University of Nebraska Lincoln

Department of Mechanical Engineering

Post Flight Report

Advisors:
Prof. Kevin Cole, Prof. Karen Stelling

Technical Advisors:
Dr. Adam Larios, Mr. Bryan Kubitschek

Team Leads:
Alex Drozda, Nate Jensen, Michael Pieper

Team Members:
Evan Bechmann, Ben Bevans, Quinn Brandt, Tanner Crable, Garrett Hill, Josh Humphrey, Ethan Krings, Dillon Margritz, Firdavs Nasimov, Isaiah Petty, Cameron Svoboda, Christina Thibodeau, Marie Wagner, Brandon Warren, Emily Welchans

May 28, 2016

Contents

1 Executive Summary

The 2016 NASA Space Grant Midwest High-Power Rocket Competition took place on May 16^{th}, 2016. Each team launched a rocket to an apogee of at least 3,000 feet, and successfully recovered it. This initial launch was then used as a benchmark for the second launch, in which each rocket uses an active drag system to reduce the launch apogee to 75% of the first flight. Our team has designed, built, and launched a 10.16 cm diameter, 281.94 cm long rocket, with an active drag system consisting of three air brake panels connected using 50-lb test fishing line to a variable speed DC gearmotor. The avionics for this system consisted of an Arduino Mega, an Adafruit 10-DOF Accelerometer-Gyroscope, and a Roboclaw 2x7A DC motor controller. This design was described in more detail in the Preliminary Design Report.

Using OpenRocket, we had initially predicted a maximum altitude of 1171.346 meters, and far exceeded this during the competition, with three flights averaging 1,471.27 meters. Unfortunately, the brake system did not deploy successfully, and we were unable to resolve the issues in the allotted launch window. Despite this, all three attempted competition launches resulted in a safe and successful launch, recovery device deployment, and recovery. This report will outline the actual flight performance, expected performance with the drag system deployed, and any safety considerations we have discovered during the testing of this rocket.

2 Introduction

The 2016 NASA Space Grant Midwest High-Power Rocket Competition allows teams like ours to come up with their own design to try and meet this year's objectives. We have designed a rocket that can be launched to an apogee of greater than 3,000 feet, safely recovered, and then launched again. The main goal is to reduce the apogee of the second launch to 75 percent of the first, using an active drag system that we have designed. We have used programs such as SolidWorks 2015 and OpenRocket 15.03 to predict the rocket's flight performance and to show that our drag system will meet the goals of the competition. The majority of the design was performed using OpenRocket, with the components modeled using SolidWorks.The completed rocket, ready for flight, is pictured below in figure 1. This report details the results we attained from our flights.

Figure 1: Our rocket, Serenity, before her initial launch

3 Performance

3.1 Flight Parameter Analysis

3.1.1 Center of Pressure and Center of Gravity

The predicted Center of Pressure and Center of Gravity were accurate. We know this to be true because our rocket did what we expected it to do in terms of flight plan and stability. The Center of Pressure had to have been lower than the Center of Gravity because the Rocket had a straight trajectory. The Center of Pressure was 186.004 cm from the nose cone and the Center of Gravity was 170.0022 cm from the nose cone. This resulted in a static stability of 1.575 calibers, which is well within competition specifications, and within our target range of 1.5 - 1.6 calibers. With the active drag system located near the center of pressure, the change in stability during deployment was minimized.

3.2 Flight with Drag System Closed (Standard Flight)

3.2.1 Flight Analysis

The flight performance of this rocket far exceeded our expectations. Using OpenRocket for simulation, and applying accurate component masses and launch conditions, we had predicted a maximum altitude of 1172.8704 meters, and a maximum velocity of 146.304 m/s. Due to inconsistencies in OpenRocket calculations, changes in mass from the time of measurement, or stronger motor performance, the rocket achieved an average maximum altitude of 1471.27 meters over three launches. A graph that exemplifies these inconsistencies is pictured below in figure 2.

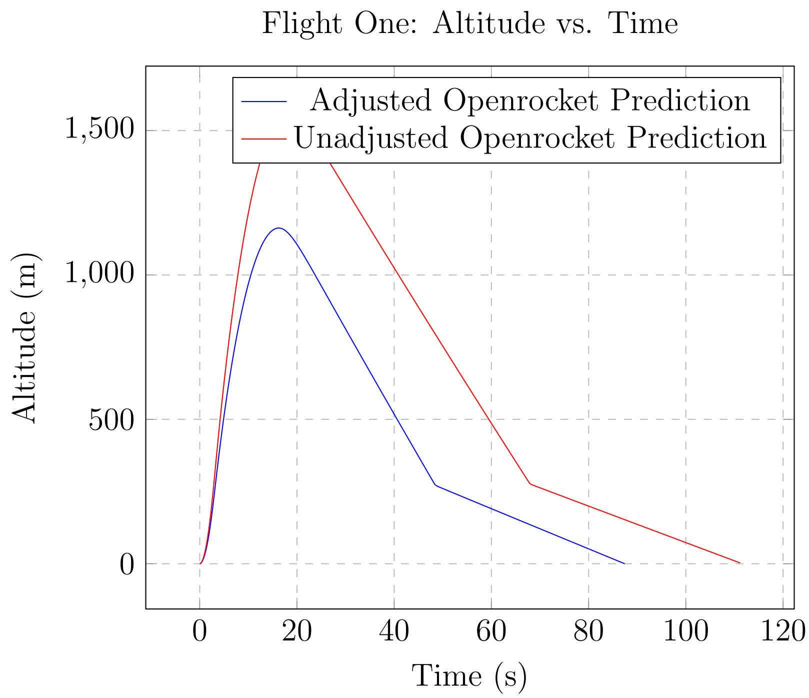

Figure 2: OpenRocket data showing discrepancies within the program; adjusted prediction uses more accurate masses, unadjusted uses OpenRocket standard mass

The first flight established a baseline altitude for subsequent launches. It was also used to test structural components, including a damaged bulkhead, that had been damaged on test launch, and then reinforced in the time between testing and official launch.This first launch, which reached an altitude of 1458.468 meters and a max velocity of 180.137 m/s, reached an altitude that was much higher than the OpenRocket predicted apogee, approximately 300 meters lower than what was attained during launch. Nevertheless, the rocket was launched and recovered safely, attaining the goal the team set. Our reinforced bulkhead and other repaired structural components did not have any adverse effect on the rocket's recovery. The coefficient of drag for this flight, obtained using data recorded from a Raven 3 Altimeter, is graphed further on in figures 5 and 6.

The second flight was meant to reach an apogee of 1093.6224 meters, or 75 percent of the first launch, by deploying air brakes. However, the air brakes did not deploy and the rocket reached an apogee of 1470.0504 meters. Post flight analysis of the rocket's electronics as well as video of the launch shows that the problem was not physical in nature, but rather electrical. Two wires that control the drag system actuation motor were unplugged from their ports. This most likely occurred during the repairs to the rocket the night before.

The third flight also suffered from problems that stopped the drag system from opening. Video evidence, a frame of which is pictured in figure 3, confirmed that these were also not physical in nature, as the drag system partially deployed from air forcing it open. However, this did not significantly lower the rocket's apogee, as the boundary layer was not exceeded by this small protrusion.The flight reached an apogee of 1485.9 meters with a maximum velocity of 175.87 m/s. This, while not ideal because of the lack of deployment, does give us a valuable information about the flight of both our rocket and projectiles in general. Specifically, this supports the suspicions our team had about the effects of shorter versus longer brake panels. Since the small opening did not affect the flight, this suggests that the air beyond the boundary layer was not disturbed. Thus, short brake panels that only extend a small amount would most likely have not have affected our flight and, therefore, the choice of extending our brake panels during the building process was sound. Given this, we are confident that, were our brakes able to deploy, a lower apogee would have been achieved. Post flight analysis shows that the reason our brakes did not deploy was related to the code controlling the deployment. A last minute change to the code to simplify the algorithm (and thus decrease the time for each step and speed up the calculations) contained an error. This error prevented the event that triggers the air brakes from being recognized by the Arduino. Unfortunately, the damage due to stress from our test launch on the 15^{th} of May had escalated. A tear in the parachute that was originally under control had propagated to the point where another safe launch was not feasible. Thus, we were unable to launch again with the issues with the air brakes fixed. However, despite our problems with materials, repairs, and time allotted, we were still able to not only launch our rocket 3 times and recover it safely each time, but to gather useful data and experience from these launches. A summary of all three flights is given in figure 4.

Figure 3: Partial deployment of the drag system, from flight number 3

Flight Number	Apogee (m)	Max Velocity (m/s)
Flight 1	1458.468	180.137
Flight 2	1470.0504	171.907
Flight 3	1485.9	175.87

Figure 4: A summary of the flight results. All three flights had a successful launch, deployment of chutes, and a safe landing.

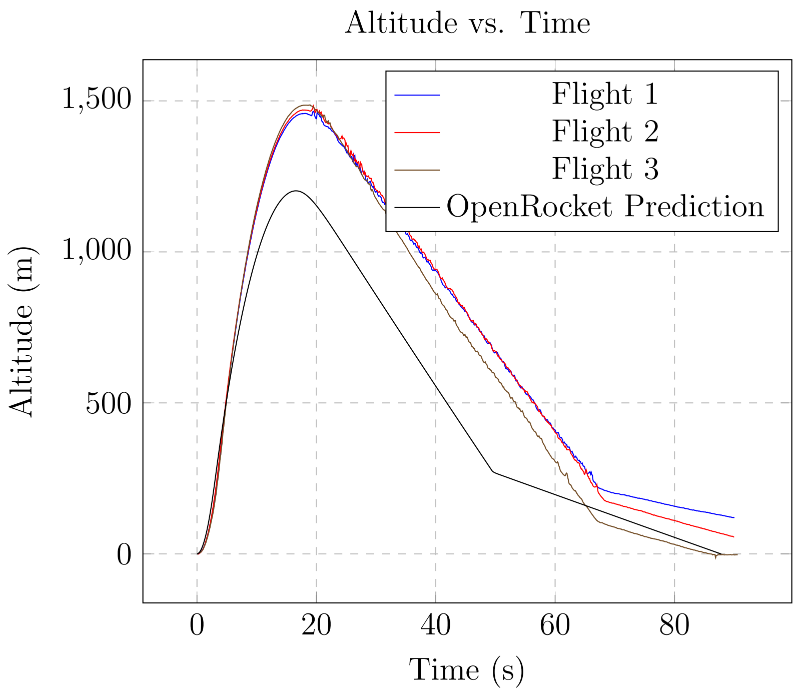

Figure 5: A comparison of the actual altitude measurements, taken from the on-board flight computer, and the predicted values given by OpenRocket.

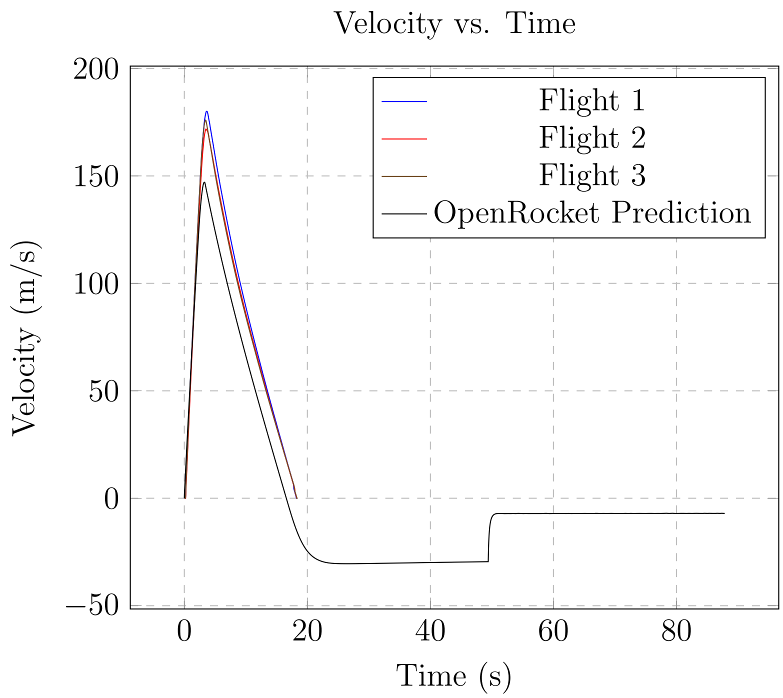

Figure 6: A comparison of the actual velocity measurements, taken from the on-board flight computer, and the predicted values given by OpenRocket.

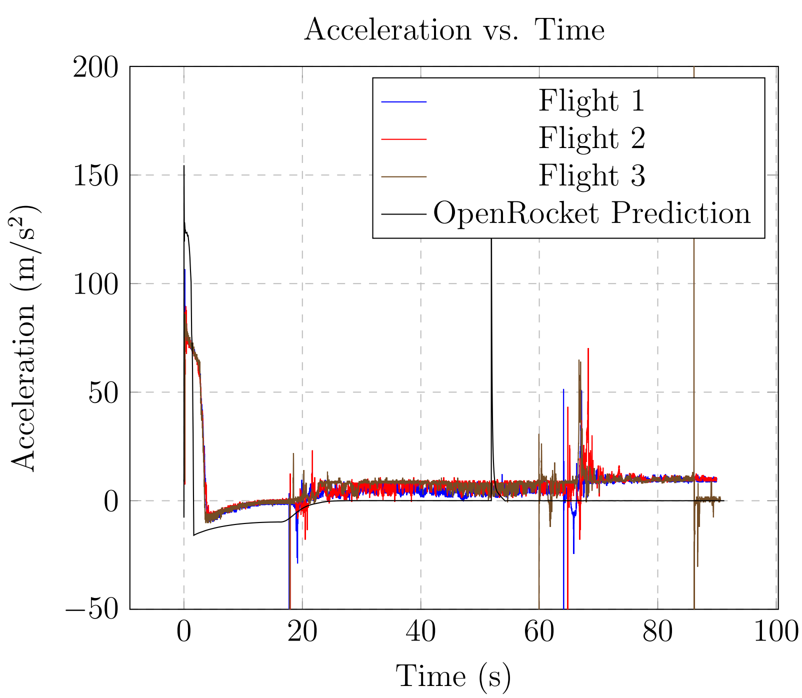

Figure 7: A comparison of the actual acceleration measurements, taken from the on-board flight computer, and the predicted values given by OpenRocket.

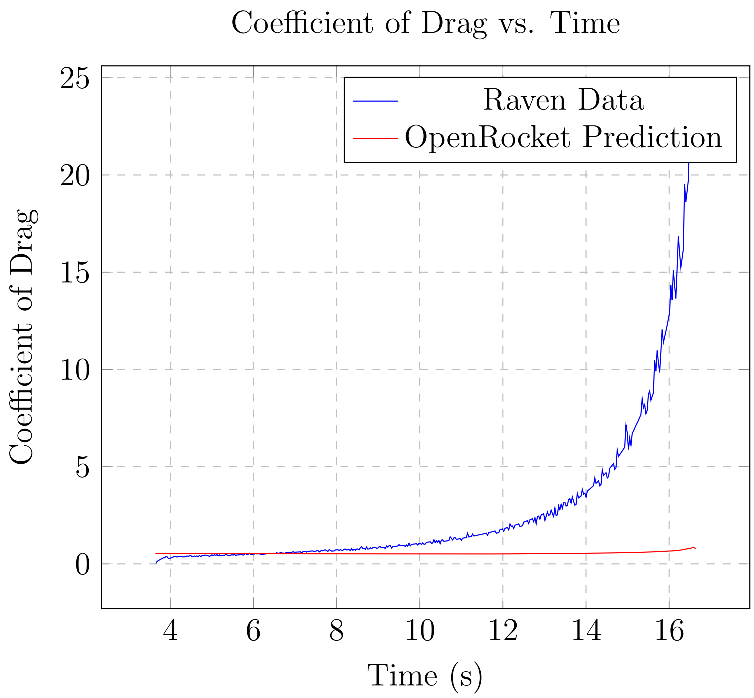

Figure 9: This is the same as Figure 3.2.1, only zoomed in to make the beginning of the flight more clear.

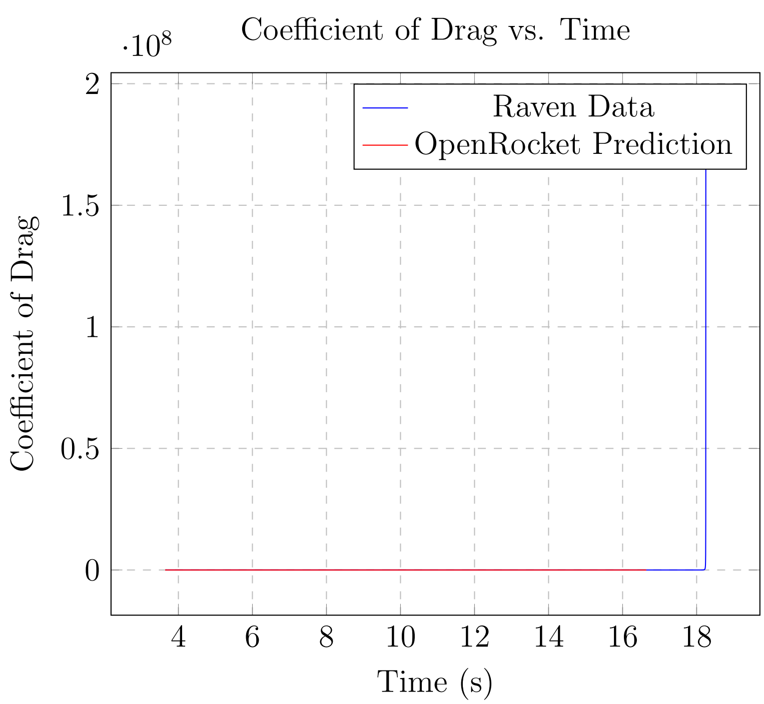

Figure 8: Comparison of coefficient of drag calculated from the data collected from the Raven, and values predicted by OpenRocket. Data was collected form flight one; the other flights look roughly the same.

3.2.2 Drag Analysis

While the drag system did not deploy as expected, we did go through the process of calculated the coefficient of drag for the launch with the brakes closed. To do this we used the standard drag force equation, altered to solve for the coefficient of drag.

$$C_d = \frac{2ma}{\rho V^2 A}$$

Where m is mass, a is acceleration caused by drag, ρ is fluid density, V is velocity, and A is the reference area; in this case, the cross section of the rocket tube. The coefficient of drag is dimensionless, so the choice of imperial or metric is arbitrary. Center [2014]

One of the difficulties found in calculating this value is that the Raven samples the various parameters at different rates. In order to solve this problem, a Python code was used to linearly interpolate between points for each timestep on those values with lower sampling rates. With the cells populated, the data for acceleration, mass of the rocket, velocity, and cross sectional area were available. Air density is a function of altitude, so that was calculated using standards from the U.S. Standard Atmosphere Oceanic et al. [1976]. Running all these values through an excel document with the necessary equations resulted in the graph shown in figures 5 and 6. Because of the V^2 term in the denominator, and velocity approaches 0 as the rocket nears apogee, the coefficient of drag increases rapidly immediately before apogee. This explains the spike at about 18 seconds. Examining the OpenRocket documentation, it was found that the OpenRocket algorithm uses a different equation for the lower Mach and Reynolds Numbers, which we did not switch to. This is why the OpenRocket data did not spike in the same way. As may be expected, these graphs are limited to the time between motor burnout and apogee.

3.2.3 Recovery Analysis

Post apogee, we ascertained the location of our rocket by visually tracking its progress and then following its descent on foot. After our test launch on May 15^{th}, the size of the parachute, combined with high winds dragged our rocket a considerable distance –we estimated about a mile– away from the launch site. The three subsequent launches on competition day landed much closer than that, but we tracked all four flights in the same manner. The recovery process could have been improved through the use of a GPS tracker so that we could have measured exactly how far our rocket drifted, and so that if our recovery team lost sight of it, it could quickly be relocated.

3.3 Difference in Flight due to Drag System Deployment

Unfortunately, the Drag System did not deploy. This was a result of either electronic or programmatic errors. Ultimately, due to time constraints, we were unable to complete a test flight with the Drag System deployed, and could not resolve these issues before the end of the

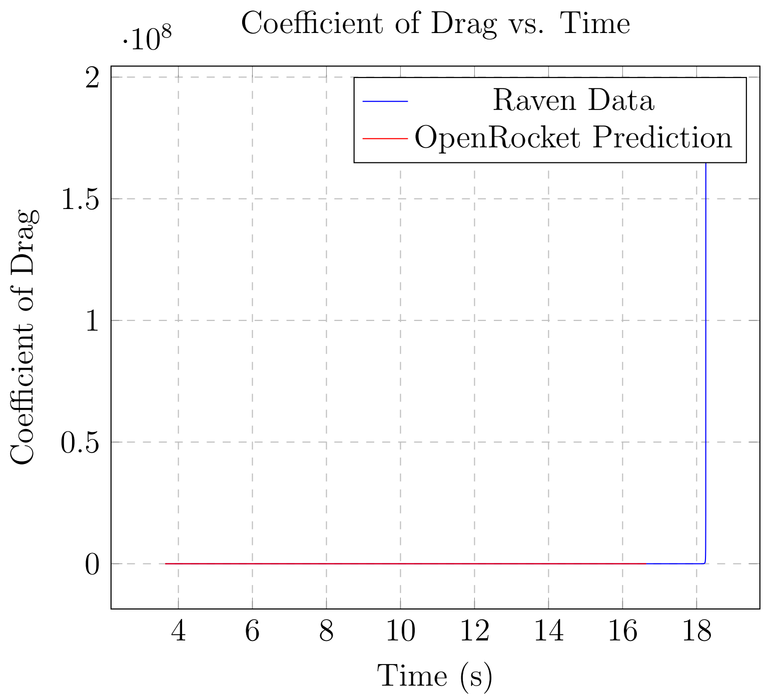

Figure 10: Comparison of coefficient of drag calculated from the data collected from the Raven, and values predicted by OpenRocket. Data was collected from flight one; the other flights look roughly the same. Note that the y-axis is scaled by a factor of 10^8.

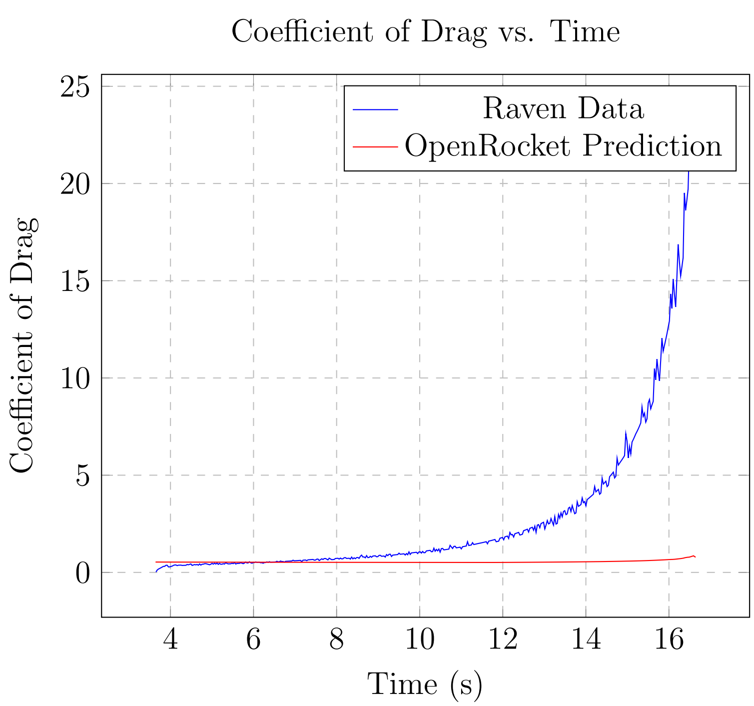

Figure 11: This is the same as above graph, only zoomed in to make the beginning of the flight more clear.

competition. The three competition flights were all non Drag System flights. However, the three launches were all very consistent, achieving an average altitude of 1471.2696 meters.

4 Safety Considerations

4.1 Design Considerations for Safe Flight and Recovery

During our test launch, we discovered three problems with the rocket construction that could have posed safety issues, the first being our Avionics Bay bulkhead. This bulkhead was designed to experience most of the forces the rocket would have to endure during the flight. Specifically, this was the mounting point for both the structure of the Active Drag System and the shock cord attached to the deployment can, and the rest of the rocket.

This bulkhead was built of two layers of 1/4" plywood, held together with epoxy resin and a large U-bolt. This construction could not handle the combination stress of the parachute separation and holding the Avionics Bay together, and started to shatter after the test launch. For the competition launches, this bulkhead was reinforced with steel plating, but after three launches, this also had been bent by the stress. Additionally, below this bulkhead, the avionics bay, active drag system, and booster are held together by three lengths of 1/4" all-thread, anchored to the above bulkhead. After our four launches, the bulkhead had been compromised to the point that it allowed significant lateral translation of these components, as viewed on the flight footage. In the future, for payloads mounted directly above the engine block, we must find a different solution for bulkhead material so that this failure point is not a concern.

For our test launch, the fire protector for our main chute was folded in a way that caused the parachute to get singed by the black powder charge, and the parachute had to be replaced. Our rocket was still capable of a safe descent and landing. For competition launches, the parachute folding technique was modified, and this was no longer an issue.

4.2 Pre-Flight Checklist

Flight Computers

- Verify flight computer configurations
- Replace flight computer batteries
- Check battery voltages
- Check flight computers
- Wire e-matches
- Set charges
- Drogue: 1^{st} ejection = 2g, 2^{nd} ejection = 3g

- Main: 1^{st} ejection = 2g, 2^{nd} ejection = 3g

Avionics Bay

- Rewire flight computers to key switches

Recovery System

- Insert wadding
- Prepare main parachute
- Fold
- Place in main parachute tube
- Connect main chute to nosecone
- Place drogue in drogue tube
- Gather shock cord in air frame
- Position nosecone and insert shear pins

Loading Motor

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

Launch Procedure

- Load vehicle on Launch rail
- Angle launch rail to vertical
- Activate flight computers
- Listen for Stratologger beeps.
- S-1: Long-5-Long-1000-PreviousAltitude
- S-2: Long-4-Long-900-VeryLong-Long-PreviousAltitude
- Clear launch pad
- Confirm continuity
- Signal Launch readiness

4.3 Post-Flight Checklist

Recovery

- Visually mark touchdown location
- Deploy recovery team
- Guide recovery team to rocket

5 References

NASA Glenn Research Center. Glenn learning technologies project (ltp), jun 2014. URL `http://www.grc.nasa.gov/WWW/K-12/`.

George J. Caporaso Gordon K. Mandell and William P. Bengen. *Topics in Advanced Model Rocketry*. MIT Press, One Rogers Street Cambridge MA 02142-1209, 1973.

Sampo Niskanen. Openrocket technical documentation. For OpenRocket version 13.05, may 2013.

National Oceanic, National Aeronautics Atmospheric Association, and United States Air Force Space Administration. *U.S. Standard Atmosphere, 1976*. US Government Printing Office, Washington, D.C. 20402, 1976.