NC STATE UNIVERSITY

Tacho Lycos

2024 NASA Student Launch

Post-Launch Assessment Review

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

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Common Abbreviations and Nomenclature

AGL	=	Above Ground Level
AIAA	=	American Institute of Aeronautics and Astronautics
APCP	=	Ammonium Perchlorate Composite Propellant
ASME	=	American Society of Mechanical Engineers
AV	=	Avionics
BEMT	=	Blade Element Momentum Theory
BP	=	Black Powder
CDR	=	Critical Design Review
CG	=	Center of Gravity
CP	=	Center of Pressure
ECD	=	Electronics, Communication, & Data
EIT	=	Electronics and Information Technology
FAA	=	Federal Aviation Administration
FEA	=	Finite Element Analysis
FMEA	=	Failure Modes and Effects Analysis
FN	=	Foreign National
FRR	=	Flight Readiness Review
HEO	=	Human Exploration and Operations
HPR	=	High-Power Rocketry
HPRC	=	High-Powered Rocketry Club
L3CC	=	Level 3 Certification Committee (NAR)
LCO	=	Launch Control Officer
LRR	=	Launch Readiness Review
MAE	=	Mechanical & Aerospace Engineering
MSDS	=	Material Safety Data Sheets
MSFC	=	Marshall Space Flight Center
NAR	=	National Association of Rocketry
NCSU	=	North Carolina State University
NFPA	=	National Fire Protection Association
PDR	=	Preliminary Design Review
PLAR	=	Post-Launch Assessment Review
PPE	=	Personal Protective Equipment
RF	=	Radio Frequency
RFP	=	Request for Proposal
RFS	=	Removable Fin System
RSO	=	Range Safety Officer
SAIL	=	STEMnauts Atmosphere Independent Lander
SL	=	Student Launch
SLS	=	Space Launch System
SME	=	Subject Matter Expert
SOW	=	Statement of Work
STEM	=	Science, Technology, Engineering, and Mathematics
TAP	=	Technical Advisory Panel (TRA)
TRA	=	Tripoli Rocketry Association
VTOL	=	Vertical Take-Off and Landing

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1.1 Flight Summary Information

Flight Summary Information	
Attribute	**Details**
Date	4/13/24
Time	12:00 pm CDT
Location	Bragg Farm, Toney, AL
Temperature (F)	69
Pressure (in Hg)	29.60
Humidity (%)	36
Wind (mph)	2.5
Motor	AeroTech L1940X-PS
Ballast (lb)	3.55
Payload	Deployment electronics, payload w/ parachute
Payload Weight (lb)	4.5
Airbrakes	N/A
Field-Measured LV Stability	2.17
Field-Measured LV Weight (lb)	48.8
Target Altitude (ft)	4050
Measured Altitude (ft)	4038

2 Vehicle Performance

2.1 Vehicle Summary

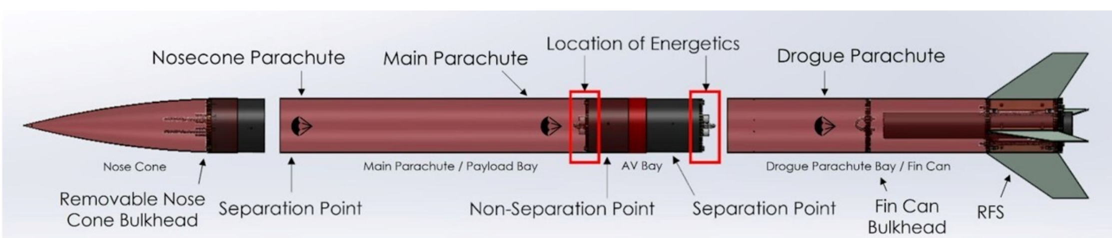

Figure 2.1: CAD model of the full-scale launch vehicle.

Figure 2.2: Photo of the as-built full-scale launch vehicle

Figures 2.1 and 2.2 above depict the final full-scale launch vehicle that was launched on April 13th, 2024 at Bragg Farms in Toney, AL. Takeoff and recovery events performed as designed, the primary altimeter recorded an apogee of 4038 feet, and the launch vehicle was safely recovered with no damage to bulkheads, shock cord attachments, airframe, or fins. Overall, the launch vehicle was successful.

2.2 Fight Profiles

The competition flight profiles of the launch vehicle from the RRC3 primary altimeter are shown below in Figures 2.3 and 2.4. The altimeter recorded an apogee of 4038 feet, occurring 15.95 seconds into flight, a maximum velocity of 503.76 feet per second, a decent time of 77.17 seconds from apogee, a drogue descent rate of 88 feet per second, and a main decent rate of 12.99 feet per second with deployment occurring at 728 feet. From the altimeter data, it was observed that data collection ended at an altitude of 275 feet. This anomaly with the RRC3 also occurred during the first VDF attempt, leading to the conclusion that a hardware or software issue exists with the RRC3 altimeter.

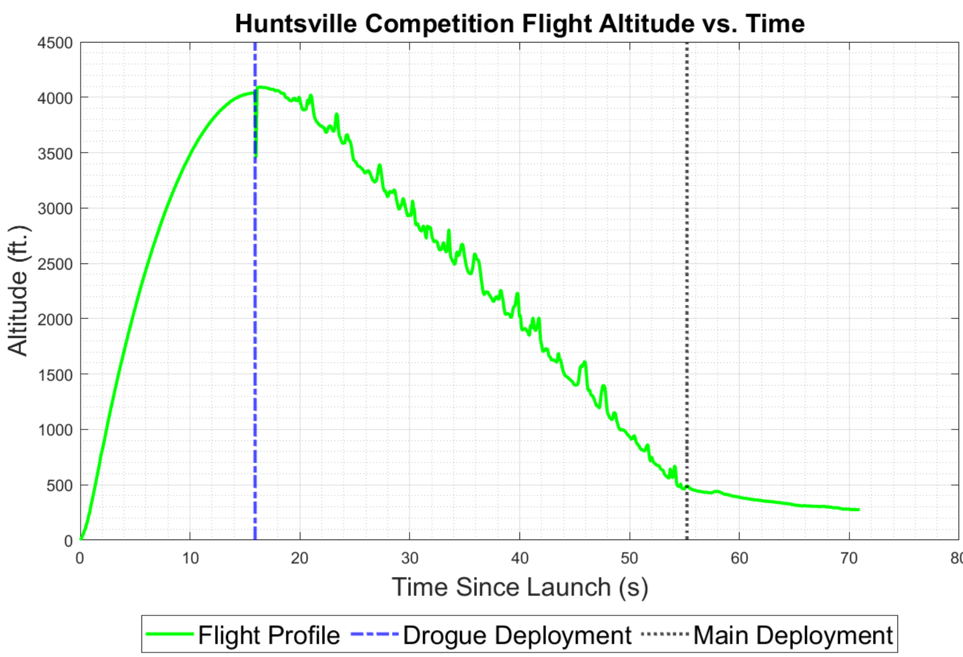

Figure 2.3: Huntsville competition launch flight profile.

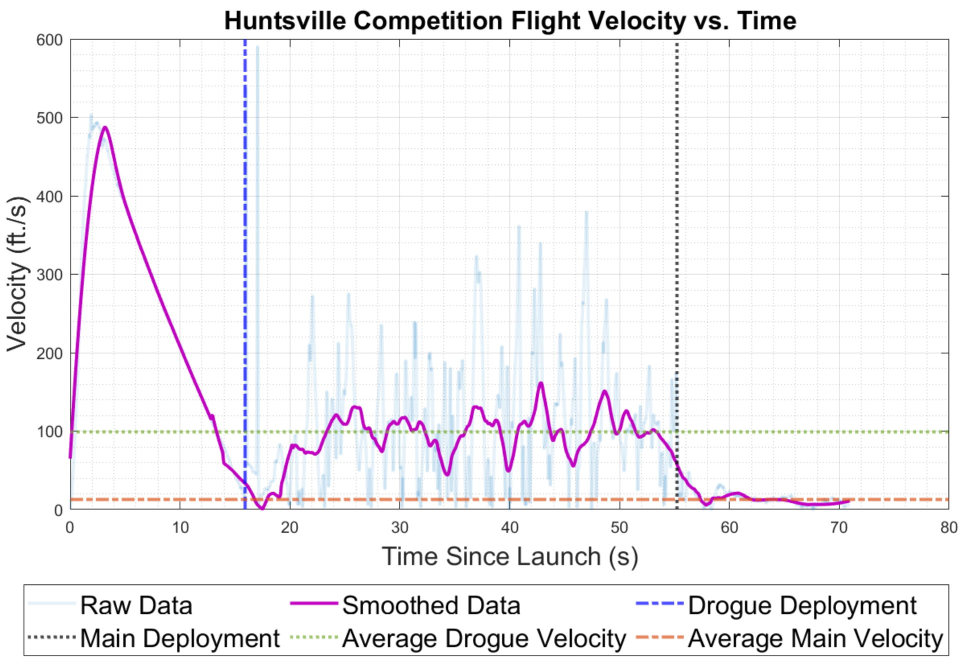

Figure 2.4: Huntsville competition launch velocity profile.

The nose cone was a separately descending section so a homemade altimeter was added to the sled inside the nose cone to record flight data. It reported an apogee of 4067 feet, a descent time of 55 seconds, and descent rate under parachute of 24.659 feet per second. Shown in Figure 2.5 is the flight profile for the nose cone.

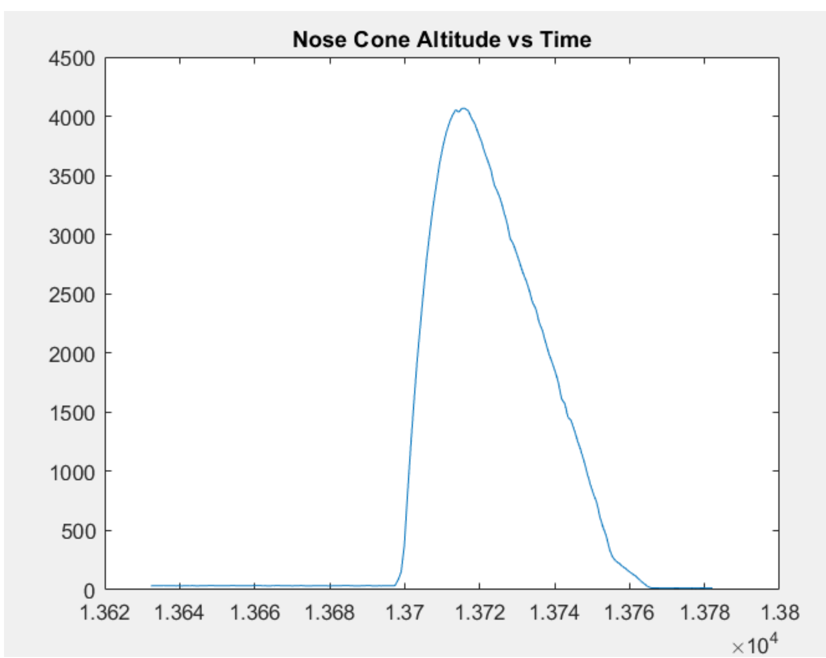

Figure 2.5: Huntsville competition launch nose cone flight profile.

2.3 Recovery

Drogue separation occurred at apogee and the launch vehicle descended under drogue until 800 feet. The primary main ejection charge deployed at 728 feet, separating the nose cone as intended. The nose cone parachute unfurled and pulled out the SAIL deployment bay which then pulled out the deployment bag out and off of the main parachute, deploying the main parachute for the rest of the launch vehicle. The payload was dropped from the deployment bay under nose cone at approximately 200 feet via the latch under its own parachute. Once the payload was dropped at 200 feet, the payload parachute deployed, allowing the payload to descend safely. The nose cone continued to descend under its parachute with the payload deployment bay until touch down. Shown in Figure 2.6 below is an image of all the separated sections after the payload was ejected at 400 feet.

Figure 2.6: Main Ejection Separation and Descent.

In Figure 2.6, one can view the launch vehicle under main parachute at the top (larger black/orange dot), and the nose cone under its parachute, with the tethered SAIL deployment bay at the bottom (red/white dot). Drogue and main recovery events and nose cone separation were successfully executed.

2.3.1 Separation Events

The separation events are as follows:

1. **Drogue Deployment**: The fin can separated from the AV bay and deployed a drogue parachute at apogee (4038 feet) on the primary charge. The secondary charge was set for one second after apogee.
2. **Main Deployment**: The nose cone separated from the launch vehicle, pulling out the attached nose cone parachute, main parachute deployment bag, and the SAIL deployment bay. Once the nose cone fully separated, the deployment bag was pulled off of the main parachute, allowing the main parachute to deploy for the launch vehicle at 728 feet. The secondary charge was set for 700 feet.
3. **Payload Deployment**: At around 200 feet, a command was sent to the latch in the deployment bay to release the payload. The payload fell out of the deployment bay and descended under a parachute.

2.3.2 As Landed Configuration

After successful recovery, the vehicle was checked for interior damage. The launch vehicle landed 2,222.936 feet away from the launch pad. No interior damage was found. The secondary drogue and main charges were both undetonated and the team had a NAR representative cut the e-matches in order to dispose of the charges safely. It was concluded that the secondary altimeter was somehow disconnected during takeoff. All recovery harnesses remained untangled during deployment, descent, and landing. No parachutes were damaged from black powder ejection charges. Overall, recovery was successful with no damage to the launch vehicle or recovery components. Figures 2.7, 2.8, and 2.9 show the as-landed configuration of all separate launch vehicle sections and the payload.

Figure 2.7: Fin can landing configuration.

Figure 2.8: Nose cone landing configuration.

Figure 2.9: Payload landing configuration.

2.3.3 Kinetic Energy At Landing

Table 2.1 contains the calculated kinetic energy values and the mass and descent rates for each relevant section. The kinetic energy at landing was determined using Equation 1. Let KE represent the kinetic energy, m represent the mass of the independent section in lbs, and V represent its velocity.

$$KE = \frac{1}{2}\frac{m}{32.174}V^2 \quad (1)$$

Table 2.1: VDF Kinetic Energy

Rocket Section	Mass at Landing (lbs)	Drogue Descent Rate (ft/s)	Main Descent Rate (ft/s)	Nose Cone Descent Rate (ft/s)	Kinetic Energy Value (ft-lb)
Nose Cone	6.2359	88.00	N/A	24.659	58.927
Main/Payload/AV Bay	11.891	88.00	12.99	N/A	31.182
Drogue Bay/Fin Can	11.963	88.00	12.99	N/A	31.371

2.4 Flight Analysis

To compare the simulated versus expected flight profiles of the launch vehicles, the following figures were generated.

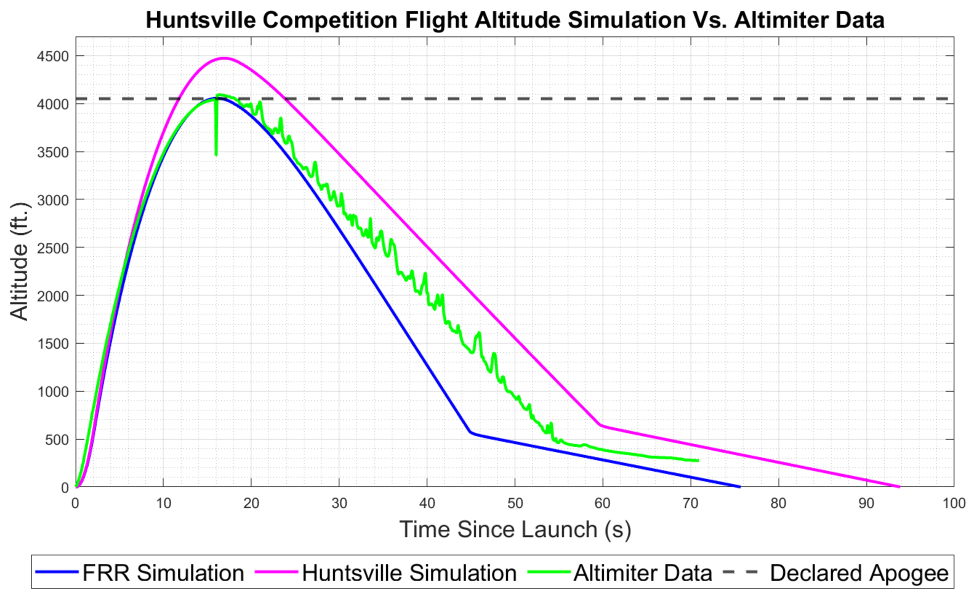

Figure 2.10: Altitude comparison between simulations and altimeter data.

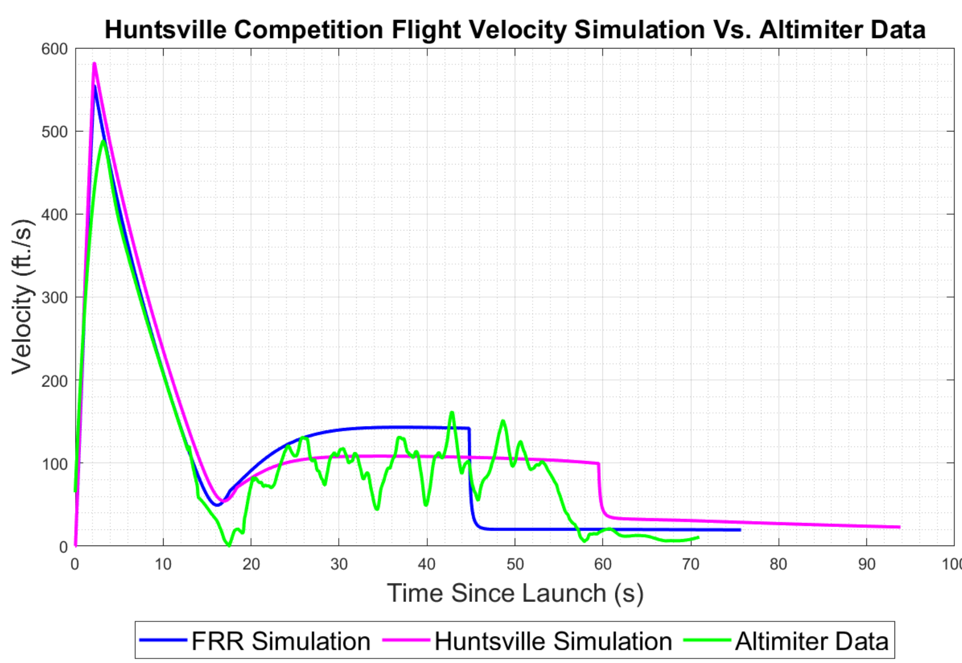

Figure 2.11: Velocity comparison between simulations and altimeter data.

From Figure 2.10 and 2.11, it was observed that the simulation completed during the FRR stage of the project closely matched the actual flight profile of the launch vehicle, while the simulations conducted on the launch field right before the Huntsville launch had a higher predicted altitude and maximum velocity. The predicted apogee during FRR was found to be 4056 feet, which was 6 feet off from the target apogee. Due to the payload kinetic energy constraints, the launch vehicle weight was lowered by 3.7 pounds via the removal of rotor blades and motor hardware from the SAIL. This was predicted to cause an increase in apogee to a value of 4473 feet, which included the field wind speeds and adjusted rail cant of 10 degrees.

During launch, it was observed that a noticeable change in pitch from the motor occurred during the trailing end of the burn. This was due to a failure of the motor's phenolic liner, causing a decrease in motor performance. This decrease in motor performance can be seen in Figure 2.11, where the maximum velocity of the launch vehicle was approximately 10% less than expected. This caused the apogee of the launch vehicle to deviate significantly from the expected value, which was predicted to overshoot the declared apogee by 423 feet. This event turned out to be highly advantageous for competition scoring requirements, as the team was able to achieve a 12 foot difference in apogee between the declared target apogee and the final competition altimeter data. Verification of this apogee measurement has been provided below directly from the MissleWorks MDACS software.

Flight Summary

Max Altitude	4038	Power Up Temp	77.0	Pad Time (min)	58.17	Descent Time	55.05
Max Velocity	504	Launch Temp	84.7	Power Up Volts	9.20	Drogue Rate	88
Ascent Time	15.95	Low Temp	83.5	Launch Volts	8.79	Main Rate	N/A

Figure 2.12: Apogee verification from MissleWorks MDACS altimeter software.

The actual drogue descent velocity measured was lower than predicted during FRR, but was similar to the descent velocity predicted on the launch field. This was due to a modification in the drag profile of the drogue parachute after analyzing the data from VDF and PDF flights. The slope of the altimeter data in Figure 2.10 and the average velocity value determined from Figure 2.11 reinforce the conclusion that the updated drag profile of the drogue parachute increased the fidelity of the simulation. The actual descent velocity of the main parachute was lower than predicted during the FRR simulation and launch field simulation, with a value most similar to the FRR simulation. It is believed that difference between actual and simulated main descent velocity was caused by the difference in launch vehicle mass from FRR to the competition flight along with wind speed differences between the flights. Drift distance reports show a far larger simulation drift than what was experienced on the launch field, and the difference in predicted versus actual wind speeds caused the expected and actual main parachute descent rates to deviate significantly due to the area of the parachute.

From these results, the team was able to come close to matching the apogee prediction and drogue descent rate of the launch vehicle through the use of simulations, despite last-minute modifications to the payload. However, this was partly due to a motor inefficiency. Nonetheless, the team deemed the competition flight a success based on team derived aerodynamic criteria.

3 Payload Performance

3.1 Payload Summary

The payload mission statement specified a STEMnauts Atmosphere Independent Lander, or SAIL, that was required to jettison from the launch vehicle during descent and reach the ground without the use of parachutes or streamers. Additionally, the lander had to be designed with the intent of proving survivability for four on-board "STEMnauts". The design chosen to satisfy these requirements was a contra-rotating rotor craft with foldable rotor blades and landing legs. The final design and the as-built SAIL is shown in Figure 3.1. In addition, a deployment bay housed the SAIL to prevent tangling with the vehicle shock cords. This included a retention and release system where a shock cord looped through an eyebolt attached to the SAIL and was held up by a latch. The latch was controlled by a servo that manually switches it open, which receives a one way radio frequency signal from a personal computer to accustom RSO command.

Figure 3.1: Final SAIL CAD and as-built configuration.

Due to an insufficient thrust test and a kinetic energy concern in the event of failing to release the SAIL, the rotor blades, gearbox, and motor were removed from the SAIL for launch. A parachute was added to the SAIL to ensure a safe descent. The as-flown SAIL is shown in Figure 3.2. The upper bulkhead had a hole drilled out in the middle to fasten a 1/4”-20 threaded eyebolt to it. The parachute was secured to the eyebolt using a quick link and the deployment bay shock cord was threaded through for release.

Figure 3.2: As-flown SAIL with modifications.

3.2 Payload Flight

3.2.1 Payload Separation Events

On descent, the payload was successfully jettisoned out of the vehicle. The deployment bay, housing the SAIL, was below the vehicle components as intended to avoid entanglement. This can be seen on the left side of Figure 3.3. At approximately 200 feet in altitude, the SAIL was released out of the deployment bay and the parachute caught wind around 150 feet (right side of Figure 3.3), allowing it to land at a safe speed as discussed in Section 3.3.

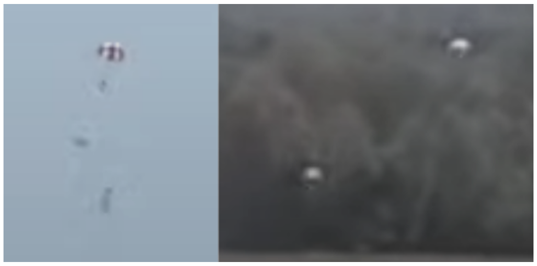

Figure 3.3: Payload Separation Events

3.2.2 Payload Landing

Upon landing, the SAIL did not land upright as the parachute underwent a severe sideways drift. However, the SAIL withstood little to no damage. The leg brackets, which had broken in PDR, only suffered a few small cracks that did not impede their overall structure seen in Figure 3.4.

One team derived requirement stated that all four STEMnauts must be retained during the whole flight. Unfortunately, one of the STEMnauts had an unplanned egress and could not be recovered, seen in the bottom right of Figure 3.4.

Figure 3.4: SAIL Landing

3.3 Payload Data Analysis

While the SAIL was flown under parachute for the competition launch in Huntsville, data was still able to be collected by the on board sensors.

Impact Velocity

To ensure that the SAIL impacted the ground at a safe velocity, a velocity estimation from the altimeter on board the SAIL was recorded. This data is shown in Figure 3.5.

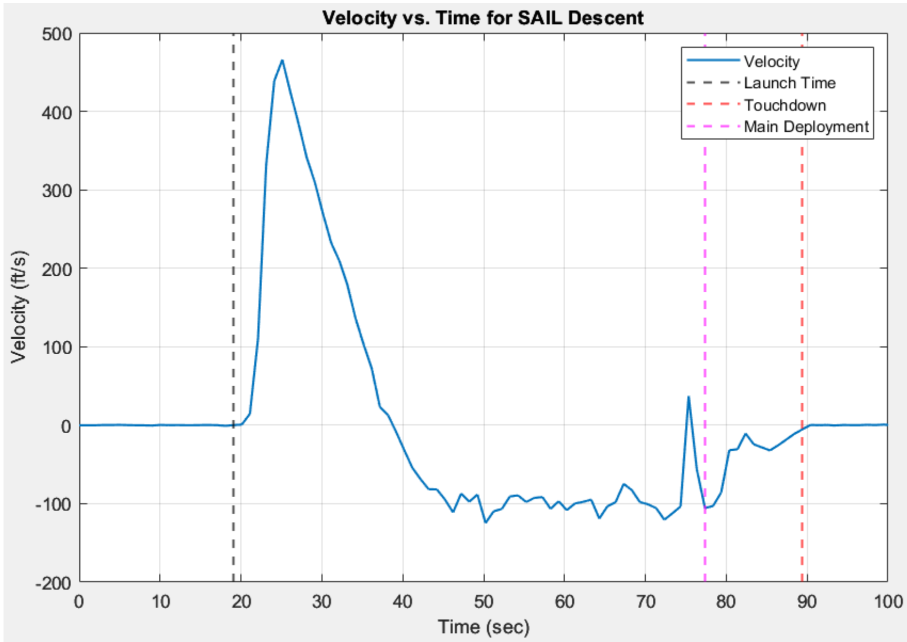

Figure 3.5: Velocity profile of SAIL between launch and touchdown

The estimated velocity at impact was recorded to be 5.23 ft/s, or 3.57 mph. This value was under team derived requirement of 15 mph. Consequently, the velocity at impact was deemed to be acceptable for STEMnaut survivability.

G Forces

Acceleration data was also recorded for the SAIL flight to determine the survivability of G forces experienced during launch. For this data, only the magnitude of acceleration was recorded. This data is shown in Figure 3.6.

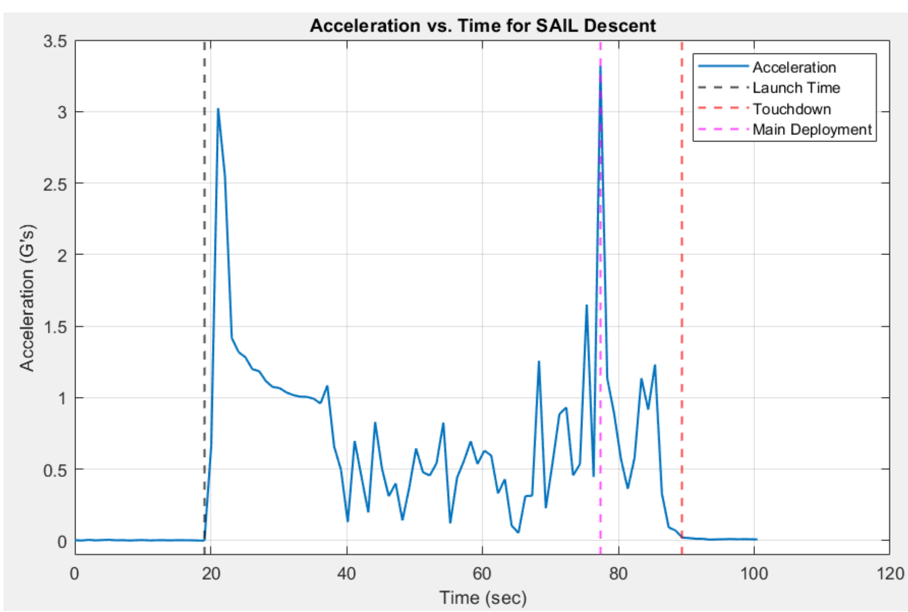

Figure 3.6: G force experienced by SAIL between launch and touchdown

For this data, only the acceleration after main deployment is considered. The maximum amount of G forces experienced by the SAIL between deployment and landing was around 1.23 Gs. This meets the team derived requirement of less than 6 Gs max and less than 3 Gs sustained.

While one of the STEMnauts did not stay retained during flight, the remaining data for the other three STEMnauts supports the idea that the as-flown SAIL would indeed be safe for human survivability.

4 Project Reflection

4.1 Scientific Value Achieved

The team was able to utilize the engineering design process to design, build, and test a hypothetically atmosphere independent lander and a launch vehicle to carry it up to operating altitudes. Though the lander was, in the end, unsuccessful, the team still managed to deploy it from the launch vehicle and collect data from it, thus producing some scientific value and insight. Upon analysing the data from the payload's decent (see Section 3.3) the team was able to determine that the payload deployment method designed met human survivability standards.

4.2 Visual Data Observed

The team observed a variety of visual data throughout the academic year. Recovery events of each launch conducted were visually confirmed by observing the plumes of smoke from ejection charges and the brightly colored parachutes unfurling upon a recovery success. When the team encountered an altimeter malfunction, this was confirmed visually by observing the unblown charges connected to the secondary altimeter which was believed to have malfunctioned. The recovery events via the primary altimeter performed as expected. Payload deployment was visually confirmed via a bright yellow parachute and signal confirmation on the deployment electronics GUI. Data was also observed visually throw the use of simulations, CAD images, plots, and graphs. All of these visualization tools were used to help the team make sense of things and to help other engineers understand the team's process.

4.3 Successes and Failures

The team had many successes this year. Proposal was accepted, milestones were complete on time, subscale and full-scale launch vehicles were successfully constructed and stayed true to their designs, all testing for vehicle was successful, the recovery system during all launches operated as designed, and the team got to celebrate four successful launches this year. There were also some failures, but the team prevailed and grew with each mistake. The altimeters failed to record data from takeoff to landing on the first VDF attempt and that attempt was deemed unsuccessful, prompting the team to make new altimeters and add them to the sections where data collection failed. The team had a successful VDF attempt the second time around. Due to shipping delays, the payload was built late and a few tests were unable to be complete before FRR, but the team still strove to complete those tests to the best of their ability to prove that their payload design was feasible. During the first payload thrust test, a rotor blade hinge failed, resulting in the damage of all four rotor blades, but the team worked hard and rebuilt all four blades in five days and resumed testing. Electrical issues resulted in two more payload thrust test failures and despite the team's best efforts, the payload was unable to launch in its true configuration, but the team worked hard to provide the necessary data in order to be able to drop the altered payload in Huntsville under parachute. The team managed to pull it off and collected usable payload data. Mistakes were made, failures were suffered, but the team did not give up, and based on that, the entire year should be considered a resounding success.

4.4 Lessons Learned

During launch vehicle design and construction, there were a few lessons learned. The most important of these lessons was to measure twice, cut once. Though not as many measurement mistakes were made this year, there were still a few. It is always important, no matter what project, to double and even triple check measurements. Another hard learned lesson came with calculations. Some numbers were overlooked which led to a last minute mass cut on the payload to be able to conduct a competition launch. It can be hard to keep track of the numbers for each vehicle section, especially if is any complete separation of sections so always make sure all calculations are accounted for and, even under the worst case, values do not exceed safe limits.

During the design and construction of the SAIL, the team learned numerous important engineering lessons. The first is that it is rare for a design to be something that has never been created before. A thorough trade study prior to the design phase of a project can save time by finding out what has worked and what has not worked for other engineers. Another lesson is that a design does not need to be complex to be effective. It is better to keep a design simple to reduce the amount of failure modes and make the manufacturing process easier. The last major lesson learned was to properly tolerance parts prior to fabrication. SolidWorks models do not translate directly to the real world. It is critical to consider the tolerances of hardware you buy as well as the tools used to fabricate parts.

4.5 Experience Overview

The team attempted to design, build, test, and launch an atmosphere independent lander payload that was capable of retaining four STEMnauts and descending without the use of parachutes or streamers, as well as the launch vehicle to propel the payload to a deployable altitude. The launch vehicle and the payload were designed and built successfully, but the payload did not pass all the tests designed to prove its feasibility. However, the team was able to accomplish the deployment of an altered payload assembly and successfully logged STEMnaut survivability data.

The 2024 NASA SL Competition presented the team with a tough problem to solve, and though the team was unsuccessful in bringing its full payload design to fruition, the journey provided invaluable experiences to everyone involved. From problem solving and developing effective construction and testing methods, to team building exercises, learning from failures, improving, and celebrating successes together, the work and progress made this year was something the team will forever be proud of. Information and lessons learned will go on to help future members of this team to improve and expand upon this year’s ideas, and will also serve beneficial in future careers.

4.6 Time Spent on Project

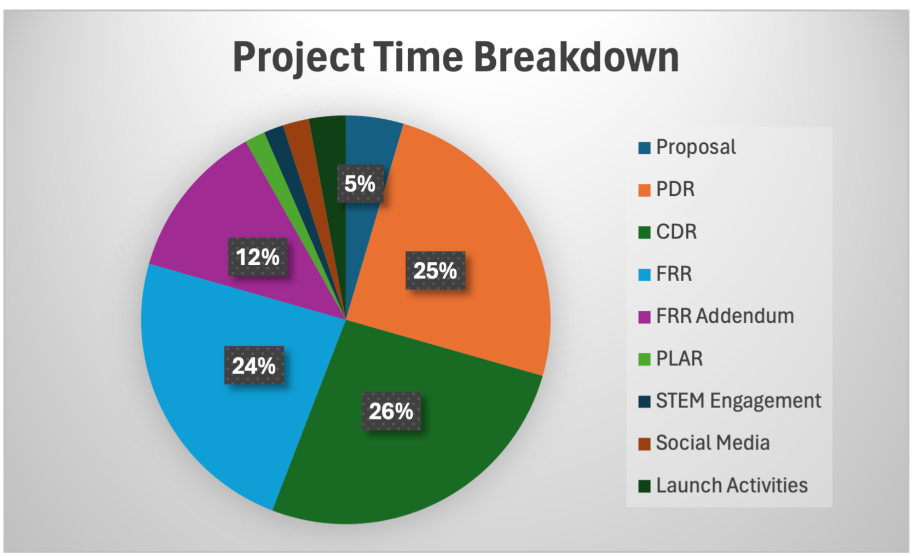

Figure 4.1: Breakdown of hours spent on project milestones and events.

The team spent a total of 1930 hours working on the 2024 NASA SL project through the months of August 2023 and April 2024. Figure 4.1 shows the breakdown of time per project deliverable and event, including time spent on STEM engagement, social media, and launch activities. The time involved for launch activities includes time spent on ejection tests, dry runs, and packing before launch as well as travel time to and from the launch field.

4.7 STEM Engagement Summary

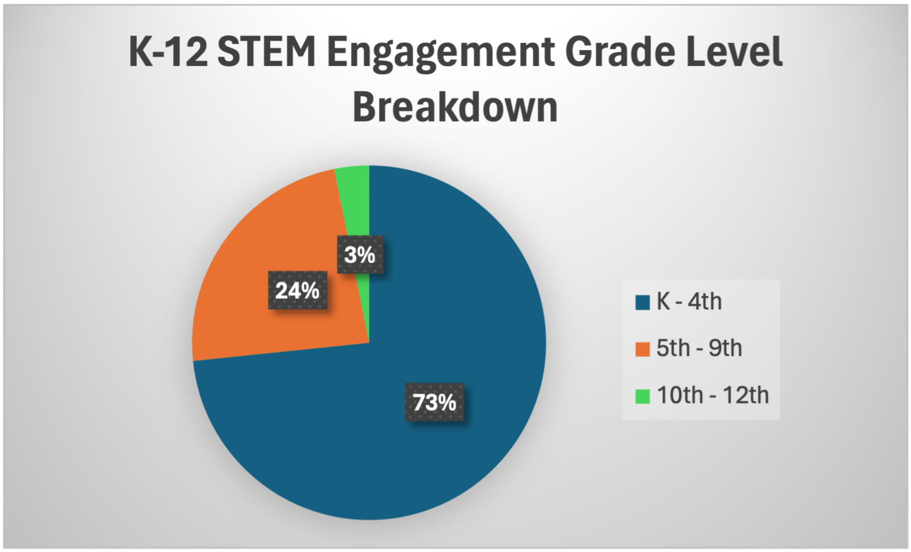

Figure 4.2: Grade range breakdown for the year's K-12 STEM outreach events.

For the 2023-2024 NASA student launch year, the team reached 1,359 students through both Education/Direct engagement and Outreach/Direct engagement events. The breakdown of age groups reached is depicted in Figure 4.2. Nine out of the ten events conducted fell under the category of Education/Direct engagement where students were taught specific things related to STEM, and then solidified their understanding through hands-on projects. To facilitate student engagement, past full-scale and subscale rockets, old experimental payloads, and parachutes were brought to events. During event presentations, students were taught about the basic physics behind a rocket launch and the engineering design cycle behind the design, construction, and testing of a high-power rocket. Based on the age range, the information would be scaled up or down. For hands-on activities, students would either make water bottle rockets, straw rockets, or Estes rockets depending on the age range.

4.8 Final Budget Summary

The finalized budget breakdown outlining all of the team's competition related expenses for the 2023-2024 Academic year can be seen in Table 4.1 below. A large majority of expenses came from the cost of travel to and stay at Huntsville, taking up 73.1% of the budget.

Table 4.1: Final Expenses Breakdown

Spending Category	Total Amount Spent
Subscale Structure	$465.69
Full Scale Structure	$2,228.29
Payload	$1,294.93
Recovery & Avionics	$792.57
Miscellaneous	$716.81
Travel	$18,651.56
Promotion	$1,366.12
Total Expenses:	**$25,515.97**

The finalized breakdown for all the team's funding sources for the 2023-2024 academic year are outlined in Table 4.2 below.

Table 4.2: Projected Funding Sources

Organization	Fall Semester	Spring Semester	Academic Year
Educational and Technology Fee	$0	$3,000	$3,000
Engineering Enhancement Fund	$0	$18,900	$18,900
NC State Student Government	$1,296	$1,284	$2,580
North Carolina Space Grant	$5,000	$0	$5,000
Sponsorship	$500	$500	$1,000
Fundraising	$550	$576	$1,126
Total Funding:			**$25,606.00**
Total Expenses:			**$25,515.97**
Difference:			**$90.03**