Flight Readiness Review Addendum

Student-Led Observations of Sinusoidal Hydrodynamics

(SLOSH)

NASA Student Launch 2025 for Middle and High School

Madison West High School, 30 Ash Street, Madison, WI 53726

March 22, 2025

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Summary of FRR Addendum

Team Information

Madison West Rocket Club
Madison West High School
30 Ash Street, Madison, WI 53726

Hours

In total, we spent 28 hours working on the FRR Addendum.

Purpose of Flight(s)

Flight performed to fulfill requirements for both payload demonstration flight and vehicle demonstration re-flight.

Flight Summary Information

Date of flight: March 22, 2025

Location of flight: Bong State Recreation Area

Launch conditions: Clear, wind: ~5 mph, temperature: 41° F

Motor flown: AeroTech K-1103X

Ballast flown: None

Final payload flown: Yes

Vehicle Mass: 19.98 lbs

Official target altitude: 4,500 ft

Predicted altitude: 4,688 ft

Measured altitude: 4,668 ft

Off-nominal events: Landed in water, minor payload integration issues

Changes made since FRR submission

Vehicle:

- Added a Raven flight computer for redundant data (no charge firing, attached in the drogue bay, attached to the bulkhead on the upper tube)
- Flight computers reprogrammed to correct deployment altitudes

Payload:

- Added sunshades
- Inertial Logger was replaced
- Added red LED lights
- Changed the baffle color to blue

Payload Criteria

Payload Objective

Slosh is defined as “any motion of the free liquid surface inside its container caused by disturbance to partially filled liquid containers,” according to Ibrahim (2005) in the book “Liquid Sloshing Dynamics: Theory and Applications”. Baffles are often used to mitigate the sloshing effect, which can cause risk due to slamming on the tank walls. We are comparing 2 baffle designs to determine which is the most effective. We are measuring slosh in an SL rocket to determine which baffles dampen the slosh the greatest and by how much during the flight.

Payload Retention System

Our payload is retained by two ¼-20 steel threaded rods and bulkheads on either end. Each payload module is attached to these rods, reducing vibrations and ensuring that every module is secure and will not come free during flight. The bulkheads on either end are also secured to these threaded rods, and they will ensure that the payload remains inside the vehicle during any high-g portions of the flight.

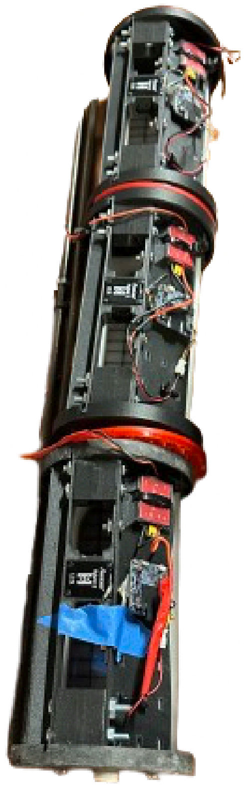

Figure 1: Fully Constructed Payload

Camera and Tank Mount

Each tank within our payload is screwed into a 3D-printed enclosure. This enclosure also contains mounting points for the RunCam Hybrid 2 Cameras, their driver boards, buck converters for regulating power to the cameras, and pass-throughs for wires and zip ties.

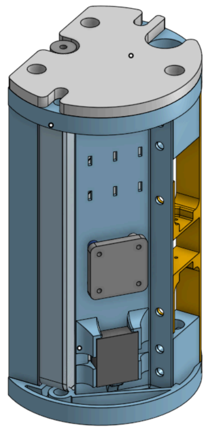

Figure 2: Payload Enclosure CAD Model

The enclosures are each slid onto the two ¼-20 threaded rods and secured in place with nuts. In between each enclosure is a 3D-printed spacer to reduce stress on the wires running between each enclosure.

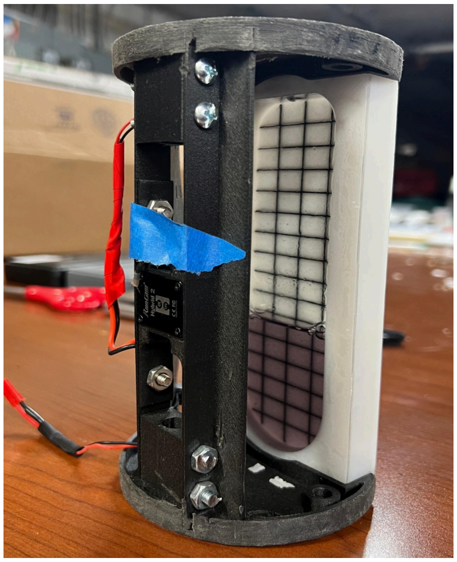

Figure 3: Payload Tank Enclosure

This method of payload retention has proved effective during both of our test flights. During the post-flight inspection of the payload components, no damage was found, proving the integrity of our payload retention system, even under inadvertent flight conditions such as the motor failure of our first test flight.

Payload Demonstration Flight Results

Purpose of Flight

We reflew our payload demonstration flight because our previous flight did not meet our team-derived requirements, as we did not get data that we could analyze. Additionally, we made changes to our payload. As the handbook requires identical payloads at competition and demonstration flights, we chose to refly with our updated payload. We wanted to fly these changes at competition, requiring us to refly our payload, as the handbook requires that payloads flown at competition are the same as demonstration flights, with no changes.

We deemed the data from our second launch unusable, as the script used to analyze the camera videos could not overcome the glare from the sun present in the video. To mitigate this issue, we added sunshades to prevent glare.

We also added a system to sync the videos. We added a board that turned on red LED lights that were on a timer based on a sensor that sensed the launch, which were visible to all 3 cameras.

These changes motivated us to redo our Payload Demonstration Flight.

Flight Overview

The third launch of the rocket concluded in a partial success. Every aspect of the flight went nominally as expected, however, one of the cameras in the payload failed due to a wiring issue, causing a lack of data from a single tank module. Additionally, the vehicle landed in a pond. This had the potential to cause damage to the electronics, but the vehicle was recovered before damage could be inflicted. The red lights that were to be used to synchronize the video footage did not turn on due to the failure of our Inertial Logger, making it difficult to synchronize the data. Despite the numerous challenges on this flight, we were still able to gather accurate and complete data from the two unaffected payload modules. Additionally, the payload performed entirely safely throughout the flight.

Payload Mission Sequence

1. Payload is armed
2. Cameras begin recording
3. Rocket is launched
4. Inertial logger detects launch and begins recording accelerometer, gyroscopic, and magnetic data
5. Slosh is observed by cameras
6. Payload is disarmed
7. SD cards are removed
8. Data is uploaded into analysis program
9. Data is analyzed
10. Baffles are evaluated to determine effectiveness

Payload Launch Preparation and Integration

To prepare the payload, we armed it using a hex wrench in the payload arming holes in the side of the rocket.

Payload Flight Analysis

Below is a graphical visualization of the data retrieved from the two active tanks of our payload (control and grid baffles) during flight, as well as a description of our data collection method. Unfortunately, our vertical baffle camera became inoperable before flight, so we were unable to evaluate the vertical baffles' performance during flight.

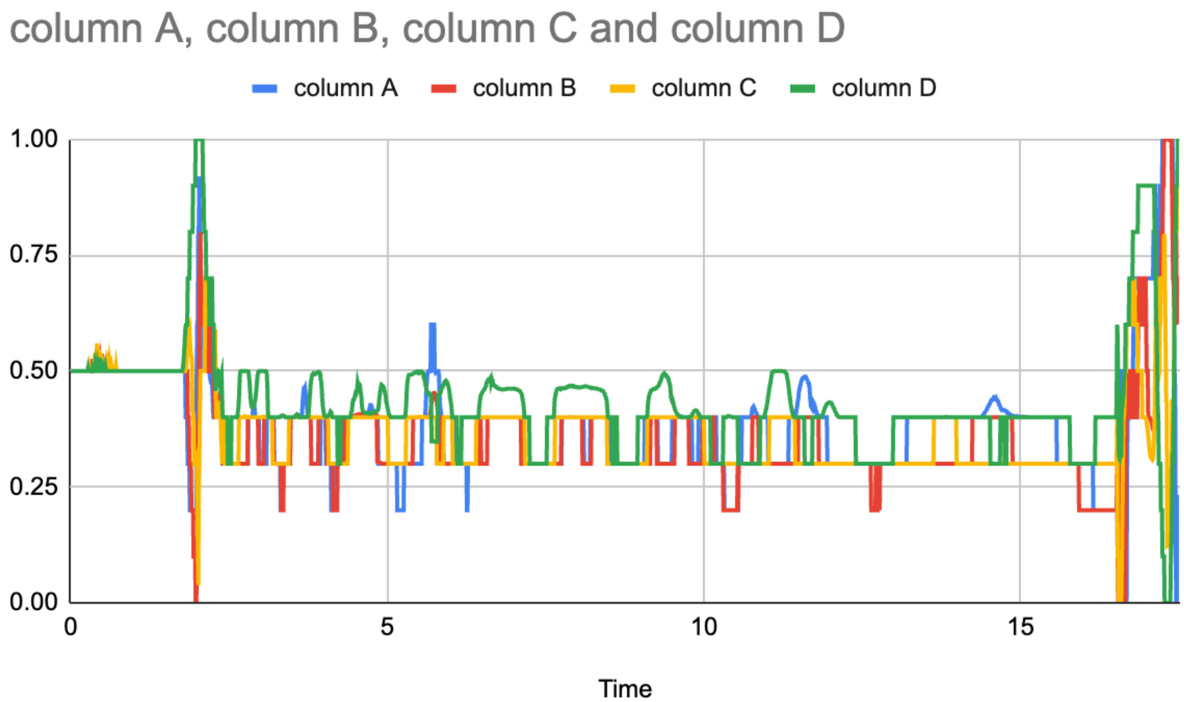

Figure 4: Control Tank Direct Payload Data Plot

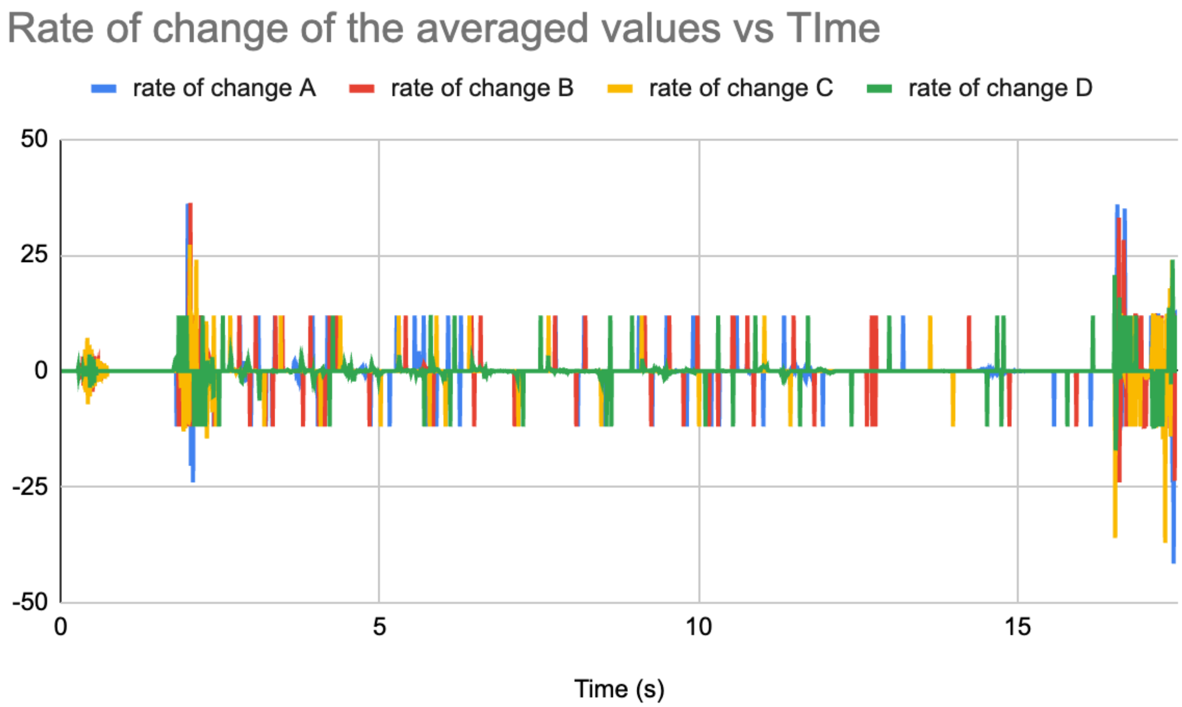

Figure 5: Control Tank Rate of Change Payload Data Plot

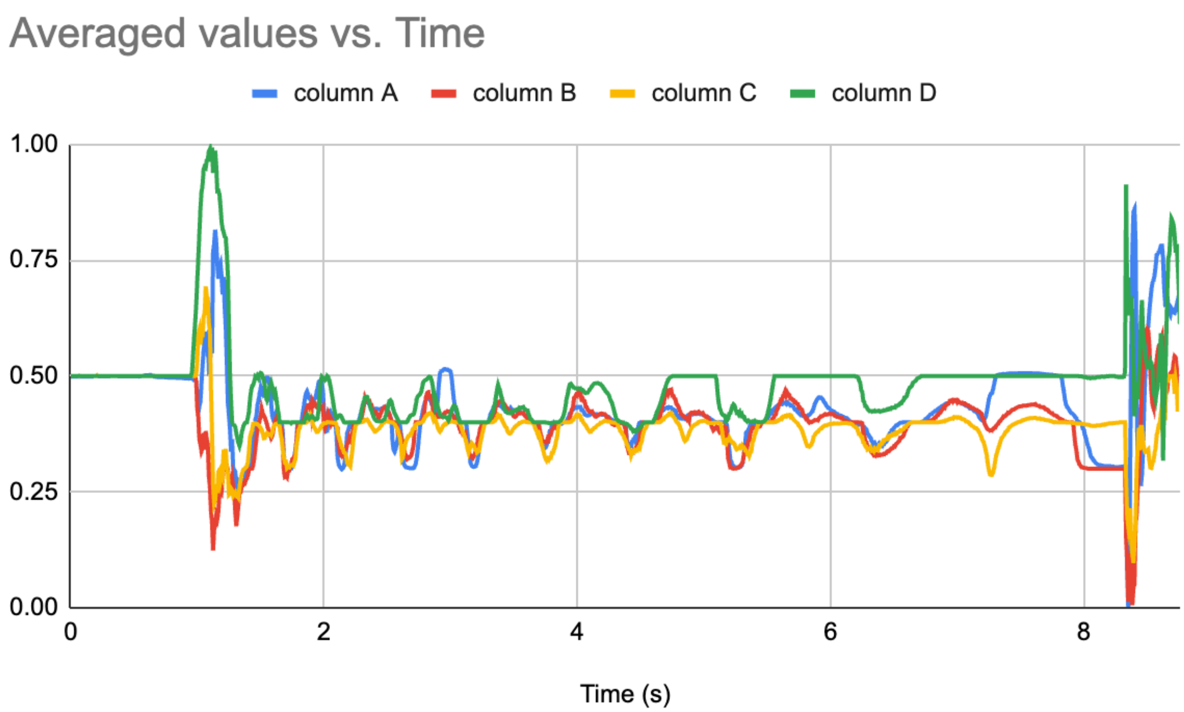

Figure 6: Grid Baffles Tank Average Values Payload Data Plot

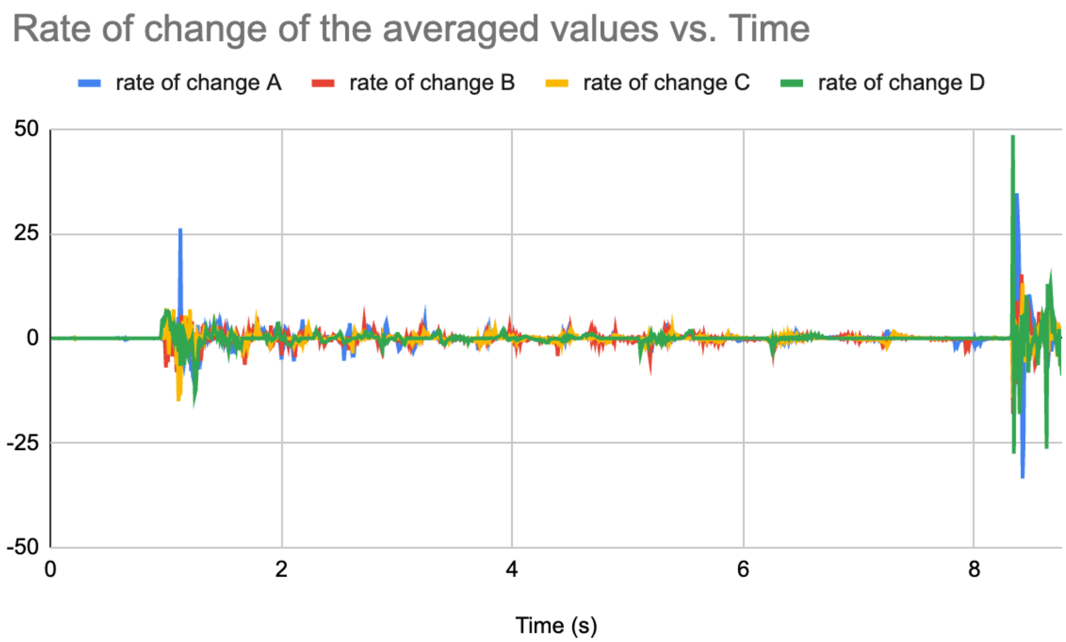

Figure 7: Grid Baffles Tank Rate of Change Payload Data Plot

Each tank grid is assigned a value from 0 to 1 based on the percentage of the grid that is covered by water. We analyzed the data by calculating the average values of each column and the rate of change of the averaged values. Based on the graphs above, we can see that the speed of water changes less significantly in the baffled tank compared to the control tank. Therefore, we concluded that the baffles reduce the slosh of water.

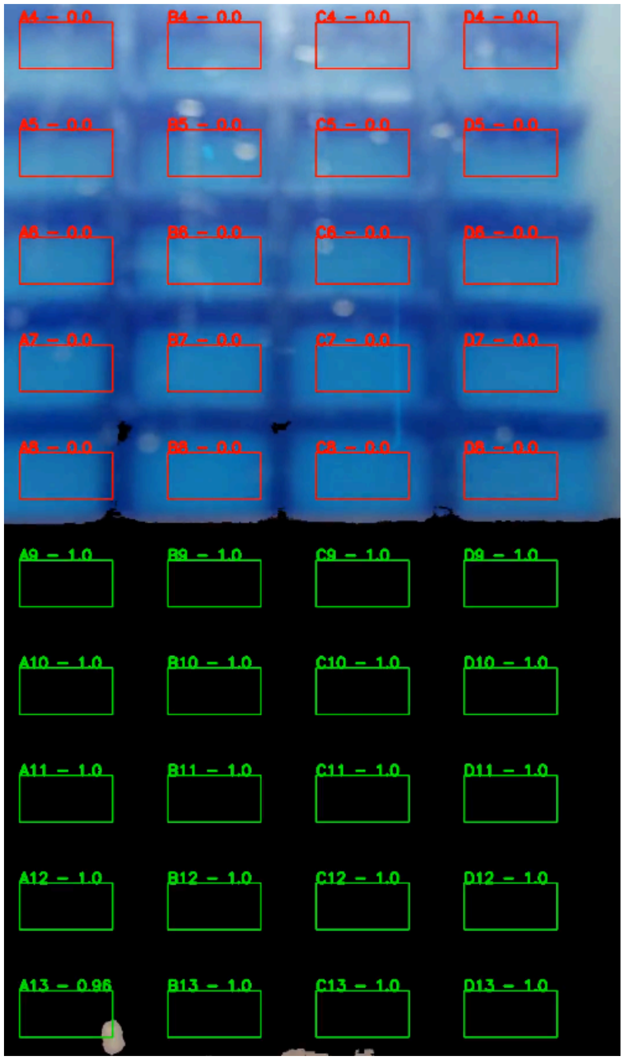

Figure 8: Payload Video Analysis Portion

Lessons Learned

From this flight, we learned that we needed to reinforce our wire joints to ensure they do not come apart during transport. Additionally, we revised our Inertial Logger design to mitigate the encountered issue, and the new system will be heavily tested before integration into the payload to ensure proper functionality during flight. We plan to secure all wires with zip ties or tape during assembly to ensure they do not come undone during payload transport. Finally, we plan to revise our Inertial Logger design to ensure it does not experience the same failure detailed below.

Payload Successes and Failures

Failures

Before launch, the board we designed to flash the red lights caused a current spike within the Teensy 4.1, rendering it inoperable. Due to this, the Inertial Logger recorded no data. To replace the board, we ordered a new Teensy 4.1. Additionally, one of the wires connecting to one of the cameras broke, failing to record data. We resoldered the wire after the launch to fix the issue, and we have created plans to secure the wires before transport and flight.

Successes

Our retention system held all payload parts in place successfully, and no damage was sustained to any pieces due to the launch. Our analysis program was also successful in analyzing the recovered video footage. Foaming was minimized, and our sunshades were successful in mitigating the glare, which previously caused our analysis to fail. Despite the vehicle landing in a small body of water, all the components of the vehicle and payload were dried out, and no water damage was sustained.

Vehicle Demonstration Re-Flight Results

Flight Overview

The third launch and demonstration flight attempt of our vehicle was a complete success. The vehicle and all its systems functioned as intended, and it reached an apogee of 4,668 feet, just 20 feet below our simulated altitude for this launch. Our vehicle landed in shallow water, but it only drifted 430 feet from the launch pad, allowing us to quickly recover the vehicle and pull it out of the water. No damage occurred to any parts of the vehicle or payload. Due to the success of this flight, we will use the vehicle's mass from this launch as our final launch mass. This flight will be the same configuration as what we plan to fly in Huntsville.

Launch Preparation and Integration

After we had arrived at the launch site, we removed the payload from the upper tube and prepared it for arming. We then armed the payload and ensured that all payload electronics were on and running. Next, our mentor connected all deployment charges to our flight computers, and we integrated the upper tube with the electronics bay with the installed PEM nuts and 4 screws.

We connected our drogue shock cord to the forged eye bolt threaded into the forward closure of our motor, and our mentor inserted the motor into the vehicle and secured it with the motor retainer. We then packed our drogue chute and shock cord, our mentor installed the drogue deployment charges into the booster tube, and we integrated the two sections with shear pins. After that, we packed our main chute and shock cord, our mentor installed the main deployment charges, and we integrated the nose cone with the upper section using shear pins. Finally, we confirmed that all systems were ready for launch, and we brought the vehicle to the pad and prepared for launch using our checklist.

Flight and Analysis

This flight launched on an AeroTech K-1103 motor on March 21, 2025, at the Richard Bong State Recreation Area. We flew with no ballast on this flight. This flight was conducted as a payload demonstration flight, but our vehicle also performed completely as intended, without any minor errors such as those on our previous attempts. Launch day was clear, with very low wind (~5 mph). We also flew our final payload on this flight. Our vehicle's target altitude is 4,500 feet, and our predicted altitude for this flight was 4,688 feet. The vehicle reached an altitude of 4,668 feet, 20 feet below the predicted altitude and 168 feet above the target. All vehicle systems functioned as intended throughout the launch. The main chute deployed as planned, and our vehicle remained within all NASA requirements. There was no damage to the vehicle or the payload from this flight.

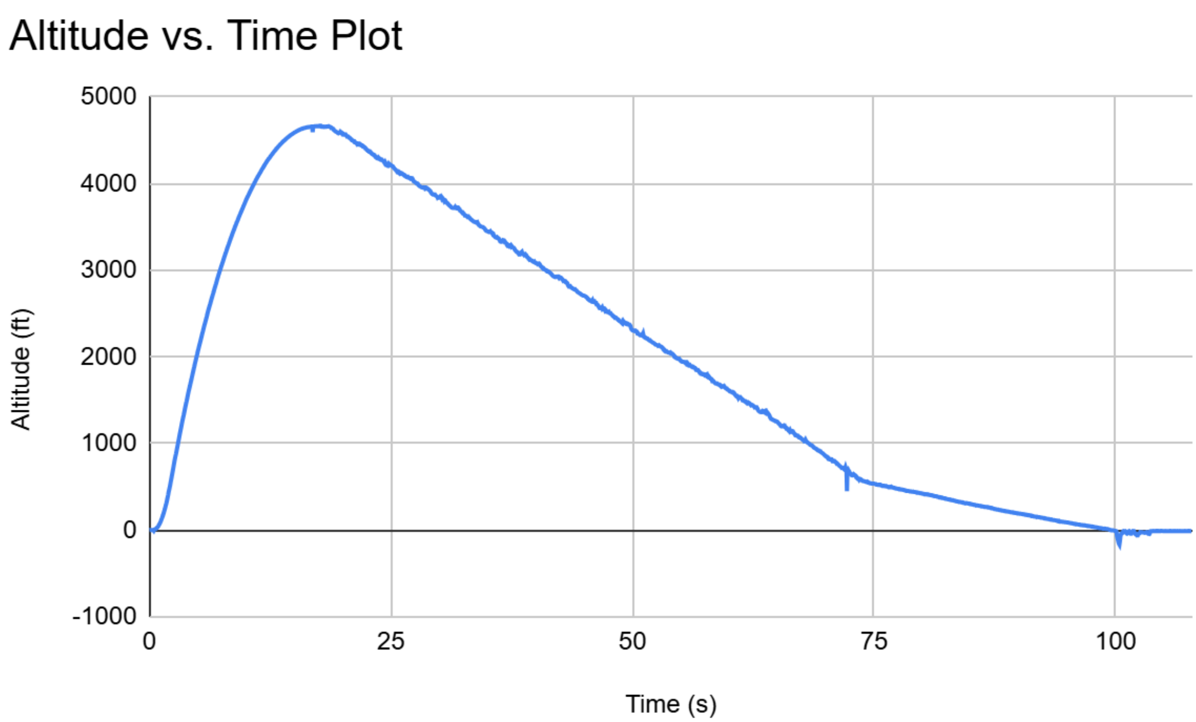

Figure 9: Altitude vs Time Plot

The figure above shows the flight profile from our vehicle's primary flight computer. Our vehicle's liftoff weight was 19.98 lbs. When the vehicle launched, the wind was approximately 5 mph, and the rocket drifted approximately 430 feet. The vehicle reached apogee after 17.6 seconds and had a total flight time of 100.4 seconds. Its descent time was 82.8 seconds, which is within requirements. There were very few differences between actual and predicted flight data, with our maximum altitude being 20ft (<1%) below our predicted altitude.

After performing calculations using the same methods detailed in our FRR report, we calculated the main parachute coefficient of drag to be 1.3 and our drogue parachute coefficient of drag to be 1.5. The vehicle's configuration as launched is the same as the one we plan to launch in Huntsville.

Kinetic Energy

Using the formula $KE = \frac{1}{2}mv^2$, we were able to calculate the Kinetic energy for each tethered section of the vehicle at impact, where the velocity was extrapolated from the altimeter flight data. The vehicle successfully separated into 3 sections by impact.

Section	Kinetic Energy
Booster Section	40.7 ft-lbf
Upper Section	72.9 ft-lbf
Nose Cone	11.3 ft-lbf

Table 1: Landing Kinetic Energy for Each Section

All of these values fall under the NASA-required limit of 75 ft-lbf.

Landed Configuration

The landed configurations of the vehicle are shown below. We prioritized removing the vehicle from the water as quickly as possible to avoid damage rather than taking quality pictures of the landed configuration, and no modifications were made to the vehicle after its removal from the water.

Figure 10: Landed Configuration of the Main Chute After Removal from Water

Figure 11: Landed Configuration of the Vehicle After Removal from Water

Figure 12: The Upper Section As Landed in Water

Figure 13: The Booster Section as Landed in Water

Lessons Learned

This flight showed us the quality simulation results that can be achieved by carefully measuring and weighing the vehicle before flight. The measured flight data we received from this flight matched very well with our simulated values, so we can be relatively certain that our simulation methods are accurate. Furthermore, we learned the importance of checklists and keeping an updated FMEA report, as we were able to learn from our past mistakes and create procedures that allowed us to efficiently prepare and launch our vehicle. Overall, this flight highlights the efforts put in by our team to learn from our past mistakes and to use that knowledge to perform a safe and efficient flight.