University of Illinois at Urbana-Champaign

NASA Space Grant Midwest High-Power Rocketry Competition 2016

Illinois Space Society

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Executive Summary

On May 16, 2016, the Illinois Space Society from the University of Illinois Urbana-Champaign participated in the NASA Space Grant Midwest High-Power Rocketry Competition. The goal was to successfully design, construct, and launch a high-powered rocket containing an active drag system that allows for the manipulation of the vehicle's apogee. The following report presents an analysis of the performance of the team's rocket in competition. Despite a few complications, the travel team, consisting of three freshmen and one sophomore, are grateful for the experience of not only the competition launch, but the entire process.

Rocket Operation Assessment

Operation	Rocket
Launch	Pass
Parachute Deployment	Pass
Recovery	Pass
Flyable Condition	Pass
Utilization of Drag System	Fail
Performance	
First Flight	3636 ft
Second Flight	3852 ft
Third Flight	4030 ft

Table 1. Flight Characteristics.

Flight Anomalies Analysis

Throughout the day, two anomalies noticeably affected, but were not catastrophic to, the rocket’s performance. The first of these anomalies occurred during the first launch. As the rocket left the guide pole, its path skewed by about 30 degrees, and shot into the sky diagonally. The vehicle’s fins were able to stabilize the rocket and straighten the flight path about 3 s into the flight. After a structural examination, the airframe was deemed not the cause of the flight behavior. Therefore, the consensus is that the pole orientation itself deviated slightly from the vertical axis, causing the slight tilt. The team attributes a slightly lower than expected first launch apogee to this anomaly as well.

The second complication in the rocket’s performance occurred during the third launch. After a pristine burn straight up into the sky, the announcer called that an event had been spotted. The main parachute had fully deployed at apogee. At a height of 4030 ft, the rocket could have possibly drifted for miles. By virtue of providence, the winds were calm and the sky was clear - the team only had to chase the rocket a few field lengths. After inspecting the Chute Release System and shock cord, the conclusion is that the Chute Release simply had not held the parachute package tightly enough, so that it slipped free upon rocket separation. No major negative consequences resulted from the parachute’s early deployment, although it resulted in quite a lengthy chase.

Propulsion System Assessment

The propulsion system using the Cesaroni J449 went as planned. At motor burnout, the rocket reached an altitude of 1192 ft, which is slightly lower than the simulations. The maximum acceleration during burn was 330 ft/s^2 and the maximum velocity was 750 ft/s. A black powder ejection charge was used for the separation of the rocket at apogee, as determined by the Stratologger, with the motor ejection charge at 15 s as a backup.

Flight Path Assessment

In terms of flight path, the third launch was by far the most successful. As mentioned above, the first launch exited the launch rail at an angle of about 30 degrees from the vertical, which likely greatly lessened distance off the rocket's apogee without deployment of the active drag system. The rocket was able to coast straight up, but the initial skewed launch angle nevertheless took a toll on the maximum altitude reached. After the first launch, however, things straightened out. The second burn resulted in a clean release from the rail, followed by a straight burn, and a clean arc at apogee. The third launch, however, was so straight that the vehicle did not even arc over at apogee, it merely separated and fell right back down into its own smoke trail, only drifting due to the released parachute. It is also worth mentioning that as the day progressed, weather conditions improved. The team believes this may have contributed to the rocket's consistently improving flight path.

Recovery System Analysis

During all launches, the rocket was recovered safely and in flyable condition. The separation of the rocket was by black powder charge and occurred at apogee, with the motor ejection charge as a backup. The engagement of the Jolly Logic Chute Release occurred at an altitude of 600 ft for the first two launches. During the last launch, the main parachute had fully deployed at apogee due to the Chute Release slipping free upon rocket separation. No major negative consequences resulted from the parachute's early deployment, although it resulted in quite a lengthy chase.

Rocket Location and Ground Recovery Analysis

Recovery of the rocket went extremely smoothly. This was no doubt aided by the fact that the event itself was held on a sod farm, making it very easy to spot the rocket upon landing. Due to the delayed release of the chute, the first two launches dropped on open turf only a few hundred feet away from the launch location. Rationalizing that the radio transmitter was interfering with the drag system's electronics, the team decided to fly without it during the last launch. Of course, this was the launch where the main parachute deployed at apogee. Thankfully, with a clear sky and a calm wind, the rocket only drifted about a quarter mile, and the team was able to successfully recover it without a problem.

Active Drag System Assessment

Preparation of the avionics that controlled the active drag system proved most difficult during the course of the day. The team ran into difficulties making the avionics board fit into the front end of the rocket. The team members had to careful not to antagonize the sensitive avionics; this proved to be a challenge under the pressure of time. Shortly after retrieval, the AltimeterTwo revealed that the rocket reached an even higher altitude of 3852 ft on the second launch. Considering that this launch was to test the active drag system, this result was not ideal. It may have come about the significant decrease in wind as well as the rocket not being angled on the launch rails during its departure. The on-board camera (whose footage was not saved by competition heads), however, seemed to capture a glint of red and blue, suggesting the deployment of the drag wedges on our rocket during this flight. The team was quite unsure of whether our drag system indeed worked or not, especially since one could not properly compare it to our first launch as it was not perpendicular to the ground during launch that time.

With an altered code for the Arduino, which removed the fail-safe determined by time, the team decided to fly a third time. The radio transmitter was also removed to avoid as much electrical noise to the accelerometer as possible and the camera was remounted to ensure it captured more useful footage of the wedges. Still, the altitude climbed to 4030 ft, suggesting that the drag system did not deploy.

If one considered the third flight to be the initial apogee, and the second flight to have deployment of the active drag system, then it is possible that originally the drag system worked to shave off 178 ft. This is only speculation, however; footage would have been the key to proving otherwise, and the camera was unfortunately lost mid-flight.

Actual vs Predicted Performance

Using OpenRocket's simulations, the calculated velocity off the pad was 62.99 ft/s, which is fairly above the average off-pad velocity for a vehicle of this size and weight. Additionally, for any flight to be successful, the vehicle's maximum velocity also factors into the performance of the vehicle. OpenRocket predicted the vehicle to have a deployment velocity of 61.8 ft/s. The vehicle's maximum velocity was also simulated at 850 ft/s by OpenRocket, approximately Mach 0.76, and at 800 ft/s by the MATLAB code. The velocity curves, shown in Figure , match up nicely in both simulations, suggesting a high degree of accuracy in this estimate.

During the competition flights, the deployment velocity of the rocket ranged from 66.59 ft/s to 71.79 ft/s, which was well within the range of the recommended deployment velocity. It was a little faster than what the team had originally calculated but within the realm of possibility. The rocket, save for the first launch, launched perfectly straight up, indicating on the quality of the rail nuts that were assembled. The maximum velocity, as indicated by the Stratologger, was marked a little below both estimates at 766.72 ft/s.

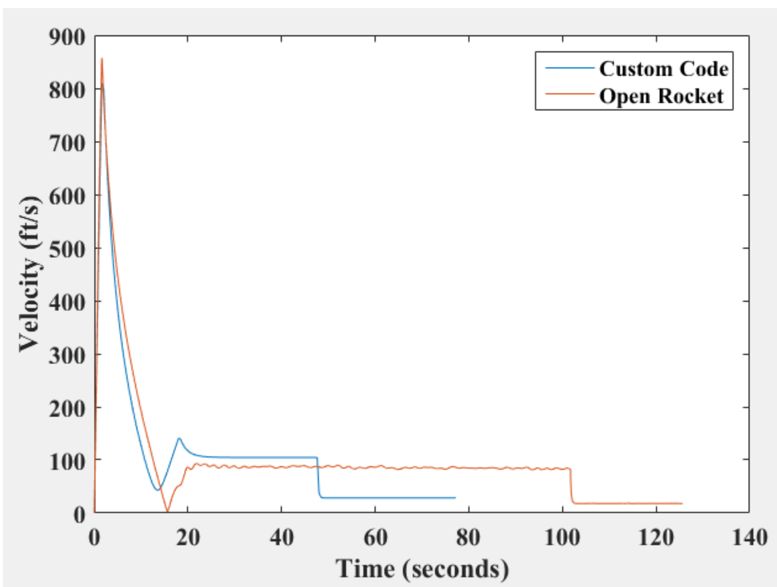

Figure 1. Predicted total velocity without drag system from both simulations.

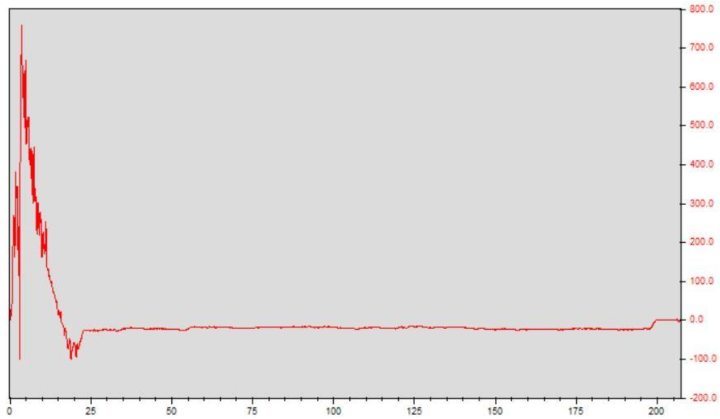

Figure 2. Total velocity without drag system.

A comparison the simulated apogees while not using the active drag system is shown below in Figure 3. The early stages of flight are nearly identical between the simulations and scales with respect to the apogee. The OpenRocket simulation predicts the vehicle will be reaching an apogee of 4900 ft while the custom code predicts apogee at 4000 ft. This is the absolute maximum apogee this vehicle will achieve since, as stated previously, this simulation assumes that the flaps will not be deployed during launch.

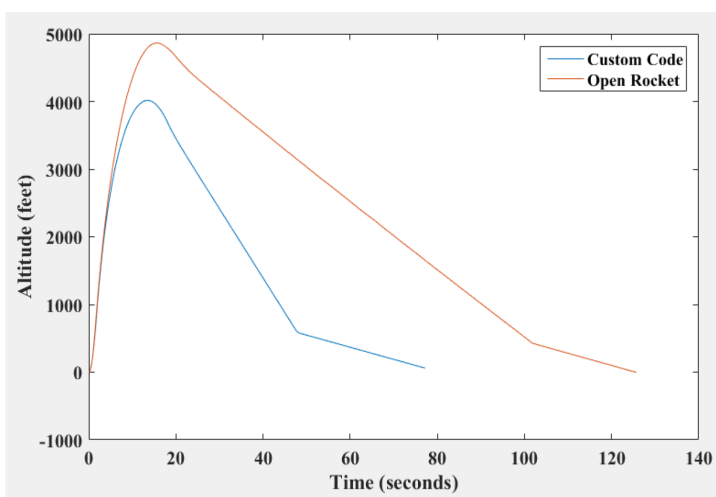

Figure 11. Predicted altitude without drag system as a function of time from both simulations.

During the competition flights, the maximum apogee achieved was 3636 ft (Flight 1) and 4030 ft (Flight 3). The loss of altitude during Flight 1 is attributed to the slight tilt of the launch rod and a slight wind; the rocket flew much straighter and in favorable weather conditions during Flight 3. The latter is closer to the custom code's estimate of initial altitude, suggesting the failure of the drag system was planned but also a better indication of the rocket's true initial apogee.

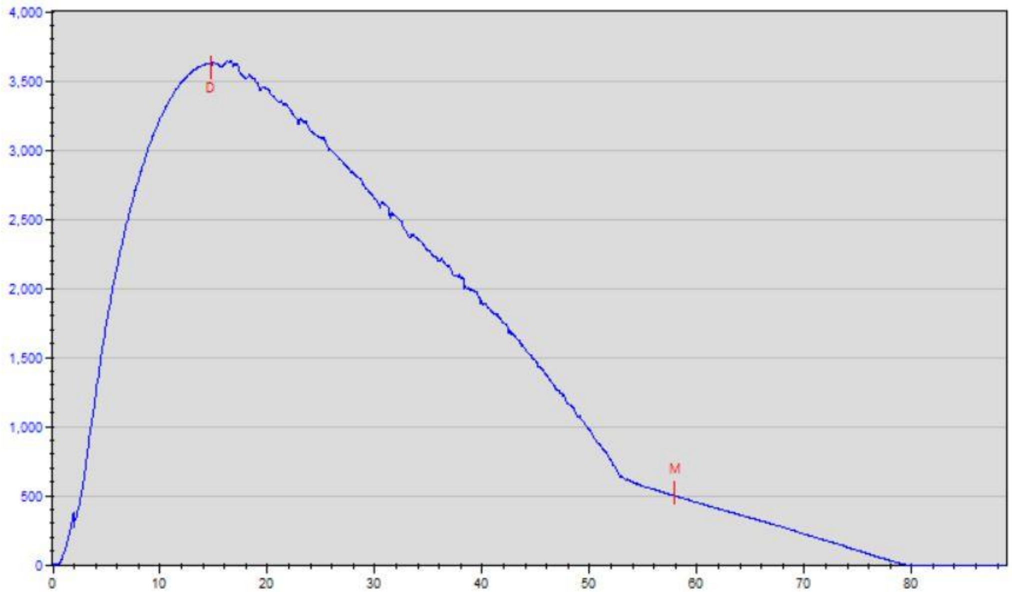

Figure 3. Flight 1 altitude over time.

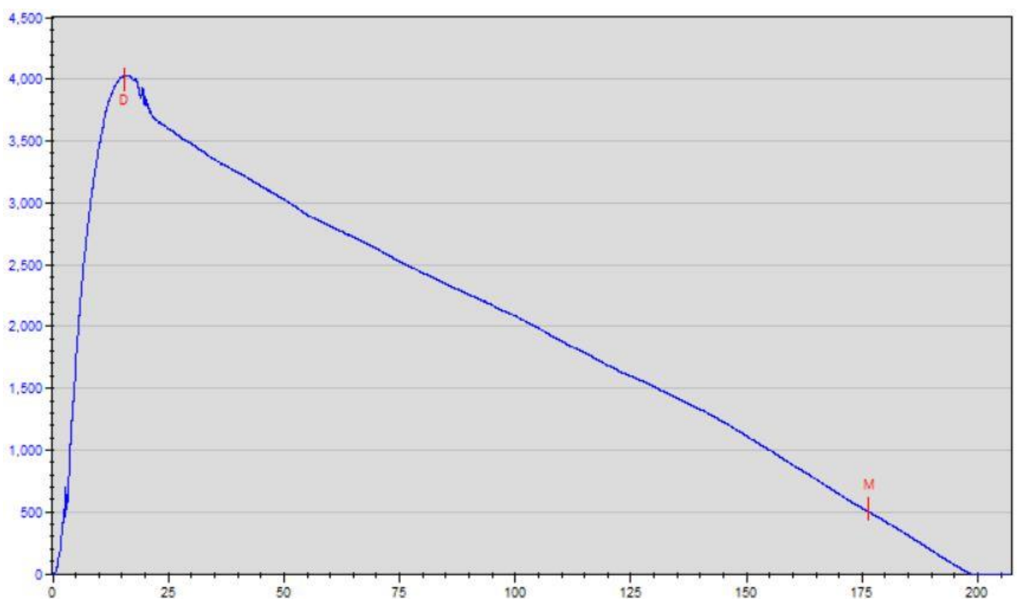

Figure 4. Flight 3 altitude over time.

The MATLAB code is also used to estimate the effects of the active drag system. With the system engaged, the rocket reaches an apogee of 3250 ft – this is 18.75% less than without the drag system. During Flight 2 (in which the drag system was supposedly engaged), the maximum apogee was 3852 ft. If considering Flight 3's altitude to be the initial height, then there was decrease in apogee by 4.42%.

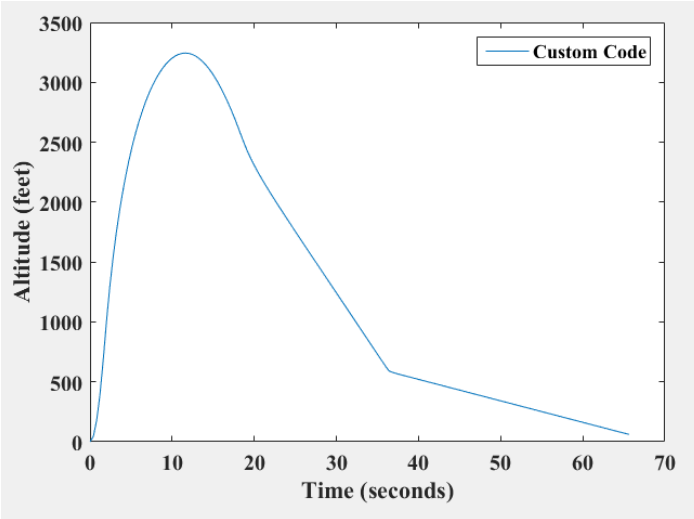

Figure 5. Predicted altitude as a function of time with the drag system engaged.

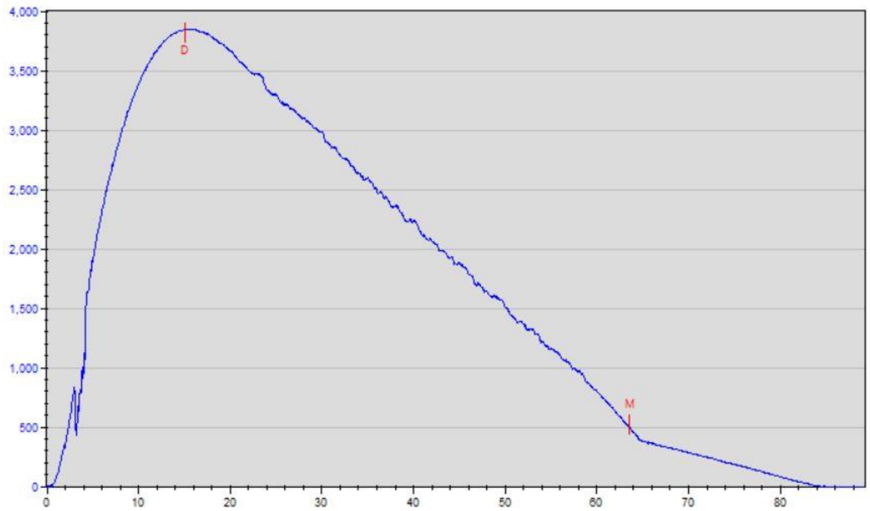

Figure 6. Altitude as a function of time with the drag system engaged (Flight 2).

Pre- and Post- Launch Procedures

Pre-Launch Procedure (First Flight)

Temperature: ________________
Relative Humidity: ____________
Wind Speed & Direction: _______

- ☐ Inspect and fold parachute
- ☐ Inspect all shock cord connection points
- ☐ Set chute release
    - Pre-determined parachute deployment altitude: _____________
- ☐ Install shock cord and parachute into aft tube
- ☐ Inspect all battery voltages
    - Altimeter Two: _____________
    - Stratologger: ______________
    - Arduino: __________________
- ☐ Inspect all widsring connections in electronics bay
    - pwm=6
    - dir=5
- ☐ Ensure battery connected to motor drive is disconnected
- ☐ Arm Altimeter Two, will display ready
- ☐ Secure electronics board into upper payload section
- ☐ Secure breadboard with accelerometer using Velcro attachment
- ☐ Secure upper payload to active drag system by plastic rivets (cover with putty if loose)
- ☐ Ensure all active drag components are secured surely by tightening screws
- ☐ Record motor type and full mass
    - Type: __________
    - Mass: _________
- ☐ Install motor (Installation by CIA members)
- ☐ Secure aft tube to payload using shear pins (2)
- ☐ Ensure top rail guide is aligned with bottom rail guide
- ☐ Place rocket on launch rail
- ☐ Arm Stratologger altimeter
- ☐ Listen for correct beep sequence
    - 2 short beeps
    - Pause
    - 5 short beeps
    - Pause
    - 10 short beeps
    - Pause
    - 10 short beeps
    - Pause
    - Sequence of beeps and pauses (describing altitude of last flight)
        - ▪ Altitude: ___________
    - Sequence of beeps and pauses (describing voltage)
        - ▪ Voltage: ____________
    - Pause
    - Non-stop pulse of 3 beeps

- ◻ Visual inspection
- ◻ Photographs
  - o Rocket on pad
  - o With team
- ◻ Launch
- ◻ Maintain visual of rocket

Post-Flight Checklist (First Flight)

- ◻ Locate rocket
- ◻ Inspect rocket for damage
- ◻ Take picture of rocket
- ◻ Disarm altimeters
- ◻ Cover pilot hole
- ◻ Remove camera from rocket
- ◻ Turn off camera
- ◻ Disconnect battery from electronics
- ◻ Retrieve all flight data
- ◻ Record empty motor mass
  - o Mass: ___________
- ◻ Clean rocket

Pre-Launch Procedure (Second Flight)

Temperature: ___________________
Relative Humidity: ______________
Wind Speed & Direction: _________

- ◻ Inspect and fold parachute
- ◻ Inspect all shock cord connection points
- ◻ Set chute release
  - o Pre-determined parachute deployment altitude: ___________
- ◻ Install shock cord and parachute into aft tube
- ◻ Inspect all battery voltages
  - o Altimeter Two: ___________
  - o Stratologger: ____________
  - o Arduino: ________________
- ◻ Inspect all wiring connections in electronics bay
  - o pwm=6
  - o dir=5
- ◻ Secure connections on MD10c
- ◻ Secure connections on accelerometer
- ◻ Ensure breadboard is secured with accelerometer using Velcro attachment
- ◻ Ensure battery to motor drive is connected
- ◻ Arm Altimeter Two, will display ready
- ◻ Secure electronics board into upper payload
- ◻ Ensure all active drag components are secured surely by tightening screws
- ◻ Secure upper payload to active drag system by plastic rivets (cover with putty if loose)

- ☐ Record motor type and full mass
  - Type: _________
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- ☐ Ensure top rail guide is aligned with bottom rail guide
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- ☐ Arm Stratologger altimeter
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- ☐ Visual inspection
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  - Rocket on pad
  - With team
- ☐ Launch
- ☐ Maintain visual of rocket

Post-Flight Checklist (Second Flight)

- ☐ Locate rocket
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