Post-Flight Performance Report

Macstronauts
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Executive Summary

This brief, unasked for, executive summary exists to explain what we knew going into launch on Sunday morning that prevented us from giving a good effort toward orienting the roll of the rocket. As a team, we discovered on Saturday night that the altimeter we were using to sense launch and apogee as required per the safety guidelines of the competition, has a data acquisition time of 1 second to 9 hours. With this discovery happening the night before the flight, we had no time to source a new physical chip, integrate it into the system, and find a new compatible python library with which to update our code. This means that we were unable to attempt the second challenge at all and were only able to give a very minor attempt at the first. We chose instead to demonstrate via the LED's that we knew which direction we should be attempting to turn and, to ensure we could abort the program at apogee, take data points as often as was practical.

For the first flight, we decided we could risk a quarter turn of our flywheel in between sensor readings to attempt to slow down the rocket's roll, but understood that small of a turn followed by ~1 second of nothing would, in effect, not change the rocket's roll. These results are confirmed with the data discussed in the rest of this paper.

For the second flight, we attempted to indicate the direction of the first turn and, knowing we would never actually be able to complete the first turn, simply left that indicator on for the duration of the flight.

In both flights, we were unable to flash the LED's at the correct "waiting for launch" intervals due to needing to take sensor data at second intervals to sense launch. We were, however, able to have both LED's on solid to indicate a sensed launch and then the additional 3 and 2 seconds respectively after motor burnout. This was followed by the main program and then the LED's went into recovery mode, flashing every 0.5 seconds.

While being unable to actually attempt the roll portion of the challenge, we are nonetheless proud of what we were able to accomplish. We offer no excuses such as lack of experience or lack of team members and expect no leeway given by the judges. We instead offer our thanks for the opportunity presented to us to compete and our lofty aspirations for the future.

— James Cannon, Macalester Team Lead

Flight Performance Comparison Sheet

- Table of Flight Characteristics

First Flight of Quantum Heavy

Mass of rocket	Motor	Maximum Altitude	Maximum Velocity	Maximum Acceleration
3.35 kg	J420-R (Aerotech)	4151 feet	579 ft/s	23.41 Gs

Second Flight of Quantum Heavy

Mass of rocket	Motor	Maximum Altitude	Maximum Velocity	Maximum Acceleration
3.35 kg	J420-R (Aerotech)	4027 feet	575 ft/s	26.21 Gs

These are similar to what we predicted using OpenRocket with a few notable exceptions. Both maximum altitudes are slightly lower than OpenRocket simulated and the maximum accelerations are higher than expected. Maximum velocity is also about 50 feet per second lower than predicted.

Roll Data and Discussion

Flight 1

As mentioned in the Executive Summary, we expected to be unable to affect the roll of our rocket due to our altimeter interrupting the program for a full second as it acquired data. Figure X shows the ***Roll Velocity*** of the rocket as a function of time since launch as our sensor suite was not set up to measure Roll Angle and given the sparseness of our readings, an attempt to calculate angle by integrating over time would induce significant error.

Figure 1 and Figure 4 have two data sequences: in blue, the reported data from our gyroscope; in red, the velocity acquired by first matching the altitude data from our non-commercial altimeter and the Raven3 to find the timestamps for which we have data from our gyroscope that can be compared to the video-retrieved values. Starting at these timestamps, we move back frame-by-frame until a landmark (ideally close to the middle of the screen) is in some convenient location. We note this angle, then move forward from the center frame the same number of frames as we went back. We note the new angle of the landmark and measure the change in angle, dividing it by the amount of time that passed between the two measurements, which results in an estimate of our angular velocity. Due to this methodology, we anticipate that for Roll Velocity, the sensor suite is the more accurate data.

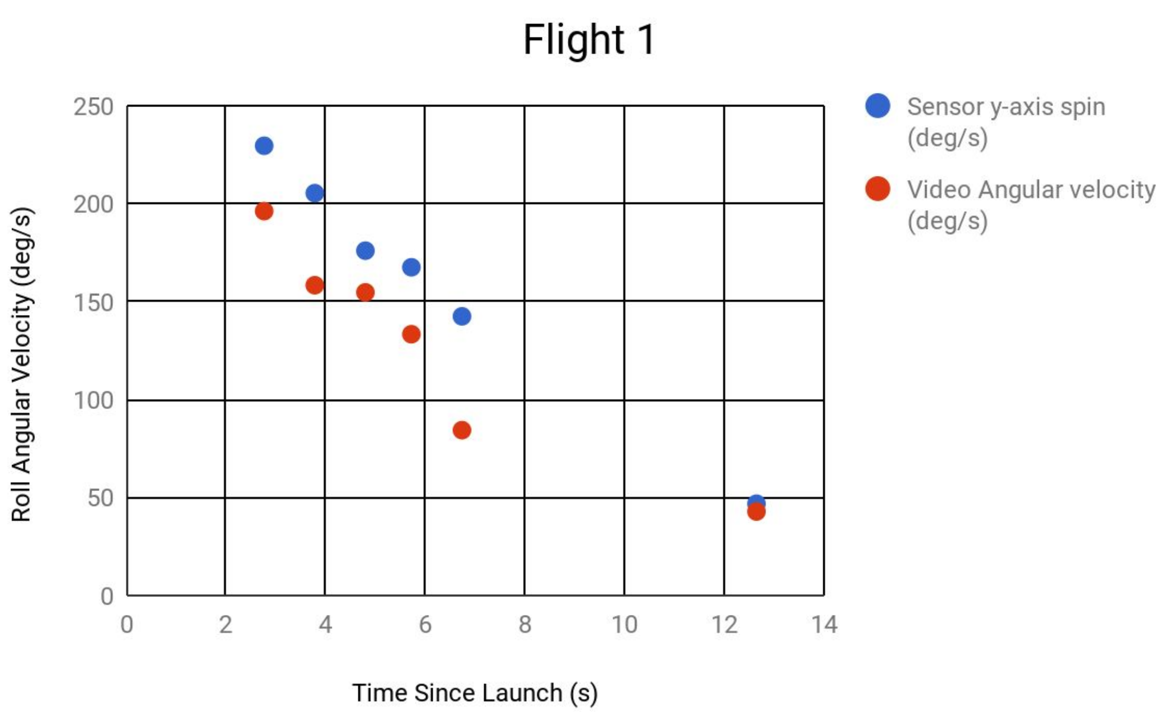

Figure 1. — Flight One Sensor Data and Calculated Angular Velocity as a function of Time Since Launch.

In the time between 8 and 12 seconds, the program turned our flywheel one quarter turn, thus accounting for the lack of data. This is unusual in that it should have taken less than one second to complete the above spin as opposed to the 4 seconds indicated by the lack of data. Checking our program indicates an incorrect value for motor speed, leftover from testing, was used in the flight, accounting for this higher than expected delay.

From this data we are able to see a number of shortcomings in our current system.

1. Our program did not sense launch until 2.7675 seconds after the Raven3 we had on board sensed launch, thus leading to a longer delay before the active control program started.
2. By extrapolating a trend line on the data both including and not including the last data point (the point after we've attempted correction) we see that there is no noticeable change from our program spinning the flywheel.

These are not unexpected shortcomings, as mentioned earlier, but it is important to note that the data matches with our pre-flight expectations.

Figure 2. —LEDs in Launched Sensed Mode (left) and Clockwise Rotation Sensed Mode (right). On the left you see both LEDs solid whereas on the right, the right LED is solid and the left is off. The latter was our signal that the rocket was rolling clockwise and our program was attempting to roll counterclockwise to stabilize.

Figure 3. —LEDs in Recovery Mode. Left shows solid for both LEDs and right shows off for both. The video shows the LEDs flashing on/off at a rate of 0.5 seconds, as per competition guidelines.

Flight 2

Again, as mentioned above, we were unable to attempt the orientation portion of the challenge. Due to limitations already discussed, no attempt was even made to spin our flywheel for the second flight. Thus the following data is not terribly enlightening, other to confirm what Flight 1's data seemed to confirm.

On the second test flight, our program sensed launch 2.28 seconds after the Raven3 sensed launch. Without attempting to spin the flywheel, we have more consistent data at intervals of ~1 second throughout the flight, with which we can see the natural decay of roll velocity as the flight continues as shown on Figure X. The LED profiles matched that of Flight 1 and are evident in the video.

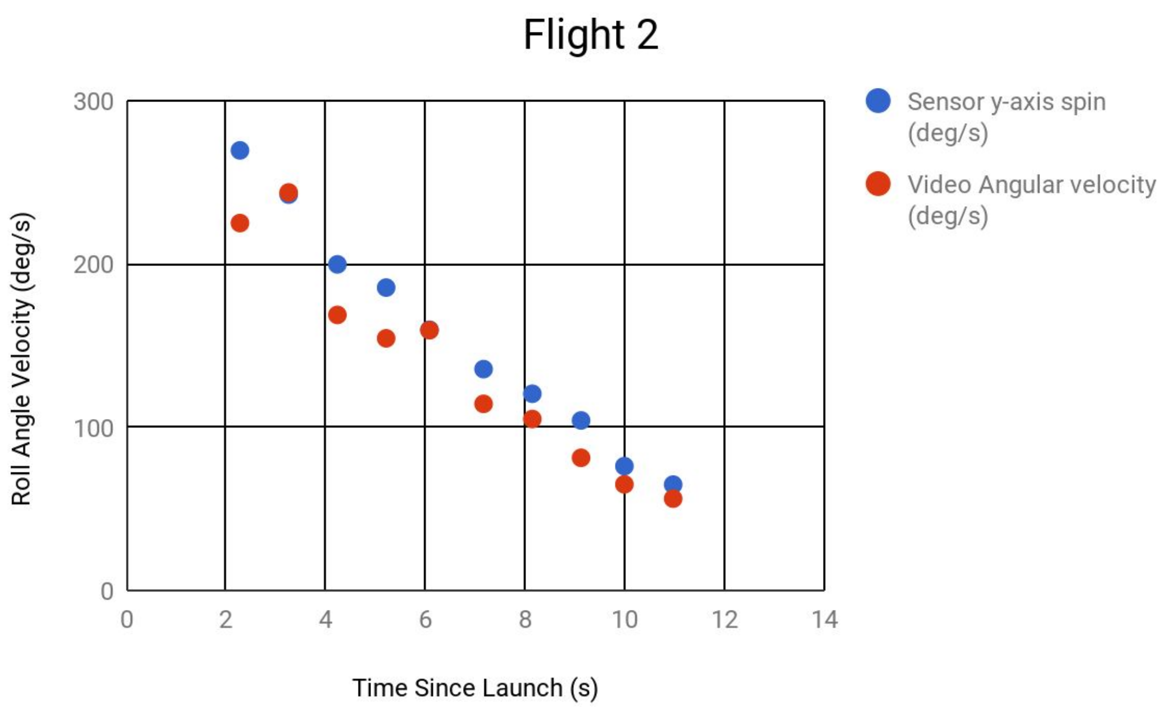

Figure 4. — Flight Two Sensor Data and Calculated Angular Velocity as a function of Time Since Launch.

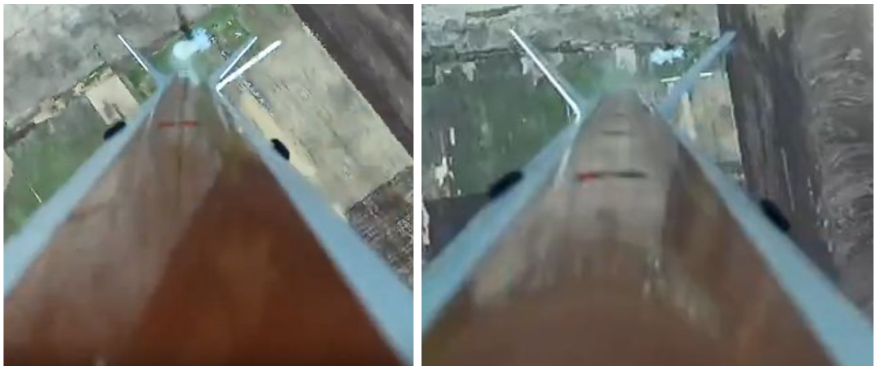

Figure 5. —LEDs in Launched Sensed Mode (left) and Turn Counter-Clockwise Mode (right). On the left you see both LEDs solid whereas on the right, the left LED is solid and the right is off. The latter was our signal that the rocket should be attempting a counter-clockwise turn.

Figure 6. —LEDs in Recovery Mode. Left shows solid for both LEDs and right shows off for both. The video shows the LEDs flashing on/off at a rate of 0.5 seconds, as per competition guidelines. As evident by the left-most image, the program sensed apogee before the parachute had even finished deploying and immediately went into recovery mode.

Video of the first competition flight can be found here (at https://drive.google.com/a/macalester.edu/file/d/1sUrhWvqMh-0tw0xsFP69gO1GRLfbguQG/view?usp=sharing).

Video of the second competition flight can be found here (at https://drive.google.com/a/macalester.edu/file/d/1oKrSANyvWflplpWe0g8B7pB9eRC0MR-2/view?usp=sharing).

Discussion of Flight Results

Rocket Operation Assessment

- Flight Anomalies Analysis

  Our first flight had no anomalies. Observers of our second flight questioned whether our roll program initiated early (i.e. well before burnout) as we observed the rocket seem to roll in an unusual fashion within the first 2 seconds of launch. This is evident in the first seconds of the video as well.

  As we have explained, it could not possibly be our program and so we are left to try and explain it in another way. A brief review of the literature surrounding roll torques on rockets indicates that gas dynamics of the solid rocket motor may be at play here causing potentially erratic torques during motor burn.

  As we cannot explain the observed behavior using our roll system (it was not engaged as evident by the data points being only 1 second apart and, more fundamentally, because we did not include a program in which it could have been engaged) or external aerodynamic imperfections (had we seen those, the anomaly would have maintained throughout flight instead of fading rapidly after launch) we believe this to be the most plausible explanation. Further evidence for this exists in that the behavior observed did not continue past motor burnout.

- Propulsion System Assessment

  Our propulsion was a J420R motor with a listed burn time of 1.54 seconds. This was listed as having a maximum thrust of 563.5 Newtons which, when adjusted for the mass of our rocket, would lead us to expect a maximum acceleration of 17.14g. On our first flight we recorded a positive acceleration (motor burn) for approximately 1.49 seconds. We also recorded a maximum acceleration of 23.41g, significantly higher than we were expecting. However, the acceleration curve drops off faster than the expected acceleration curve leaving us with a total impulse similar to the expected value of 658 Newton-seconds.

  Beyond these discrepancies, the physical motor was assembled adequately, following the AeroTech directions both times. As performance was as expected, we saw no reason to thoroughly investigate the motor casings upon recovery, opting instead for more time spent on thorough cleaning before the second launch.

- Flight Trajectory Assessment

  The coast phase of the rocket matches well with our simulations and show standard characteristics of a rocket in coast phase. The higher predicted apogee and maximum velocity can be partially explained by mass discrepancies from the simulation to the actual flight. There was ~ 150 grams of "extra" mass in the launch vehicle than in the simulation. Additionally, the external camera mount was not accounted for when predicting drag forces on the rocket using OpenRocket and as such, would have inhibited the maximum height and velocity

- (In-flight) Recovery System Assessment

  Our recovery system consisted of a parachute released at apogee protected by a kevlar flame protector. This system functioned perfectly as intended on both flights. However, on the first flight the parachute protector was not attached to anything inside the rocket and so flew away at stage separation. This is evident in the video of the first flight. This was rectified on the second flight by attaching a new protector to the quicklink that attached the parachute to the shock cord.

- Ground Recovery Assessment

  I'm not sure we can include the first launch in "ground" recovery as we landed in a tree. Two of our team members climbed the tree and used dead branches retrieved from the ground to maneuver the rocket to the ground. Because of our quicklink recovery and the exact circumstances under which the rocket landed, we were able to detach the parachute before maneuvering the rocket body to ensure the parachute did not get torn in the branches. This process took ~30 minutes after which time our camera had run out of battery. However, the camera splits video files every 3 minutes and writes to the SD card so we were still able to recover footage from the first launch. The flight computer was powered by batteries capable of powering it for 3 hours of constant use and so was still on when recovered.

  The second launch was recovered successfully in the dirt field to the south of the launch pole. Recovery procedures dictated that we check the camera, were able to determine via the embedded LEDs that it was still recording, stop the recording, power down the camera and continue with recovery. While on landing site, we also powered off the Raven3 via the screw switched used to arm it. The rest of our recovery assessment, after a preliminary visual inspection of the airframes and nosecone, was saved for our prep station.

- Pre- & Post-Launch Procedure Assessment

  We discovered that our Pre-Launch Procedure did not explicitly list a step for starting the competition program once on the pad. This was an obvious enough oversight that it was never missed when we were actually on the pad. Beyond this, the procedures we put in place allowed us to work efficiently to prepare our rocket in well under an hour with the 4 team members able to attend launch.

  Our Post-Launch Procedures allowed us to recover and submit data efficiently to the judges and also for our own review within minutes of bringing back our rocket to our ground station.

Actual versus Predicted Performance

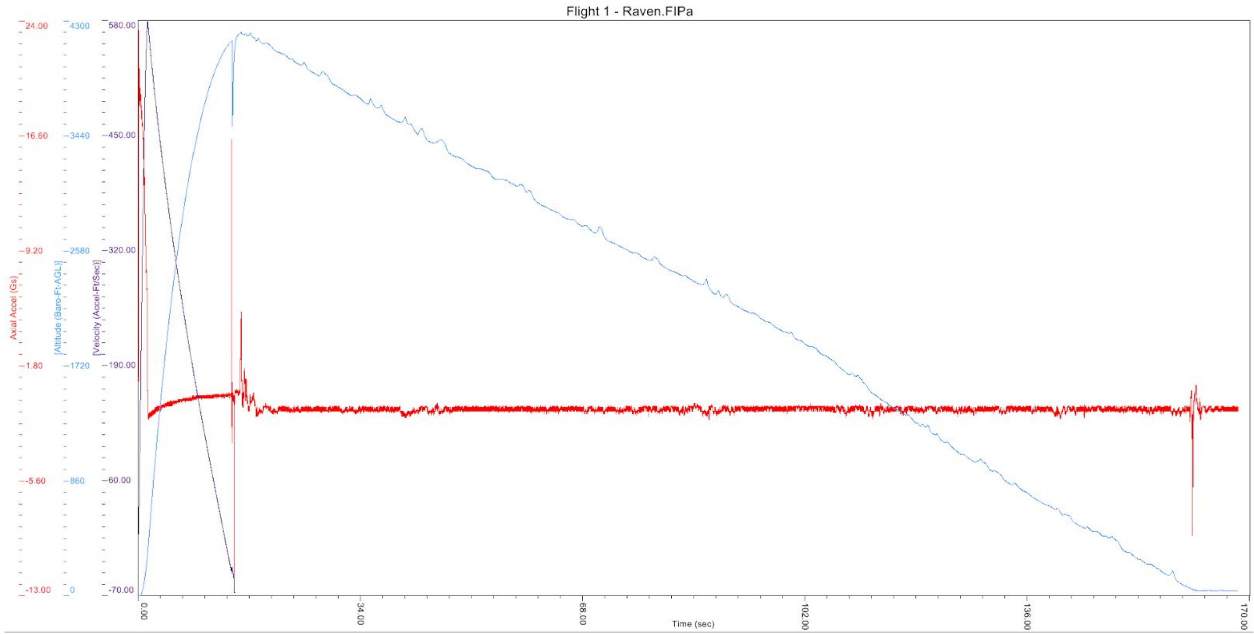

Figure 7. — Flight One data recorded with Raven3 Altimeter. In red is Axial G forces, blue is altitude, and purple is velocity all as a function of time since launch.

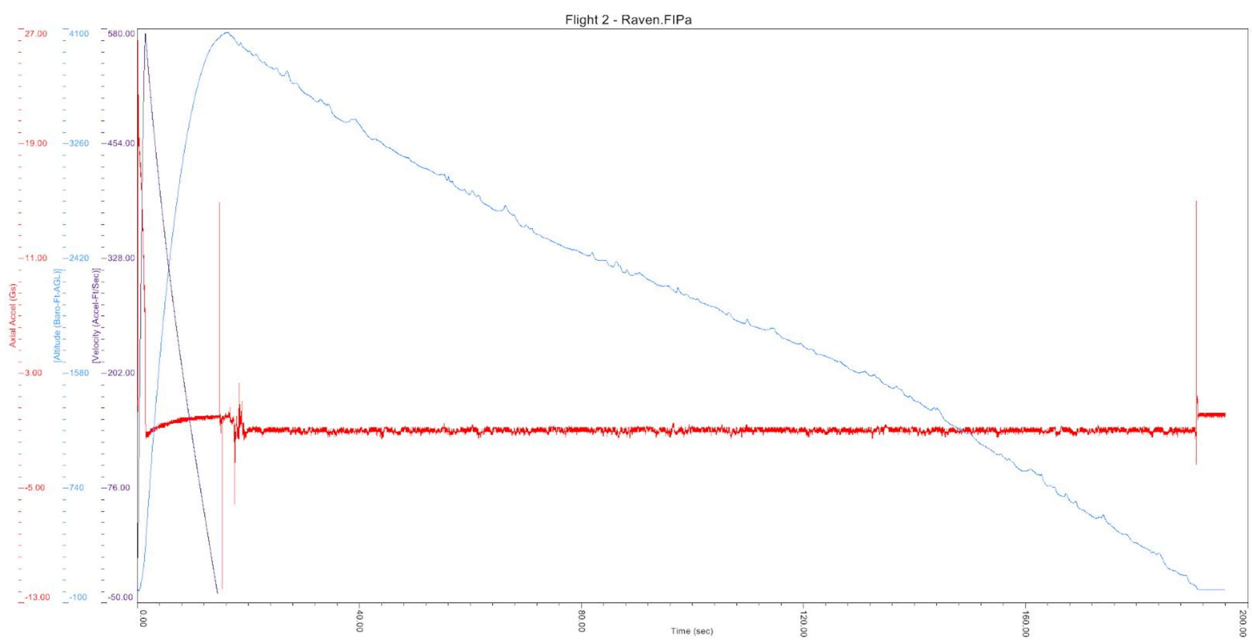

Figure 8. — Flight two data recorded with Raven3 Altimeter. In red is axial G forces, blue is altitude, and purple is velocity all as a function of time since launch.

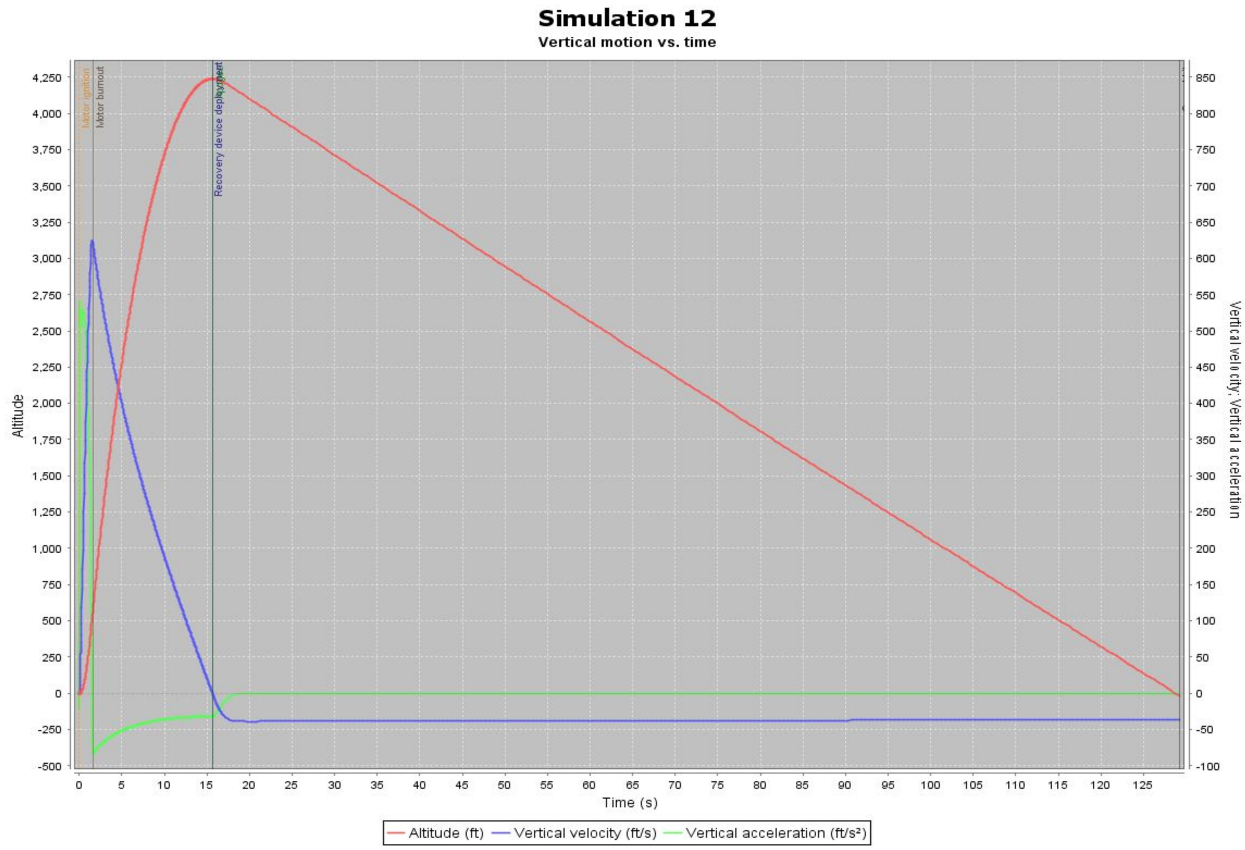

Figure 9. — Simulated flight data using OpenRocket. This simulation is 150 grams lighter than the rocket we flew. In green is axial G-forces, red is altitude and blue is velocity all as a function of time since launch.

- Peak Altitude Comparison to Expectations

  Discussed already under Flight Trajectory of the previous section, our peak altitude was under that of our predictions. We believe this to be due to 3 major factors:

  1. Additional Mass of 150 grams from simulation
  2. Higher Drag Coefficient than simulated due to camera mount, rail guid, and series of 10 plastic rivets
  3. OpenRocket known faults
     a. As presented by one of the other teams during oral presentations, OpenRocket is known to overestimate peak altitudes by as much as 10% as compared to actual values.

- Peak Velocity and Peak Acceleration Comparison to Expectations (10 pts)

  Our peak velocity and peak acceleration were both significantly different than simulated. We believe the peak velocity to discrepancy (–50 feet per second) to be due to many of the same factors that impacted the altitude discrepancy. Additionally, a shorter acceleration curve than expected potentially also impacted this.

Peak acceleration was measured for the first flight at ~6gs higher than expected and ~9gs higher than expected for the second flight. We explain this by variability in the motors. Both motors burned faster than the listed 1.54 seconds (or 1.6 seconds depending on which source you use) with the first motor burning in 1.49 seconds and the second in 1.52 seconds and yet delivered comparable maximum heights to those we expected. This leads us to believe the motor grains delivered the same amount of total impulse as listed but on a faster time scale leading to higher than expected peak accelerations.

- Recovery System Performance and Descent Velocity Comparison to Expectations

  Our recovery system deployed slightly ahead of apogee, as expected because the motor delay grain was ~0.2 seconds too short based on our simulations. This was the maximum motor delay grain and so we were unable to change this.

  Unfortunately, the Raven3 does not record descent velocity and the AltimeterTwo checked out from the judges was returned without retrieving this datum.