Actively Minimize Rocket Roll-Rate During the Coast Phase

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Abstract

In the 2021-2022 Collegiate Rocket Competition, participating teams were tasked with the development and implementation of an active roll-control system onboard their rocket. To reduce the rotation of an object, the principal of conservation of momentum was applied by adjusting the angular momentum of a mass inside the object. This principle was implemented in the Phantastic Phoenom's 2022 rocket to minimize the roll-rate during the coast phase of flight. The components utilized to accomplish this include a three-inch steel tube, Raven4 altimeter, six-axis accelerometer, Arduino Nano microcontroller, and a stepper motor. The mass housed inside the rocket was reduced by 40% to achieve the weight needed to reach the predicted apogee. Despite several unforeseen challenges the day of the competition launch, the rocket completed a successful launch. The Phantastic Phoenoms are proud to be able to win third place in this competition.

Introduction

2022 Collegiate rocket launch objectives. In the 2022 Collegiate Rocket Launch (CRL), participating teams were called upon to develop a method of actively minimizing a rocket's roll-rate during the coast phase of the flight. Additional competition objectives included recording downward facing video of rocket flight, executing dual parachute deployments, and successfully recovering the rocket in flyable condition after landing. Furthermore, while constrained to the use of an Aerotech I435T-14 rocket motor, each team's rocket was required not to exceed an apogee of 3500 feet. Pictured in Figure 1 is the final flight configuration for the Phantastic Phoenoms, the CRL team of the University of Wisconsin – Green Bay.

Figure 1: Phantastic Phoenom's rocket designed for the 2022 Collegiate Rocket Launch.

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Design solution. The Phantastic Phoenoms balanced the competition requirements by implementing an Arduino-controlled flywheel system into the rocket. The flywheel system was designed to produce a counter-torque on the rocket to reduce roll-rates detected by onboard sensors. Figure 2 shows an early rendition of the flywheel system where two bulkheads—the same diameter as the body tube coupler—supported a threaded rod and the mass. The bulkhead farthest from the mass served as an eyebolt for the main parachute.

Figure 2: Spinning mass used to produce control the rocket's angular momentum.

Materials and Methods

Construction. The rocket constructed by the Phantastic Phoenoms was comprised mainly of fiberglass. The body tube consisted of three fiberglass tubes, each with a four-inch diameter, joined together by fiberglass couplers. Fins were made from a G-10 fiberglass sheet. To ensure the fin's aerodynamic characteristics were in agreement with predictions given by RockSim, a laser cutter was used to precisely cut each fin.

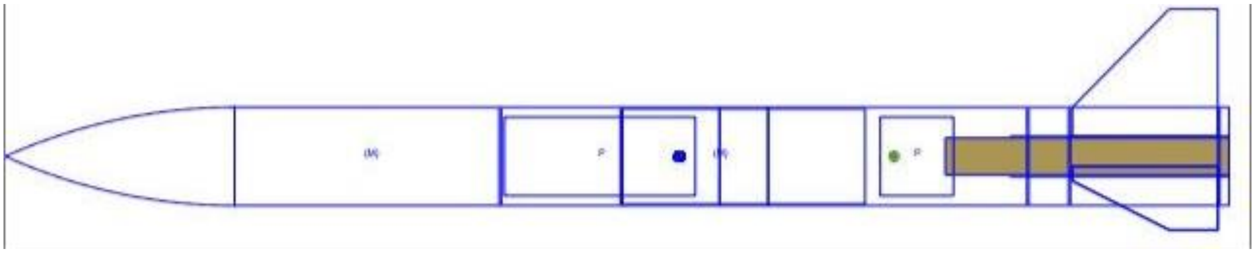

Figure 3: RockSim illustration of rocket design showing the forward, coupler, and aft sections. Additionally, the rocket's center of mass and center of pressure are indicated by the blue and green circles, respectively.

To meet the dual deploy parachute requirement, the rocket was constructed in three modular sections: the forward section, coupler section, and aft section. In the forward section, the flywheel system and main parachute were housed. Inside the coupler section were the electronic systems, which allowed for convenient wiring to systems stored in the forward and aft section. Housed in the aft section were the drogue parachute and rocket motor. At the union of each section, shear pins were placed to prevent premature rocket separations. Figure 3 shows a cross-sectional view of the flight configuration, including all structural components, the main and drogue parachutes, and the center of mass and center of pressure.

Payload overview. The flywheel system reduced the roll-rate of the rocket by rotating a mass in the same direction as the rocket to produce a counter-torque neutralizing both rotations. The mass of the flywheel system was a three-inch steel DOM tube fastened to a rod with couplers. The electronics within the system included a Raven4 altimeter, a six-axis accelerometer, an Arduino Nano microcontroller, and a 42 N cm stepper motor. Figure 4 shows the electrical configuration for the active roll control system during lab testing.

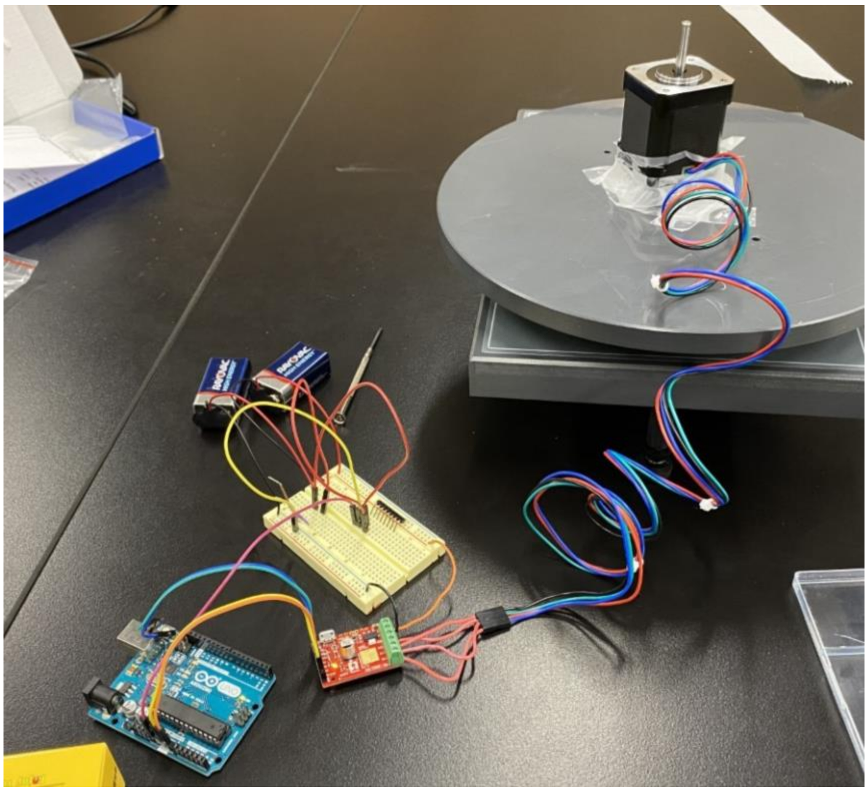

Figure 4: Components of active roll control system shown during the design phase, prior to final installation.

Payload operation. To detect the beginning of flight and the end of the boosted flight phase, the accelerometer monitored the rocket's vertical acceleration. When the accelerometer indicated that the powered flight phase was complete, marking the beginning of the coasting phase, the active roll control systems became operational. While the system was active, the accelerometer continuously updated the roll rate of rocket with respect to ground, $\omega_{R/E}$. Using this information, the microcontroller evaluated the following expression to obtain the stepper motor velocity—relative to the rocket—required to minimize the rocket's roll rate, $\omega_{F/R}$.

$$\omega_{F/R} = \left(\frac{I_R + I_F}{I_F}\right)\omega_{R/E}$$

Because the accelerometer's least count of $0.49°s^{-1}$ subceeded the stepper motor's angular velocity least count of $1.8°s^{-1}$, the program's response was accelerated when the rocket's roll rate was near zero. This was accomplished by skipping all calculations and rapidly sampling the rocket's roll rate while the accelerometer reported a roll rate below $1.8°s^{-1}$. Throughout development, the flywheel system was able to spin at a precisely determined speed, providing the team confidence that the flywheel system would work during flight.

Results

Test launch. The rocket assembly, excluding the stepper motor, underwent a test launch prior to the competition day. A precursive simulation showed a predicted apogee of 800 feet using an H-550 motor. The actual apogee recorded by the Raven4 altimeter was found to be 1200 feet, achieved 10.5 seconds after launch. Shown below, in Figure 5, is the recorded altitude with respect to time from the test launch. Evident by the graph and onboard video, both the drogue and main parachutes deployed at apogee.

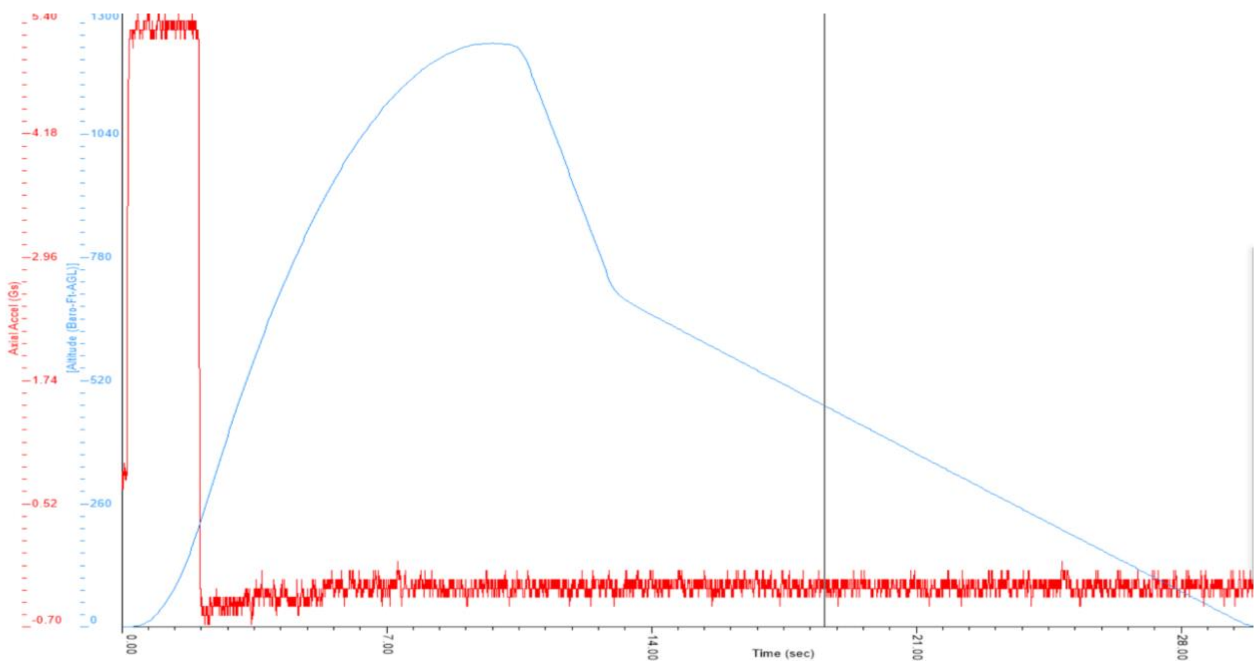

Figure 5: Test launch altitude plotted with respect to time. The apogee point is at 1,200 feet, occurring at 10.5 seconds after launch.

Design improvements. Drawing from insights provided by the test launch, design alterations were made to prevent premature deployment of the main parachute, and to reconcile mass of the rocket during the competition flight. To mitigate the risk of prematurely deploying the main parachute, the shock chord connecting the parachutes to the rocket were replaced and extended. To account for the mass of the stepper motor, which was not included in the test flight, the flywheel mass was reduced by 40%.

Competition launch. Due to a cable defect on the competition day, the flywheel system was rendered inoperable. As such, the roll-control system's in-flight performance could not be assessed. A precursive simulation of the competition launch showed a predicted apogee of 1958 feet using an I-435 motor. After retrieving the rocket in recoverable condition, the altimeter data revealed the actual apogee to be 2330 feet, achieved 13 seconds after launch. Figure 6 provides the recorded altitude with respect to time of the competition launch. Similar to the test launch, a single-stage deployment was made apparent after reviewing the graph and onboard-video.

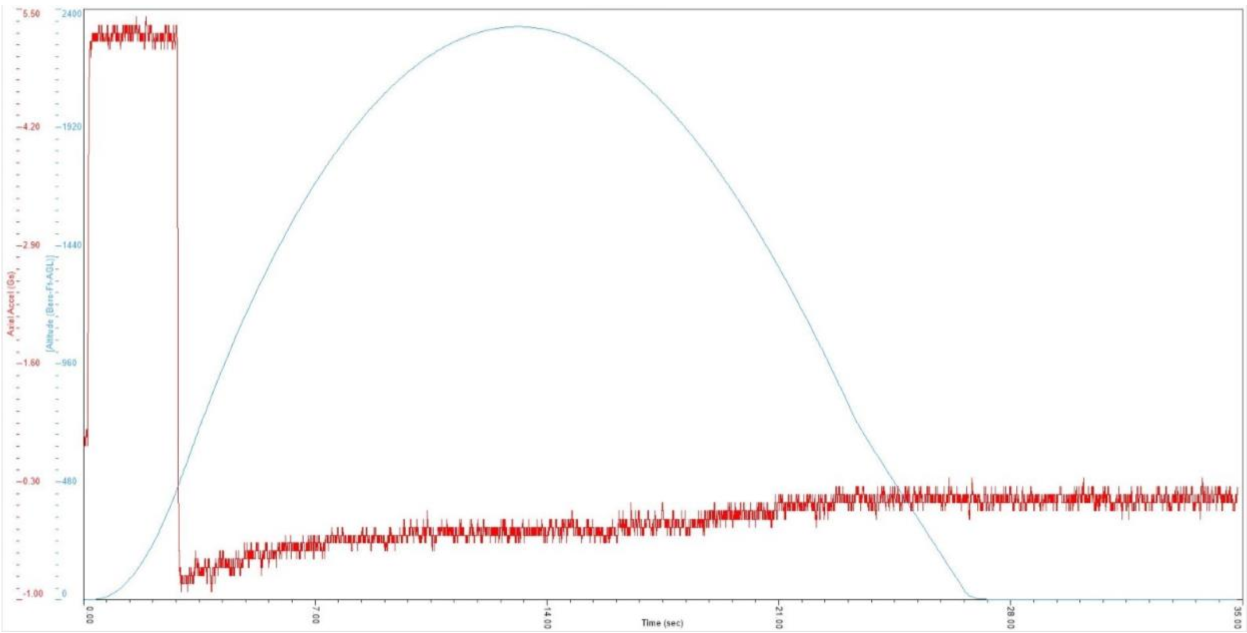

Figure 6: Competition launch altitude plotted with respect to time. The apogee point is 2,330 feet, occurring at 13.0 seconds after launch.

Discussion

The Phantastic Phoenoms were able to create a flywheel system with the ability to sense the angular momentum of an object and produce the proper amount of counter-torque to equalize rotation. Due to a mishap with a wire, the team was unable to test the system during the competition launch, thus the rocket rolled naturally during the flight.