# Tacho Lycos

# 2025 NASA Student Launch

# Post-Launch Assessment Review

High-Powered Rocketry Club at NC State University
1840 Entrepreneur Drive
Raleigh, NC 27606

May 19, 2025

## Common Abbreviations and Nomenclature

| | |
|---|---|
| ADC | = Analog to Digital Converter |
| AGL | = Above Ground Level |
| AIOC | = Ham Radio All-in-one Cable |
| APCP | = Ammonium Perchlorate Composite Propellant |
| APRS | = Automatic Packet Reporting System |
| ARR | = Always Ready Rocketry |
| AV | = Avionics |
| AVAB | = Avionics and Air Brakes Bay |
| CAD | = Computer Aided Design |
| CATO | = Catastrophe At Take Off |
| CDR | = Critical Design Review |
| CG | = Center of Gravity |
| CHARGE | = Current Handling & Automatic Regulation for Grid Energy |
| CNC | = Computer Numerical Control |
| CP | = Center of Pressure |
| CT | = Central Time |
| ECE | = Electrical and Computer Engineering |
| E Council | = Engineering Council |
| EMF | = Electromotive Force |
| ETF | = Educational and Technology Fee |
| EYE | = Engineer Your own Experience |
| FAA | = Federal Aviation Administration |
| FM | = Frequency Modulation |
| FMEA | = Failure Modes and Effects Analysis |
| FRR | = Flight Readiness Review |
| FSM | = Finite State Machine |
| FUSE | = Flight Unit for Sensing & Evaluation |
| GPS | = Global Positioning System |
| HPRC | = High-Powered Rocketry Club |
| IMU | = Inertial Measurement Unit |
| IPL | = Inverted Pursuits Lab |
| LED | = Light-Emitting Diode |
| LiPo | = Lithium Polymer |
| LRR | = Lab Rat Rocketry |
| LRR | = Launch Readiness Review |
| LV | = Launch Vehicle |
| MAE | = Mechanical & Aerospace Engineering |
| MSFC | = Marshall Space Flight Center |
| N/A | = Not Applicable |
| NACA | = National Advisory Committee for Aeronautics |
| NAR | = National Association of Rocketry |
| NASA | = National Aeronautics and Space Administration |
| NCSG | = North Carolina Space Grant |
| NCSU | = North Carolina State University |
| PCB | = Printed Circuit Board |
| PDF | = Payload Demonstration Flight |
| PDR | = Preliminary Design Review |
| PETG | = Polyethylene Terephthalate Glycol |
| PH | = Performance Hobbies |
| PID | = Proportional-Integral-Derivative |
| PLA | = Polylactic Acid |
| PLAR | = Post-Launch Assessment Review |
| PPE | = Personal Protective Equipment |
| Q&A | = Questions and Answers |

RMFS = Removable Modular Fin System
RMS = Reloadable Motor System
RTC = Real Time Clock
RSO = Range Safety Officer
SDS = Safety Data Sheets
SGA = NC State Student Government
SGov = Student Government
SL = Student Launch
SPI = Serial Peripheral Interface
SST = Shear Stress Transport
STEM = Science, Technology, Engineering, and Mathematics
STEMCRaFT = STEMnaut Capsule Radio Frequency Transmitter
STL = Stereolithography (File Format)
SWITCH = Scheduled Wireless Information Transmission & Compilation Hub
TAP = Technical Advisory Panel (TRA)
TBD = To Be Determined
TNC = Terminal Node Controllers
TORCH = Transmission Operations Relay for Capsule Handling
TRA = Tripoli Rocketry Association
TTS = Text to Speech (TRA)
UART = Universal Asynchronous Receiver/Transmitter
USLI = University Student Launch Initiative
VDF = Vehicle Demonstration Flight
VV&T = Verification, Validation, and Testing
WARHEAD = Wireless APRS Relay for High-altitude Environmental & Atmospheric Data

# Contents

## List of Tables

## List of Figures

# 1 Competition Launch Summary

Table 1.1: Launch Summary

| Attribute | Details |
|---|---|
| Date | 5/4/25 |
| Time | 9:45 am CDT |
| Location | Bragg Farms, Toney, AL |
| Temperature (F) | 62 |
| Pressure (in. Hg) | 29 |
| Wind (mph) | 7 |
| Motor | AeroTech L1520T |
| Ballast (lb) | 0.77 |
| Payload | 'WARHEAD' STEMCRaFT, Air Brakes System |
| Payload Weight (lb) | 2.6 |
| Air Brakes | Active but not deployed |
| Stability (Calibers) | 2.09 |
| Vehicle Weight (lb) | 39.8 |
| Target Altitude (ft) | 4600 |
| Measured Altitude (ft) | 4226 |

# 2 Vehicle Performance

## 2.1 Vehicle Summary

The as-flown launch vehicle was unchanged from the Flight Readiness Review milestone. The launch vehicle consisted of four multi-purpose sections with the overall dimensions depicted in Figure 2.1. The launch vehicle met all, except one, of the full success criteria specified in previous milestones. The only exception was not achieving within 200 ft. of the target apogee, instead meeting 'Partial Success' criteria with an official altitude difference of 374 ft. This is assessed to be due to an off-nominal motor ignition during launch, where it took several seconds to build up to full thrust for liftoff. In all other aspects, the vehicle performed as designed during flight and was recovered successfully with no damage to any vehicle or payload systems. Overall, the vehicle met or exceeded the initial design goals for safety, reliability, and re-usability.

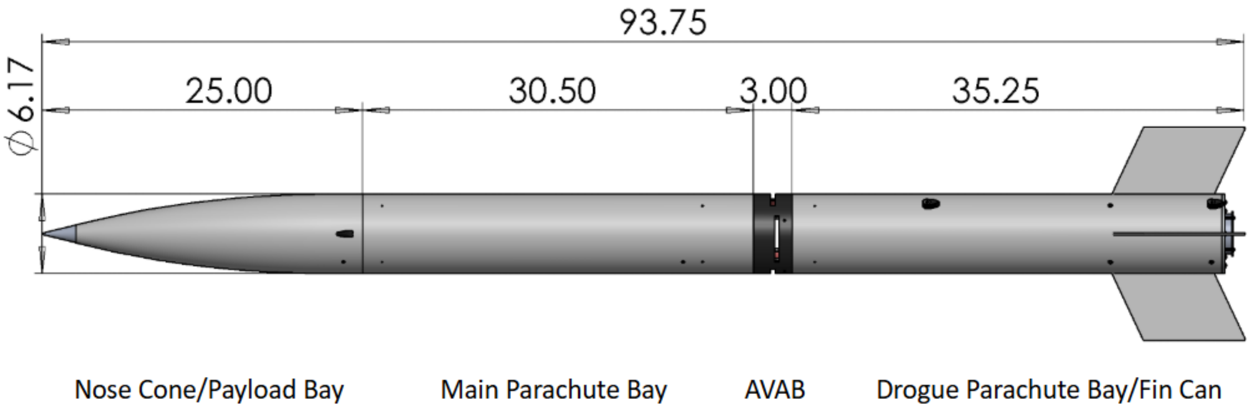



Figure 2.1: Overall external vehicle dimensions in inches.

Figure 2.2: The fully integrated launch vehicle on the pad at Bragg Farms.

## 2.2 Flight Profile Data

Figure 2.3, below, shows the data from both altimeters against the predicted flight profile from RocketPy simulations. The main difference between these profiles is the altitude reached, which is attributed to wasted thrust from the off-nominal motor ignition. The predicted apogee was 4609 ft and the apogee reached was 4226 ft. Further analysis on the motor ignition is detailed in Section 2.6.1.

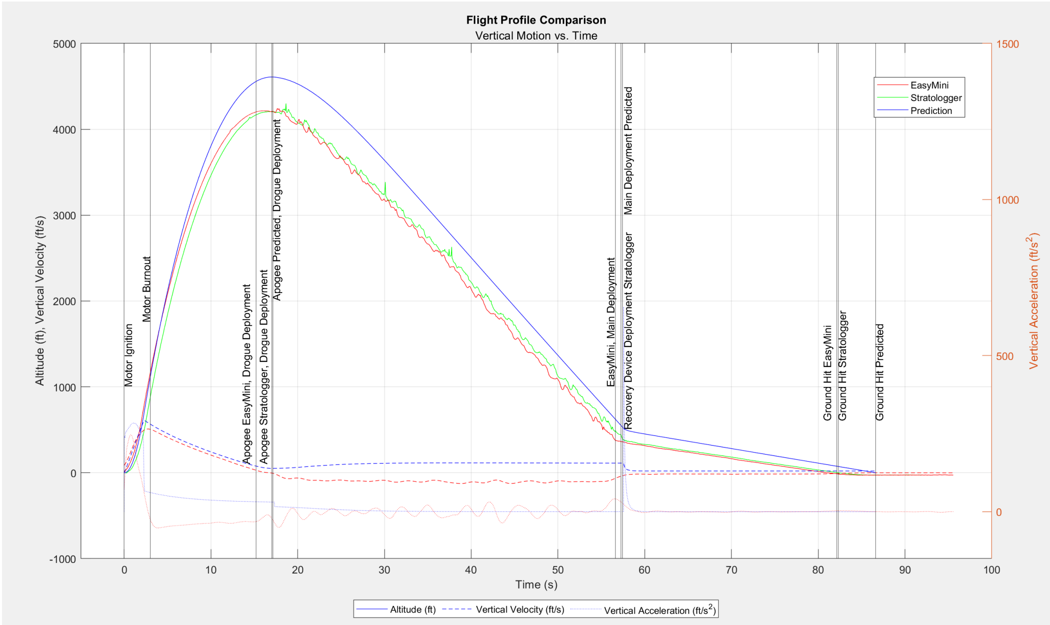



Figure 2.3: Flight Profile Comparison

## 2.3 Altitude Prediction

Altitude is predicted using various simulation suites. Generally, RocketPy is the most reliable. From this software, the predicted apogee was 4609 ft, close to the target of 4600 ft. These simulations were run at launch conditions prior to placement on the pad.

Table 2.1: Apogee Prediction Across Software Suites

| Software | Predicted Apogee |
|---|---|
| OpenRocket | 4701 ft. |
| RasAero II | 4854 ft. |
| RocketPy | 4609 ft. |

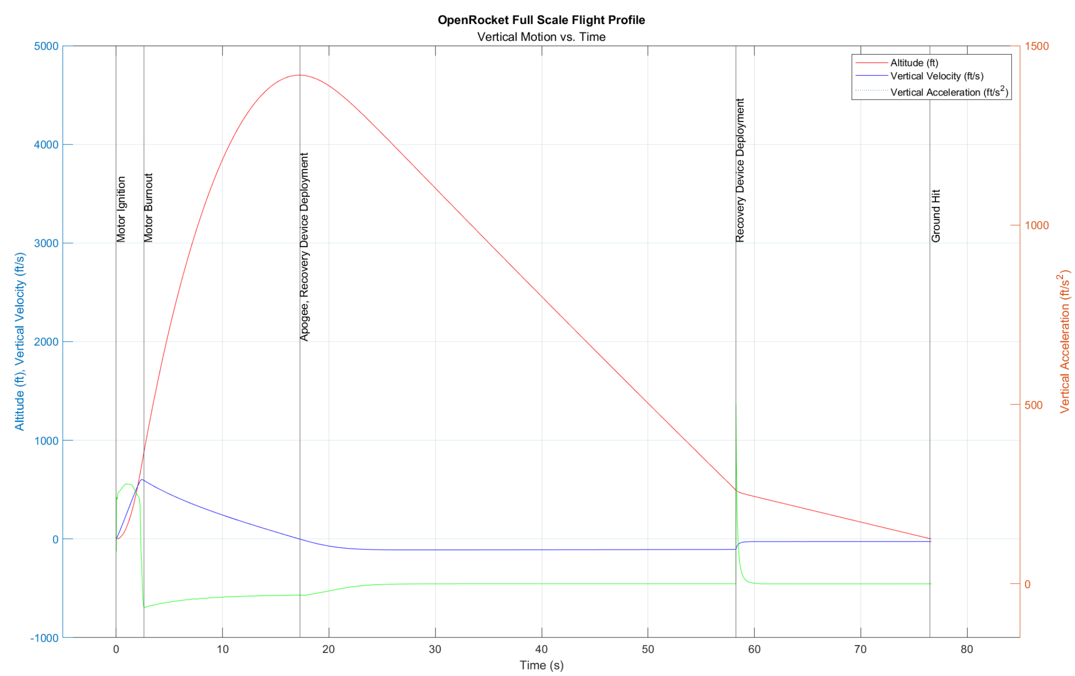



Figure 2.4: Flight Profile, Open Rocket

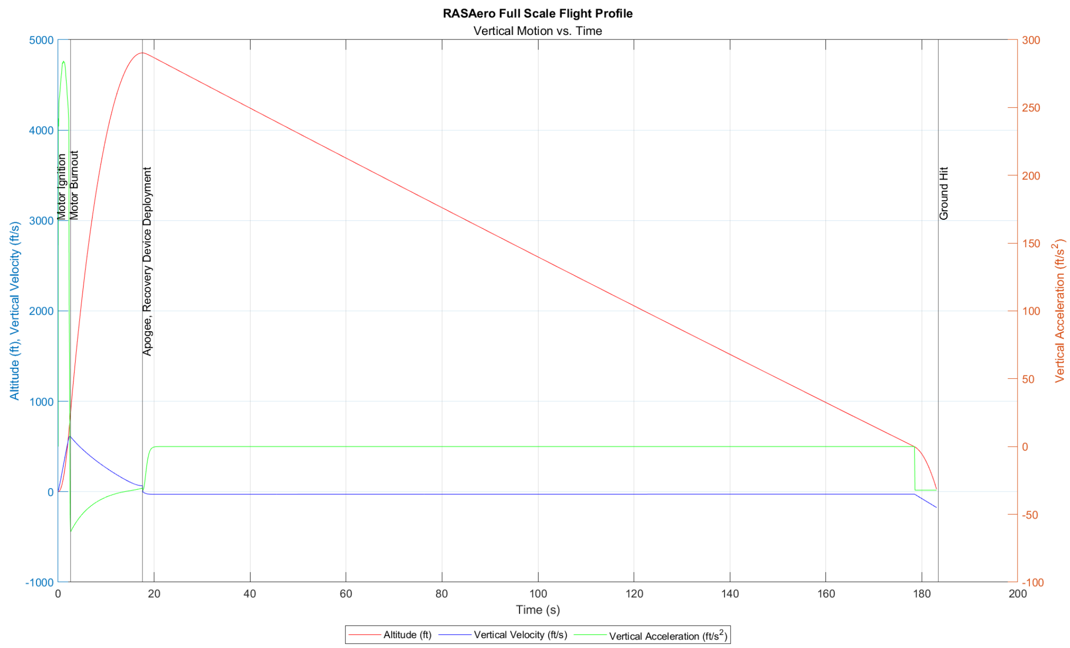



Figure 2.5: Flight Profile, RAS Aero II

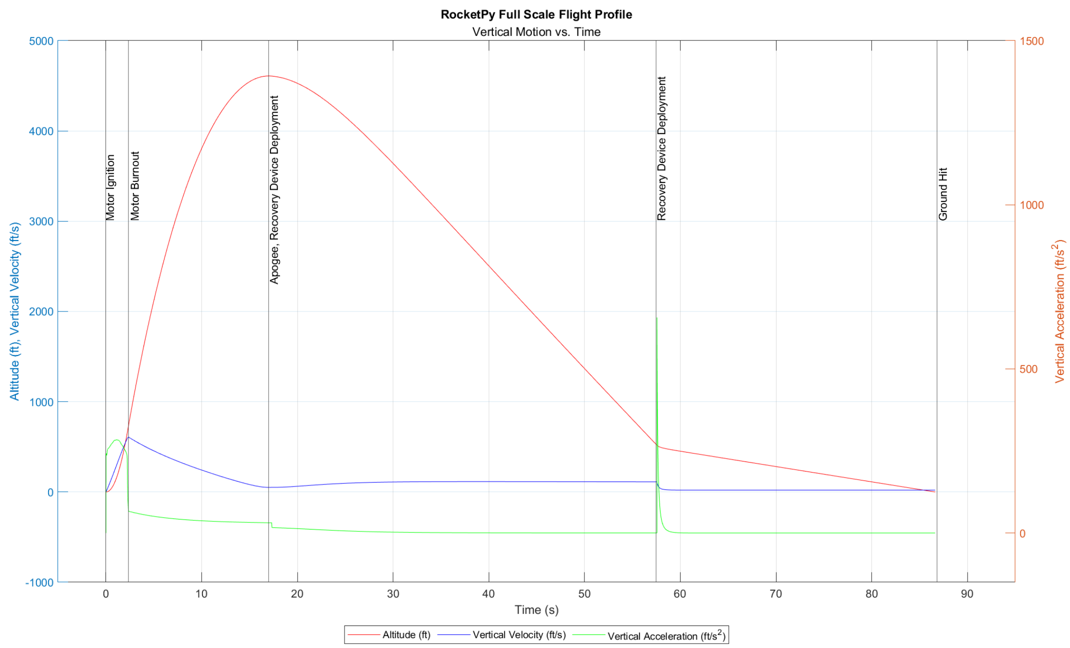
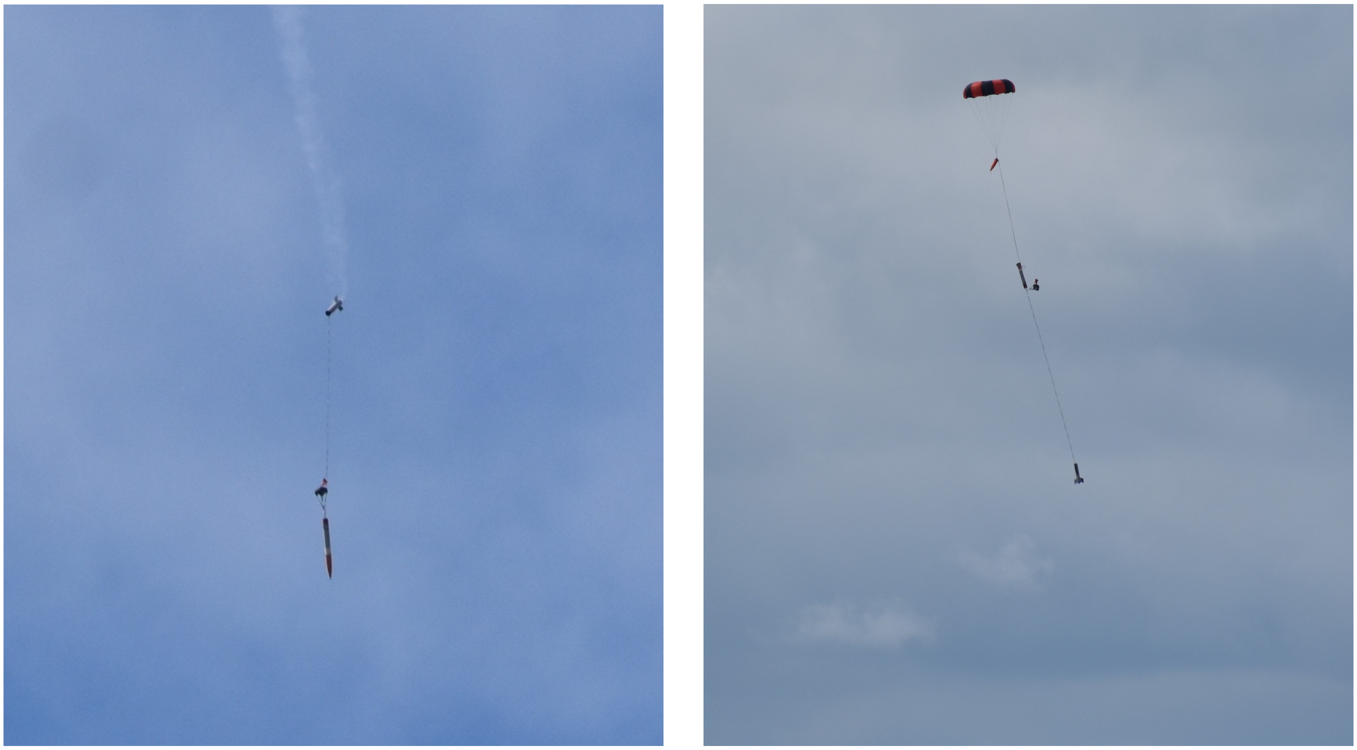



Figure 2.6: Flight Profile, RocketPy

## 2.4 Recovery System

On Launch Day, the recovery system performed nominally with the drogue parachute deploying and inflating successfully at apogee. It then descended in the drogue parachute configuration until 550 feet when the main parachute deployed and inflated successfully. The vehicle then descended safely under the main parachute until landing. Figure 2.7 below shows still images of the drogue and main parachutes captured during descent. As seen, both parachutes deployed and inflated as expected.



(a) Drogue Parachute Descent

(b) Main Parachute Descent

Figure 2.7: Images of the deployed parachutes during descent

### 2.4.1 Separation Events

All separation events were nominal, with all four deployment charges ignited as expected.

**Drogue Deployment**

At an apogee of 4226 feet, the primary drogue deployment charge was ignited and the vehicle separated at the AVAB/ Fin Can connection point, deploying the drogue parachute. One second later, the secondary drogue deployment charge was ignited, but was not necessary.

**Main Deployment**

At 550 feet, the primary main deployment charge was ignited and the vehicle separated at the Nose Cone/ Main Parachute Bay connection point, deploying the main parachute. At 550 feet, the secondary main deployment charge was ignited, but was not necessary. The main parachute deployed as expected without entanglement.

### 2.4.2 Landing Configuration

Due to the high winds on launch day, the Launch Vehicle was dragged a considerable distance by the main parachute after landing. A small portion of the trail left by the Fin Can can be seen in Figure 2.8 below.

Figure 2.8: Fin Can after it was dragged by the wind

Figures 2.9a and 2.9b show the configuration of the Launch Vehicle upon landing. In order to prevent the launch vehicle from being dragged further by the wind, a safety representative collapsed the main parachute and inserted it into the main parachute bay prior to retrieval by the team.

(a) AVAB and Main Bay Landing Configuration

(b) Fin Can Landing Configuration

Figure 2.9: Flight landing orientation

As shown in Figure 2.9, the Launch Vehicle landed as expected with the main parachute attached to the Nose Cone, the drogue parachute attached to the aft end of the AVAB, and all sections of the Launch Vehicle tethered together by the shock cord. Despite the appearance of the Launch Vehicle due to all the mud, no components of the launch vehicle sustained damage.

### 2.4.3 Kinetic Energy at Landing

The data from the primary altimeter, the PerfectFlite StratologgerCF, was used to obtain the drogue and main descent speeds for the flight. Figure 2.10 below shows the altitude plotted against time for this flight.

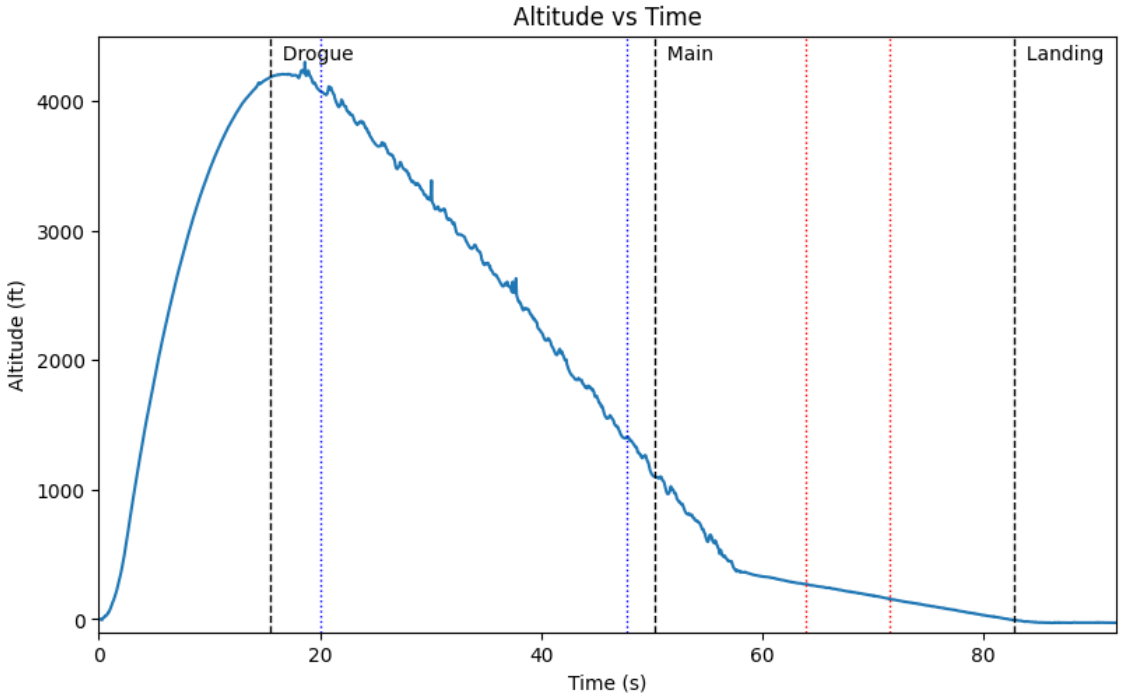



Figure 2.10: Primary Altimeter Altitude Plot

Since there was a lot of instability in the drogue and main descent rates just after parachute deployment and just before the Launch Vehicle touched the ground, only portions of these phases were used to compute the descent velocities. In Figure 2.10, the dotted blue lines show the start and end of the stable drogue descent used for calculations, and the dotted red lines show the start and end of the stable main descent used for calculations. Using those data ranges, the descent velocities were calculated by taking the change in altitude over the change in time.

$$Drogue\ Descent\ Velocity = \frac{47.75 - 20.00}{1401 - 4077} = -96.4fps \tag{1}$$

$$Main\ Descent\ Velocity = \frac{71.50 - 64.00}{160 - 271} = -14.8fps \tag{2}$$

Using those descent rates and the masses of all sections of the Launch Vehicles, their kinetic energies were calculated. The results can be seen in Table 2.2 below.

Table 2.2: VDF Kinetic Energy Values

| Section | Take-off Mass (lbm) | Landing Mass (lbm) | Drogue Descent Velocity (fps) | Drogue Kinetic Energy (ft-lbf) | Main Descent Velocity (fps) | Main Kinetic Energy (ft-lbf) |
|---|---|---|---|---|---|---|
| Nose Cone | 8.3 | 8.3 | 96.4 | 3148 | 14.8 | 28.3 |
| AVAB + Main Bay | 13.5 | 13.5 | 96.4 | | 14.8 | 46.0 |
| Fin Can + Drogue Bay | 18.3 | 14.2 | 96.4 | 2051 | 14.8 | 48.3 |

Table 2.3 below compares the data from the competition flight to the projected values. The predicted values are based on the masses of the vehicle during the flight and the recorded apogee of 4226 ft.

Table 2.3: Competition Flight Descent Data Comparison

| Parameter | Actual Value | Predicted Value | Difference |
|---|---|---|---|
| Drogue Descent Velocity (fps) | 96.4 | 90.5 | 6.5% |
| Main Descent Velocity (fps) | 14.8 | 16.7 | -11.5% |
| Total Descent Time (sec) | 67.3 | 68.6 | -1.9% |
| Nose Cone Landing KE (ft-lbf) | 28.3 | 36.1 | -21.6% |
| AVAB + Main Bay Landing KE (ft-lbf) | 46.0 | 58.6 | -21.6% |
| Fin Can Landing KE (ft-lbf) | 48.3 | 61.7 | -21.6% |

#### 2.4.4 Drift Distance and Descent Time

The vehicle launched from the coordinates of 34.89459°N, 86.61646°W and was recovered at the coordinates 34.88886°N, 86.61492°W. This brought the total drift distance to 2141 feet, after it was dragged by the wind, meeting the 2500 ft requirement.

While the drogue descent speed was slightly higher than anticipated and the main descent speed was slightly lower than anticipated, these values meet all team derived and NASA derived requirements. With an underestimation of drogue descent speed, and an over-estimation main descent speed, these differences canceled out to make the team's descent time prediction accurate to within 2%.

### 2.5 Air Brakes System

The Air Brakes performed as expected. The system correctly predicted a flight profile that was undershooting the target apogee, and kept the Air Brakes fins retracted.

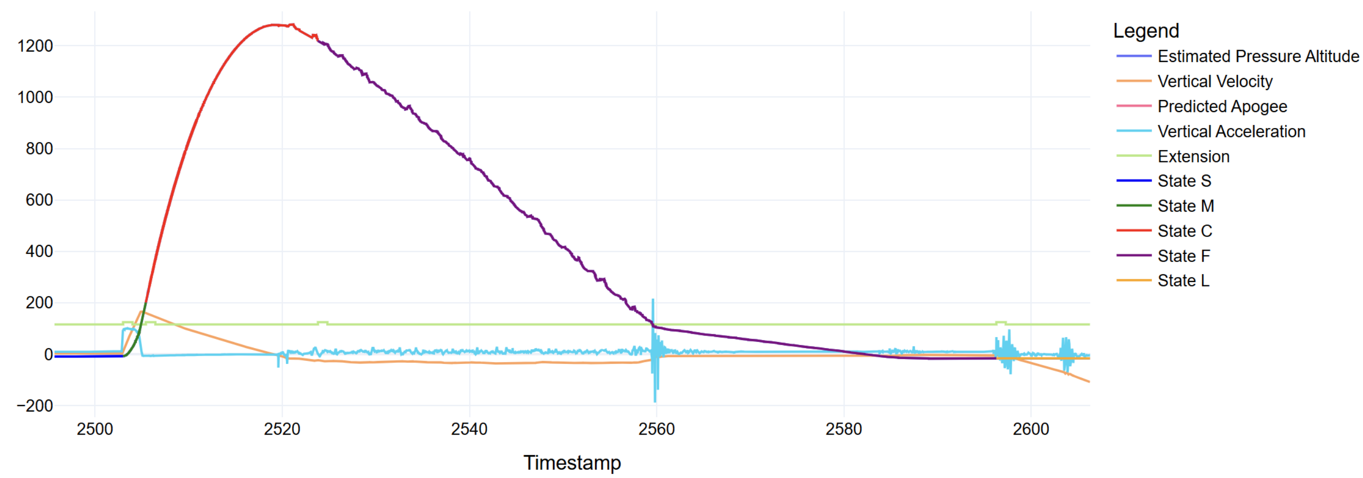



Figure 2.11: Flight data recorded by the Air Brakes system.

Figure 2.11 shows the flight data from the Air Brakes flight computer. The system correctly logged the entire flight, with an accurate flight profile prediction, as well as correct state changes. The predicted apogee was 4097ft which is a 3% error from the actual apogee recorded from the altimeters. This is an incredibly high margin of error, which was the largest the team has experienced so far, and was due to a culmination of several factors. While on the pad, the overall pressure in the area had increased enough to cause the pressure sensor to read a negative 26ft. The Air Brakes flight computer zeroes out the launch pad altitude when the script starts, while the altimeters will retroactively zero out after launch is detected. Another discrepancy was that the FSM transitioned into coast state while there was still some transient effects of the motor burn state. This can be attributed to the faulty ignition which caused the motor to burn unevenly. Due to the early state transition, the curve fit used for predicting the trajectory included some noise from the transition into coast which skewed the predicted trajectory slightly lower.

### 2.6 Flight Analysis

#### 2.6.1 Ascent Analysis

Table 2.4 details various attributes of the vehicles ascent. This compares the measured competition values to the predicted values from RocketPy simulation. The large differences are attributed to the faulty motor ignition.

Table 2.4: Ascent Analysis

| Attribute | Measured | Predicted | Percent Error |
|---|---|---|---|
| Apogee | 4226 ft | 4609 ft | 8.67 |
| Time to Apogee | 15.62 sec | 17.02 sec | 8.6 |
| Rail Exit Velocity | 63.78 fps | 70.18 fps | 9.6 |
| Maximum Acceleration | 246.8 fps$^2$ | 284.2 fps$^2$ | 14.09 |
| Maximum Thrust | 1932.05 N | 1765.3 N | 9.02 |
| Maximum Velocity | 509.78 fps | 608.21 fps | 17.61 |

As seen in Figure 2.12, the motor used in the competition flight at Huntsville, depicted by the purple line, had significantly lower performance than the previous flights flown with the same motor. Most notably, the initial peak thrust usually seen with these motors was not present. A majority of this performance loss can be attributed to a faulty ignition witnessed at the beginning of the launch.

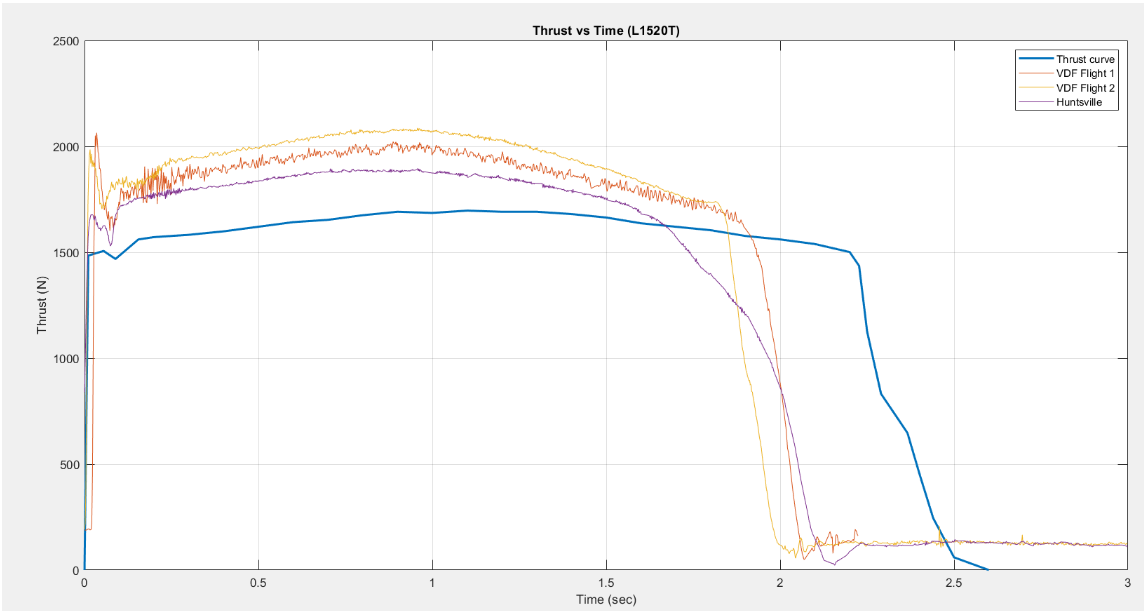



Figure 2.12: Thrust Curves as measured from Air Brakes flight log.

The onboard camera captured the events leading up to takeoff, which included the faulty ignition. Figure 2.13a is when there is some noticeable smoke indicating ignition of the motor. Figure 2.13b shows a small flame burning steady for about 3 seconds. Lastly, figure 2.13c shows the motor burning with max thrust, starting to leave the rail. The 3 second burn before full ignition had used significant fuel which ultimately resulted in a lower performance flight.

(a) Start of ignition. (b) Motor slowly burning. (c) Full ignition.

Figure 2.13: Stages of motor ignition.

### 2.6.2 Post Flight Simulation

This flight was subjected to off-nominal motor performance due to issues at ignition, leading to a delayed liftoff. The grains did not ignite properly, leading to a severe hit to motor performance. In Figure 2.14, below, the thrust curve from this flight was compared against the actual flight profile, showing the impact of this unpredictable error. This likely was a main contributor to the 300 ft altitude discrepancy. This adjustment brings the simulation within an accuracy of 29 ft with a percent error of 0.7%.

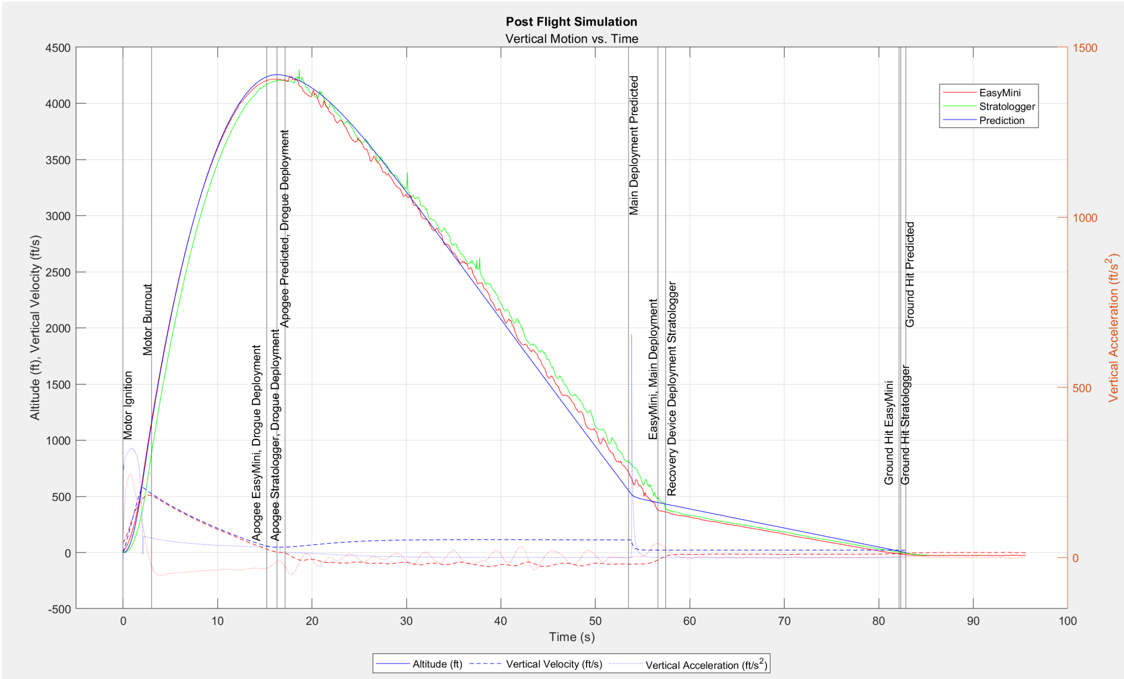



Figure 2.14: Post Flight Simulation

### 2.6.3 Estimated Drag Coefficient

The estimated coast phase drag coefficient for this vehicle was approximately 0.45. Based on flight data from the competition launch, the experimental value was approximately 0.43. This is a 0.45 percent difference. As shown in Figure 2.15, below, the drag coefficient curves follow similar profiles under flight conditions.

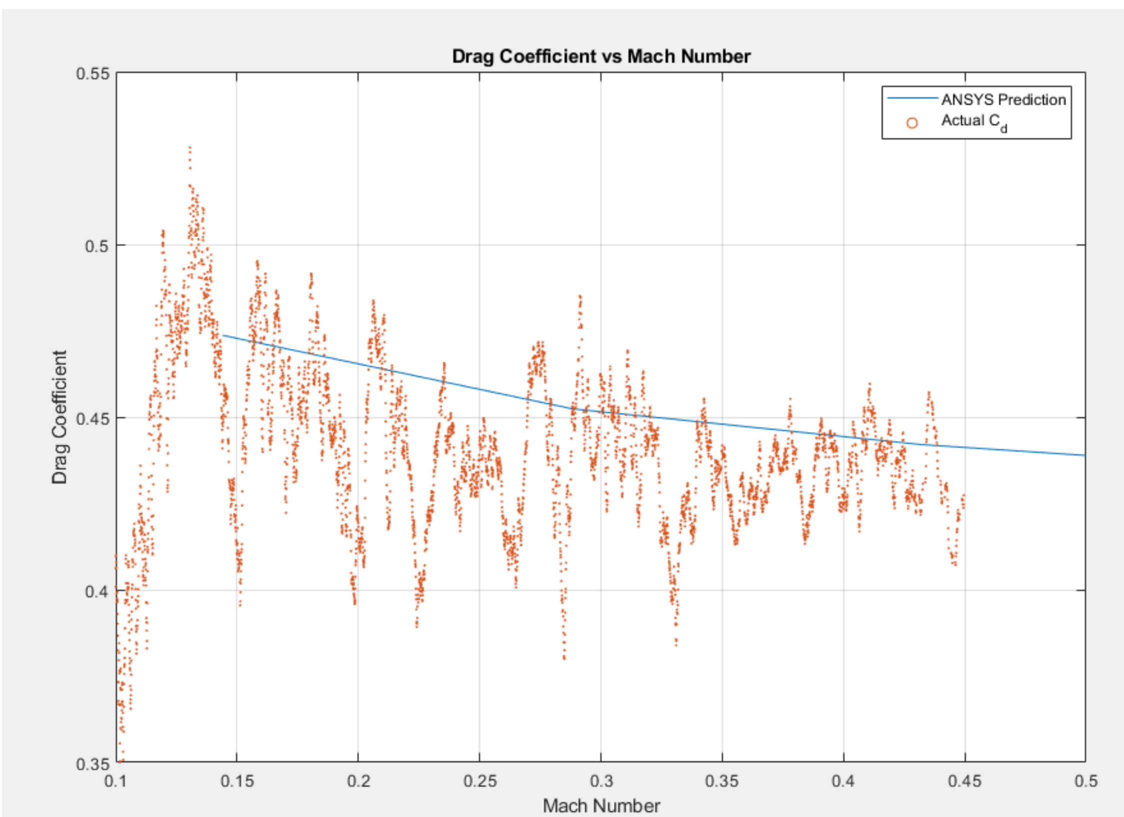



Figure 2.15: Drag Coefficient Comparison

# 3 Payload Performance

## 3.1 Payload Summary

The objective of the Wireless APRS Relay for High-altitude Environmental and Atmospheric Data (WARHEAD) payload was to record data throughout the launch and, upon landing, transmit key data points to a NASA receiver via the 2-meter band using APRS, all while safely retaining four STEMnauts.

During the flight, the WARHEAD successfully identified each phase of flight, including landing, and recorded all required data points. The transmission system functioned as intended, with the APRS message detected by the team's ground station. The capsule kept the electronics safe as well as successfully retaining the four STEMnauts throughout the entire flight. Additionally, the payload operated safely with no injuries or safety risks. Based on the team's predefined success criteria, the mission is considered a complete success, assuming the APRS transmission was also received and decoded by NASA, although formal confirmation has not yet been obtained.

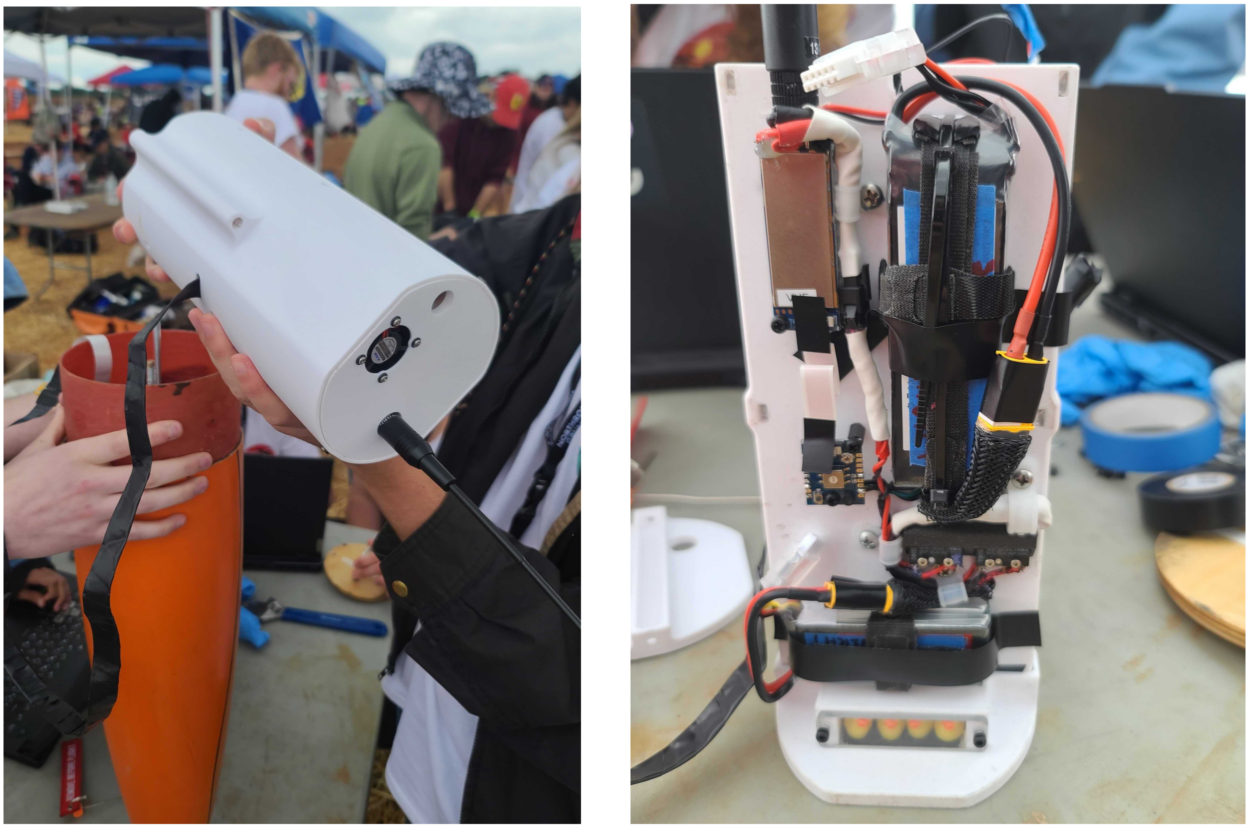
(a) STEMCRaFT without the capsule shell.

(b) STEMCRaFT with the capsule shell.

Figure 3.1: As-flown STEMCRaFT with and without the capsule shell.

## 3.2 Retention System

The STEMCRaFT retention system worked properly throughout the flight. The payload remained securely positioned between the Nose Cone's permanent ring bulkhead and removable bulkhead. Post-launch inspection confirmed that neither the bulkheads nor the STEMCRaFT sustained any damage.



(a) STEMCRaFT removed from the Nose Cone. (b) Electronics safely mounted post-flight.

Figure 3.2: Successful STEMCRaFT retention.

## 3.3 Payload Data Analysis

Included below is the transmission data as logged by the WARHEAD's Raspberry Pi.

Table 3.1: Transmitted Flight and Landing Data

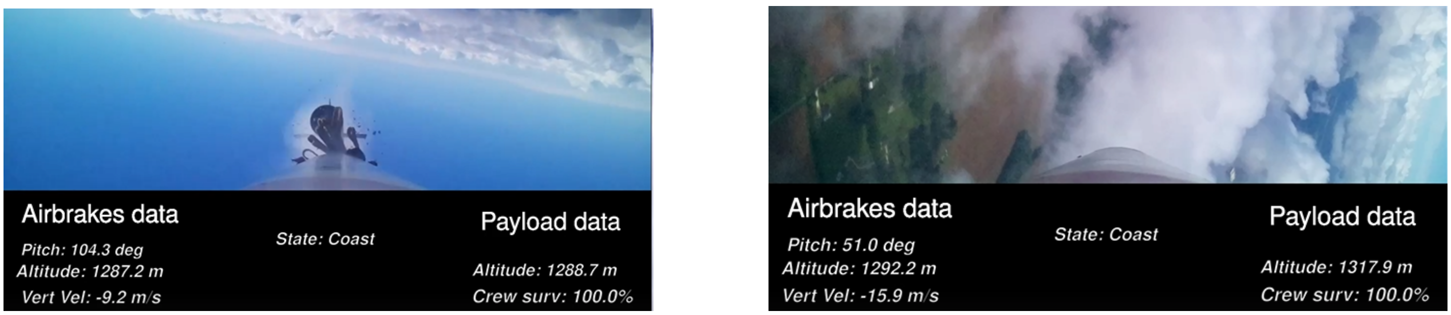
| Attribute | Value | Units |
|---|---|---|
| Temperature of landing site | 71.33 | °F |
| Apogee reached | 4310.35 | ft |
| CPU Power status(battery level) | 81.15 | % |
| TX Power status(battery level) | 75.99 | % |
| Orientation of on-board STEMnauts | (p= -4.27, r= -57.86, y= 151.41) | $^o$ |
| Time of landing(central time) | 09:46:37 AM | hh:mm:ss [AM/PM] |
| Maximum velocity | 622.26 | ft/s |
| Landing velocity(G-forces sustained) | -16.06 | ft/s |
| Calculated STEMnaut crew survivability | 48.89 | % |
| Landing Coordinates | (34.8890, -86.6160) | $^o$ latitude, $^o$ longitude |

The team was unable to decode the APRS transmission during the competition flight, due to interference surrounding the launch field. Despite this, the team was able to audibly confirm that the transmission has begun and concluded as desired through the APRS tones heard on the field. Due to this interference, no full packet could be received using the teams ground station, which has not been an issue at prior launches where fewer teams were present.

| Transmission Packet as logged by WARHEAD |
|---|
| "temp=71.33, apo=4310.35ft, batt=CPU:81.15% \| TX:75.99%, ori=(r=-4.27, p=-57.86, y=151.41), ToL=09:46:37, m_vel=622.26ft/s, l_vel=-16.06ft/s, surv=48.9%" |

The temperature recorded 45 minutes prior to launch was 62°F and the temperature recorded by the WARHEAD at landing was 71°F. This is a discrepancy of 13% and is a reasonable value. Without the fan running, the electronics may heat up the capsule past 90°F, as indicated with flight data before the incorporation of the fan. With the implementation of the ventilation system, a change reflected between PDR and CDR, the 71°F reflects a reading much closer to the temperature of the atmosphere. The recorded temperature of 62°F was also outdated for the time the launch vehicle landed, so the error should be even lower.

The STEMCRaFT reported an apogee of 4310.78ft, while the value recorded by the altimeter was 4226 ft. This is a discrepancy of 2% and is an overall acceptable value. From the onboard camera synced with the flight data, the pressure altitude recorded by the WARHEAD can be seen at drogue separation.




(a) Data at drogue separation.

(b) Data moments after drogue separation.

Figure 3.3: Apogee data at and moments after drogue separation.

As seen by the data from figure 3.3, the true apogee measured was 1290 meters or 4232 ft. When the drogue parachute inflated, the pressure sensor data momentarily read 1317 meters or 4320.86 ft. Since the reported value of 4310 ft. is lower than the recorded maximum value, it is apparent that the data was being filtered and averaged as intended, however, the filtering did not remove this outlier. The recorded value of 1290 m or 4232 ft., as seen by figure 3.3a, would have been a significant increase to the accuracy of the data reported.

The battery levels for the FUSE and SWITCH were 81.15% and 75.99% respectively.

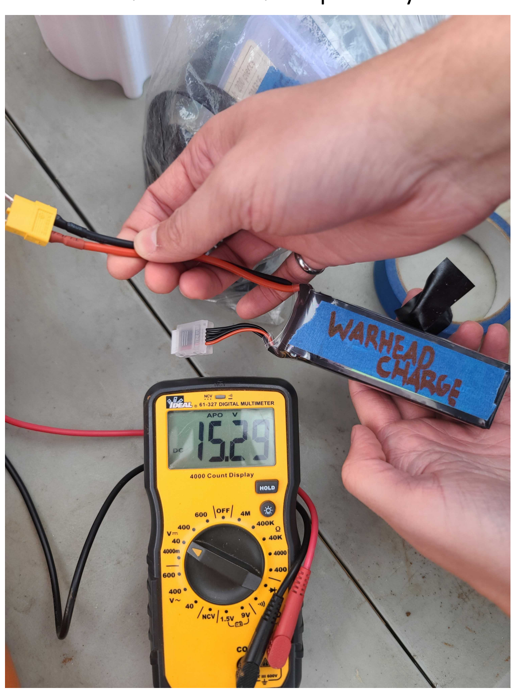



Figure 3.4: FUSE battery voltage after recovery.


Figure 3.5: SWITCH battery voltage after recovery.

These battery level percentages correspond directly to the voltages recorded during recovery, indicating the battery level sensing system functioned as intended.

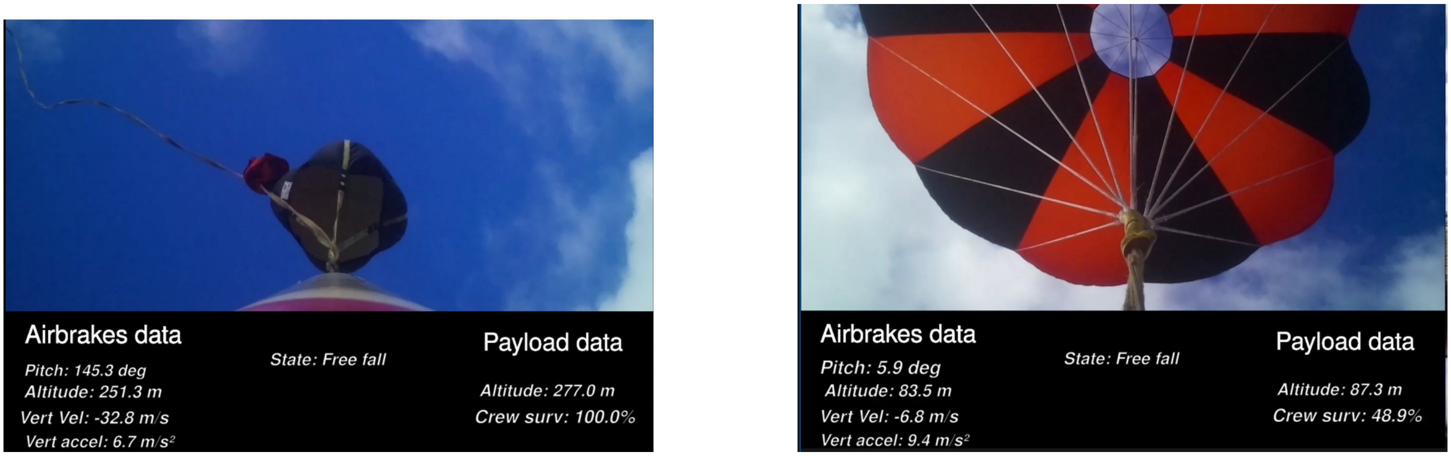
The landing orientation was reported as Pitch = -4.27°, Roll = -57.86°, Yaw = 151.41°. The orientation was measured based on a 9DoF IMU with an integrated magnetometer, using a Davenport filter based on the data from the magnetometer and accelerometer. The resulting orientation is taken as an absolute orientation based upon the initial orientation of the WARHEAD at time of initialization. There is no error in integrating for position/orientation, so the reported orientation is trusted as reliable data.

The time of landing was reported as 09:46:37 AM, which is an accurate measurement. The real-time clock was calibrated prior to launch, through the use of a WiFi connection to a world clock, and does not have any substantial error. This recording corresponds correctly to the time of landing, as recorded through team member videos and photographs of the launch.

The maximum velocity was reported as 622.26 fps while the altimeter data measured 509.78 fps. This is a discrepancy of 22%, with the error being attributed to abnormal pressure effects during the initial ascent of the launch vehicle. The velocity is integrated from the height measured from the pressure sensor, which is sensitive to noise. The filtering done to the data could have been more intense as to catch any outliers, such as the data point reported as 622.36 fps.

The landing velocity was measured to be 16.06 fps while the recovery altimeter recorded a descent speed of 14.8 fps under the main parachute. This is a discrepancy of 8%, which is within an acceptable margin of error. The difference can largely be attributed to how the different systems calculate landing velocity, with the WARHEAD using a rolling average, which could have been disrupted during the chaotic kinematics that take place during touchdown of the different sections of the launch vehicle.

The reported crew survivability was 48.89%. This metric starts at 100% and will reduce based on a combination of magnitude and duration of positional, and rotational acceleration above a predefined threshold. The algorithm was tweaked using prior flight data to begin impacting STEMnaut survivability after the burn phase, and to reduce the STEMnaut survivability by a reasonable percentage throughout the flight. In the immediately prior flight, the STEMnaut survivability reached 28%, indicating a consistent algorithm.



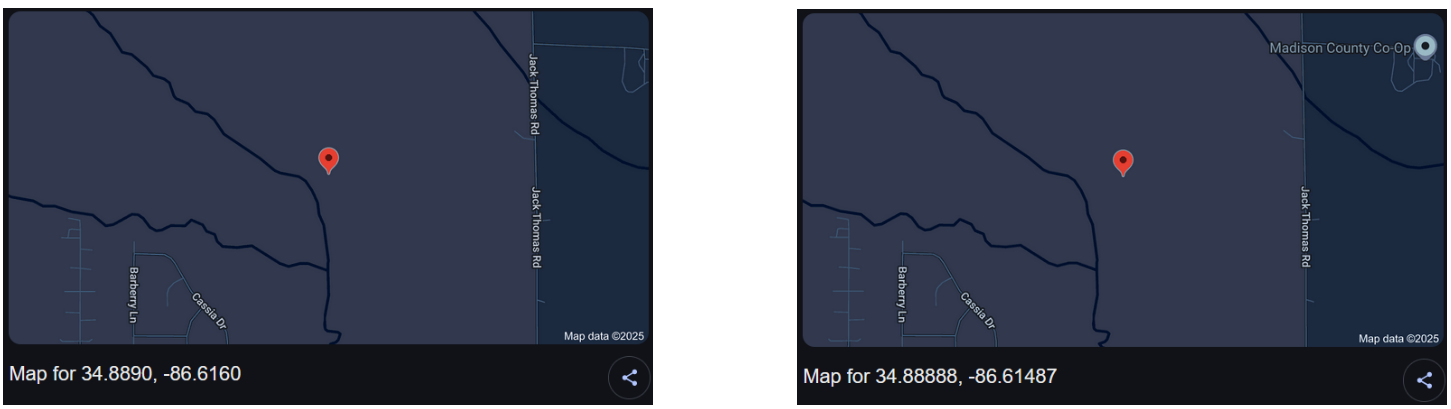

(a) Crew survivability before main parachute deployment.

(b) Crew survivability after main parachute deployment.

Figure 3.6: Crew survivability measurements before and after main parachute deployment.

As seen by 3.6, nearly all reduction of the survivability metric is attributed to main deployment, which makes sense, as this event can experience high G forces. Despite the main deployment being a traumatic experience, 2 of the STEMnauts were unharmed. Unfortunately, the other 2 STEMnauts did not survive. Although upsetting, these results are not unexpected, as the survivability metric reported close to 50%. This data shows that the survivability metric was an accurate representation of the forces experienced during the flight.

The reported landing coordinates were (34.8890, -86.6160), which is comparable to the recovery GPS data. As seen by Figure 3.7, the WARHEAD recorded landing coordinates nearly identical to the recovery GPS. The discrepancy of the recovery GPS reporting further east can be largely attributed to the rocket being dragged that direction after the initial landing.




(a) Landing coordinates from STEMCRaFT.

(b) Landing coordinates from recovery GPS.

Figure 3.7: Landing coordinates from STEMCRaFT and recovery GPS.

## 4 Project Reflection

### 4.1 Scientific Value Achieved

The team used the engineering design cycle to develop a launch vehicle capable of carrying a scientific payload designed to record and transmit relevant flight and landing sight data. The payload developed successfully measured and transmitted all 8 possible data points required by the competition, demonstrating sensor accuracy and reliability'. This supports the use of the payload in missions to collect and transmit data that may be relevant to human survivability. The scientific value of the payload thus lies in the accuracy of the sensors, the reliability of the transmission, and it's successful integration in the launch vehicle.

## 4.2 Lessons Learned

### 4.2.1 Vehicle Lessons Learned

The biggest issues encountered during the vehicle development process were with the Subscale vehicle. The airframe material difference from the full-scale design, the attempt to minimize required section lengths, and the excessive weight at the aft from the initial RMFS materials resulted in a very ”inflexible” vehicle that required significant, permanent forward ballast to meet stability and CG position requirements. These issues were rectified by making minor adjustments, adding some length to the overall vehicle design, and incorporating a forward adjustable ballast system. This ensured the full-scale vehicle had the flexibility to perform as required despite uncertain final payload and other component masses until later in the project development process.

The importance of material choice and robust structural design was well understood from the start, but was reinforced multiple times throughout the project cycle. Water landings, ground impact, and post-landing drag from the main parachute were known to be potentially more hazardous to vehicle survivability than forces experienced in flight. Understanding this, destructive testing was performed early on in the design process to test viability of some initial novel fin attachment methods which proved to be insufficient. The final designs and material choices of the overall airframe and Removable Modular Fin System were justified after encountering each of the hazards listed above during the project cycle. Knowing this lesson beforehand allowed for development of a highly resilient and reusable vehicle.

One issue that was not considered during the development process was the free-fall behavior of the two main vehicle sections after drogue deployment separation at apogee. Due to the small size of the drogue parachute attached to the forward section, and the large surface area of the fin can, the fin can tended to fall at roughly the same velocity or slightly slower than the forward section. This created a collision hazard where the fin can or drogue shock cord could interfere with main parachute deployment. This was encountered during the second VDF attempt, and while not catastrophic, created an off-nominal main parachute opening and higher than allowed kinetic energy at landing. To attempt to mitigate this, the team swapped to a slightly larger drogue parachute for the final VDF and competition flights. This slightly improved the drogue descent orientation, yet the hazard was still present. Fortunately, no further issues were encountered, and descent requirements were met. This interference hazard will be considered earlier on in future projects and competitions.

During the course of this competition, apogee prediction was a source of error. Many launches sustained high winds which reduced the accuracy of altitude predictions. In order to correct this, upper level wind simulations were implemented and weather cocking due to wind was estimated. This significantly increased the accuracy of apogee predictions. Additionally, it was found that thrust curves provided by the motor supplier are not perfectly accurate. Implementing motor thrust curves from previous launches can significantly improve apogee prediction. In the future, hopefully these considerations can be implemented more effectively.

### 4.2.2 Recovery Lessons Learned

This team ran into several problems with the recovery system this year and learned a lot through the three VDF attempts and the final competition launch in Huntsville. The most important lesson was the need to fully integrate the recovery system exactly as it will be flown and to physically pull the vehicle apart in the manner that it will separate during flight. This is helpful in visualizing any potential issues with the system and catching any problems in a safe and controlled manner.

The team also experienced a lot of variations in descent velocity with the drogue and main parachute when flown in the exact same configuration, but on different days. This has encouraged the team to lean on the more conservative side for recovery descent velocity and descent time requirements in future years.

### 4.2.3 Payload Lessons Learned

The Payload Team encountered several challenges throughout the competition that provided important lessons for future work. One takeaway was the importance of using high quality components. Lower quality parts led to reduced data quality and a higher risk of failure. The team also learned to start working as early as possible. Delays in development limited the time for troubleshooting problems and thoroughly testing the payload systems.

Another significant takeaway was the danger of working on powered electronics, which led to critical damage to flight hardware such as the Raspberry Pi. Additionally, the lack of backup components caused delays in the construction process when replacements were needed. Spare parts should be purchased early if the budget allows. Finally, redundant component retention methods should be used to ensure reliability in flight conditions. This was highlighted when insufficient retention methods caused a battery to disconnect mid-flight, preventing the STEMCRaFT from completing its objective.

In future competitions, extensive fault analysis should be utilized to assess risks during assembly and fabrication, in addition to the current analysis on competition performance. Having a more detailed risk assessment would allow the team to more easily assess which components may be prone to damage/failure, and plan accordingly. Applying this risk management method could have aided in reducing time lost to electronics failure, and reduced the expenditures required to replace damaged components.

### 4.2.4 Air Brakes Lessons Learned

For the first few failed attempts, the team thought that the Air Brakes system was having mechanical issues and that the software was not the issue. It was not until the team put a camera on board to view the flight that a critical software issue was found. There was a 10 second latency from when the IMU was recording data to when the Pi was able to process it. After some further optimizations, the software was fixed and the next flight proved to be a successful Air Brakes launch. The team learned to be open minded about the causes of a system failure and to be thorough when trying to find the source of the issue.

The team also realized a little too late that the declared apogee was too high to account for the weight creep and potential winds that could be expected on launch day. The simulations initially used did not take winds aloft into account due to the difficulty of making an ideal prediction, all of which led to declaring an apogee that did not leave enough room for our competition flight. An important note to this is that the motor experienced an off-nominal ignition which took a few hundred feet off our flight and is something that is impossible to account for. It is now understood that a lower declared apogee for our given design would have not only benefited the Air Brakes system by reducing the possibility that the rocket would undershoot the target apogee, but it would also in theory help recovery meet descent times while using bigger parachutes, giving more margin for error across multiple systems.

### 4.2.5 Overall Project Lessons Learned

Many lessons have been learned in regard to overall project management, mainly in regard to completing tasks on time and properly delegating work. Beginning with the submission of the project proposal and PDR, it became clear to the team that although the work on the launch vehicle and payload was complete for the milestone, documentation needed to be started and prioritized earlier. This led to a large proportion of the documentation being completed within a couple of weeks of the milestone deadline. This often did not limit the team on the amount of work produced, but the quality of the work and the amount of time left at the for review of the document at the end. With more time between the completion of document writing and the milestone deadline, peer review could have been better implemented, resulting in increased consistency and caliber of the work submitted. This would be implemented with stronger enforced soft deadlines and a commitment to starting work on documentation earlier.

Another recurring issue throughout the project was ordering components on time and experiencing shipping delays. Often, construction was completed well ahead of schedule and component arrival was the limiting factor. Although this did not negatively affect the intended launch schedule, it added additional stress on the team during construction and reduced the testing timeline completed prior to launch. Had a vehicle component failed during testing, there would not have been enough time to redesign and reconstruct the vehicle prior to the predetermined launch date. In regard to payload testing, there were often electrical issues that compromised the performance of some components, resulting in an inoperable payload system. Had the budget allowed, extra components should have been ordered prior to testing, allowing for unforeseen electrical mistakes to be made without compromising payload performance prior to a launch.

One final lesson learned in the overall completion of the project was the proper delegation of work. At the beginning of the project, some of the team member roles were not clearly defined. This initially led to some members taking on responsibilities intended for a specific other team member, both to learn the foundational aspects of that role and to ensure the task was completed fully. Additionally, this led to the uneven distribution of work between team members for initial future milestones, as the workload between roles changed throughout the duration of the project. A potential solution could have been clearly defining roles at the start of the project, while accounting for potential changes, and revising responsibilities as the project developed.

## 4.3 Successful Systems

The vehicle airframe and structural sub-assemblies performed very well throughout this project and were primarily responsible for the reusability of the launch vehicle. Specifically, the G12 fiberglass airframe and the G10 fiberglass fins proved to be highly resilient to a very hard landing during the first VDF attempt, multiple instances of being dragged long distances through soil post-landing, and being submerged in water. The robust nature of the material and its connections meant that no rebuilding of the airframe was needed after off-nominal events,though extensive cleaning was required.

Similar to the airframe body, the Removable Modular Fin System proved to be highly resilient throughout the project and provided a robust system for motor mounting/retention and recovery gear anchoring. While the team was fortunate to not experience fin damage during any our flights, we would have been prepared to quickly swap out a fin or other components if needed. The fully modular nature also allowed for complete disassembly and inspection of all components after the hard landing experienced during the initial VDF attempt, which allowed the team to confirm the vehicle was still safe to fly.

The payload retention system in the Nose Cone/Payload bay proved to be a simple, effective, and easy to use design while not being overbuilt. The WARHEAD capsule body was designed to integrate perfectly into the payload bay and was retained via the aft bulkhead. This design provided ample security for the primary payload without the need for additional adjustments during launch preparation.

In the Nose Cone, the adjustable ballast system allowed flexibility in tuning vehicle stability. This allowed the team to fly the launch vehicle as close to the required minimum stability at the competition launch in order to minimize any weather-cocking effects from wind gusts.

After the team's failed VDF, small iterations were made in the sizing of the drogue parachute to allow for a more consistent recovery system. This resulted in a fully successful recovery during the team's final VDF flight, as well as the competition flight at Huntsville. Not only did the team safely recover the launch vehicle, the team also achieved all available bonus points for recovery during the final competition launch.

The Air Brakes system was successfully retained and remained functional for the entire flight. The flight computer successfully predicted a flight profile below the target apogee, and the control algorithm correctly kept the fins retracted the entire flight.

The WARHEAD payload fulfilled its objective of collecting and transmitting the required data to the NASA ground station while safely retaining four STEMnauts throughout the flight. Following a series of hardware and software issues throughout the year, the team implemented design and programming improvements that led to a fully functional system during the final flight. The electronics and software performed as intended, providing stable power, accurate sensor data, and radio transmission during the mission. The modular design of the STEMCRaFT further supported this success through simple assembly, easy troubleshooting, and effective protection of internal components during launch and recovery.

## 4.4 System Failures

No outright system failures were experienced during the competition flight, and any issues or oversights encountered during the project were rectified by its conclusion.

The exact cause of the off-nominal ignition experienced during the competition launch could not be ascertained, however, the team conjectures that there was an issue with the igniter. The motor grains were all stored properly in a cool and dry environment and inspected prior to motor assembly. All additional motor components were inspected and a proper motor assembly procedure was followed. Furthermore, post-flight inspection of the phenolic liner and combustion remnants did not indicate any abnormalities.

## 4.5 Overall Experience

### 4.5.1 Vehicle Experience

The design intent for the vehicle initially described in the mission statement at the Preliminary Design Review milestone was "to enable successful execution of the payload mission while being safe, reliable, and reusable." Through this project, the team was highly successful in developing a launch vehicle that accomplished this mission while incorporating innovations such as the Air Brakes payload. While some lessons were learned along the way, the overall development process went smoothly and resulted in a well-designed, well-built, and capable launch vehicle.

The manufacturing process was executed safely and efficiently with a high-degree of teamwork and precision. Process improvements were implemented in bulkhead fabrication that greatly reduced work hours, required resources, and waste. The use of 3D printed guides and precision tools during manufacturing also contributed greatly to the overall quality and consistency of the launch vehicle.

A high degree of collaboration within the team led to smooth integration of all vehicle and payload subsystems, and an emphasis on simulations and testing during the design process ensured that the final vehicle met or exceeded all requirements.

### 4.5.2 Recovery Experience

The primary objective of the recovery system has always been to get the launch vehicle back to the ground safely, while meeting all of NASA's descent time, drift distance, and kinetic energy requirements. The secondary objective for the recovery system was to meet the bonus points requirements for kinetic energy at landing and overall descent time, which the team successfully completed in the final competition flight at Huntsville.

Through designing and prototyping AV sleds, testing altimeters, GPS' and parachutes, as well as doing general component and safety research, the team has gained invaluable experience related to recovery systems in High-Powered Rocketry.

Throughout the competition the team has gotten first hand experience in the entire engineering design process with a strong emphasis on testing and vehicle verification. Despite numerous altimeter and ejection tests, on two separate flights, one of the four ejection charges did not ignite properly, further reinforcing the importance of redundancy in a recovery system.

### 4.5.3 Payload Experience

The goal of the payload team was to complete the NASA payload challenge by successfully recording and transmitting all required data points, while also creating an innovative solution to the problem. Despite setbacks such as hardware failures, design changes, and software issues, the team achieved reliable data transmission with sufficient accuracy.

Throughout the year, multiple iterations of the STEMCRaFT were flown on both subscale and full scale launches, providing valuable hands-on experience constructing the payload. The team gained practical skills in electronics, programming, radio communication, wire management, and 3D printing.

#### 4.5.4 Air Brakes Experience

Integrating Air Brakes with the competition rocket came with many challenges. For the 2023-24 academic year, the team started with a new design and software implementation for the Air Brakes system that was tested on some subscale flights outside the scope of the NASA SL competition. Building off the research from last year, the team was eager to implement the system onto the competition rocket for the 2024-25 Student Launch competition. Re-designing the Air Brakes system for a Full-Scale rocket took extra time and a few iterations before the final design was achieved. The software implementation was also tedious. It took 7 flights before a critical software issue was caught, and the team finally had a successful Air Brakes deployment. Overall, the team has built a working system that next year's competition team can build on and improve.

#### 4.5.5 Overall Project Experience

Overall, the team considers the project a success. All milestones were completed on time, the vehicle was successfully launched and did not sustain significant damage throughout flight, and the payload challenge was fully and accurately completed. This project was a valuable experience between all members, using the full engineering design cycle to develop the project over the course of 9 months. The team gained experience in hands-on problem solving, construction and testing methods, and analysis methods that resulted in the production of high quality work. The team is proud of the work that has been completed throughout the course of the project and the knowledge gained will be applied to future projects and careers. The lessons learned from the project will be passed on to future teams to further increase performance in the competition and build upon all knowledge gained.

### 4.6 Time Spent on Project

The team spent a total of 5212 hours working on all of the deliverables for the 2025 NASA Student Launch Challenge.

Table 4.1: Time Spent on Each Individual Milestone and Project Section

| | Proposal | PDR | CDR | FRR | FRR Addendum | PLAR | STEM Engagement | Social Media | Launch Activities | Total |
|---|---|---|---|---|---|---|---|---|---|---|
| Hours | 256 | 1052 | 1021 | 1972 | 250 | 279 | 140 | 200 | 42 | 5212 |

Additionally, a visual time breakdown can be seen in the pie chart below. It is important to note that FRR took a considerably larger amount of time due to three VDF/PDF attempts. Two launches occurred prior to the FRR submission deadline and one launch occured prior to the FRR Addendum submission deadline. Also, the leadership roles for each respective team are as follows.

- **Project Management Team:** Team Lead, Integration Lead
- **Vehicle Team:** Structures Lead, Recovery Lead, Aerodynamics Lead
- **Payload Team:** Payload Electronics Lead, Payload Software Lead, Payload Structural Integration Lead
- **Officer Team:** Safety Officer, Treasurer, Outreach Officer, Social Media Officer

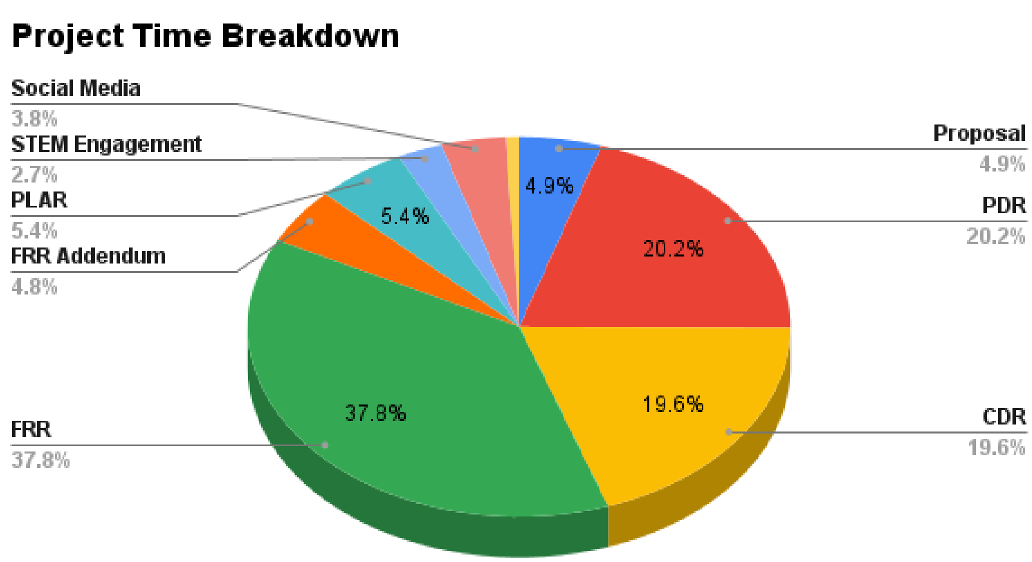



Figure 4.1: Breakdown of hours spent on project milestones and events.

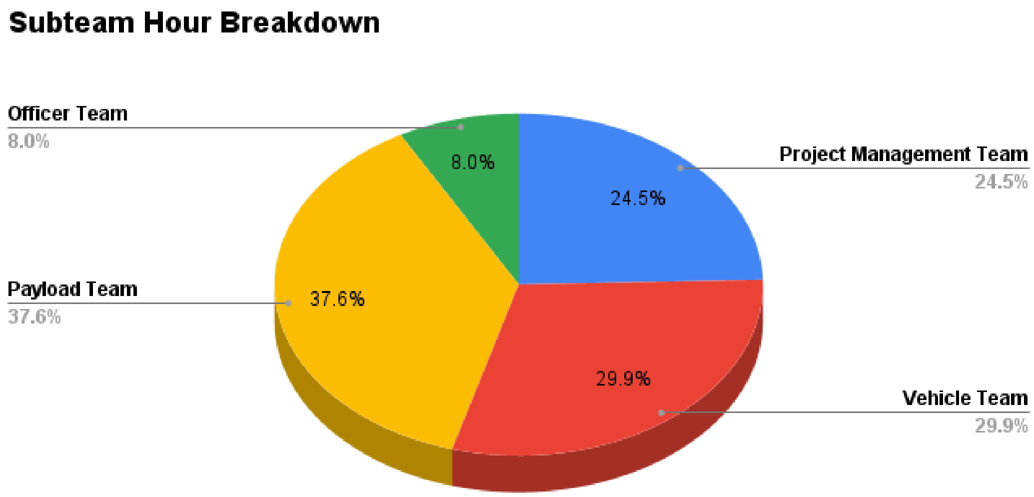



Figure 4.2: Breakdown of hours spent per subteam.

## 4.7 STEM Engagement Summary

In the 2024–2025 NASA SL year, we engaged 2,108 children across 18 STEM outreach events. These 18 events included 7 educational direct engagement events, 9 indirect engagement outreach events, and 2 direct engagement outreach events (Figure 4.3). In these events, we were able to teach a variety of concepts through bottle rockets, straw rockets, and other rocketry presentations. With bottle rockets, we were able to teach basic rocket stability by explaining how different choices in the construction of rockets can affect the flight. We also discussed basic rocket propulsion by deciding how much water and air we want to fill the bottle. With straw rockets, we delved into more rocket construction and taught the kids about the sections of a basic rocket model. Our presentations were designed to give a general overview of our club and what it does in the various subteams. We also would give a small lesson that would prepare the kids for the upcoming activity. At these presentations we would bring various visual aids such as previous competition rockets, experimental projects from our WolfWorks team, and other various rocket components and experimental payloads. Some specific items we regularly bring to events are last year's rocket 'Shake N' Bake' and the payload 'SAIL'. We also consistently bring experimental rockets such as our square rocket 'Squakit' to explain the rocket construction process.

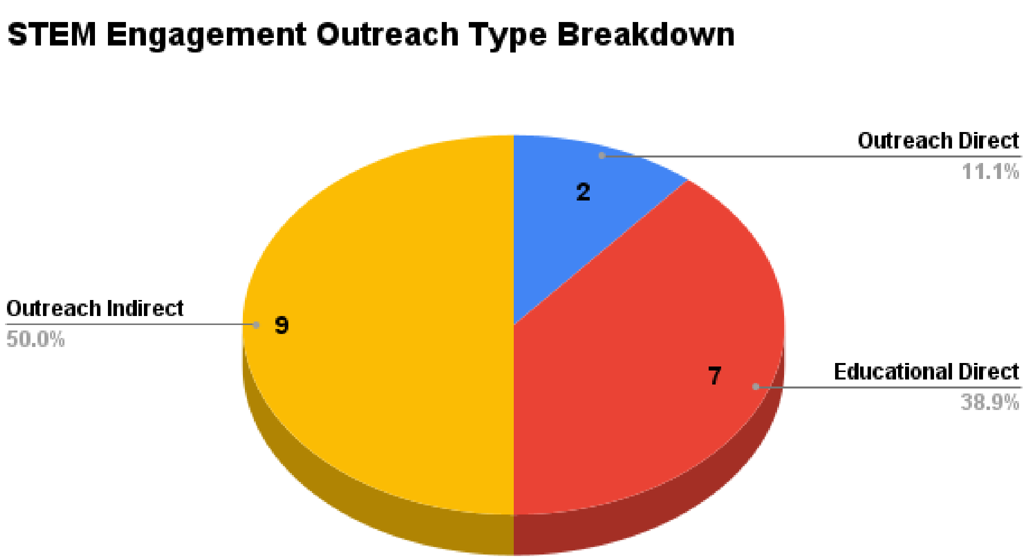



Figure 4.3: Breakdown of STEM engagement outreach types.

Of the 2,108 children we were able to work with, at STEM events, a majority were in elementary school. This is because a lot of open events such as STEM nights and museum events attract a younger audience. A total of 1,217 came from elementary school students. Our second highest total was middle schoolers, at 714. High school students and undergraduates combined for 177 total. This can be seen in Figure 4.4 below. For our events, 7 were educational direct engagement events, 9 were Indirect Engagement Outreach events, and 2 were Direct Engagement Outreach events (Figure 4.3).

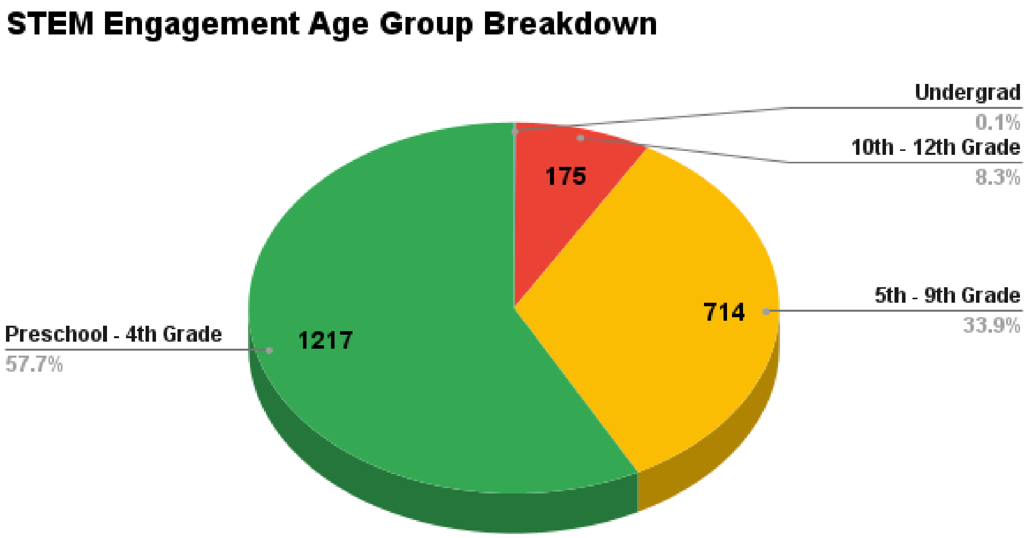



Figure 4.4: Age group breakdown of STEM outreach participants.

## 4.8 Final Budget Summary

Table 4.2 shows the total spending of the team and Table 4.3 shows the total funding of the team throughout the project. It is important to note that 63.5% of the budget was dedicated to travel to Huntsville for the competition launch, due to the amount of students that the team brought to the competition.

Table 4.2: Project Spending

| Spending Category | Amount Spent |
|---|---|
| Subscale Structure | 552.99 |
| Full-scale Structure | 1428.28 |
| Payload | 1102.08 |
| Recovery | 1243.81 |
| Miscellaneous | 1983.25 |
| Travel | 11000 |
| **Total** | **17310.41** |

Table 4.3: Project Funding

| Organization | Fall Semester | Spring Semester | Academic Year |
|---|---|---|---|
| NC State Student Government | $796 | $596 | $1,392 |
| North Carolina Space Grant | $5,000 | $0 | $5,000 |
| Engineer Your Experience | $0 | $8,500 | $8,500 |
| Educational and Technology Fee | $0 | $2,500 | $2,500 |
| **Total Funding:** | | | **$17,392.00** |
| **Total Expenses:** | | | **$17,310.41** |
| **Difference:** | | | **$81.59** |

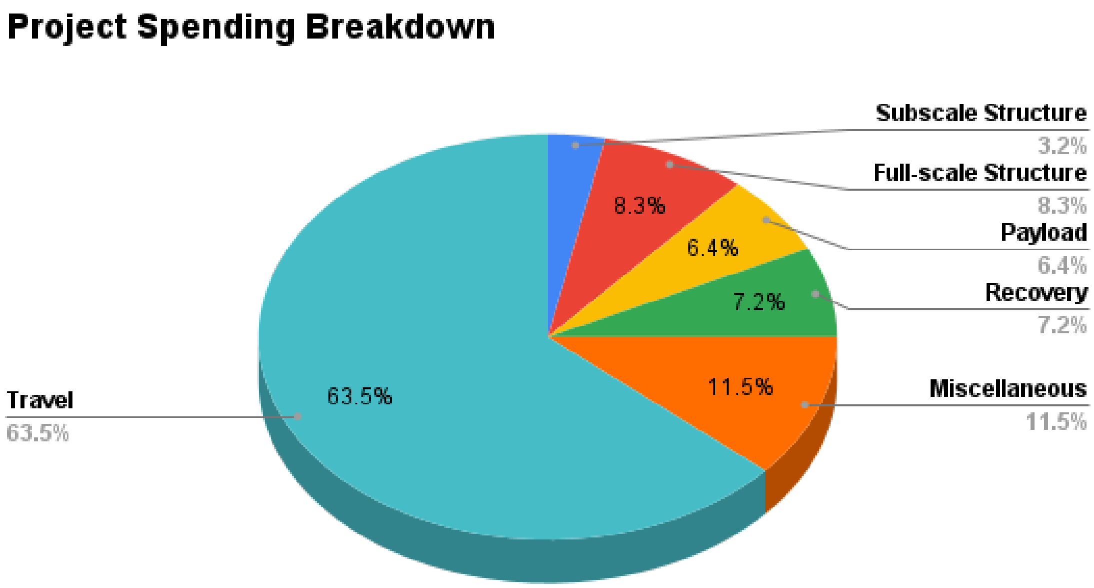



Figure 4.5: Project Expenses.

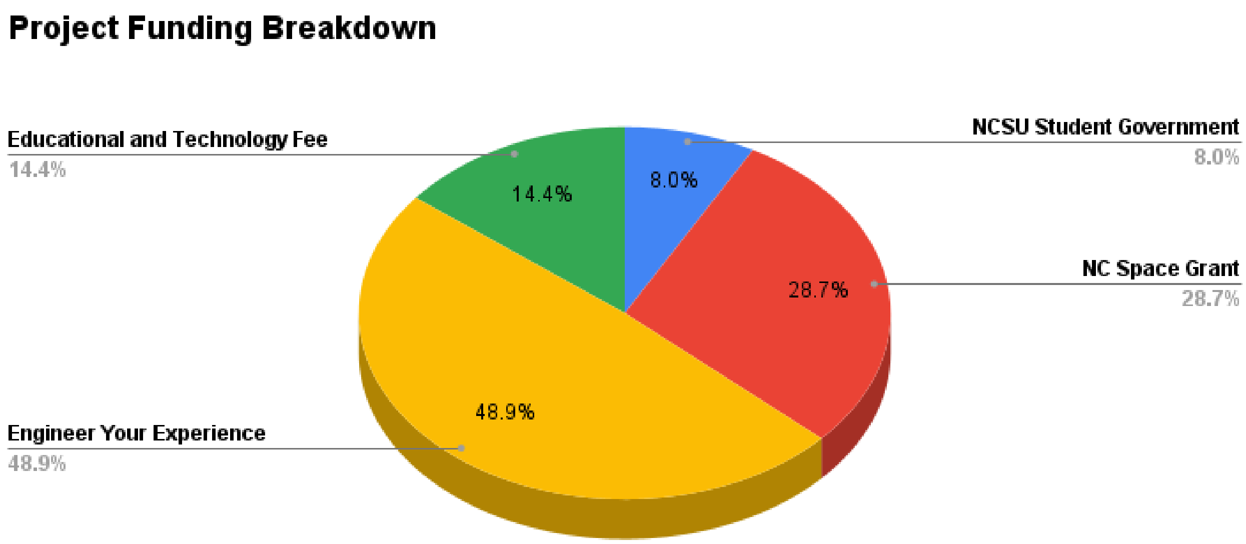



Figure 4.6: Project Funding Sources.

## References


[1] 18" Elliptical Parachute - 1.2lb at 20fps. URL: https://shop.fruitychutes.com/collections/classic-elliptical-12-to-60/products/18-elliptical-parachute-1-2-lb-20fps.

[2] 6 Inch G12 Fiberglass Tube. URL: https://www.compositewarehouse.com/index.php?route=product/product&path=25_28_35&product_id=68.

[3] Adafruit 9-DOF Accel/Mag/Gyro+Temp Breakout Board - LSM9DS1. URL: https://www.adafruit.com/product/3387.

[4] ADS1115 16-Bit ADC - 4 Channel with Programmable Gain Amplifier - STEMMA QT / Qwiic. URL: https://www.adafruit.com/product/1085.

[5] AeroTech L1390G Motor Data. URL: https://www.thrustcurve.org/motors/AeroTech/L1390G/.

[6] AeroTech L1520T Motor Data. URL: https://www.thrustcurve.org/motors/AeroTech/L1520T/.

[7] AeroTech L850W. URL: https://www.thrustcurve.org/motors/AeroTech/L850W/.

[8] Aerotech RMS-75/3840. URL: https://www.apogeerockets.com/Rocket-Motors/AeroTech-Casings/75mm/RMS-75-3840-Casing.

[9] AIOC - Ham Radio All-in-one-Cable. URL: https://na6d.com/products/aioc-ham-radio-all-in-one-cable.

[10] Barrowman Equations. URL: https://www.rocketmime.com/rockets/Barrowman.html.

[11] Blue Tube 2.0. URL: https://alwaysreadyrocketry.com/blue-tube-2-0/.

[12] BNO085. URL: https://www.digikey.com/en/products/detail/ceva-technologies-inc/BNO085/9445940.

[13] Justyn Bunkley. "Design Analysis of Rocket Tail Fins Aimed at Higher Apogee by Computer Simulation". In: American Society For Engineering Education (Apr. 2022).

[14] Compression Tests of Tubing Used In Rocketry. URL: https://www.apogeerockets.com/Peak-of-Flight/Newsletter510.

[15] Digi XBee-PRO® XSC S3/S3B Long-Range RF Modules. URL: https://www.mouser.com/new/digi-international/digi-xbee-pro-xsc-s3-s3b-modules/.

[16] Direwolf Software. URL: https://github.com/wb2osz/direwolf.

[17] Double Pull Pin Switch Kit - LRR. URL: https://inverted-pursuits-lab.square.site/product/DoublePullPinSwitch/44?cp=true&sa=false&sbp=false&q=false&category_id=10.

[18] DPS310. URL: https://www.infineon.com/cms/en/product/sensor/pressure-sensors/pressure-sensors-for-iot/dps310/.

[19] EASYMINI DUAL DEPLOYMENT ALTIMETER. URL: https://www.apogeerockets.com/Electronics-Payloads/Dual-Deployment/EasyMini.

[20] Fehskens-Malewicki Equations. URL: https://www.rocketmime.com/rockets/rckt_eqn.html.

[21] Fin Flutter Revisited (Again). URL: https://www.apogeerockets.com/Peak-of-Flight/Newsletter615.

[22] GRF5020. URL: https://www.mouser.com/ProductDetail/Guerrilla-RF/GRF5020?qs=sGAEpiMZZMv9d7nAGy9nTBPfu2Zia4eAkYoUGvERvCSAa 3D%3D.

[23] M.K. Gupta. "Investigations on Properties of Glass Fibre Reinforced Polymer Composite". In: American Journal of Polymer Science and Engineering (2018).

[24] IMU: BMI160. URL: https://www.bosch-sensortec.com/products/motion-sensors/imus/bmi160/.

[25] Iris Ultra 96" Compact Parachute - 50lb @ 20fps; 28lb @ 15fps. URL: https://shop.fruitychutes.com/collections/iris-ultra-compact-chutes/products/iris-ultra-compact-parachute-96inch-50lbs-20fps-28lbs-15fps.

[26] LM2596. URL: https://www.ti.com/product/LM2596.

[27] Magnetic Switch. URL: https://www.featherweightaltimeters.com/store/p4/Magnetic_Switch.html.

[28] MPL3115A2. URL: https://www.digikey.com/en/products/detail/nxp-usa-inc/MPL3115A2/2817529.

[29] MPU-9250. URL: https://www.digikey.com/en/products/detail/tdk-invensense/MPU-9250/4626449.

[30] Notes on a generic parachute opening force analysis. URL: https://arc.aiaa.org/doi/10.2514/6.1986-2440.

[31] OpenRocket User's Guide. OpenRocket wiki. URL: https://wiki.openrocket.info/User%27s_Guide.

[32] Othermill Pro - Compact Precision CNC + PCB Milling Machine. URL: https://www.adafruit.com/product/2323.

[33] Parachute Deployment Bags, Parachute Liners, Nomex Blankets. URL: https://fruitychutes.com/parachute_recovery_systems/parachute-deployment-bags-parachute-liners-nomex-blankets#successful-deployment.

[34] Pressure sensor BMP280. URL: https://www.bosch-sensortec.com/products/environmental-sensors/pressure-sensors/bmp280/.

[35] Raspberry Pi 4 4GB Model B. URL: https://www.canakit.com/raspberry-pi-4-4gb.html.

[36] RocketPy's User Guide. Version 1.0.1. URL: https://docs.rocketpy.org/en/latest/user/index.html.

[37] Charles Rogers and David Cooper. Rasaero II User Guide. URL: https://rasaero.com/dloads/RASAero%20II%20Users%20Manual.pdf.

[38] Screw Switch. URL: https://www.missileworks.com/store#!/Screw-Switch/p/38076724/category=5760490.

[39] Si4464. URL: https://www.silabs.com/wireless/proprietary/ezradiopro-sub-ghz-ics/device.si4464?tab=specs.

[40] SparkFun GPS Breakout - Chip Antenna, SAM-M10Q (Qwiic). URL: https://www.sparkfun.com/products/21834.

[41] StratoLoggerCF Altimeter. URL: http://www.perfectflite.com/SLCF.html.

[42] Summary of Flutter Experiences as a Guide to the Preliminary Design of Lifting Surfaces on Missiles. URL: https://ntrs.nasa.gov/citations/19930085030.

[43] Tacho Lycos 2023 NASA Student Launch Critical Design Review. URL: https://tacholycostesthome.files.wordpress.com/2023/01/nc-state-university-2023-cdr-1.pdf.

[44] Tacho Lycos 2024 NASA Student Launch Critical Design Review. URL: https://ncsurocketry.org/wp-content/uploads/2024/01/north-carolina-state-university-2024-cdr-report.pdf.

[45] West Systems 105/206 Epoxy Resin Datasheet. URL: https://www.westsystem.com/app/uploads/2022/12/105-206-Epoxy-Resin.pdf.

# 5 Appendices

### 5.0.1 Social Media Accounts

| Website | Instagram | Facebook | X | LinkedIn | Tiktok | Youtube |
|---|---|---|---|---|---|---|
| ncsurocketry.org | @ncsurocketry | /TachoLycos | @NCSURocketry | /tacholycos | @ncsurocketry | @tacholycos2206 |