University of Nebraska-Lincoln

2017-2018 Midwest High Power Rocketry Competition

Husker Rocketry Post Flight Performance Report

Team Leads:

Dillon Margritz, dillondmargritz@gmail.com, (308) 325-8466
Conner Vokoun, vokounc@gmail.com, (402) 419-3921
Brandon Warren, bwarren109@gmail.com, (402) 525-3707

Team Members:
Quinn Brandt, Joseph Broadway, Eric Burbach, Nathan Jensen, Grant King, Bricen Margritz, Nathan Mann, Elizabeth Spaulding, Cameron Svoboda, Kenneth Thomason, Stephanie Vavra, and Emily Welchans

Team Faculty Adviser:
Karen Stelling, kstelling2@unl.edu, (402) 472-5253
Department of Mechanical and Materials Engineering, UNL

Team Mentor:
Thomas Kernes, tkernes@buckwestern.com

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1 Rocket Operation Assessment

1.1 Flight Characteristics

The flight characteristics of the rocket ACROBAT are found in Table 1. ACROBAT was one of the larger rockets at the competition and one of the only to use an internal roll control mechanism. A Cesaroni J760 was used due to its small burn time which maximized coast time.

Table 1: Flight Characteristics

Flight	Mass	Motor	Apogee	Max. Velocity	Max. Acceleration	Time to Apogee
1	13.7 lb	Cesaroni J760	4124 ft	728.36 ft/s	478.32 ft/s^2	16.0 s
2	”	”	4333 ft	638.72 ft/s	451.67 ft/s^2	16.4 s

1.2 Flight Anomalies Analysis

Only one major flight anomaly occurred in the two flights of the rocket. On the first flight, the rocket was slightly unstable immediately after leaving the launch rail. The rocket swung back and forth a few times before becoming stable. This was a new occurrence from the test launch and wasn't repeated in the second launch. It is difficult to tell what caused this instability. A few factors such as wind, launch pad, and assembly inconsistencies could have caused such an event.

1.3 Propulsion System Assessment

The chosen motor was a Cesaroni J760. The predicted average and maximum thrusts were 757.7N and 937.3N, respectively. Total impulse was projected to be 1265.7Ns. The motor's predicted burn time was 1.7s. The burn time was measured to be 1.95s on flight 1 and 2.00s on flight 2.

1.4 Flight Trajectory Assessment

On the first launch, our rocket was blown westward off the rail, leading to the substantial recovery distance. It was evident from the spiral smoke trail that roll was initially induced, but visual confirmation of control was not possible. The trajectory was otherwise stable.

For the second launch, the wind had shifted to the south and had a lessened influence on our flight and recovery. The smoke trail was identical to the previous flight, with the trajectory being equally stable but more vertical.

Figure 1: ACROBAT ascending during flight 2.

1.5 Recovery System Assessment

Based on the altitude data from the second flight, it seems that the primary electronic charge caused separation. Due to using a Jolly Logic Chute Release, we do not have visual confirmation of this, but the onboard audio recording only has one report. This further indicates that the primary charge succeeded, and the backup motor charge redundant.

The Jolly Logic Chute Release was set to deploy at 800 and 600 feet for the first and second flights, respectively. These altitudes were chosen to minimize drift.

The horizontal travel during flight 1 caused by a wind gust immediately off the launch rail led to a near-entanglement with a grove of trees to the west of the launch pad. The parachute narrowly avoided entanglement by chance; had the wind conditions been slightly different, the rocket would have likely landed in the trees. A lower deployment altitude was chosen for flight 2 to prevent drift into the trees.

1.6 Ground Recovery Assessment

Touchdown wasn't able to be verified visually due to the drifting into the grove of trees. A team of four went to recover the rocket. When recovered, the rocket appeared to be entirely intact with only superficial cosmetic damage sustained. After the rocket was brought to the prep area, the initial assessment of no major damage was confirmed.

Wind direction changed by the second launch, and the rocket drifted south from the launch pad. Touchdown was visually verified. A two-person deployment team was sent to recover the rocket. Upon recovery, only minor aesthetic damage was noted. A more thorough visual inspection after returning to Nebraska verified the lack of damage to any integral components of the rocket.

The flywheel mechanism was found to still be active on the ground at the time of recovery. Caution was used to disassemble the rocket in the field to de-energize the flywheel prior to its transportation back to post-flight check-in. Review of the code found that a command to stop the motor after descent was detected was not included in the final version of the software.

1.7 Pre- and Post-Launch Procedure Assessment

The pre-launch procedure was followed with only a few adjustments that needed to be made. A test rail was used to make sure the rocket would easily slide on the launch rail and clear the bolt heads. It was found that the upper button did not slide on the rail. A new button was installed which allowed the rocket to slide more easily on the test rail. The old button was probably overtightened which squeezed and deformed the plastic.

The AV bay electronics were also prepared during the pre-launch procedure. The ground station could not initialize the SD card, but due to the use of the serial communication, all data could be saved after the flight by copying the text from the monitor. Besides this, all systems successfully initialized with calibration being performed on the accelerometer and gyroscope systems. Radio telemetry was confirmed to be operational prior to final assembly, and the flywheel motor remained disarmed until the rocket was placed on the launch rail. The pre-flight programming discussed in the bonus section was conducted as expected, with no issues occurring.

Despite not having a paper copy of the post-flight procedure, the recovery team followed the procedure as closely as possible. Both flights were tracked visually, due to the weakness of the GPS tracking signal. The recovery team verified that the rocket was safe to recover, making sure to de-energize any electronic or moving parts. Data was collected from the ground station and onboard

Figure 2: ACROBAT on the launch rail.

SD card logging systems, as well as flight video where available. These files were submitted to the judges and saved for analysis.

It should be noted that in the process of analyzing data, it was discovered that the SD card containing onboard flight data from the first flight had become corrupt. It was retrieved from the judges for use in completing this report.

2 Actual VS Predicted Performance

2.1 Peak Altitude Comparison to Expectations

The predicted peak altitude for the flight of the rocket was 4425.85 ft. This prediction was obtained by performing an OpenRocket simulation while taking into account the predicted weather conditions of the day of launch including air temperature, atmospheric pressure, and wind speed and direction. In order to accurately simulate the conditions of the day of launch, International Standard Atmosphere data was used for the air temperature and atmospheric pressure, and a wind speed of 7 mph was assumed.

For the first flight, the apogee recorded by the Stratologger was 4124 ft above ground level. For the second flight, in which a chute release delay was used, the apogee recorded was 4333 ft. These

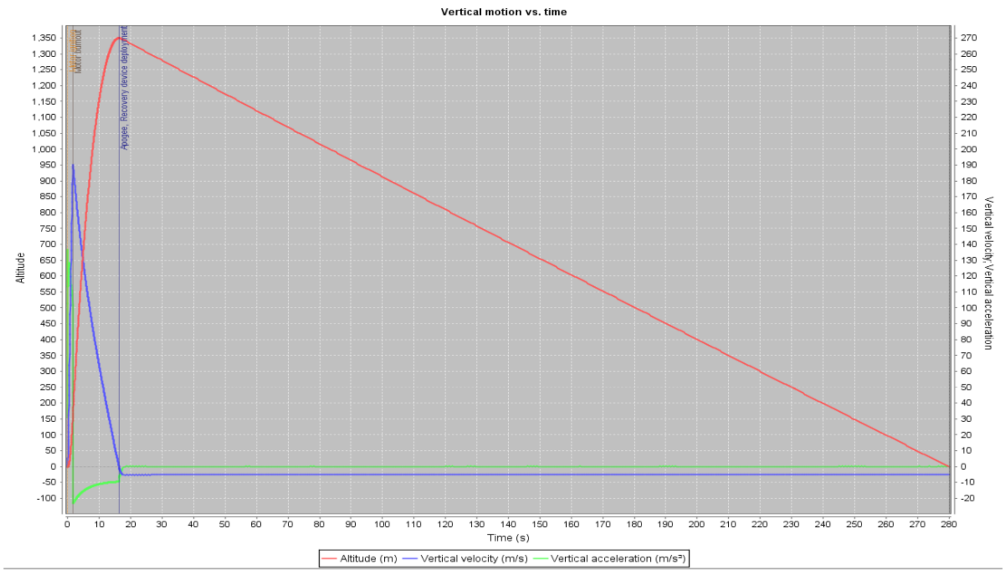

Figure 3: Simulation of rocket apogee, vertical velocity, and vertical acceleration on day of launch

were both less than the predicted value of 4425.85 ft, though the second one was somewhat within expected tolerances. The substantially lower value for the first flight can be explained by the instability experienced during the beginning of flight 1. The rocket stabilized, but the instability still had a noticeable impact on flight performance.

2.2 Peak Velocity and Peak Acceleration Comparison to Expectations

In the aforementioned simulation of the weather conditions of the day of launch (see the figure in the previous section for predicted flight data), the predicted maximum velocity was 623.36 ft/s, and the predicted maximum acceleration 446.19 ft/s^2. In the first flight, the measured peak velocity was 728.36 ft/s with a peak acceleration of 478.32 ft/s^2, and the second flight observed a peak velocity of 638.72 ft/s accompanied by a peak acceleration of 451.67 ft/s^2. The numbers of the first flight can once again be attributed to the instability during the first few seconds of the flight, causing additional nonlinear acceleration to be factored into the flight. The second flight was more in line with the predicted data, with the observed peak velocity being very close to the predicted velocity as well as the acceleration.

2.3 Recovery System Performance and Descent Velocity Comparison to Expectations

To avoid high-speed parachute deployment errors in Open Rocket, the simulation of the recovery system in flight did not account for the delayed parachute release mechanism, and instead simulated the parachute deploying just after the separation of the rocket at apogee. Because of this, the predicted drift distance of 3887 ft (1185 m) does not accurately depict the drifting the rocket experienced. The actual drift distance for flights 1 and 2 are 3823 ft (1165 m) and 1250 ft (381 m), respectively.

The predicted separation mode was for the electronic ejection charges to ignite at apogee. The actual separation mode, as shown by the footage from flight 2 as well as Figure 4 was through the predicted electric ejection charges. In Figure 4 the expected motor ejection charge ignition time is represented by the vertical orange line. Before the motor ejection charge, there is the presence of noisy altitude data that is consistent with the tumbling motion caused by a separation event. This indicates that the electronic charge caused separation in flight 1 because separation occurred before the motor charge would have ignited. In the footage from flight 2, only one charge can be heard going off during flight. It can be concluded that it was the first charge that went off, the electronic charge, that caused separation in flight 2.

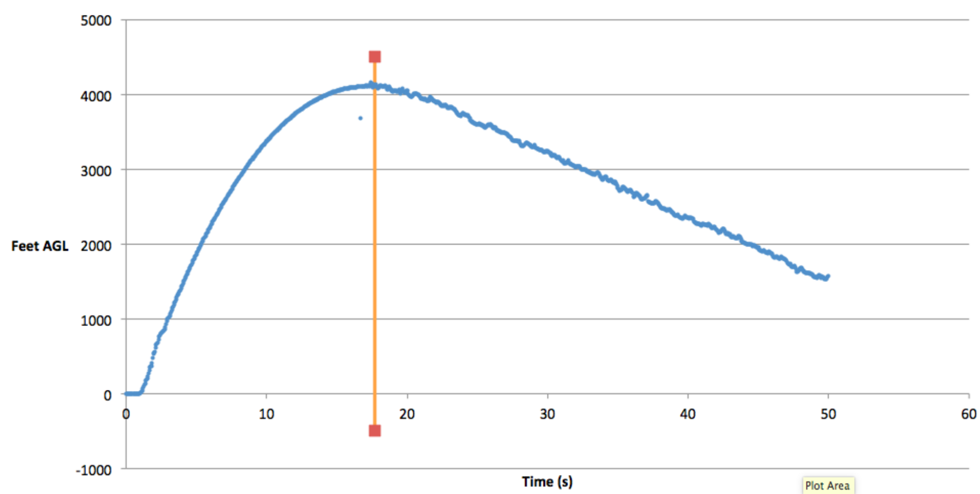

Figure 4: Stratologger altitude data for flight 2 with motor ejection charge marked by a vertical orange line.

The predicted and actual parachute release heights for flight 1 and flight 2 were 800 ft (244 m) and 650 ft (198 m), respectively, and the predicted and actual parachute release heights for flight 2 were 600 ft (183 m) and 380 ft (116 m), respectively. The difference between expected and actual parachute release heights is to be expected since it is common for the parachute to require 100-200 feet (30-61 m) after the parachute release has opened to fully deploy. Furthermore, differences between the Jolly Logic parachute release and the altimeter could also cause discrepancies between the recorded and actual release height.

Due to the simulation not accounting for the tumbling of the rocket, there was no predicted speed for the rocket between separation and parachute deployment. The recorded speed of the rocket during that period in flight 1 was 84.0 ft/s (26 m/s), and the recorded speed during that period in flight 2 was 85.0 ft/s (26 m/s). The predicted speed of the rocket after parachute release and during ground hit was 16.27 ft/s (5 m/s) and the actual speeds for flights 1 and 2 were 10.45 ft/s (3.2 m/s) and 16.06 ft/s (4.9 m/s), respectively. The difference between ground hit velocities in the two flights could be caused by a variance of wind speed and direction as well as a change in air density between the two flights.

3 Active Roll/Orientation System Data Collection and Analysis

3.1 Roll/Orientation Monitoring Data

Visual confirmation of roll angle was unable to be determined for either flight. During the first flight, the SD card became disconnected from its receptacle during assembly, and video of the flight was not recorded. The SD card was taped into the receptacle for the second flight to prevent dislodgement during assembly. A video was recorded during the second flight, however, the camera's brightness adjustment led to the video becoming washed out.

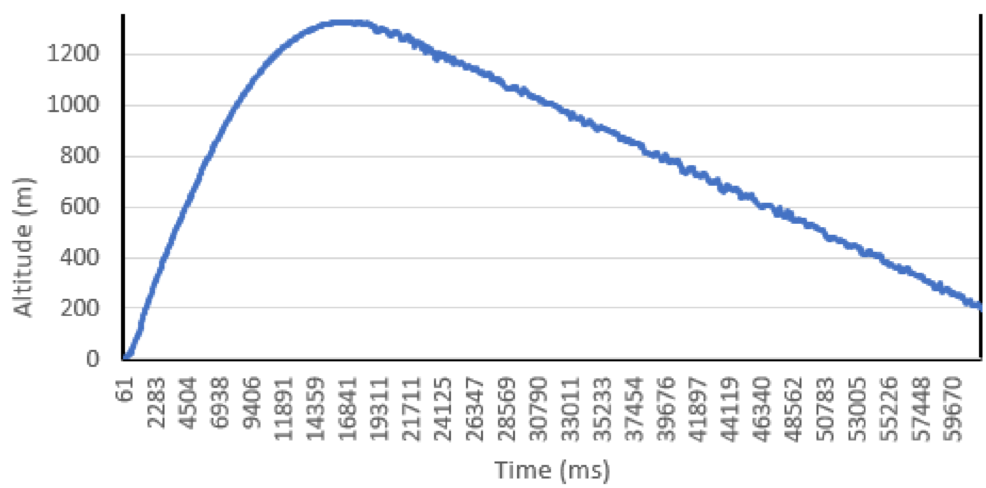

Figure 5: Altitude data collected from the non-commercial avionics.

Flight data collected from the non-commercial sensor package matches similarly to data collected by the Stratologger and Jolly Logic altimeters. Analysis of the second flight shows a maximum altitude of 4353 ft (1327 m), which is within 20 ft of the Stratologger data. The acceleration of the rocket is enough to pass the maximum value measurable by the sensor in its current configuration, so acceleration data from the avionics package is not useful for analysis. Roll orientation and angular velocity data collected have been used to measure the performance of the flywheel in a later section.

3.2 Flight Footage

https://youtu.be/87VPRhoDMLU

The camera used for collecting flight footage is mounted behind a curved polycarbonate window within the AV bay. Due to this mounting system, the camera focus can be severely affected, having a dramatic effect on video quality. The video from the second flight shows that the sunlight being refracted through the window is bright enough to severely limit what can be seen in the camera footage. However, the roll maneuver LEDs can be seen in the footage regardless of the sunlight through the window, suggesting that this placement and intensity are effective to show the roll of the rocket. Cross-referencing the camera footage with the onboard data shows that the respective LEDs are being lit during roll and heading hold maneuvers.

Figure 6: Camera View from flight 2

Figure 7: Camera View from flight 2 with parachute

3.3 Data Interpretation and Comparison to Expectations

Simulink models performed during assembly and testing suggested that the flywheel would have a settling time of 1.95 seconds, allowing for several roll maneuvers to be performed during ascent. During the first flight, the rocket would attempt to hold a set heading for the duration of the ascent. In our program, the heading that would be held is due north (360°). The rocket flight begins with a very high angular rate, with a maximum of 16 rad/s. This slows down after motor burnout and prior to the activation of the roll control mechanism. At five seconds after motor ignition, the flywheel is activated, slowing down the angular acceleration of the rocket, and holding the rocket at a heading of about 035°. While this is not exactly the heading programmed, the roll mechanism is capable of holding the rocket on a steady course during flight. The settling time is slower than expected.

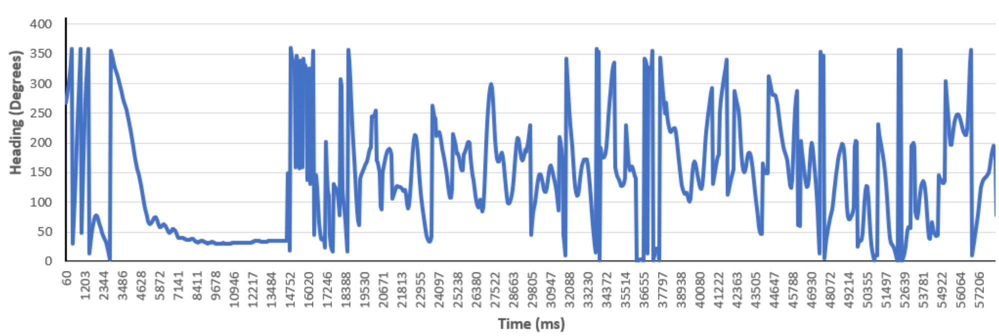

Figure 8: Heading data for flight 1. Note: the camera heading is offset from the sensor heading by 90 degrees. Therefore 360°indicates that the camera is pointing to 090°.

For the second flight, the rocket was programmed to roll to specific headings and hold them for a predetermined time period. As can be seen in the first 16 seconds of Figure 9, the rocket establishes a baseline roll rate of about 3 rad/s counterclockwise. The roll mechanism activates five seconds after motor ignition, three seconds after motor burnout. The flywheel spins up rapidly, changing

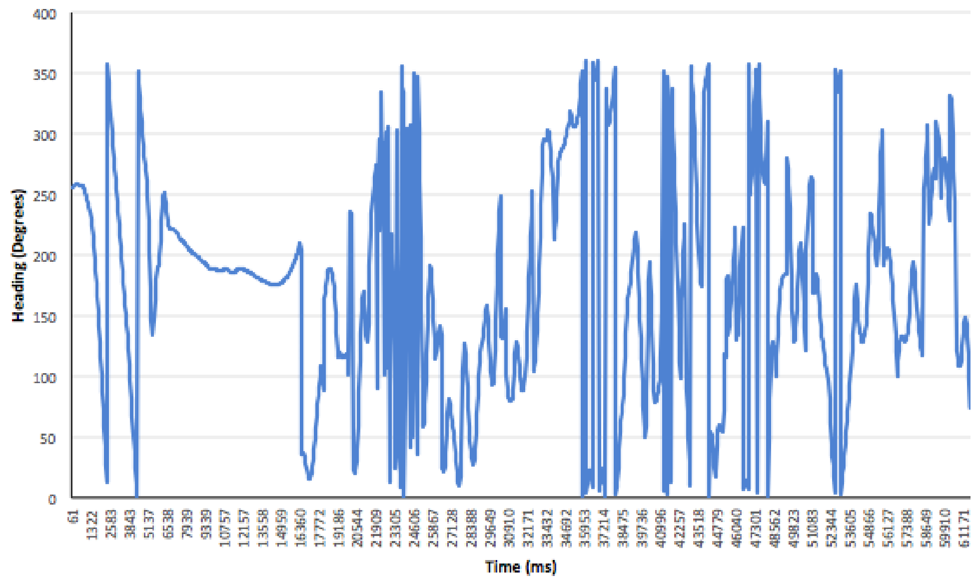

Figure 9: Heading data for flight 2. 360°indicates due North.

the roll rate to a maximum of 3 rad/s clockwise, the complete opposite of the initial roll rate. This brings the rocket to a complete stop in a period of about 1.3 seconds. This is where the simulation differs from the actual event, as it takes nearly six seconds to rotate to within 5 degrees of the target heading of 270°. This is much slower than expected and could be due to several factors. The first is that the flywheel is not as powerful as the simulation model suggests. A larger mass or a faster rotation would improve performance in this aspect. The other consideration is that the aerodynamic roll damping force is much greater than expected. In this case, the aerodynamic surfaces of the rocket are actually counteracting the roll force of the flywheel, requiring more force to overcome.

4 Bonus Challenge

4.1 Pre-Flight Programming

For the first bonus challenge, the roll control mechanism is programmed to await commands from the ground station. The program has no preset roll commands programmed. An initial transmission prepares the rocket to receive multiple commands that define the heading, direction, and holding time of each orientation. This logic performed exactly as expected for both the first and second flight. For the first flight, rather than programming several commands, a single roll command is programmed, which is repeated for the duration of the flight. On the second flight, the modified commands were uploaded to the rocket while sitting on the pad and activated prior to flight. The telemetry system sent confirmation that these commands were received.

4.2 In-Flight Telemetry and Logging

To complete the second part of the bonus challenge, an Arduino based monitoring and logging station was used to receive in-flight data from the Xbee telemetry system. This data was received at the same interval as the onboard data logging system, which is about 13Hz for the first flight, and 16Hz for the second flight. Some small optimizations were made to the data logging algorithm in-between the two flights. The data collected in this file includes flight time, altitude above sea level, heading, temperature, and pressure. A simple flight model can be produced from this data, but onboard logging data will be used to analyze roll maneuvers. The data collected via telemetry is formatted as shown:

```
NU, Launch Detected!
NU,0,61,256.25,3.37,32.84,993.71
NU,2,181,257.06,6.79,32.83,993.31
NU,3,241,257.75,9.01,32.83,993.05
NU,4,301,258.50,11.51,32.83,992.76
NU,5,361,258.88,14.94,32.84,992.35
NU,6,421,259.06,17.77,32.85,992.02
NU,7,482,258.69,22.52,32.84,991.46
NU,8,542,257.69,26.65,32.85,990.97
```

Figure 10: Ground Station Data Output

It is common knowledge that carbon fiber rocket construction is detrimental to radio signal transmission. This project is no different. External antennas were used to try to improve the signal strength to the ground station, but ground testing demonstrated that this improvement may not have been enough to mitigate the effects of the carbon fiber components. During the two competition flights, the signal was not strong enough to transmit data at a long enough range to be effective. Data was received for the first second of the flight, and for a small period of time during descent and recovery. The data that was received, however, matches exactly with the data stored in the onboard logfile, suggesting that the performance of the system under perfect conditions are more than adequate for the amount of data being transferred.

4.3 Possible Changes and Improvements

The strength of the telemetry signal is a major point of change in any future implementations of this system. One method of improving signal strength from the rocket is to use components that are not manufactured from carbon composites, such as fiberglass, Bluetube, etc. However, line-of-sight communication greatly improves the quality of the data transmission, so an additional improvement that can be made would be to use a larger ground antenna to improve the quality of the signal.

On the software side of the telemetry system, the programming logic used to send and receive telemetry data was not particularly efficient and would benefit from improved optimization and better programming techniques. Interrupt logic that would stop and start sensor collection to allow roll maneuvers and telemetry would improve the performance of the system. It also seems that the Arduino UNO-based ground station is not fast enough in parsing and analyzing data strings. An improved ground station with a faster microcontroller unit would improve the system, allowing faster data transfer speeds, while improving accuracy.