Predicting Performance and Roll-Rate Minimization of a High-Powered Model Rocket

Jordan Faber, Patrick Naumann, Nicole Schilder

Marquette University

Milwaukee, WI, USA

Abstract

The Collegiate Rocket Launch is a competition sponsored by the Wisconsin Space Grant Consortium which challenges student teams from colleges throughout the state of Wisconsin to design, build, and launch a high-powered model rocket. Teams are scored based on quality of technical reports, project management, outreach, and the competition flight. The 2022 competition challenged teams to create an active control system that minimized the roll rate of the rocket while in flight, as well as reach but not exceed a target altitude of 3,500 feet. Marquette Rocketry is proud to have placed first in the competition and given the title of mission grand champion.

Competition Objectives and Design Constraints

The rocket has several required main components, such as the Aerotech I435-T (38 mm) motor and Jolly Logic AltimeterTwo flight data recorder. The rocket also needs to have a camera that can capture down-looking video during flight. This is a single-stage rocket with a 5:1 minimum thrust to weight ratio and a maximum apogee of 3,500 ft. All materials used to build the rocket must come from a credible high-powered rocketry vendor, otherwise the team must come up with an engineering analysis of the other materials used. The final rocket must also be able to pass a safety inspection.

The rocket is also required to have an avionics system that actively minimizes the roll-rate of the rocket during the coast phase only (not the boost phase). The active control surfaces cannot be more than 15% of the total fin surface area. The avionics system must also record the rocket's axial acceleration, roll-rate, and signals used to control the roll-rate. It also should have some sort of visual indication of "ready", "stand by", and "ready to fly" system status and must be able to be controlled while on the launch pad with a wired remote with magnetic breakaway connector.

The primary recovery method should be an electronic, dual deploy of a parachute and have motor deployment as a backup. A drogue parachute will be deployed at apogee while a main parachute will be deployed a set distance from the ground. There must be a downed rocket location aid, and in order to have a safe and successful flight the rocket must have a stable ascent after launch and be recovered in ready-to-fly condition.

Structural Design Process

While designing the structure of the rocket, the team made sure to design around parts that were either commercially available or easy to 3D print. The final design, as is illustrated in figure 1, ended up being 3.1" in diameter and 57.2" long. The diameter of the rocket has a major effect on the rocket's altitude, and a diameter of 3.1" was large enough to keep the powerful competition motor under control while not being so large that the rocket wouldn't be able to reach the target altitude of 3,500 feet. The rocket made use of a commercially available nose cone, and 1/8" thick plywood fins that were cut with a laser cutter. The fins were shaped to ensure stability according to OpenRocket and RockSim simulations. These fins were mounted "through the wall" meaning that the body tube had slots cut into it for inserting the fins rather than just attaching them to the outside surface of the tube. This is the preferred method of attaching fins

---

Acknowledgements: Thanks to the Wisconsin Space Grant Consortium for hosting this competition, providing us with the funding to complete our project, and inviting us to present at the 2022 Wisconsin Space Conference. Also, thank you to Tripoli Rocketry Association for their help with the competition and hosting the launch site for both our test flight and the competition flight. Additionally, we would like to thank our advisor Dr. John Moore for both supporting us in the competition and supporting aerospace at Marquette.

for high power rocketry as the fins are much less likely to shear off during flight or break off upon landing. Epoxy was used throughout the rocket's construction, including internal and external fillets on the fins to ensure maximum strength.

Since there are many extra electronic components that need to be added to the rocket to operate our actively controlled fins and the required monitoring systems, we decided to ensure that all these electronics are contained as compactly as possible in the center of the rocket's body. If the components were throughout the body, it would be difficult to maintain an even weight distribution. Our design contains two sets of fins, with fixed fins at the back of the rocket and smaller fins that act as our active control surfaces in the center of the body tube. We chose to make the control surface fins smaller than the back fins, because that way the aerodynamics of the rocket are improved as the rocket is the thinnest at the tip of the nose cone and still gradually gets wider. This way, the control surfaces are able to do their job in controlling the rocket with minimal unintended interference with the rest of the flight. The avionics bay and control surfaces were 3D printed using ABS filament.

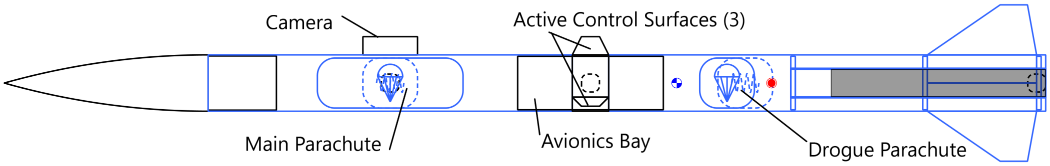

Figure 1: Rocket design as created in OpenRocket. The center of gravity (blue cross CG symbol) is at least one rocket diameter in front of the center of pressure (red dot), indicating that the design is stable. All parts are modeled after commercially available parts or ones that we were confident in manufacturing.

Active Control System

To minimize the roll-rate of the rocket, the team decided to utilize servos attached to small fins that would be controlled using an Arduino programmed using Simulink utilizing PID control loops (see figure 2). The Arduino would take in data from an MPU6050 3-axis gyroscope and 3-axis accelerometer and use that data to adjust the control surfaces accordingly.

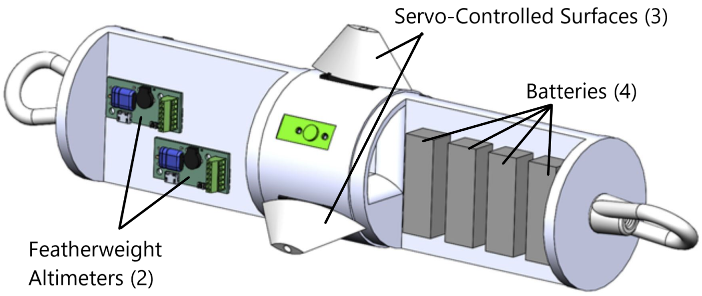

Figure 2: 3D model of the avionics bay including the active control surfaces. This was modeled in SolidWorks and 3D printed using ABS filament.

There are three servos mounted evenly around the switch band and each has its own control surface. The competition requires that control surfaces be moved to a neutral state during any system failure. To achieve this, two springs are mounted on either side of the servo which force the servo back to neutral when powered off. While powered on, the servos specified have enough torque to overcome the force of the springs and the roll of the rocket can be controlled and stabilized.

The response of the control system was tested during programming and before the competition flight. When rotating the avionics bay by hand, the control surfaces did move indicating that the sensors were working and servos were able to respond. This gave the team confidence the system would also respond while experiencing similar rotations while in flight.

Recovery System

The team decided to go with a redundant dual deploy recovery system using two altimeters and four black powder charges. To control ejection events, the team chose two Featherweight Raven4 altimeters. These were chosen because of their accuracy and reliability, maximizing our chances of a safe and successful flight.

The recovery system is powered with 300mAh LiPo batteries. The backup and primary ejection systems are electronically isolated from each other so a failure on either the primary or backup will not affect the other system. To power on the electronics while vertical on the pad, screw switches are installed to make sure that the black powder charges are not live until in the proper area.

All deployment electronics are mounted in the central avionics bay. The altimeters are mounted using screws and the batteries are mounted using zip ties and are constrained in all directions. This method has been used for competition and student projects in the past and the team finds this easiest to work with and reliable. In the rare event of a double failure in the electronics systems, the motor backup charge was set for predicted apogee time plus 2 seconds.

Each section of the rocket is tied together using ¼" tubular Kevlar shock cord. The drogue side uses 25ft of Kevlar and the main side uses 20ft with two sewn loops at each end. The shock cords are connected to each part of the rocket using ¼" quick links to make the parts usable in the future. With a 14-inch main parachute the rocket is predicted to descend from apogee to 600 feet a rate of around 80 ft/s. At 600 feet the main will deploy and slow down the rocket to a safe descent velocity of around 20 ft/s. Each parachute will be protected from the hot black powder gases by a Kevlar blanket.

Flight Results

Upon ascent, the control system did not activate. The team identified possible disconnection of the cables due to the harsh acceleration of the motor. Due to this, there was no data collected on roll rate. Even though this part of the system failed, it did not result in any adverse or dangerous flight characteristics.

Figure 3: A post-flight image of the rocket. The upper body tube only suffered slight zippering, but the lower body tube, including each of the fins, remained intact.

The recovery system performed as expected, with both the drogue and main parachute deploying successfully. Even with the dual-deploy setup, the winds were so strong on launch day that the rocket drifted far enough from the launch pad that it landed on the highway. We were able to track our rocket using the Featherweight GPS tracker, but it was first recovered by a passerby who brought it back into the park for us. Upon examining our rocket post-flight, the main damage was on the nose cone where it had been ran over and there was slight zippering of the body tube as shown in figure 3. It is unclear whether the zippering was from the flight itself or from the damage from vehicles, but none of this damage occurred during a previous test flight. Other than this, all additional parts of the rocket including the fins and all electronics were undamaged and intact.

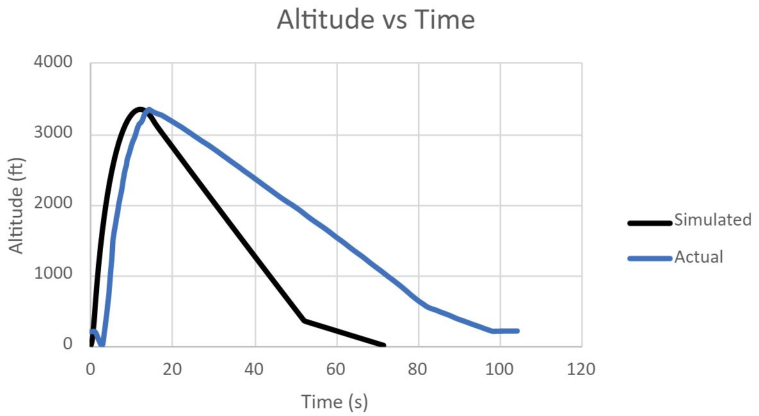

Figure 4: A graph comparing the simulated altitude (black) and actual altitude based on altimeter data (blue) showing our accurate apogee prediction and the effect of strong winds on descent.

Figure 5: Our rocket taking off on competition day. The structural design ensured a stable ascent.

As shown in figure 4, the actual altitude throughout the flight started out nearly matching the simulation upon ascent, but upon descent the actual flight took longer to hit the ground than the simulation. Upon ascent, the rocket was less affected by the wind due to its velocity and margin of stability. Figure 5 shows an image of the rocket taking off, and it is going up straight despite the winds. Upon decent, the high winds caused the rocket to drift under the parachute and take longer to hit the ground.

Our predicted apogee from our simulation was 3,505 ft, and our actual apogee was just under that. The competition altimeter reported an apogee of 3,362 ft and our altimeter reported an apogee of 3,340 ft. According to the competition altimeter, our predicted apogee was 96% accurate, and the team ultimately ended up winning this year's competition.