ISS Space Grant Team

Exocoetidae

Illinois Space Society

University of Illinois at Champaign-Urbana

May 9, 2018

Post Flight Report

Faculty Advisor: Diane Jeffers (dejeffer@illinois.edu, 217-898-5888)

Team Lead: Shivani Ganesh (ssg3@illinois.edu, 309-912-8457)

Team Mentors: Mark Joseph, Jonathon Sivier, Connor Latham

Team Members: Linyi Hou, Avery Moore, Jake Hawkins, Noah Henricks, Spencer Murdoch, Hunter Schoff, Matthew Zhang, Courtney Steele, Lydia Kurtz

Table of Contents

1 Rocket Operation Assessment

1.1 Flight 1: Minimizing Roll

1.1.1 Launch Phase

During the first attempt to mount the rocket onto the launch rail, the team noticed the rotary switch holes (which are further described in the Flight Readiness Report) did not correctly align with the rotary switches as intended. After removing the rocket and examining the issue - seen in Figure 1 - members found the avionics sled to have been positioned further down the length of conjoining threaded rod, which resulted in a change of the rotary switch locations. After readjusting the avionics bay, reassembling the rocket and testing the rotary switch holes again, the *Exocoetidae* was mounted once more on the rail and ready for launch.

Figure 1: Team Troubleshooting Prior to the First Flight

The launch phase fell accordingly with the OpenRocket simulations and the test launch. The motor burned for 3.50 seconds and initiated a straight flight with a velocity of 92.3 ft/s off the rail, as documented by ground footage. No malfunctions, as illustrated by the onboard camera video, occurred with the propulsion system either. Both can be seen in Figure 2.

Figure 2: Launching the *Exocoetidae* (Left), In-Flight Video (Right)

1.1.2 Coast Phase

The *Exocoetidae* continued along a straight flight path after motor burnout, resulting in a coast phase of 10.4 seconds. The rocket turned in a clockwise motion. Roll, however, slowed down significantly between then and apogee. This can be attributed to the intrinsic countering from the fins. Further explanation on the active roll control performance during this phase can be found in Section 3.1.1.

1.1.3 Descent and Ground Recovery Phase

The recovery protocol performed as anticipated. The drogue parachute deployed as a result of the primary ejection charge at an apogee of 3476 ft, resulting in a descent speed of 65.174 ft/s thereafter. Components remained attached during this portion of the fall.

Detailed in FRR, the coded main deployment heights were 600 ft AGL for the primary Stratologger and 500 ft AGL for the backup altimeter. The team has reason to believe the main chute deployed as a result of the backup ejection charge – therefore, at 500 ft AGL. Recovery of the rocket revealed that primary main ejection charge was not ignited, and subsequent examination of the Stratologger data showed that maximum current across the primary main charge was only 1A instead of the typical 4 or 5 amps. The rocket and shock cord system remained intact and reached the ground at a descent speed of 18.505 ft/s.

Figure 3: Rocket Post-Main Deployment during Flight 1

The rocket fell within the team's line of sight, so while the tracker was attached to the booster tube's length of shock cord, the team did not have to use the device to detect location. As seen in Figure 4, all rocket components were in good shape to be flown again. According to the launch procedures, as found in Section 1.4, the team checked for any unexploded black powder charges and found the main's primary to be active. More information regarding this anomaly can be found in Section 1.5. After listening for the appropriate beep sequences, members safely removed the charge and prepared the *Exocoetidae* for the subsequent flight.

Figure 4: Recovered Rocket Components (Left and Middle), Team Examining Condition (Right)

1.2 Flight 2: Implementing Set Directions for Roll

1.2.1 Launch Phase

Due to a structurally successful first launch, the team decided to pursue a second flight. The payload sub-team downloaded the in-flight video and Stratologger data to submit to the judges, while the structures sub-team assembled the rest of the rocket body and refolded the parachutes in preparation for launch. After the rocket was wired with the ejection charges and shear pins and screws were set in place, the team mounted the rocket on the rail for the second flight.

Figure 5: Mounting the Rocket for Flight 2 (Left), Initiating Flight 2 (Right)

In similar fashion to the first competition flight, the launch phase went smoothly. The motor burned for 3.53 seconds, and attained a velocity of 98.0 ft/s off the rail. As depicted in Figure 5, the rocket experienced a straight flight through the boost phase.

1.2.2 Coast Phase

The intent of this flight and its respective phase was to move to certain cardinal directions and hold said position for a certain period of time. According to the in-flight video, the *Exocoetidae* slowed down and attempted to reach a certain position due to the active roll control system. Beginning with a clockwise motion, the active roll system induced roll control in a counterclockwise direction after motor-burnout. Near apogee, the rocket was able to hold the position right before the drogue had deployed. All of these efforts were made during a coast time of 11.5 seconds. More information on the payload's effectivity can be found in 3.2.2.

1.2.3 Descent and Ground Recovery Phase

Upon completing the coast phase, the drogue parachute deployed at an apogee of 3232 ft, due to its primary ejection charge. This resulted in a drogue descent speed of 62.73 ft/s. The booster tube and coupler, upper airframe and nosecone unit stayed attached by shock cord.

As stated previously, the primary and backup deployment heights for the main parachute were 600 ft AGL and 500 ft AGL, respectively. Per the altimeter readings and the lack of unexploded ejection charges, the main parachute deployed around 600 ft AGL as a result of the primary ejection charge.

Figure 6: Ground Recovery After Flight 2

Once more, the rocket fell within the team's line of sight, so members did not utilize the tracker. The *Exocoetidae* landed in nearly the same location as it did during the first flight. As seen in Figure 6 above, the rocket did not experience any damage and correctly followed through the recovery timeline. After submitting the necessary information to the judges, the team disassembled and stored the rocket after a successful launch day.

1.3 Propulsion System Assessment

The team chose to use an Aerotech J415W-L motor based on predictions for the rocket's mass, which was calculated through the OpenRocket program. In order to hit an apogee of at least 3,000 feet, it was decided that this motor would provide enough thrust for a rocket of this size. The delay between burnout and apogee was 10.5 seconds in flight one and 11.5 seconds in flight two. The team chose not to use the delay drill to shorten the delay, as it was not necessary.

One of the members worked with the team's mentor to assemble the motor before the first flight, and did likewise between the two competition flights. In order to prevent any error with the motor during launch, both the team member and the mentor were careful to make sure that black powder residue was not found on any non-relevant parts during the motor assembly process. Additionally, the team's mentor helped clean out the motor casing thoroughly for its next use, leaving no trace of black powder or grain behind from the previous launch.

1.4 Pre- & Post-Launch Procedure Assessment

Between the Flight Readiness Report and the competition flights, a concrete set of procedures – as seen in the left of Figure 7 – was made to be followed on launch day. This list encompasses the pre-flight and post-flight directions for both competition launches.

Phase of Flight	Actual Task	Completion
	Pre-Flight 1	
1.1	Connect all electronic systems and assemble coupler tube	
1.2	Turn off electronic systems in preparation for charges	
1.3	Attach, fold, and pack drogue and main parachute	
1.4	Attach parachutes with quick links to shock cord	
1.5	Attach shock cord between booster tube to coupler	
1.6	Attach shock cord between coupler to upper airframe / nose cone	
1.7	Attach tracker to booster tube shock cord	
1.8	Place black powder charges on terminals	
1.9	Assemble rocket airframe	
1.10	Put in shear pins and coupler tube / upper airframe screws	
1.11	Run through last checks with team mentors	
1.12	Insert motor into lower airframe	
1.13	Set rocket on launch pad	
1.14	Turn on rotary switches	
1.15	Listen for appropriate altimeter settings and check tracker	
	Post-Flight 1	
2.1	Check for unexploded black powder charges	
2.2	Assess rocket for damage	
2.3	Remove motor from lower airframe	
2.4	Decide on pursuit of flight 2 (dependent of outcome of flight 1)	
2.5	Implement repair measures (if needed)	
2.6	Download camera and sensor data, submit to judges	
	Pre-Flight 2	
3.1	Charge batteries and camera as needed	
3.2	Repeat steps 1.1 to 1.15	
	Post-Flight 2	
4.1	Repeat steps 2.1 to 2.6, omitting 2.4	
4.2	Turn off all electronic systems	
4.3	Detach drogue and main parachutes	
4.4	Disassemble and store rocket airframe	

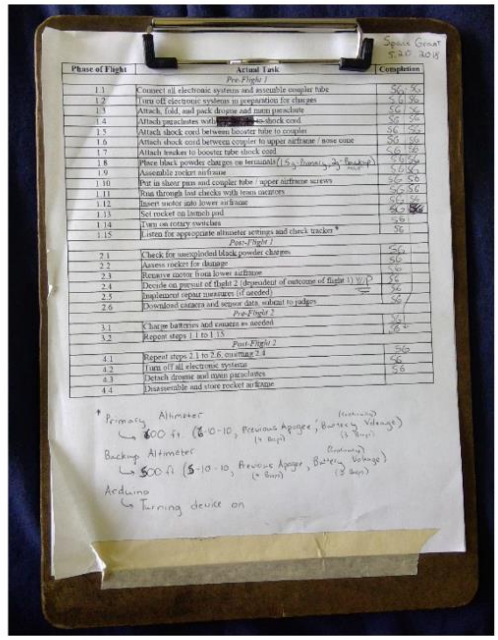

Figure 7: Launch Procedures from FRR (left) and Launch Procedures used at Competition (right)

During the team's safety inspection, the Range Safety Officer suggested two key additions. Firstly, to "Phase of Flight" section 1.8 in the procedures, specific amounts for the black powder ejection charges were added. Secondly, the team further detailed both Strataloggers' beep sequences and their respective meanings. Using the updated version, the team lead checked off each section after every task was completed. The final checklist can be seen on the right of Figure 7.

1.5 Flight Anomalies Analysis

As detailed in the FRR, the rocket's main parachute did not deploy during the test flight in late April. Therefore, the structures sub-team specifically prepared and checked the parachutes during competition assemblies. Both flights featured successful recovery systems, therefore the previous issue was mitigated.

The sole detected flight anomaly occurred during the first competition flight with an unexploded ejection charge. Upon undergoing ground recovery, the team discovered the main chute's primary ejection charge did not go off, while the backup had. Members believe there to have been a minor break in the altimeter's continuity, as witnessed on the ground computer during that portion of the launch. After checking the Stratologger data, however, the loop still experienced 1.0 ampere of current during this time, so the team's explanation was most likely incorrect. Individuals are still in discussion to explain the anomaly. The situation, nevertheless, was handled safely and appropriately, and the rocket did not experience any damage as a result.

2 Predicted vs. Actualized Performance

2.1 Flight Characteristics

Table 1: Comparison of Flight Characteristics

Flight Characteristic	Simulation	Test Flight	Competition Flight 1	Competition Flight 2
Motor	J415W-L	-	-	-
Mass (lbs)	10.0	13.81	14.24	14.24
Apogee (ft)	3372.7	3271	3476	3231
Max. Velocity (ft/s)	492.12	508.0	481.4	493.1
Max. Acceleration (ft/s^2)	239.83	211.062	205.803	207.045
Drogue Parachute Descent Speed (ft/s)	80.46	76.5	65.174	62.73
Main Parachute Descent Speed (ft/s)	16.7	-	14.505	13.79
Motor Burn Time (s)	3.54	3.51	3.50	3.53
Time to Apogee (s)	14.6	14.5	13.9	15.03

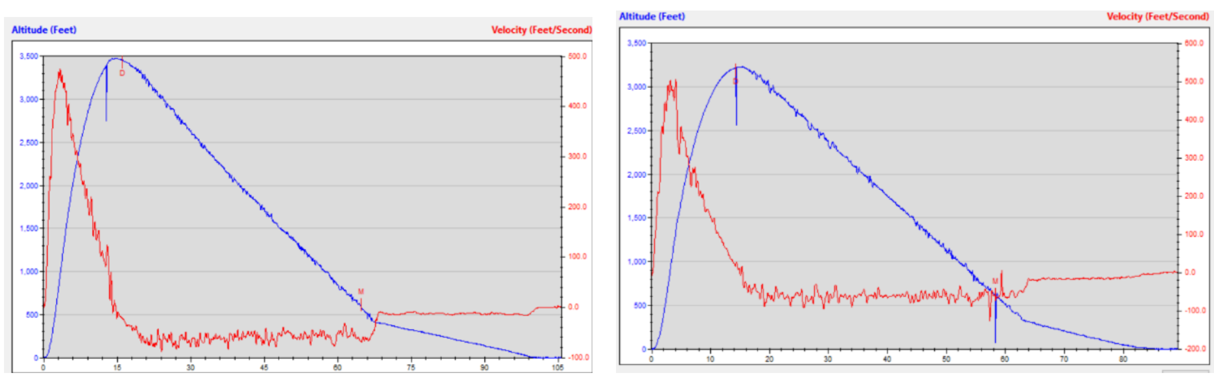

Figure 8: Primary Altimeter Data from Flight 1 (Left), Flight 2 (Right)

2.2 Peak Altitude

The apogee reached during the competition flights was greater than both the test flight and Open Rocket simulation, which can be attributed to total rocket mass. Since the test flight's performance resulted in a number of needed repairs, the team was concerned that the added mass would cause the overall apogee to be lower than 3000 ft (seen as the test flight apogee was close to that value). To combat this, the team decided to omit as many quick links as possible from the shock chord connection points and replace them with double back hand knots wherever possible. Furthermore, the first flight's apogee was about 200 feet higher than the second flight's apogee, since there were no drag induced by the rocket's roll control fins during the first flight. The altitude data collected from the primary altimeter for both flights can be seen in Figure 8.

2.3 Peak Velocity and Peak Acceleration

The maximum velocities and accelerations were both lower than the simulated values and those from the test launch. Simulations were higher because the calculations used a lower estimated mass. The test launch values were lower as the mass of the rocket at the test launch was less than the mass on competition day. Lastly, the velocity and acceleration of the rocket may also have been affected by the varying weather conditions on at both launches. The primary altimeter data for the velocity throughout each flight can be seen in Figure 8.

2.4 Descent Velocity and Recovery System Performance

The competition's descent velocities produced the largest disparity between numbers the team calculated and collected from simulations and the test flight. This is mostly due to the varying weather conditions at the test flight and competitions flights. The increased wind speeds allowed for the rocket to drift more and reduce its vertical descent velocity significantly from the predicted and previously collected values. At the test flight, no main parachute descent speed was calculated as the main parachute did not deploy, negating a possibility for comparison.

3 Active Roll Orientation System Data Collection and Analysis

3.1 Collected Data during Flights

3.1.1 Flight 1

Roll orientation data was logged both via the onboard SD card and the XBEE downlink. Video footage of the entire flight was also successfully collected. Unfortunately, SD card data logging resulted in corrupted files unable to be opened. Since XBEE downlink data and SD card data were backups of one another, flight results are still able to be analyzed without any loss of information.

3.1.1.1 Flight 1 Launch Phase

XBEE downlink performed nominally from system startup throughout flight until landing. The accelerometer successfully sensed gravitational acceleration on the launchpad to be between 9.80 m/s and 10.00 m/s. Motor ignition was also sensed, with initial acceleration measured at 68.80 m/s or 7.01g, and peak acceleration occurring 0.558 seconds later, achieving 103.63 m/s or 13.32g. Acceleration readings of critical launch events and their respective timestamps are provided in Table 2 below. A plot of acceleration from motor ignition to burnout is shown in Figure 9. Note the jagged contours, caused by issues with XBEE transmission quality on Flight 1 which resulted in poor transmission timing due to buffering.

Table 2: Launch Events Timeline – Flight 1

Event	Acceleration (m/s^2)	Timestamp
Liftoff	68.80	12:58:01.848
Max Acceleration	103.63	12:58:02.406
Burnout	1.70	12:58:05.477

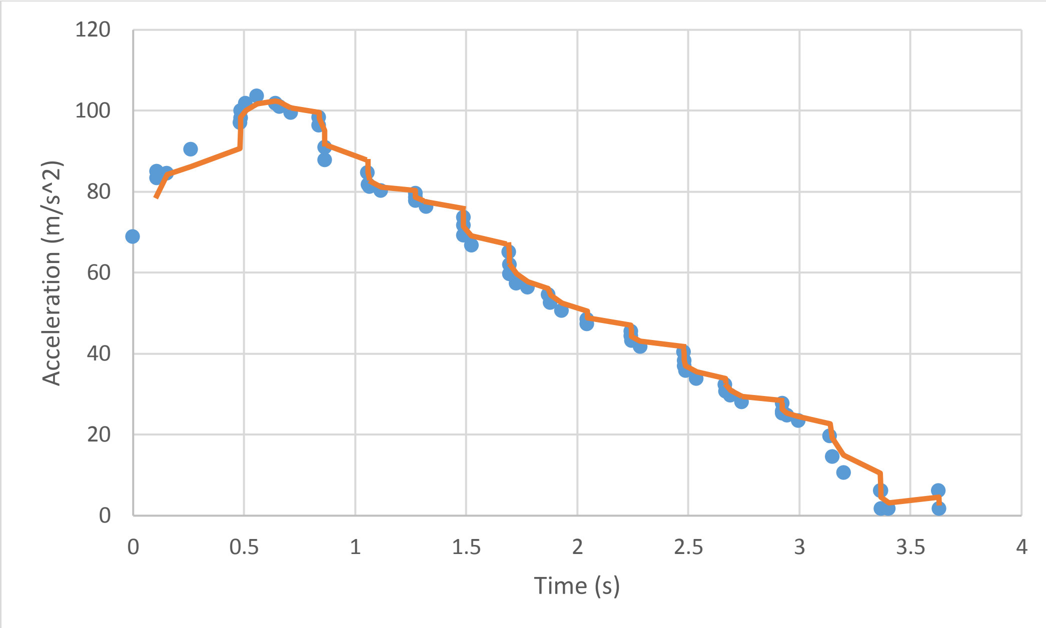

Figure 9: Acceleration vs. Time - Flight 1

3.1.1.2 Flight 1 Coast Phase

Roll orientation, control flap orientation, time, x-axis tilt, and y-axis tilt were all collected during flight. X-axis tilt measurements immediately exceeded the 90-degree threshold following burnout, causing the control system to detect apogee and set controls to neutral. Thus, control flap data throughout the flight remained at 90 degrees. Using roll orientation and time data, the team constructed the following plots to illustrate vehicle roll performance.

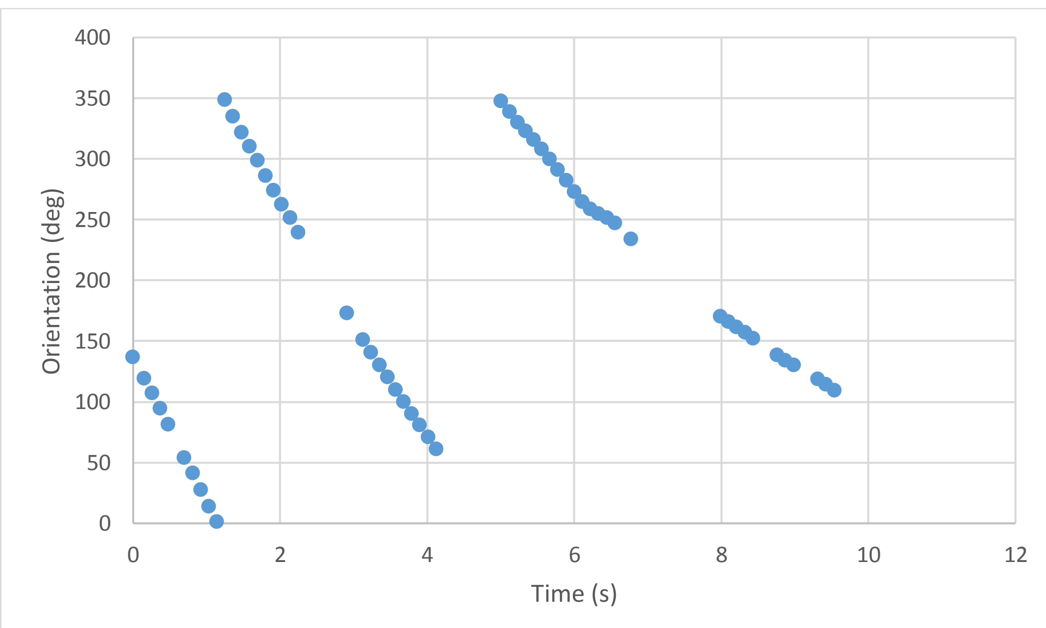

Figure 10: Vehicle Orientation Over Time - Flight 1

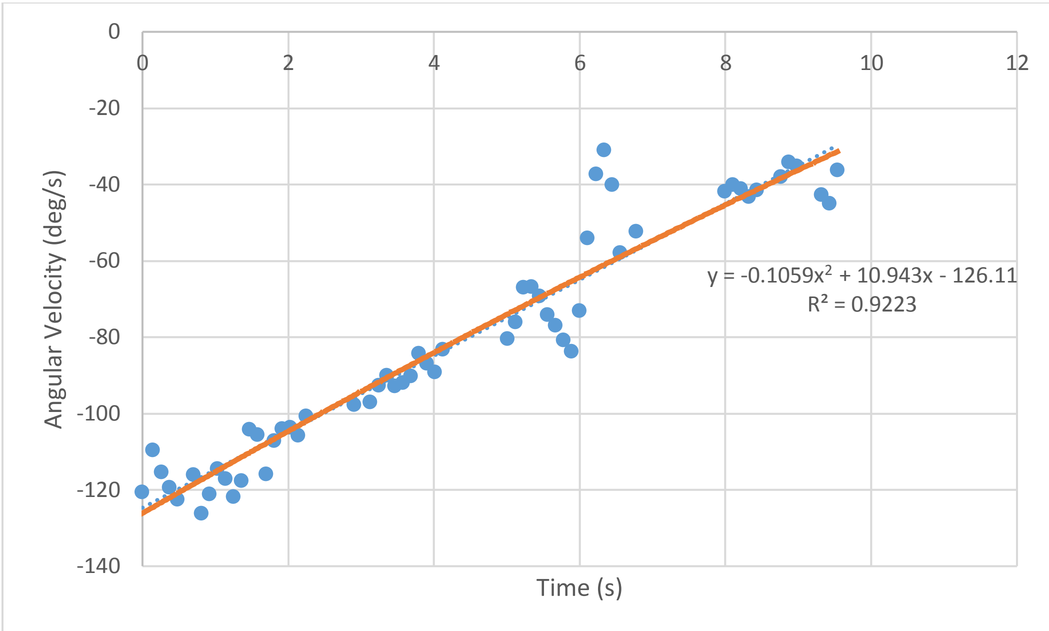

Figure 11: Angular Velocity Over Time, Flight 1

3.1.2 Flight 2

Similar to Flight 1, both XBEE downlink and SD card logging were attempted. XBEE downlink still performed to expectations and delivered data from launch until landing, yet SD card logging still failed to function. No log file was created to document Flight 2. Again, since XBEE data and SD data were backups of one another, all information was still collected. Onboard footage provided key insights to the performance of the vehicle also.

3.1.2.1 Flight 2 Launch Phase

From the experience of Flight 1, the team delayed datalogging until approximately 10 seconds before launch, significantly reducing log file size and clutter. Edits to the control code to address Flight 1 issues also resulted in better transmission quality, which provided enhanced data quality. As seen in Figure 12, the acceleration plot for Flight 2 had much more realistic contours. A summary of key launch events is also included in Table 3. Peak acceleration occurred 0.508 seconds after motor ignition, and the total burn time of the motor was 3.095 seconds.

Table 3: Launch Events Timeline – Flight 2

Event	Acceleration (m/s^2)	Timestamp
Liftoff	60.06	16:08:05.339
Max Acceleration	95.94	16:08:05.847
Burnout	3.33	16:08:08.434

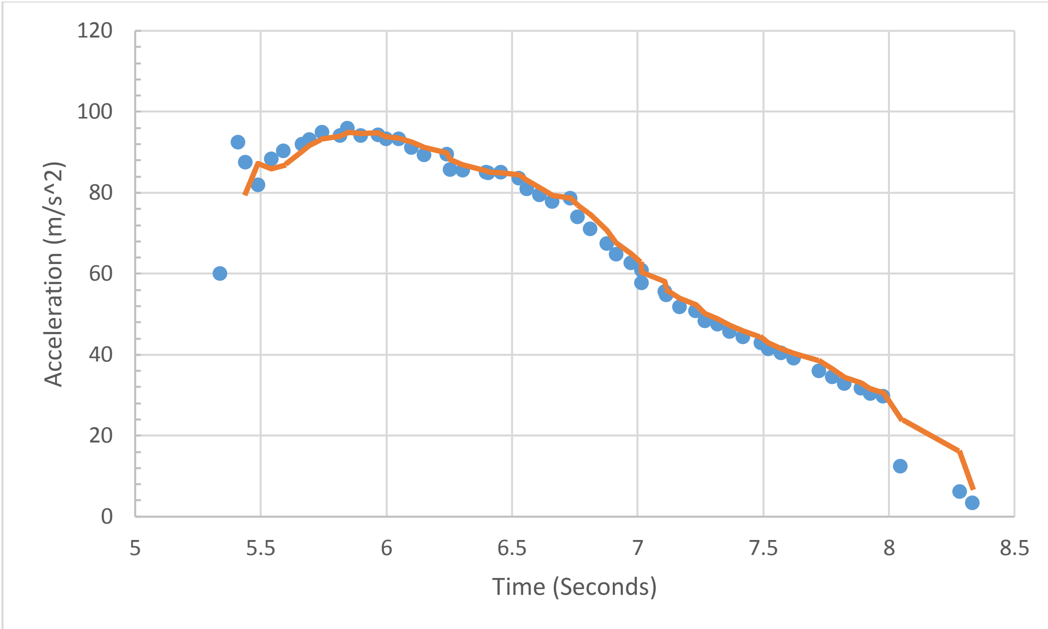

Figure 12: Acceleration vs. Time - Flight 2

3.1.2.2 Flight 2 Coast Phase

Data was successfully collected in the same fashion as Flight 1. The team debugged the apogee detection system such that controls were enabled and executed during Flight 2. Figure 13 illustrates the roll orientation and attempted controls through flight. Since the onboard orientation system recorded orientation data within 0-360 degrees, any rotation past those thresholds would be converted by addition or subtraction of 360 degrees. Thus, while the graph may appear to show the vehicle suddenly reversing direction, it is in fact continuing its rotation.

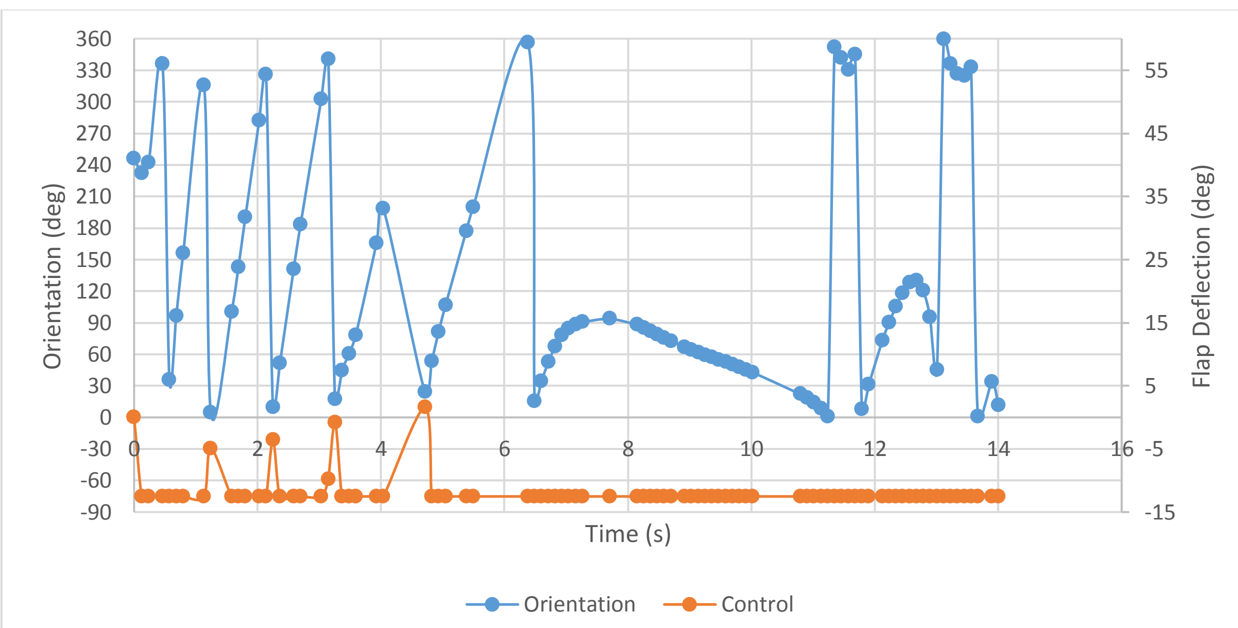

Figure 13: Vehicle Orientation and Control Over Time – Flight 2

3.2 In Flight Video and Respective Links

As described in FRR, the team used a Mobius Basic ActionCam to collect in-flight video. Mounted externally on the upper airframe, the camera logged the LEDs responses and the roll-control results. This video can be found at the Illinois Space Society's YouTube channel, under this link.

3.3 Data Interpretation and Comparison to Expectations

3.3.1 Flight 1 Data Analysis

3.3.1.1 Flight 1 Launch Phase

The measured maximum acceleration of 103.63 m/s^2 was significantly greater than Stratologger measurement of 62.73 m/s^2. While motor performance variations may have partially contributed to the outcome, it is unlikely that performance variations of 65% occurred. Sensor errors are likely, therefore, to be the greatest source of error. During extensive testing in the weeks leading up to launch, the team found that accelerometers returned approximately 1/8th of the expected acceleration. A hard-coded fix was applied to scale up measurements from the accelerometer. While errors were scaled up also, they still deviated less than 0.2 m/s^2, as demonstrated by the previously mentioned acceleration measurements on the launch pad. Non-linear scaling could explain the large deviation, meaning at greater accelerations the measured value might be greater than 1/8th of the actual value. It is also possible that the accelerometers become significantly less accurate at higher acceleration values, although they were rated up to 16g's.

Total motor burn time was derived to be 3.629 seconds, close to the measured value of 3.50 seconds during the team's test flight. Possible sources of error include the 10-15% variance in motor quality, as well as transmission processing time for the XBEE system, and a maximum 25ms resolution for the custom sensor suite. The similarity to prediction and testing values ultimately validated the method of launch and burnout detection via accelerometers, albeit significant issues with maximum readings.

3.3.1.2 Flight 1 Coast Phase

Downlink data indicated that upon motor burnout the vehicle immediately detected apogee by sensing an over 90-degree tilt around the x-axis. This is incorrect since the rocket did fly nominally, and the root issue was traced to faulty integration methods used in the code for while the rocket was standing by on the launchpad.

Premature apogee detection also resulted in the vehicle failing to calibrate its control flaps, which was a planned step that would happen after the 3-second idle time post-burnout. The purpose of this step was to identify the true "neutral position" for control fins where no net torque was induced, such that the controller would give more accurate outputs. The lack of such calibration caused the flaps to have an incorrect neutral position that induced a small torque along the negative z-axis, causing the vehicle to rotate clockwise, as seen in the video.

Nonetheless, the apogee protocol was correctly executed with the vehicle locking both control flaps to neutral. The LED's did not function as expected, and only the "holding position" light (center, orange) was illuminated for the remainder of Flight 1. The team suspects errors for the timer system to be the source of error, but have not been able to confirm the hypothesis.

The graphs shown are orientation data and angular velocity plotted over time. The vehicle exhibited a smooth clockwise rolling motion (clockwise defined as negative rotation by the right-hand rule) that gradually slowed down. This is due to the deceleration of the vehicle, thereby decreasing velocity such that control flaps exhibited less authority over the roll of the vehicle.

3.3.2 Flight 2 Data Analysis

3.3.2.1 Flight 2 Launch Phase

A similar range of acceleration values were recorded in Flight 1 as compared to Flight 2. Flight 2 measurements once again differed from Stratologger measurements, its value being 95.94 m/s^2 as compared to the altimeter's 63.11 m/s^2. A shorter burn time of 3.095 seconds was measured as compared to the altimeter value of 3.53 seconds. This might be attributed to inaccuracies approaching the end of the burn, where a very low thrust might be discarded by the controller code (which had a 5 m/s^2 cutoff) but included by the altimeter.

3.3.2.2 Flight 2 Coast Phase

The corrected version of code used in Flight 2 successfully overcame the apogee detection issue. Following motor burnout, the vehicle did not idle for 2 seconds as intended, and instead immediately began its roll control process. The idle timer was controlled by a timer similar to the LED's, which made the team believe that the timer system was indeed to blame for both issues.

As noted in 3.1.2.2, the data shown for Flight 2 was wrapped around when they exceeded the 0-360 degree limit. A critical disagreement between camera footage and XBEE data was noted – while the downlink data indicated that the vehicle was rolling counterclockwise, camera footage showed the vehicle rotating clockwise at the beginning of launch. The same code was used to integrate angular velocity for both Flights 1 and 2, yet only Flight 2 had the issue. The team has yet been able to identify the cause of negation.

The negation of orientation mostly likely cause the controller to apply force in the opposite of the intended direction, thus accelerating the vehicle's roll instead of regulating it. It may be seen, however, that the vehicle's roll was reduced when approaching alignment with "North," the first command. Nevertheless a stable and correct orientation was not achieved, and thus the controller never moved past the first command.

While the LED system was tested with the working version of code, the red LED that indicated "roll counterclockwise" was damaged due to friction while assembling the avionics bay. Since the vehicle was attempting to roll counterclockwise for the majority of the flight, little LED output was observed.

Apogee was not detected. The team had used a timer to forcibly prevent apogee triggers before 10 seconds of flight as extra precaution, but as previously mentioned, the timer issue that most likely caused LED and idling failures recurred and prevented the apogee trigger. The vehicle descended with controls locked to maximum counterclockwise.