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NASA Student Launch Post Launch Assessment Review

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Induced Vehicle Roll by Reaction Wheel

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Motor Used

The motor that we used is the Aerotech L1420R. This motor provides a total impulse of 4,603 N-s and has a maximum thrust of 1,814 Newtons. It has an average thrust of 1,420 Newtons and a burn time of 3.2 seconds.

Dimensions

The launch vehicle was made of 5.5-inch diameter fiberglass and was 110 inches long.

Altitude Reached

During the competition, the launch vehicle reached an apogee of 5,196 feet.

Vehicle Summary

The launch vehicle weighs 22.583 kg (49.79 lbs) on the pad. The center of pressure is at 83.086 inches and the center of gravity is at 66.784 inches. This results in a 2.96 caliber stability margin. It is composed of a booster section, avionics and payload bay, recovery bay, and nose cone. Its recovery subsystem features a 30-inch drogue parachute and 168-inch main parachute with two Missile Works RRC3 Altimeters, the second being for safety and redundancy. The drogue parachute was set to deploy at apogee and the main parachute was set for 1000 ft. The kinetic energy on impact was designed to be 73.5 ft-lb, and the max velocity that the launch vehicle achieved was 0.52 mach. The body of the vehicle was made of fiberglass with three swept clipped delta fins, constructed using a through-the-wall configuration.

Data Analysis and Results of Vehicle

The launch vehicle was observed to be very stable in flight with no angular oscillations about its axis. It also had perfect deployment of the drogue at apogee and main at 1000 feet with no shock cord entanglement as had happened in previous test launches. Upon inspection, there was also no damage to any sections of the vehicle.

In terms of the numerical data of our flight, the launch achieved an apogee of 5,196 feet, just shy of the one-mile mark. This was slightly above our simulated altitude, but this variation could be due to launch day conditions or variation in the motor. Overall, the flight was extremely stable, had a perfect recovery, and reached an extremely satisfactory altitude.

Payload Summary

An electrical motor rotates a reaction wheel (flywheel) inside the launch vehicle post-motor burnout, which induces a counter-spin of the vehicle body via the conservation of angular momentum. The flywheel is powered by a brushless DC motor, which paired with the BNO rotation sensor and a feedback system, induces a controlled roll of the launch vehicle. The flywheel sits on a shaft that is supported by thrust-radial bearings in a face-to-face orientation. The equipment of the reaction wheel is secured to the launch vehicle with 5 custom aluminum bulkheads that slide into the payload bay, and get bolted to the fiberglass shell.

Data Analysis and Results of Payload

Our microcontroller records several types of data from the time it is started until flight apogee and saves it to an SD card. Through this data we were able to visualize how many turns the rocket was undertaking throughout its flight. What our data showed us is that our rocket spun in a counter-clockwise direction, first to oppose its initial rotation, than to try to get to two rolls. From our data, we conclude that it was successful in stopping its initial rotation, getting under the 20° per second of rotation we considered as no rotation. From there, the motor rapidly accelerated to attempt to rotate the launch vehicle a further 720°. Unfortunately, the launch vehicle only rotated approximately 350°. From our data on the turn speed of the rocket, we observed a sudden loss of speed a quarter of the way to apogee. We theorize that this loss of speed is what impacted our ability to reach two revolutions. Various different reasons could have caused this sudden loss of speed, such as wind gusts. One reason that has been a problem during ground tests was bearing slippage, which has produced speed fluctuations similar to the one shown in our data. While the motor did try to correct for this loss of speed, our power supply was not strong enough to give it the extra speed needed to overcome the massive loss of angular momentum. It is likely that if the momentum loss had not occurred partway through the flight, the two rolls would have been easily reached.

Scientific Value

Our rotation system utilized the conservation of angular momentum and a PID controller, which created a simple, self-adjusting system. Reaction wheels are used to control many types of spacecraft, including the Hubble Space Telescope, and feedback systems are used in the automotive, energy, and manufacturing industries, among many other applications.

Visual Data Observed

The following figures visually demonstrate the data that was recovered from the SD card within the launch vehicle post launch. All 3 figures can be used to determine the amount of roll of the vehicle at a given time. Time zero on the figures represents 2 seconds after motor burnout while the data ends at time 15.09 seconds because that is when apogee occurred.

Since a minimum of 2 rolls was required for the competition, ideally the relative roll position of the launch vehicle would have reached 720 degrees. However, as it can be seen in Figure 1, about only 1 roll happened during flight.

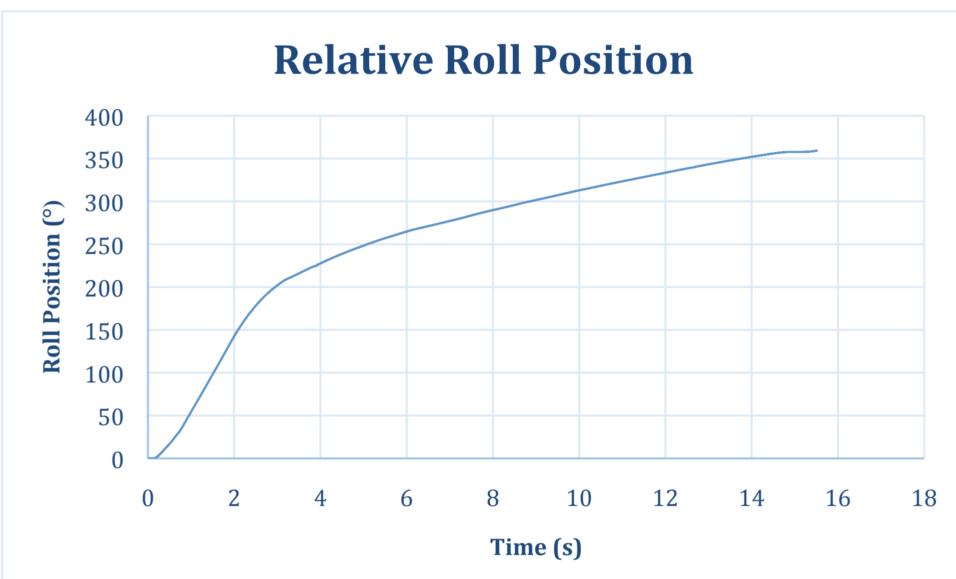

Figure 1: Relative Roll Position of the Launch Vehicle

Figures 2 and 3 demonstrate the angular position and velocity of the launch vehicle, and though do not provide as clear results as Figure 1, still are interesting and relevant to the launch.

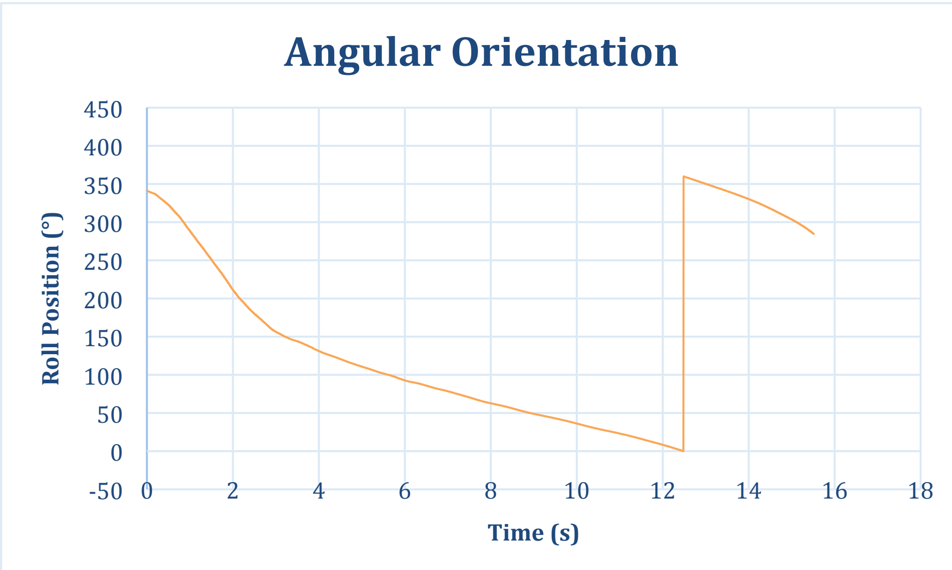

Figure 2: Angular Orientation of the Launch Vehicle

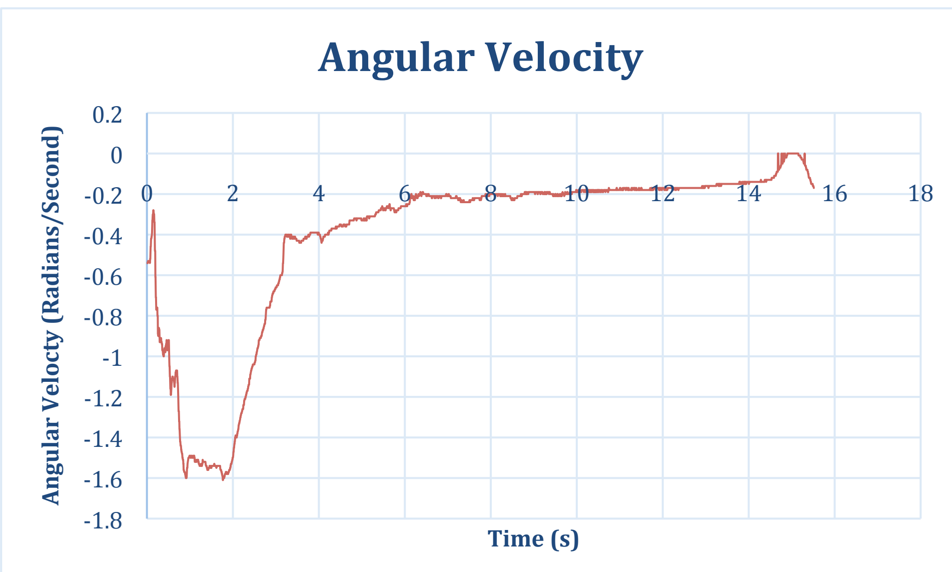

Figure 3: Angular Velocity of the Launch Vehicle

Lessons Learned

We learned a lot of important lessons throughout this project. At the beginning of the year, we were planning on attempting multiple payloads (the rotation challenge and the fragile material protection challenge), but we soon realized that we did not have enough committed team members or time to attempt both. We also had two alternatives for the rotation challenge that we considered in depth until CDR. This was a mistake, as while it was good to consider our alternatives and pick the one we thought was best, we spent way too much time deciding between the alternatives and as a result did not have enough time to fully perfect our chosen design of the reaction wheel. Brainstorming is a critical part of the design process, but we let it go on for too long and hurt our final design as a result. Next year we will set much stricter deadlines for our design process and set realistic goals for our team.

We also had a couple of different methods for leading the sub-teams, to varying success. With our dynamic fins team, which we ultimately decided to dissolve because we went with the reaction wheel design, we had a senior member as the primary lead with an underclassman as a secondary lead to learn how to run a team and prepare them to lead the team next year. This seemed to work very well, as their design and documentation, as well as sub-team involvement, was by far the best out of all our sub-teams. However, with our electronics sub-team, we had three co-leads, which became a problem when no one knew what each person's role was. This made it take a lot longer to schedule their team meetings or work on their section of the project as no one was really in control. Next year we want to implement the primary/secondary lead system, as it is a great way to include/train younger members and help with knowledge transfer.

We also have a separate education/outreach team as part of NUSTARS, which lead to some confusion about completing the documentation for NSL, as their leads are not directly part of our NSL team. This lead to us turning in our education documentation much later than it should have been, and we will work on this for next year. Inter-team communication is challenging but it is an important skill to learn.

Perhaps the most important lesson we learned is that nothing ever works on the first attempt and it is critical to have backups for testing. Testing is so important and we should have given ourselves more time for testing. The time pressure we put ourselves under for testing and our inability to do a test-flight with the fully functional payload is our biggest regret of this year.

Summary of Overall Experience

Overall we are very pleased with the experience. The project was very frustrating at times and nothing worked on the first try, but we are very pleased with how our launch went and that our payload mostly succeeded. We are disappointed that the payload only completed ~1 rotation, but given that we had to solder on a new microcontroller the morning of the launch and had not flown the fully-functional payload prior to the competition launch, it is pretty amazing that it worked at all.

Educational Engagement Summary

Over the course of our 7-week programs at Walker Elementary School, Haven Middle School, and Nichols Middle School, along with a few education events sponsored by Northwestern, we engaged 464 students in the basics of rocketry and aerodynamics. This program taught elementary and middle school students on the fundamentals of the cosmos, the basic forces behind rocketry, and how to construct model rockets. The program was overwhelmingly successful, as every student we engaged said that they were happy to be a part of it and wanted us to come back next year. Almost all of the model rockets were launched successfully, much to the happiness of the students who built them.

Budget Summary

Item	Cost
Full scale launch vehicle	$2,984.03
Sub scale launch vehicle	$367.58
Rotation System	$2,429.31
Building supplies	$560.98
Safety supplies	$410
Travel Costs	$6,118.72
TOTAL	$12,870.62