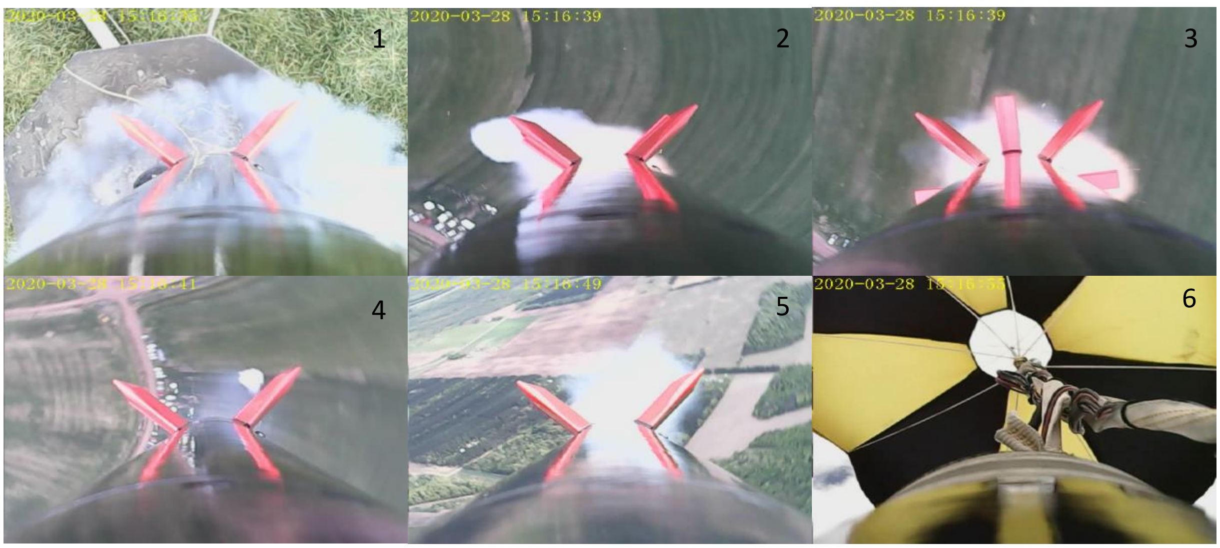

Figure 4: The drag system throughout competition drag launch.

The airbrake deployed exactly as designed and had no delay in the transition period from stow to deploy and deploy to recover. This means that the alterations Bulldog Rocketry made after the test flights worked exactly as designed. The design changes are noted in the Flight Readiness Report.

Recovery System Analysis

As seen in table 2 and figure 6 the rocket had an average decent rate of -6.6 m/s (-21.7 ft/s) for the first flight and -7.2 m/s (-23.6 ft/s) for the second flight. The launch and landing area can be seen in figure 5. The first flight the rocket drifted 1.1 miles to the south and landed undamaged in a cornfield, the second launch the rocket drifted .34 miles to the south and landed undamaged in a dirt field.

Both flights were deployed by the primary ejection charges and not the motor backup. In the future Bulldog Rocketry will look into either a two stage system or parachute release in order to shorten the recovery time / distance.

Figure 5: Launch site and position of both landings.

Pre-flight / Post-flight Procedure Analysis

The pre-flight / post-flight procedure was extremely successful and the modifications that were made after the test launches proved to be helpful. A second signature line was used during the competition to ensure no steps were skipped. Bulldog Rocketry is proud to announce no steps in the flight procedure were skipped which resulted in two safe, and successful launches. Due to every team member being assigned a specific task, the Bulldog Rockery team was the first off the rail in the morning at 09:13 and successfully completed the second drag launch before 10:13. The team actually turned around their rocket for launch in under 40 minutes and had plenty of time to check things over.

Data and Video Collection Analysis

As seen throughout the report the video and data collection performed as designed and there were zero problems with the systems. Both cameras recorded the flights from launch to landing, and the data collection provided valuable data from launch to landing. No anomalies were recorded and the team is content with the results collected.

Flight Predicted vs. Actual Performance

Below are the graphs from the test launches compared to the predicted performance. All launch data was pulled from the custom built data collection package.

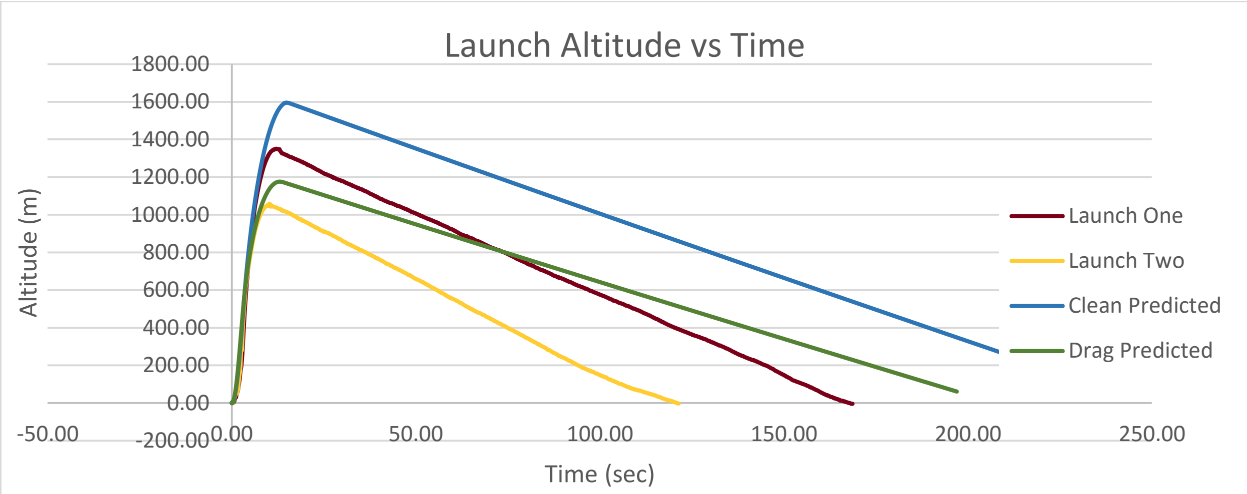

Figure 6: Competition launch altitude vs predicted.

The first launch did not achieve the predicted altitude. This is likely due to the airbrake peeking out slightly from behind the fins and rocket weighing slightly more from the test launches. The clean apogee was approximately 1364 m. The drag system altitude was below what was predicted due to the lower first flight. Since the rocket uses predicted altitude instead of a time based system, the lower first launch did not eliminate our chance to reduce the altitude but merely shrunk the window of time available to do so. The second drag launch achieved an altitude of 1055 m which is a 22.7% reduction in altitude. This is close to the 25% reduction the team was seeking. We attribute any error to the fact that we were forced to rely on test launch data for programming the second flight.

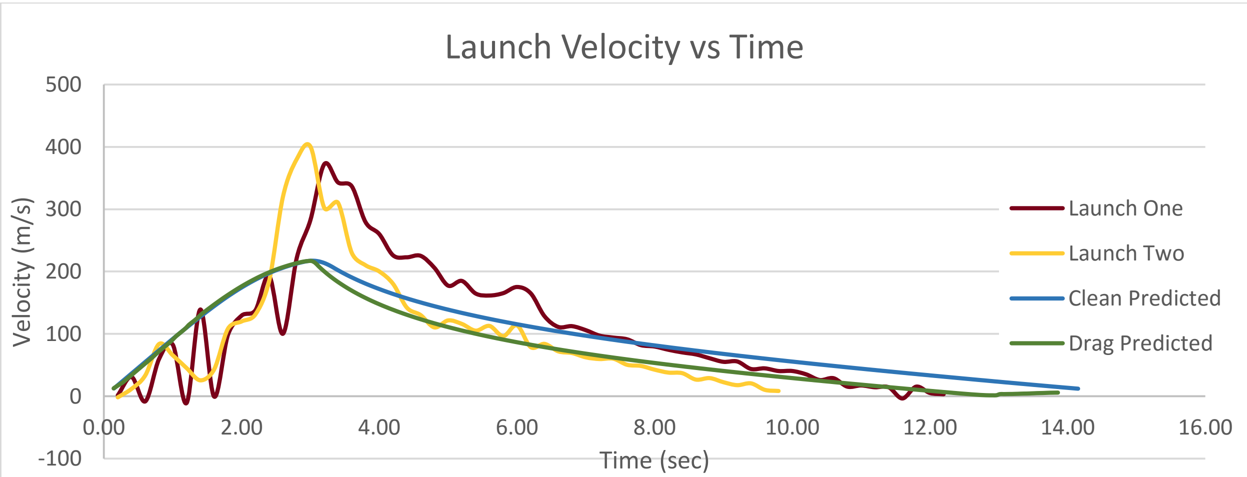

Figure 7: Competition launch velocity vs predicted.

According to the custom data package the first launch velocity approached 372 m/s and the second launch approached 400 m/s which are both above Mach 1. The predicted velocity and actual velocity show significant error. The inaccuracy is 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 expect 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 test launches and the competition launches. One interesting thing to note is the velocity drop off of the second flight. The decrease is much more dramatic than the first launch velocity profile which also resulted in a decrease in altitude.

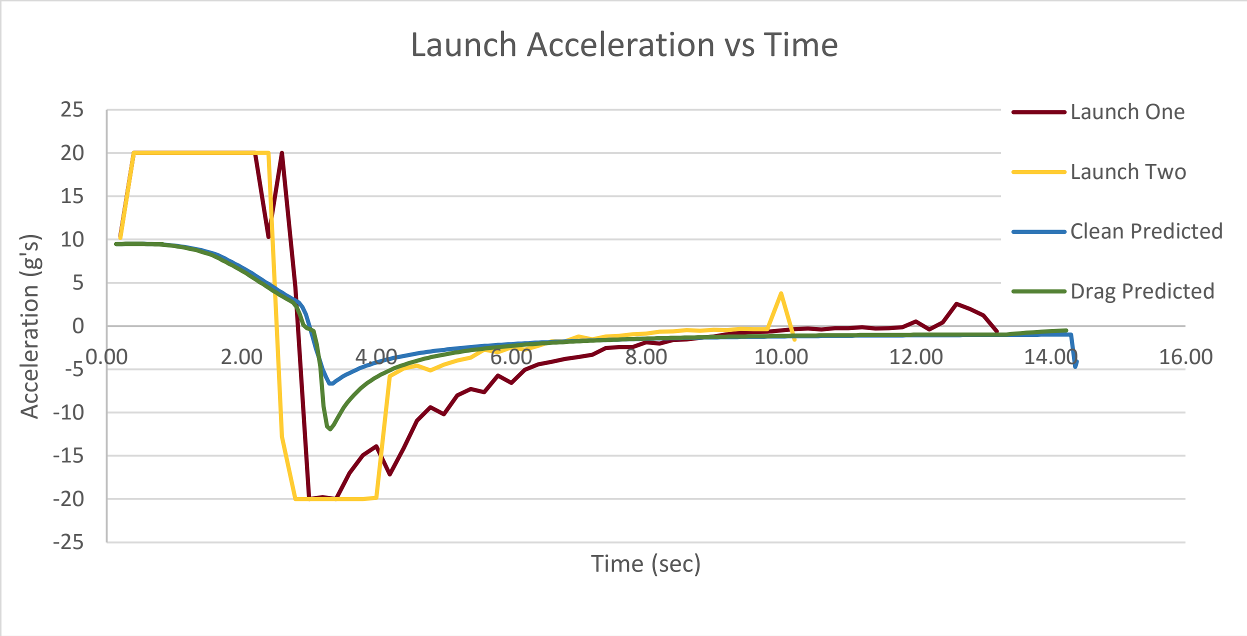

Figure 8: Competition launch acceleration vs predicted.

The acceleration also had notable error between predicted data and competition data which is due to the thrust curve being incorrectly modeled in OpenRocket. It is apparent that the acceleration limit of 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 since it did not affect the drag system. The altimeter two's showed that both launches had a peak acceleration at around 30 g's. Although during the second flight the airbrake caused over 20 g/s of deceleration while it was deployed. Since the accelerometer was maxed out during that period an exponential fit was used in order to accurately calculate the coefficient of drag during the maxed out window.

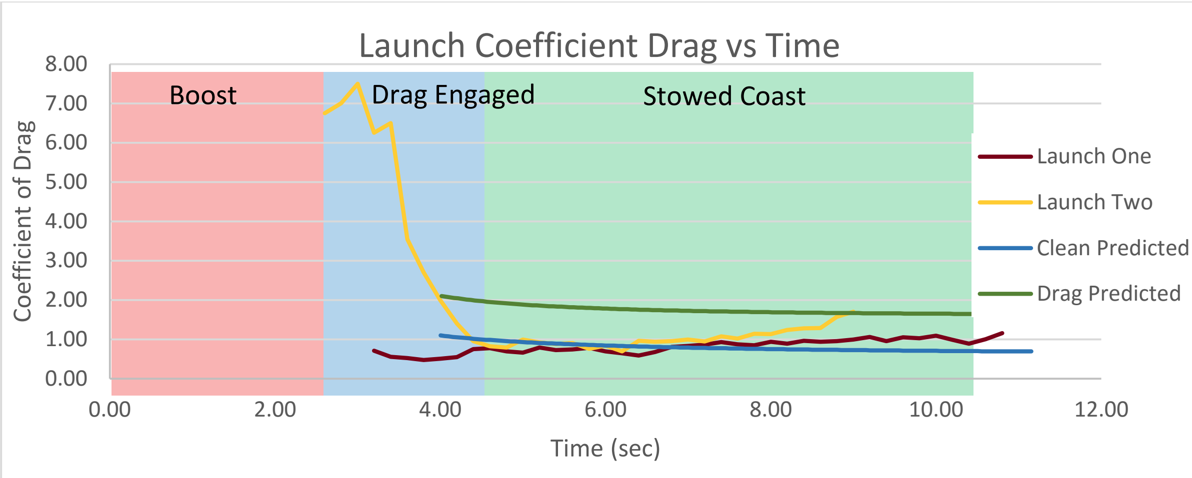

Figure 9: Competition launch coefficient of drag vs predicted.

The team is extremely proud of the results from the coefficient of drag sensor readings seen in figures 9 and 10. The predicted clean average coefficient was calculated to be .84 and we found the average clean coefficient of drag at .88 during the competition. During the time the drag system was out, the rocket had a peak coefficient of drag of 7.5. Even though the drag system was only deployed for 2 seconds the velocity was decreased from 400 m/s to around 200 m/s causing over 20 g's of deceleration. In figure 9, at burnout the coefficient of drag spikes up to 7.5 and then 2 seconds later drops right down to follow the clean drag trend. The team predicted an average coefficient of drag for the drag flight to be 1.51 and found the average real coefficient of drag to be 2.07. The differences found between predicted and real are due to the estimated time for the airbrake to be effective. In simulation we estimated that the airbrake would need to be open for nearly 6 seconds were in the competition we only had to have the airbrake out for 2 seconds. The airbrake was much more effective than predicted likely due to an excellent slip stream that flowed from the doghouse directly into the airbrake.

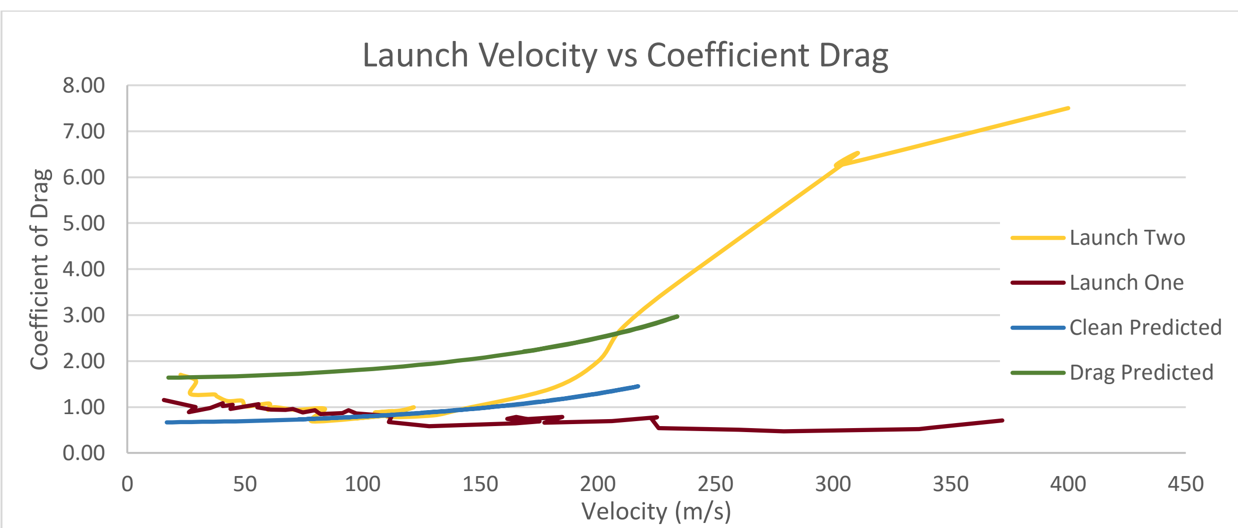

Figure 10: Competition launch coefficient of drag against velocity vs predicted.

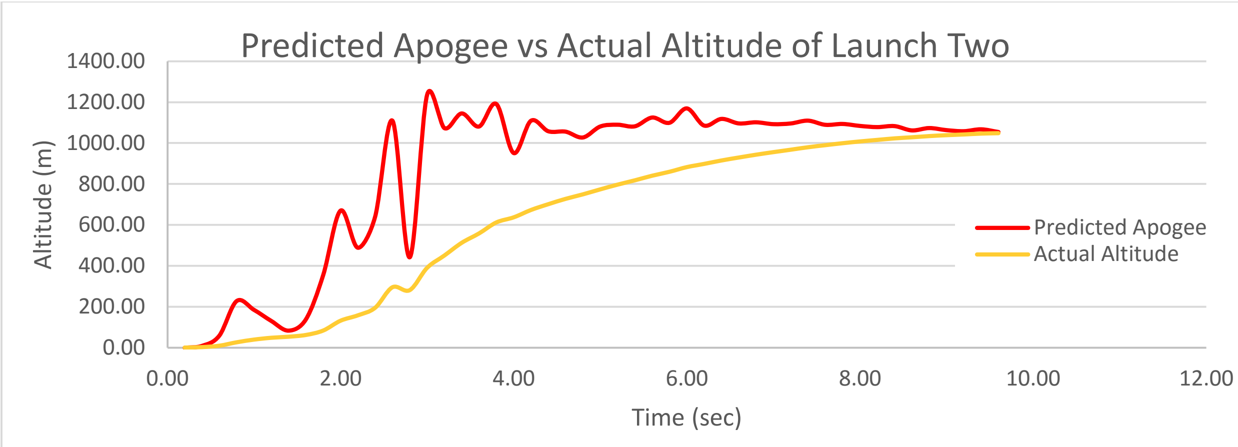

Figure 11: Predicted apogee vs actual altitude.

As seen in figure 11 the predicted apogee of the rocket at 2 seconds after burnout is approximately 1027 m which is what the rocket needed to achieve to reach the 25% reduction, so the airbrake stowed. After the drag system stowed at around 4.6 seconds the predicted altitude rose due to a small miscalculation in the coefficient of drag. If we did launch again we would correct the coefficient of drag and make a small change in the software to have several predicted readings in a row that were below 75% in order to be more accurate with our drag system.

Team Performance

The UMD Bulldog Rocketry team had 12 members in attendance at the competition. Each member had a specific task assigned to them to streamline the process of preparing the rocket for each launch. Because the pre and post launch procedures were practiced prior to the competition, each member was able to perform their tasks quickly to then assist those who required multiple hands for their portion. In this way, Bulldog Rocketry was able to prepare the rocket for both the first and second launch in just 40 minutes while never neglecting, or even rushing, the proper safety checks.

Due to the efficiency of the team and their familiarity with the rocket, Bulldog Rocketry was the first group off the rail and the first to completely finish their launches. The UMD team had no reason to perform multiple launches because the rocket performed precisely as it was designed to, resulting in data that the team was very satisfied with. The team operates on an efficient budget, so to spare extra expense in motors the team ensured that the rocket would only require two launches.

Overall, the members of Bulldog Rocketry operated as a professional and efficient team in preparing the rocket for each launch and collecting the data. This is attributed to preparation, practice, and the high level of responsibility that each member of the team took to ensure that everything was done properly.

Figure 12: Bulldog Rocketry team at the competition presentation.

Key Findings/Potential Design Improvements

Given the chance to perform these flights again, only a few slight changes would be made to the rocket. A pin would be inserted into the air-brake to ensure that it could not rotate out as it did slightly during the clean flight. This was considered previously but it was seen as a violation of the rule that the rocket could not be altered between flights. The team would have also altered the placement of the doghouses for the cameras. We believe some slight error in epoxying these to the rocket is the root cause of the tremendous amount of rotation that was seen in the on-board video. The rotation was not seen as a significant performance issue but the video would have certainly turned out cleaner without it. The amount of data readings could also be increased from five times per second to ten. This may help close the margin of error for when the air-brake is stowed thus increasing the accuracy of the rocket's apogee.

Conclusion

Overall, Bulldog Rocketry spent nine months designing, manufacturing, and testing a high-powered rocket for the NASA Midwest High-Powered Rocketry Competition. This lead to two incredibly successful competition flights in which every hour of tedious design, precision construction, and rigorous testing, culminated into a design that worked exactly as anticipated. The 23% reduction is satisfyingly close to the 25% that the design intended to reach. The team also successfully recorded video of the drag system deployment while also recording the coefficient of drag. The data collection system functioned just as intended and provided copious amounts of valuable information from each launch.

The team worked together efficiently and performed well overall. This was due the clear launch procedures and how the team practiced and prepared. The team takes great pride in how it operated throughout the competition and how the rocket performed at the competition launches. As is generally true, the team's hard work and attention to detail paid off through performance.